

## **The Effect of Epiphyte Accumulation on Light Attenuation of Eelgrass (*Zostera marina*) Over a Depth Gradient in the York River, Virginia**

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### ABSTRACT

Seagrass populations, including those of eelgrass (*Zostera marina*) have had major declines worldwide. Excessive periphyton accumulation on plant leaves is one contributing factor as light to the leaf surface is reduced exponentially with increased loadings. Loadings rates are related to a complex interaction of factors including nutrient and turbidity levels, biological grazing, and physical factors. To evaluate the effect of these factors, the accumulation of algae, total solids, and periphyton specific light attenuation were measured using Mylar strips over a four-week period (June 13-July 11, 2002) at various depths in the shallows of the York River, Virginia, a tributary of Chesapeake Bay. Similar data were collected from periphyton on eelgrass plants immediately adjacent to the sites. Concurrent measurements of turbidity, suspended solids, and water column nutrients were incorporated into a model used to predict periphyton total solids, chlorophyll a, and percent light reduction at the leaf surface. Statistical analysis indicated a difference in total solids and chlorophyll accumulations between Mylar strips and eelgrass relative to depth. The model under-predicted both total solids and chlorophyll accumulations with depth.

### INTRODUCTION

Submersed aquatic vegetation (SAV), including eelgrass (*Zostera marina*), is an important component of estuarine ecosystems. Marine angiosperm communities provide habitat and protection for shellfish and food for waterfowl and serve as indicators of water quality conditions (Dennison *et al.*, 1993). Studies of the Chesapeake Bay estuary have shown major declines in SAV populations since the 1960's. Many of the Chesapeake's major lower tributaries, such as the York River, support only sparse coverage of eelgrass where historical photographic evidence shows there were extensive populations. Despite numerous restoration efforts there has only been a slight increase in populations of *Z. marina* over the last several years (Moore *et al.*, 2001).

Several hypotheses were proposed to explain the decline in eelgrass populations and their inability to recover despite numerous transplant efforts. Many of these hypotheses were based on

the relationship between epiphytes and eelgrass (Sand-Jensen, 1977; Howard, 1982; Silberstein *et al.*, 1986; Dennison *et al.*, 1993; Howard and Short, 1986; Neckles, 1990; Neckles *et al.*, 1993; Lin *et al.*, 1996; Nelson and Waaland, 1997). For the purpose of this project, epiphytes are defined as organisms that grow on eelgrass as well as all the organic and inorganic material that is collected on the plant surface. Epiphyte and other fouling growth on *Z. marina* cause a decrease in availability of light for photosynthesis and may decrease production of the individual plants (Sand-Jensen, 1977; Borum and Wium-Andersen, 1980; Moore *et al.*, 1996).

Investigating factors that affect epiphyte accumulation rates would clarify the relationship between reduction in available light and SAV population growth. Increased epiphyte coverage on eelgrass blades could be due to a decrease in periphyton grazers that would result in SAV transplant failure and slow natural recovery in the Chesapeake Bay (Orth and Moore, 1983). Studies have shown that grazers do not have a large effect on initial epiphyte growth stages (Neckles, 1990); however, over time, grazers can significantly and effectively reduce the overall abundance of epiphytes on eelgrass (Howard, 1982; Orth and Moore, 1983; Howard and Short, 1986). Numerous investigations have attempted to measure the effect of nutrient availability on eelgrass and epiphyte growth (Williams and Ruckelshaus, 1993; Neckles *et al.*, 1993; Lin *et al.*, 1996; Moore and Wetzel, 2000). There has also been the suggestion that light availability could have a large limiting effect on epiphyte populations (Neckles, 1990). Reduced light availability thorough the water column has also shown to be related to epiphyte accumulation rates (Moore *et al.*, 1997).

Only a few have examined the effects of light availability and epiphytes accumulation rates (Sand-Jensen, 1977; Borum and Wium-Andersen, 1980; Moore *et al.*, 1996). During the summer months when seasonal epiphyte growth is greatest, light available to eelgrass would be at a minimum (Moore and Wetzel, 2000). By studying epiphyte growth on an artificial substrate over a depth gradient, the effects of light availability, depth, and time on epiphyte production can be quantified. The objectives of this research were to relate the effects of epiphyte fouling on light availability and to quantify the role that epiphytes play in limiting the maximum depth of eelgrass growth.

