An Ecological Model of Seagrass Dynamics in Florida Bay: Hypothesis Testing and Sensitivity Analysis

A.A. McDonald (amcdonal@sfwmd.gov)
C.J. Madden (cmadden@sfwmd.gov)

Coastal Ecosystems Division
South Florida Water Management District

Introduction

Florida Bay is a subtropical, karstic estuary that receives fresh water input from the Florida Everglades. To understand mechanisms of seagrass growth, production, distribution and community structure in the bay, an ecological model of Thalassia testudinum dynamics was developed. There are two primary objectives of the model:

- to predict quantitative effects of proposed Everglades restoration plans to be implemented by water management agencies;
- to understand the ecology of seagrasses and causes of seagrass die-off.

Here, we present four applications of the model to demonstrate its versatility and the types of analyses that are being performed in support of Florida Bay restoration.

Conceptual Model

Basins in Florida Bay vary in the relative influence of controls on seagrass production. There is a gradient of increasing concentrations of salinity and sediment depth from east to west with the westernmost basin having the most fresh and most nutrient-rich environment. Nutrient limitation is the dominant control for all basins.

The relative impact of additional controlling factors was determined by sequentially removing the influence of seagrass growth rate imposed by each of the potential stressors: salinity, light, sulfides, and temperature. Model sensitivity was quantified as the % increase in net annual production (NAP) resulting from optimization of the controlling factor.

The four stresses examined, Little Madeira, impacted by low salinity, low light, higher organic input and cooler temperature is most constrained. Rankin Lake, subjected to higher nutrients and epiphyte loads, showed light to be the most significant control. Rabbit Key Basin has a stable seagrass salinity regime, rendering other controlling factors more significant, but the overall environment in Rabbit is more benign than other basins, reflected in higher biomass accumulation (see calibration figures on this poster).

Sensitivity Analysis of Factors Controlling Production

Hypotheses testing for 1992 Biomass Decline

In late 1992, data from several basins reflect a sharp decline in Thalassia testudinum biomass coincident with the passage of Hurricane Andrew. In August 1992, the Rabbit Key Basin model reproduced the possible mechanisms for the decline in biomass via two potential impacts of a strong storm affecting Florida Bay:

- Removal of 25% of biomass
- Optical reduction of photosynthesis by 10% and reduction of sulfide by 10% through increased aeration and oxidation.

Simulation of a wind event

Wind creates a shearing force at the sediment surface resulting in mechanical detachment of above ground seagrass biomass and perturbation of surficial sediments:

- Removal of 25% of biomass
- Optical reduction of photosynthesis by 10% and reduction of sulfide by 10% through increased aeration and oxidation.

Simulation of increased land run-off

Increased flow of water from precipitation may have resulted in nutrient additions to the bay and subsequent changes in seagrass biomass:

- Increase in chlorophyll a concentrations from 0.5 to 2.0 µg/l, thereby increasing organic input to sediments.

Spatial Variability Within Basins

To investigate the influence of local heterogeneity within basins, and to validate the model, the calibrated model for inner Little Madeira Bay was applied to a second location in the outer bay that is exposed to different environmental forcings. Simulations applied local salinity, water temperature, and water column nutrient concentration data from two sites within Little Madeira Bay:

- Inner Bay (ranked lake)
- Outer Bay (rabbit key basin)

Figure 1: Florida Bay conceptual model.

Study Sites

Three site-specific models were calibrated that include a range of community types and environmental conditions: 1) in the northern transition zone with direct freshwater input (Little Madeira Bay); 2) in the western central bay with more oceanic influences (Rabbit Key Basin); and 3) in an intermediate region which experiences hypersalinity events (Rankin Lake).

Model Specifications

- dt: 3 hrs
- 1st order, spatially averaged unit model, basin-specific
- units: mg C m⁻²
- MATLAB platform

Acknowledgements

Data used in this study provided by J. Zieman (UVA), J. Boyer (FIU-SERC), M. Koch (FAU), T. Frankovich (UVA), E. Bricker (UVA), M. Durako (UNCW), J. Fourqurean (FIU), W.M. Kemp (UMD), Florida Coastal Ecosystems Program, and the U.S. Geological Survey.

Summary

This model of seagrass dynamics in Florida Bay allows the exploration of hypotheses that would be impossible to examine through empirical experiments. Model simulations can separate the effects of environmental parameters that are often correlated or confounding and can identify possible mechanisms of changes in seagrass community structure due to climate, management, or stochastic events. Multiple sites within basins can be modeled to produce fine-scale understanding of spatial variability in seagrass production within the bay.

Figure 1: Florida Bay conceptual model.

Figure 2: Calibration results for Rankin Lake.

Figure 3: Map of Florida Bay basin sites displaying the relative impacts of controlling factors on seagrass production.

Figure 4: Salinity curve (1990-2000) used as a forcing function for Rankin Lake model with the average hypersalinity (40-50) event lasting for 40-50 days. This curve is an average of monthly salinities over a 10 year period centered on May 15. Dotted grey lines are one standard deviation.

Figure 5: Flaring peak salinity while holding the duration of the hypersalinity event constant resulted in a decrease in net annual production. At 60 psu, net annual production was negative.

Figure 6: Shifting the salinity curve from the base case centered on May 15 caused significant changes in seagrass productivity. Moving the event forward resulted in a decrease in net annual production because hypersalinity stressed plants in the critical early summer growing season. Earlier salinity stress also increased Vannamei shrimp mortalities associated with the cold temperature stress from early in the year. Delaying the salinity stress 15 and 30 days resulted in a return between temperature and salinity stresses and an increase in biomass.

Figure 7: Results from changing duration of a hypersalinity event that peaked at 60 psu from the base case of 49 days to 60 and 30 d. Shorter periods of exposure to high salinities increased the net annual production.

Figure 8: Initial calibration of Rabbit Key Basin without considering storms. Data show a rapid biomass decline coincident with the passage of Hurricane Andrew.

Figure 9: Simulation results incorporating both a wind event and a persistent algal bloom closely fit the calibration data. In August 1992, a persistent algal bloom began due to the increased runoff caused by Hurricane Andrew. The hurricane also elevated wind speeds in the bay causing shearing of above-ground biomass.

Figure 10: Simulation results incorporating both a wind event and a persistent algal bloom closely fit the calibration data. In August 1992, a persistent algal bloom began due to the increased runoff caused by Hurricane Andrew. The hurricane also elevated wind speeds in the bay causing shearing of above-ground biomass.

Figure 11: Map of the two sites in Little Madeira Bay used for simulations with continuous data sets starting in 1990.

Figure 12: Comparison of nutrient and salinity data from the inner and outer Little Madeira Bay sites used to investigate heterogeneity.

Figure 13: Using the same calibration but different environmental conditions for two points in Little Madeira Bay, the model yielded the appropriate sensitivity to determine the optimum environmental conditions for seagrass growth. This indicates that the other parameters are relatively uniform across the bay.

Figure 14: Model simulations show that epiphyte loads may be partly responsible for the decrease in seagrass standing stocks at the outer Little Madeira Bay site. Application of an additional factor enhancing inner bay production may be a higher organic matter content (not pictured) yielding higher nutrient concentrations in the sediment.