Horizontal Sighting Range and Secchi Depth as Estimators of Underwater PAR Attenuation in a Coastal Lagoon

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ABSTRACT: Attenuation of photosynthetically available radiation (PAR) measured using a light meter, was related to Secchi disk, horizontal black disk and horizontal sighting ranges observed in a coastal lagoon of the Southern California Current System. Vertical attenuation coefficient (K_{PAR}) was calculated from radiometric PAR profiles. Vertical (Z_{SD}) and horizontal (HS) sighting ranges were measured with white (Secchi depth or Z_{SD, W}) and black (Z_{SD, B}) targets. Empirical power models for the K_{PAR, Z_{SD}} (K_{PAR} = 1.47 Z_{SD}^{1.13}), K_{PAR, Z_{SD, W}} (K_{PAR} = 0.98 Z_{SD, W}^{1.28}), K_{PAR, HS_{W}} (K_{PAR} = 0.73 HS_{W}^{1.07}) and K_{PAR, HS_{B}} (K_{PAR} = 0.73 HS_{B}^{1.07}) relationships were developed. The parameters of these models may not apply to other water bodies because their values depend on the range of water reflectance in each case, as reported in the literature. This is the first contribution reporting K_{PAR}–HS empirical relations in an estuarine environment but their application may be limited to this coastal lagoon. While this approach may be universal, more data are needed to explore the variability of the parameters between different water bodies.

Introduction

Light availability in the water column of a coastal water body is a fundamental issue in primary productivity models (Gallegos 1994; O’Donohue and Dennison 1997). Water transparency is also a key parameter for monitoring water quality and can be used for detecting the anthropogenic impact due to dredging, erosion, and eutrophication (Iannuzzi et al. 1996; Ruffink 1998). For example, O’Shea and Brosnan (2000) used water clarity as a measure of eutrophication trends in Western Long Island and the Hudson-Raritan estuary.

The underwater light attenuation in the visible range (400–700 nm) can be quantified with the vertical attenuation coefficient (K_{PAR}) of photosynthetically available radiation (PAR). Because of the relative high cost of radiometric measurements, K_{PAR} is sometimes estimated with Secchi depth (Z_{SD}) in which a white or black and white disk is lowered into the water until it disappears from view (Tyler 1968; Holmes 1970; Smith 2001; Steel and Neuhauser 2002). Coastal lagoons often have strong tidal currents and large shallow areas that make the vertical sighting observation (Z_{SD}) difficult. Tidal currents inside the lagoons can be as fast as 1 m s^{-1} (Knoppers 1994) and such fast currents are likely to increase the variability of Z_{SD} measurements. Coastal lagoon waters, in common with other estuarine environments, have higher turbidity than those of open ocean (Kirk 1994), which permits vertical Secchi disk readings in shallower water, but these measurements cannot be performed when Z_{SD} is greater than bottom depth (Z_{B}). A possible solution to these methodological problems is presented by horizontal sighting (HS) range or the maximum distance a target can be seen when viewed horizontally (Davies-Colley 1988). In this case, the visual target can be positioned just below the water surface so as to avoid some of the drag effect of the water current.

Measurement of visual water clarity involves attenuation of contrast of an image with respect to background. Use of the Secchi disk maximizes the contrast because the target is coated with highly reflective white paint and is viewed vertically against the relatively dark background color (Davies-Colley 1988). According to Preisendorfer (1986)

\[ Z_{SD} = \frac{\ln(C_0/C_T)}{(c + K_{PAR})}, \]

where C_0 is the Secchi disk contrast at depth zero, C_T is the threshold contrast where the maximum visual range occurs, and c is the beam attenuation coefficient, equal to the sum of the total absorption and scattering coefficients (c = a + b). C_0 varies with water reflectance—the ratio of upwelling to downwelling irradiance (Davies-Colley and Vant 1988). Reflectance is an apparent optical property that varies with the ambient light field, or angular distribution of light, and the optical components of water—organic detritus, inorganic suspended matter, phytoplankton, and color dissolved organic matter (Kirk 1994). Numerical modeling of the underwater light field for waters of various optical types reveals that reflectance is proportion-
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Fig. 1. Study area. Only every other sampling location is numbered. Filled circles are locations A, and open circles are locations B. Time series location (A16/H11032) is symbolized with an open square. Main channel is indicated with a dotted line. On the southern-left corner (dashed area) there is a zone affected by an artificial dike built in the early 1980s. The construction planned for the area inside the dike was not done. A high turbidity plume from the Estero can be seen extending into Bahía de Todos Santos.

The objective of this study was to develop empirical relationships to estimate K_{PAR} as a function of Z_D and HS in a sub-tropical coastal lagoon of the California Current System. Both white and black targets were used for Z_D and the horizontal sighting viewer. We explored the variability of parameters of the K_{PAR} - Z_{SD} relationship when comparing different seasons and portions of the lagoon where Z_{SD} < Z_B. We developed and tested empirical models to estimate K_{PAR} by measuring the horizontal sighting range of white (HS_w) and black (HS_b) targets throughout the lagoon, with different bottom depths (1.0–4.7 m).

**Materials and Methods**

**STUDY AREA**

Estero de Punta Banda (EPB) is a coastal lagoon in the southern California Current System, located 123 km south of the U.S.-Mexico border (San Diego), 12 km south of Ensenada, Baja California (Fig. 1). The lagoon is L-shaped with a long arm of 7.5 km, and a short arm of 3 km. It has a single entrance at the extreme of the long arm. The long arm is separated from Bahía de Todos Santos by a sandbar. The short arm is characterized by large mud flats with sediments finer than those of the long arm. Extensive salt marshes, mud flats, and beds of the eelgrass *Zostera marina* are the main ecological sub-systems of Estero de Punta Banda. The most extensive salt marshes are located in tidal creeks and are particularly well developed at the head of the lagoon (Ibarra-Obando and Poumian-Tapia 1991).

Maximum depth (6.5 m) is at 1.5 km from the lagoon entrance and it decreases to the head (0.5 m) and to the mouth (4.5 m). In general the lagoon behaves as a negative estuary, with salinity and temperature increasing from the mouth to the internal extreme (Acosta-Ruiz and Alvarez-Borrego 1974; Pritchard et al. 1978), due to high evaporation in the lagoon. During El Niño events higher winter precipitation causes estuarine conditions in