## METHODS

The epiphyte growth sampling site was located offshore of Gloucester Point, Virginia (37° 14.8' N, 76° 30.3' W)). Four replicate sampling arrays were set out at three depths: 0.4 m, 0.95 m, and 1.45 m MSL (mean sea level). The sampling arrays were 2 ft x 2 ft square PVC pipe frames from which four plastic epiphyte strips were secured. Li-Cor, Inc. spherical underwater light sensors (LI-1935A) were deployed at all three depths (approximately 10 cm above the bottom) and a surface sensor (LI-1905A) was used to measure surface insolation. The integrated data was collected every ten minutes using LI-1000 data loggers for the entire sampling period of twenty-six days. The fouling strips were sampled every six to seven days for four weeks. After the first six days one strip was removed from each sampling frame and replaced with a new epiphyte strip. After twelve, nineteen, and twenty-six days, two strips were removed and one strip was replaced. This permitted measurements of both the total amount of periphyton fouling for up to twenty-six days and comparison of one-week initial rates of periphyton growth throughout the study period. Once collected, the epiphyte strips were transported back to the laboratory for measurement in separate PVC pipe tubes filled with 1 $\mu$  filtered seawater

Light attenuation due to periphyton fouling was measured using a "Light Attenuation Measurement Apparatus" or "LAMA." A LI-1925A underwater light sensor was used to

measure the amount of light passing through each plastic strip with attached epiphytes from an artificial stationary light source. Each epiphyte strip was then placed on a supporting surface in a water bath under the light. Three light measurements were taken through the middle one-third section of the strip. Finally, all strips were completely scraped of periphyton. The periphyton were placed in filtered seawater and well mixed. Replicated subsamples were removed for analysis of total solids, organic solids, and chlorophyll a (Stankelis *et al.*, 1999).

Live eelgrass plants were collected from each sampling depth. Six plants were collected at each depth and divided into two replicates of three plants each. Once the eelgrass shoots were collected, the leaves were removed and separated by age, collected in plastic bags, and taken back to the laboratory in a cooler. Leaf age was estimated after Moore *et al.*, 1996, who previously measured leaf production rates at this site. Each leaf was scraped of periphyton and measured for total area. The periphyton were then placed into a 1 $\mu$  filtered seawater solution and measured for chlorophyll a and total solids using the same methods as those used with the epiphyte strips.

Water quality data collected on June 11, June 25, and July 9, 2002, from the York River at Gloucester Point, Virginia, were incorporated into a model used to predict photosynthetically available radiation (PAR) at the leaf surface of underwater plants. Dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), total suspended solids (TSS), and the PAR coefficient  $K_d$  from each sampling date were entered into the model for each sampling depth. The predicted amounts of periphyton total solids, chlorophyll a, and percent light reduction at the leaf surface were then determined (Batiuk *et al.*, 2000).

Statistically, means of periphyton accumulation and light availability among the sampling periods and among depths were compared using two-way ANOVA. The main factors for the ANOVA were depth and sampling date. When the ANOVA showed significant differences ( $P < 0.05$ ), individual depths were compared using Fisher's post-hoc multiple comparison test. Total periphyton accumulation was also compared among epiphyte strips, live plants, and the predicted rates from the PAR model. Finally the relationships between periphyton fouling and light availability were determined using regression analysis.

## RESULTS

As time increased over the twenty-six-day sampling period, there were significant increases ( $P < 0.0001$ ; Table 1) in total accumulation of chlorophyll a on the plastic epiphyte strips (Fig. 1). This increase over time occurred at each sampling depth. The depth of the strips made no significant difference ( $P > 0.05$ ) in chlorophyll a accumulations over all three sampling depths for the first twelve days of exposure. After nineteen and twenty-six days of exposure, chlorophyll a accumulations were significantly higher ( $P < 0.0001$ ) at the 0.95 and 1.45 m depths than at the 0.4 m depth. Weekly accumulation rates showed significant differences over time ( $P < 0.0001$ ) and depth ( $P < 0.0001$ ). However, no one depth showed consistently higher weekly chlorophyll a accumulations than the other two depths. Chlorophyll a levels varied at each depth for the entire sampling period. When used to predict chlorophyll a levels, weekly accumulation rates were not accurate after nineteen days of exposure (Fig. 1). Weekly accumulation rates underestimated total chlorophyll a accumulation at all three sampling depths after nineteen days of exposure and overestimated after twenty-six days of exposure.

