Physiological Responses of Red Mangroves in the Florida Everglades to Physical Climate

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Introduction

In this research, we test the hypothesis that forests can augment their carbon sequestration by modifying the environmental irradiance at the ecosystem scale through the presence of clouds and aerosols. This hypothesis will be tested through two investigations. First, we will establish the source strength of terpenes from the mangrove ecosystem. Terpenes are photo-oxidized in the atmosphere and condense to form secondary organic aerosols (SOAs) (**Figure 1**), which can produce a positive feedback effect on plant carbon uptake as aerosols modify the incoming light into diffuse irradiance. We will determine the physiological characteristics of the mangroves. This information will be incorporated in a biospheric model to study the 2-way interactions between forests and local atmosphere. Here, we present the results from field measurements of July and August 2001 to learn the physiological characteristics of mangroves in the Everglades.

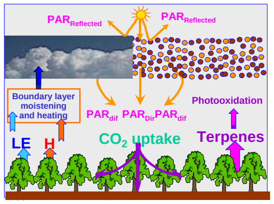

Figure 1. Feedback Mechanisms Between Forests and Climate

Field Measurements

Air samples from cuvette enclosed mangrove foliage were collected in 3.2 L electropolished stainless steel canisters. Samples were analyzed for biogenic hydrocarbons using gas chromatography coupled with a mass selective detector. Carbon dioxide and water vapor fluxes (**Figure 2**) at the foliage level were made on red mangrove leaves (Rhizophora mangle L.) along precipitation and salinity gradients within Florida Bay (**Figure 3**). Done at Key Largo, these measurements included net photosynthesis (A_N), transpiration (Trans), and stomatal conductance of water vapor (g_s). Concurrent meteorological measurements were made from a nearby 10-m tower.

Figure 2. LiCor 6400 Cuvette and Sensor Head

Figure 3. Field Sites within Florida Bay

Results

The mangrove ecosystem emits isoprene and several terpene compounds (**Figure 4**). The hydrocarbon source strength is weak and likely insufficient to produce high yields of aerosol formation. Therefore, the feedback mechanism identified in Figure 1 may not be present over the mangrove forests. Available PAR is suppressed on July 26 (mostly overcast conditions), yet net photosynthesis (**Figure 5**) compares favorably to rates on both August 7 (**Figure 6**) (partly cloudy) and August 13 (**Figure 10**) (mostly cloudless). On all 3 days, maximum rates are achieved around 10 am local time, before maximum levels of PAR are reached (**Figure 7** and **Figure 8**). In response to high midday PAR levels on August 7 and August 13 compared to July 26, transpiration and stomatal conductance increase to remove energy from leaves and maintain favorable temperatures.

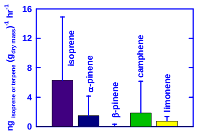

Figure 4. Average Fluxes of Isoprene and Selected Terpenes from Mangroves

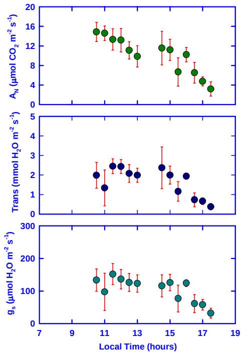

Figure 5. Diurnal Trends of Net Photosynthesis, Transpiration, and Stomatal Conductance Key Largo – July 26, 2001

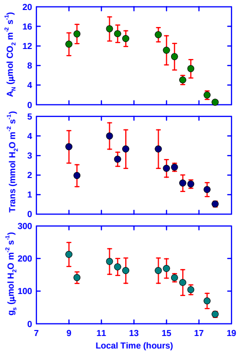

Figure 6. Diurnal Trends of Net Photosynthesis, Transpiration, and Stomatal Conductance Key Largo – August 7, 2001

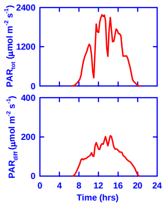

Figure 7. Diurnal PAR Trends August 7, 2001

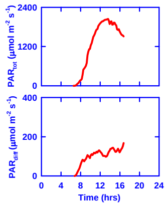

Figure 8. Diurnal PAR Trends August 13, 2001

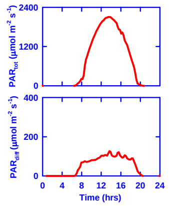

Figure 9. Diurnal PAR Trends July 19, 2001

Mangrove forests received comparable amounts of PAR on August 13 (**Figure 8**) and July 19 (**Figure 9**). Net photosynthetic and transpiration rates for the dwarf mangroves at Taylor River were suppressed by greater than 5 times around midday on July 19 (**Figure 11**) compared to rates measured at Key Largo (**Figure 10**). When modeling carbon sequestration, dwarf mangroves need to be treated differently from 'tall' mangroves as dwarfs clearly exhibit much reduced carbon dioxide and water vapor exchange rates.

