Optical Properties of Three Beach Waters: Implications for Predictive Modeling of Enterococci

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Background

Sunlight plays an important role in the inactivation of fecal indicator bacteria in recreational waters (1,2,3,4). Solar radiation can explain temporal trends in bacterial counts (5,6) and is commonly used as an explanatory variable in predictive models. Broadband surface solar radiation (300-1100 nm) and photosynthetically active radiation (PAR, 400-700 nm) provide basic measures of sunlight exposure. However, the amount and quality of light that bacteria are exposed to is largely dependent on the optical properties of the water. Chromophoric dissolved organic matter (CDOM), the major light absorbing component of natural waters, is largely responsible for light attenuation in the water column.

In this study, we investigated the optical properties of waters at three beaches as part of a larger project to evaluate the applicability of predictive models at different types of beaches. Detailed studies were carried out in the summer of 2008 at a sub-tropical marine beach (Hobie Beach in Miami, FL), a tropical marine beach (Balneario La Monserrate in Luquillo, Puerto Rico), and a temperate freshwater beach (South Shore Park Beach on Lake Michigan in Milwaukee, WI).

Study Design

Water samples were collected at three locations in the swim area of each beach (Figure 1) at waist and shin deep, four days a week for twelve week periods during June to October. Culturable enterococci were measured (EPA Method 1600) one to three times per day and water was 0.2-µm filtered for determination of dissolved organic carbon (DOC) and absorption spectra (i.e., CDOM). Weather stations and Sondes were deployed to continuously monitor meteorological and biogeochemical conditions. Ultraviolet (UV) sensors (Figure 2) were installed close to the beach sites at two depths underwater.

Figure 2. UV tower support with sensors attached at two different depths. Each sensor measures irradiance at 305, 325, 340, and 380 nm. Distance between sensors was ~ 0.6 m at Hobie and South Shore and ~ 1.5 m at Luquillo.

Figure 1. Beach study sites.

Table 1. Beach characteristics.

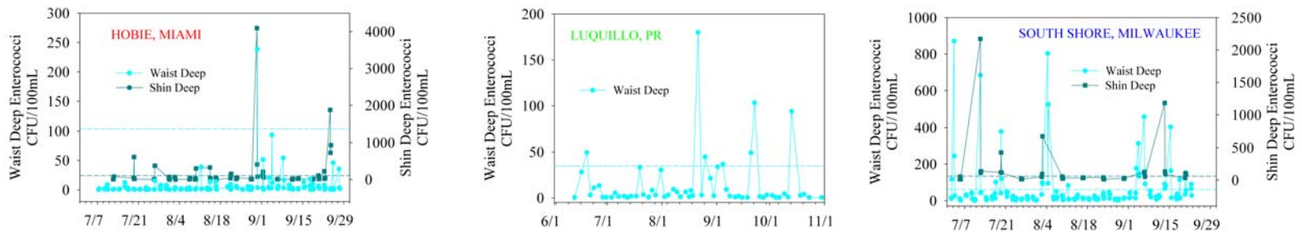
	Hobie Miami, FL	Luquillo Puerto Rico	South Shore Milwaukee, WI
Latitude	25°44'21.42"N	18°23'7.20"N	42°59'39.60"N
Longitude	80°10'9.90"W	65°43'46.50"W	87°52'48.60"W
Solar Radiation (300-1100nm)*, W m^{-2}	746.94	833.52	585.20
PAR (400-700nm)*, µEin m^{-2} s^{-1}	1599.73	1723.36	1223.84
Water Temperature, ºC	30	29	19
Salinity	33	35	0.2
pH	8.1	8.1	8.5
Turbidity, NTU	1.7	1.6	3.1
Chlorophyll, RFU	0.4	0.1	0.8
Maximum Tidal Height, m	1.0	0.7	
Criteria, Enterococci, CFU/100mL	104	35	61
Exceedances (Waist)	1% (6/410)	10% (17/174)	16% (67/409)
Exceedances (Shin)	22% (40/186)		36% (36/99)

*Average noon value.