Total solids (TS) also showed significant increases ( $P < 0.0001$ ) in accumulation over time and depth (Fig. 2). TS accumulation increased at all sampling depths for the entire twenty-six-day sampling period. Differences in accumulation among the three sampling depths occurred

after nineteen days of exposure. At this time, both the 0.95 m and 1.45 m sampling depths had significantly higher levels of TS than the 0.4 m depth. Also, the 1.45 m site accumulated more TS than the 0.95 m site. Similar to chlorophyll a, the weekly TS accumulation rates showed significant differences over time ( $P < 0.0001$ ) and depth ( $P < 0.0001$ ) (Figs. 1 and 2). Again, one sampling depth did not show consistently higher TS levels than the other depths. Also, comparable to chlorophyll a, the weekly TS accumulation rates did not accurately predict total accumulation after nineteen days of exposure. After nineteen days TS was overestimated for all sampling depths except for 1.45 m on day 26. On this sampling date the total accumulation of TS was significantly underestimated (Fig. 2).

In contrast to the epiphyte fouling strips, chlorophyll a levels from epiphytes collected from the surface of individual eelgrass leaves decreased over depth. Chlorophyll a levels for all three leaf ages (approximately six, twelve, and eighteen days) were the highest at the 0.4 m depth and decreased until reaching their lowest levels at the 1.45 m depth. Over all three depths the twelve and eighteen-day-old leaves had significantly higher chlorophyll a levels than leaves that were approximately six days old. There was no significant difference ( $P > 0.05$ ) in chlorophyll a levels between leaves that were approximately twelve and eighteen days old.

When compared, mean chlorophyll a accumulation was markedly higher in the eelgrass samples than that measured from the epiphyte strips collected after twelve days or predicted by the PAR model. The greatest difference between the samples occurred at the 0.4 m site, where the mean chlorophyll a accumulation of the eelgrass sample was  $343.58 \mu\text{g}/\text{cm}^2$ , the mean epiphyte strip accumulation was  $58.21 \mu\text{g}/\text{cm}^2$ , and the model prediction was  $1.4 \mu\text{g}/\text{cm}^2$ . There was little difference in the chlorophyll levels between the epiphyte strips and the PAR model. Both the eelgrass samples and the PAR model show chlorophyll a levels decreasing with depth. The epiphyte strips did not show any trend in chlorophyll a accumulation over depth.

Total solid levels in epiphytes scraped from the surface of individual eelgrass leaves showed no significant change over depth (Fig. 3). The highest TS levels for six-day-old leaves occurred at a depth of 0.95 m, twelve-day-old leaves at a depth of 0.4 m, and eighteen-day-old leaves at a depth of 1.45 m. Therefore, no relationship between depth and TS accumulation was demonstrated by the eelgrass shoots. Total solid levels increased with the age of the individual leaves. This increase was supported at all sampling depths, with the greatest difference occurring at the 1.45 m sample. At this depth leaves that were eighteen days old showed TS levels of  $10.8 \text{ mg}/\text{cm}^2$  and leaves that were twelve days old showed TS levels of only  $3.5 \text{ mg}/\text{cm}^2$  (Fig. 3).

When compared, total solid levels between the eelgrass and epiphyte strip samples collected after twelve days showed similar accumulations over all three depths (Fig. 4). The greatest difference in TS levels occurred at 1.45 m; eelgrass concentrations were  $5.6 \mu\text{g}/\text{cm}^2$  and epiphyte strip concentrations were  $4.4 \mu\text{g}/\text{cm}^2$ . The PAR model underestimated TS accumulations for all depths. The greatest difference between eelgrass and epiphyte strips and the PAR model also occurred at 1.45 m. Eelgrass and epiphyte strips accumulated TS loads of  $5.6 \mu\text{g}/\text{cm}^2$  and  $4.4 \mu\text{g}/\text{cm}^2$  respectively, whereas the model predicted TS accumulations of only  $1.0 \mu\text{g}/\text{cm}^2$  (Fig. 4).