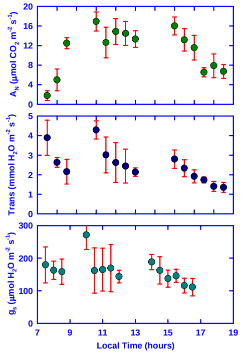

Figure 10. Diurnal Trends of Net Photosynthesis, Transpiration, and Stomatal Conductance Key Largo – August 13, 2001

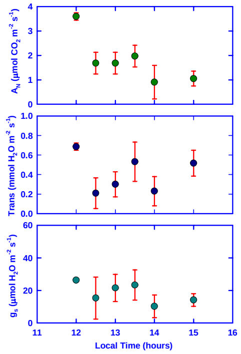

Figure 11. Diurnal Trends of Net Photosynthesis, Transpiration, and Stomatal Conductance Taylor River, Dwarf Mangroves, July 19, 2001

Under favorable climatic conditions, photosynthetic rates varied with PAR according to Michaelis-Menten kinetics (**Figure 12**). The average photosynthetic efficiency (α) and the light saturation point (P_m) were computed . On July 24, a very different trend was observed (**Figure 13**). Around midday with PAR levels near maximum, photosynthetic rates and stomatal conductance declined sharply. Cloudless conditions and high air temperatures contributed to water stress prompting the mangrove leaves to close their stomata. This response resulted in increased afternoon leaf temperatures despite efforts to maintain a constant leaf temperature of 30 C with our measurement system.

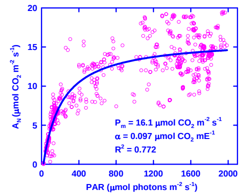

Figure 12. Net Photosynthesis Response to PAR - August 13, 2001

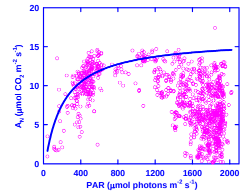

Figure 13. Net Photosynthesis Response to PAR -July 24, 2001
(regression uses parameters from Figure 12)

Suppressed photosynthetic rates of dwarf mangroves correspond to low light use efficiency (LUE) levels (≅ 2 μmol mol^{-1} photons) (**Figure 15**). The dwarfs maintain comparable water use efficiency (WUE) levels as the 'tall' mangroves at Key Largo (**Figure 14**). Regardless of species, the mangroves exhibit a nearly constant and relatively high (8 μmol $mmol^{-1}$) WUE during the middle of the day. The WUE is low during the low-light periods, namely in the early morning (before 10 AM) and late afternoon periods. These WUE patterns are controlled by the stomatal dynamics .

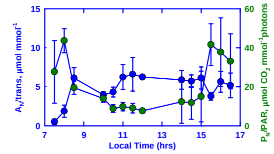

Figure 14. Diurnal Measures of Water and Light Use Efficiencies Key Largo – August 13, 2001

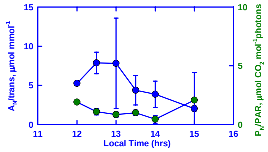

Figure 15. Diurnal Measures of Water and Light Use Efficiencies Taylor River – July 19, 2001

Outside of Taylor River, physiological responses of mangrove foliage to local climate can be described by several key characteristics (**Table 1**). These include the maximum Rubisco capacity per unit leaf area (V_{cmax}), light-limited carbon assimilation rate (J_{max}), daytime ($R_{daytime}$) and nighttime ($R_{nighttime}$) respiration rates, and the Ball and Berry (Collatz et al., 1991) slope (m_{bb}) and intercept (b_{bb}). Ball and Berry parameters are used to predict stomatal conductance (**Figure 16**) and thus water vapor exchange from net photosynthetic rates.

Table 1. Summary of Photosynthetic Characteristics

Parameter	V_{cmax}	J_{max}	$R_{daytime}$	$R_{nighttime}$	m_{bb}	b_{bb}
Mean	80.0	87.3	6.94	1.72	4.33	0.023
± σ	± 20.0	± 29.2	± 2.05	± 0.61	± 2.28	± 0.036

Units: V_{cmax}, $R_{daytime}$, $R_{nighttime}$ in μmol CO_2 m^{-2} s^{-1}, J_{max} in μmol electrons m^{-2} s^{-1}, T_{leaf} = 30 C, m_{bb} is unitless, b_{bb} in mol H_2O m^{-2} s^{-1}

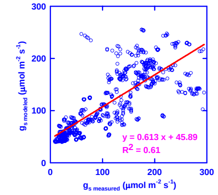

Figure 16. Stomatal Conductances Predicted by the Ball and Berry Model Key Largo – August 7, 2001

Discussion and Conclusions

I. The biogenic aerosol driven portion of the feedback loop identified in Figure 1 may be of minor importance for the mangrove ecosystem. However, sea salt or other aerosols may constitute an important driver for the radiative feedback over this ecosystem.

II. The water vapor and cloud formation portion of the feedback mechanism is of critical importance to this ecosystem. We presented evidence in this poster that clouds act to enhance diffuse PAR and also act to prevent water stress during cloudy conditions.

III. Dwarf mangroves exhibit low rates of gas exchange but their WUE is comparable to the WUE for the 'tall' mangroves.

IV. Mangrove physiological characteristics are similar to those found for deciduous tree species (Wilson et al., 2000), but photosynthetic rates are larger than the quantities previously reported for red mangroves (Lin and Sternberg, 1992).

V. Based on physiological characteristics of this ecosystem, assimilation of carbon dioxide through gross photosynthesis is 57 metric tons carbon ha^{-1} yr^{-1}. In reality, gross photosynthesis is lower than this value since we have not accounted for water stresses, lower physiological activity during winter months, and entirely overcast days. Still, this value is of the same order as the gross photosynthesis (30.4 metric tons carbon ha^{-1} yr^{-1}) measured over a tropical forest in central Amazonia, Brazil (Malhi et al., 1998; Malhi and Grace, 2000).

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Acknowledgements

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