Results

- Significant differences observed between beaches.
- Waist deep counts were highest at Milwaukee beach and lowest at Luquillo beach. Shin deep sample counts were higher (Figure 3).
- Tropical marine beach (Luquillo) had most intense solar irradiance (Table 1) and clearest water (Figure 4) compared to the sub-tropical marine (Hobie) and temperate freshwater (South Shore) beaches.

Figure 3. Enterococci counts at waist and shin deep sampling sites. Date are averages of counts from three sampling locations. Samples were collected at 9:00, 11:30, and 15:00 local time at Hobie and South Shore and at 10:00 at Luquillo. Dashed lines indicate enterococci criteria values.



Conclusions

- UV-induced inactivation of fecal indicator bacteria has the most potential to be significant at Luquillo beach (deepest light penetration).
- At Hobie Beach, the role of UV is likely minor relative to other processes (sediment resuspension, tidal effects).
- Underwater UV light measurements will improve accuracy of predictive models and provide information for process based work.

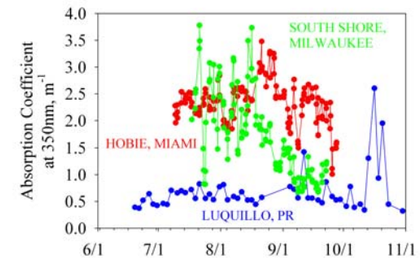
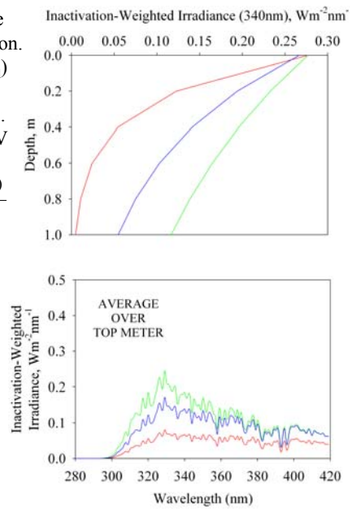


Figure 4. Comparison of chromophoric dissolved organic matter, quantified as absorption at 350 nm, at each beach over the course of the study. Absorption coefficients were correlated with DOC ($R^2 = 0.7$) at Hobie and South Shore beaches (DOC ~ 150 to 300 µM compared to ~ 50 to 150 µM at Luquillo)

Figure 5. Inactivation-weighted irradiance decreases with depth due to light attenuation. Corresponding attenuation coefficients (k_d) at 340 nm are: 4.1, 1.6, and 0.9 m^{-1} for Hobie, South Shore, and Luquillo beaches. Surface irradiance was obtained from TUV model (7).

$$k_d = \ln \frac{(\text{Irradiance}_{\text{top sensor}} / \text{Irradiance}_{\text{bottom sensor}})}{(\text{depth}_{\text{bottom sensor}} - \text{depth}_{\text{top sensor}})}$$

$$\text{Irradiance}_{\text{depth,z}} = \text{Irradiance}_{\text{surface}} \exp(k_{\text{d depth,z}})$$



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Acknowledgements

Water sample collection and culturable enterococci measurements were done by contractors from ERG at Hobie and South Shore and by the Puerto Rico Environmental Quality Board at Luquillo. We thank Diana Aranda, Maria Vega-Rodriguez, and Lindsay Olson for equipment maintenance and data downloading, Jon Wong for the processing of UV data files, O'Niell Tedrow for DOC analyses, and John Varner for performing the absorbance measurements. The help of Erich Bartels, Milton Carlo, Jed Campbell, Alan Humphrey, and Richard Henry was essential to equipment deployment and retrieval. We are also grateful to Chris Sinigalliano, Angel Meléndez, and Robert Paddock and for their assistance.