The relationship between epiphyte dry weight accumulation ( $\text{mg}/\text{cm}^2$ ) and percent light attenuation can be best expressed by an “exponential rise to maximum” model from Sigma Plot shown in Fig. 5 ( $r^2 = 0.84$ ). As the dry weight increased, the percent attenuation increased exponentially. This relationship continued until dry weight reached levels between 10 and 15  $\text{mg}/\text{cm}^2$ . At this accumulation level, percent attenuation reached 100 percent and stabilized. The average epiphyte dry weight measured from the epiphyte strips at the 0.95 m depth after twelve days was  $4.1 \text{ mg}/\text{cm}^2$ . According to the relationship found here between dry weight

accumulation and percent attenuation, the light attenuation at the surface of the epiphyte strip was 69 percent. After nineteen days at the same depth the average epiphyte dry weight was 8.8 mg/cm<sup>2</sup>. Percent attenuation at the epiphyte strip surface was 91 percent (Fig. 5).

Light levels (PAR mol/m<sup>2</sup>/day) measured above the water surface (deck) and at the 0.4 m, 0.95 m, and 1.45 m depths varied throughout the entire twenty-six-day sampling period (Fig. 6). On average, 74 percent of available light reached the light sensor at the 0.4 m depth, 40 percent reached the 0.95 m depth, and 19 percent reached the 1.45 m depth. On days 10 (June 23, 2002) and 26 (July 9, 2002), the 0.4 m light reading was higher than the deck reading. On these dates low tide was approximately 0.0 m MLLW and the 0.4 m light sensor was observed to be out of the water (<http://www.co-ops.nos.noaa.gov>, 2002) (Fig. 6).

#### DISCUSSION

Overall accumulation of epiphytes, measured as both TS mg/cm<sup>2</sup> and chlorophyll a µg/cm<sup>2</sup>, occurred in greater amounts at the mid (0.95 m) to deep sampling depths (1.45 m) where light availability was lower than at the 0.4 m depth. This is contrary to what was initially predicted and is supported by both total and weekly TS and chlorophyll a accumulation rates over the twenty-six-day sampling period (Fig. 1 and 2). During collection of samples from the York River, several physical factors were observed that could have influenced total accumulation of TS and chlorophyll a on the epiphyte strips at the various depths. The most influential was wave and tidal action. The epiphyte strips located at the 0.4 m depth were exposed to the greatest wave action, and this could have physically removed epiphytes from the strips. The waves and current also carried debris such as dead eelgrass leaves and various species of seaweed that were observed to wrap around the strips at the 0.4 m depth. In addition, on day 10 and day 26 low tides reached approximately 0.00 m MLLW (<http://www.co-ops.nos.noaa.gov>, 2002). During these low tides the epiphyte strips at the 0.4 m depth were completely out of the water and exposed. This decreased the amount of time the epiphytes had to attach onto the epiphyte strip and may have removed some of the epiphytes that had already accumulated on the strips previous to the low tide (Fig. 1 and 2).

Data collected from epiphyte strips in this investigation suggest that epiphyte chlorophyll a accumulation is not light limited. These data show that more chlorophyll a accumulated at either the 0.95 m and 1.45 m depths than the 0.4 m depth after only twelve days of exposure (Fig. 1). However, after the same approximate time of fouling, the eelgrass samples and PAR model do not support this conclusion. Both show chlorophyll a levels to be significantly higher at the 0.4 m depth than at either of the two deeper depths. Overall, the average percentage of incident light measured in this study decreased from 74 percent at 0.4 m, to 40 percent at 0.95 m (a difference of 34 percentage points), and finally to only 19 percent at 1.45 m (a difference of 55 percentage points) (Fig. 6). Similarly, the amount of chlorophyll found on the eelgrass samples at the 0.95 m depth was 34 percent less than the amount of chlorophyll found at the 0.4 m depth and the amount of chlorophyll found at the 1.45 m depth was 55 percent less than amount of chlorophyll a found at the 0.4 m depth. This pattern is seen again in the PAR model. The amount of chlorophyll projected at the 0.95 m depth is 32 percent less than that at the 0.4 m depth, and the amount of chlorophyll found at the 1.45 m depth is 60 percent less than at the 0.4 m depth. Thus the chlorophyll data from the eelgrass samples and the data predicted by the PAR model suggests that epiphyte chlorophyll a accumulation is light limited.

Several factors could have affected the accumulation of chlorophyll a on the epiphyte strips and caused this discrepancy. As stated before, physical influences may have decreased the overall accumulation of chlorophyll a on the strips relative to the model. The actual shape of the epiphyte strips could have also influenced the lower chlorophyll a level relative to the eelgrass

leaves. The length and width of an average epiphyte strip was approximately 12.7 x 2.6 cm compared to an eelgrass leaf that is approximately twelve days old with an approximate length and width of 20.0 x 0.3 cm. The greater width of the epiphyte strips could have increased sedimentation patterns, which then decreased the amount of diatoms and algae that settled and grew on the epiphyte strips, and therefore decreased the total amount of chlorophyll a present. The physical factors combined with the different shape of the epiphyte strip would have had the greatest impact on the strips found that 0.4 m depth and could then account for the decreased level of chlorophyll a.

As expected, total accumulation of chlorophyll a and TS increased over time (Figs. 1 and 2). Total solids showed a significant increase throughout the entire twenty-six-day sampling period with no signs of a plateau at the 0.95 m and 1.45 m depths (Fig. 2). The net actual accumulation of total solids was markedly less than the gross projected accumulation (bars less than dots; Fig. 2) at the 0.4 m and 0.95 m depths. This suggests that some removal mechanism was affecting total accumulation at the two shallowest depths. At the 0.4 m depth the much lower TS accumulation over time suggests that the physical limiting factors were greatest here. The high levels of net TS, compared to gross, accumulation at 1.45 m after twenty-six days may have been related to growth of small barnacles and other invertebrates on the strips. Stankelis (per. comm.) repeated similar fouling on longer-term deployed strips in the Patuxent River, Maryland. At the 0.4 m and 1.45 m depths chlorophyll a levels increase steadily over the first twelve to eighteen days (Fig. 1). However, after nineteen days of exposure, chlorophyll a levels at the 0.4 m depth stabilized at around 600.0  $\mu\text{g chl/cm}^2$  until the end of the twenty-six-day sampling period. The same pattern was observed at the 1.45 m depth. After nineteen days of exposure, chlorophyll levels at this depth remain around 800.0  $\mu\text{g chl/cm}^2$ . The chlorophyll a levels measured at the 0.95 m depth are thought to be higher than normal due to large amounts of macroalgae accumulation on the epiphyte strips by nineteen days of exposure. The algae accumulation could have increased the chlorophyll a levels at that time. This hypothesis is supported by the decrease in chlorophyll a levels after twenty-six days of exposure, when no macroalgae were observed on the epiphyte strips (Fig. 1). Unlike the patterns of net and gross TS accumulation, the net and gross chlorophyll a accumulations (Fig. 1) were more similar. Changes in the composition of the algal epiphyte community over time have been observed. Initial development of diatom assemblages is replaced by other microalgae, then macroalgae, as the substrate or leaf age increases. This change in composition further complicates the patterns of chlorophyll a accumulation.

Eelgrass leaves in the York River at this site have been found to produce approximately one leaf every ten days at this time of year (Moore et al., 1996). It is hypothesized that the youngest leaf is responsible for producing the highest amount of chlorophyll a in the entire eelgrass plant. The mean epiphyte accumulation on the eelgrass leaves after six days of exposure was 1.9  $\text{mg/cm}^2$  at 0.4 m (Fig. 3). According to the relationship between epiphyte dry weight and percent light attenuation (Fig. 5), after only six days of exposure at a depth of 0.4 m, light attenuation at the leaf surface equals 42 percent. If eelgrass plants are primarily relying on the youngest leaf for chlorophyll a production, then they are only able to use 58 percent of available light. The average available light for the entire sampling period was the highest at the 0.4 m depth with 74 percent available light. Therefore, after six days of exposure only 43 percent of available light can be used by eelgrass (Fig. 6). This suggests that epiphyte fouling is a very important factor affecting existing and potential eelgrass survival in this region.

In conclusion, based on the data from the eelgrass samples and PAR model, epiphyte chlorophyll a accumulation is light limited. However, TS epiphyte accumulation is not light limited and accumulates in large enough quantities after only six days to reduce light availability to the eelgrass leaf surface by 42 percent at even the shallowest depths. This doubles the light limitation factor influencing eelgrass. In addition, the epiphyte model developed and published by EPA, Chesapeake Bay Program (Batiuk *et al.*, 2000) appears to underestimate both the TS and chlorophyll a accumulations as compared to the actual eelgrass sampled here. Differences in epiphyte accumulations among depths, time, degree of exposure, and substrate types suggest that many factors interact to effect the rates of substrate fouling in shallow waters.

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