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Modeling Sea Level Rise Impact on Coot Bay Hammock, Florida Everglades

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Abstract

The low-lying Florida Everglades ecosystem maintains a delicate dynamic balance between freshwater and seawater. Hence, the Everglades is vulnerable to sharp salinity alterations induced by climate variations. The associated increase in surface seawater inundation and subsurface saltwater intrusion will reduce the availability of fresh groundwater. This would pose a risk to the Floridan surficial aquifer that provides potable water supply for millions of inhabitants in Florida. The increased salinity and decreased freshwater inputs will also alter coastal ecosystems by facilitating the establishment and encroachment of plants with higher salinity and flooding tolerance. In the Florida Everglades, coastal hardwood hammocks are particularly

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vulnerable to saltwater intrusion induced by sea level rise (SLR). This paper aims to project a possible change in the Coot Bay Hammock of Florida Everglades subject to gradually rising sea level. For this purpose, the simulation model MANTRA is enhanced to simulate the vegetation zonation pattern at a cross section of Coot Bay Hammock in this paper. MANTRA couples two USGS models MANHAM and SUTRA. Model simulation reveals SLR could cause a regime shift from the glycophytic hardwood hammocks to the halophytic mangroves.

1 Introduction

Global climate change and the associated sea level rise (SLR) present major challenges to the functioning and persistence of South Floridas existing coastal ecosystems. The challenges arise due to a combination of flat topography, porous limestone aquifers, and aging flood control facilities. SLR in South Florida has accelerated to 3-4 mmyr^{-1} faster than the reported rate in the previous three millennium [1]. Intensified seawater inundation and saltwater intrusion induced by SLR pose a significant threat to the Floridan surficial aquifer, which is a primary source of potable water supply for the state of Florida. Already, several public water supply wells in Florida have been abandoned due to saltwater contamination [2], thereby threatening the sustainability of local water security (SDG6). In South Florida, gentle elevation gradient partitions vegetation into two distinct elevations. Mangroves occupy lower elevations around sea level, while hardwood hammocks tend to dominate at slightly higher elevations of between 1 to 2 m above sea level. The transitional boundaries between the plant communities are relatively sharp. Increased salinity stress due to higher sea levels has been causing replacement of coastal upland freshwater communities by salt-tolerant and flood-tolerant wetland communities such as mangroves. Since 1940, it has been documented that the mangrove zones have migrated 1.5 km and 3.5 km inland in the Key West and Florida Bay areas respectively [3]. There is strong evidence that this salinization process is being further exacerbated by upstream water management practices, which reduce the amount of freshwater flowing through the Florida Everglades [4]. It has been reported that only 30 % of coastal areas in the Florida state have been set aside for conservation [5]. Therefore, effective climate change mitigation and adaptation (SDG13) strategies for restoring the South Florida ecosystem are critically needed.

Launched in 2000, the Comprehensive Everglades Restoration Plan (CERP) aims to restore the hydrological systems of South Florida and to reverse the compositional and structural changes in its coastal wetlands. However, predicting the success of such a restoration project is challenging. Climate-driven changes in salinity in the natural system may be larger than salinity changes resulting from CERP activities. This has imparted urgency to the documentation and scientific study of the physical and biological systems in adaption to climate change. There is a need to develop a quantitative framework for assessing SLR impacts on coastal groundwater and vegetation shift in South Florida. In a previous study [6], the competing plant species is limited to two. Moreover, the impact of water deficit and inundation stresses are not explicitly modeled. In this study, MANTRA is enhanced by adding a third competing species. Further, the enhanced MANTRA explicitly models the combined effect of salinity, water deficit, and inundation stresses on the water uptake of plants. These enhancements enable an improved evaluation of the coastal landscape transformation under future SLR scenarios. The following section provides a description of the study site. Next, an overview of the enhancement made to MANTRA is provided followed by a replication of existing groundwater salinity and vegetation zonation at Coot Bay Hammock by MANTRA. Finally, the effect of SLR on the plant communities in the study site is simulated and presented, followed by some concluding remarks.

2 Study Site

The study site Coot Bay Hammock is a large tropical hardwood hammock habitat located in the southwestern part of the Everglades National Park (ENP) between Whitewater Bay and Florida Bay. Figure 1(a) shows the location of the study site, along with a 400-m wide, southwest-northeast transect B-B$'$ oriented approximately subparallel to the Coot Bay Hammock [6]. A schematic sketch of the elevation and vegetation profile along the transect B-B$'$ is shown in Figure 1(b). The tropical hardwood hammock is in the middle of slightly elevated coastal ridges (0.9-1.5 m above mean sea level (MSL)), which are formed by the deposition of calcitic marl and peat during hurricanes and storms. It is characterized by a diverse assemblage of self-maintained broad-leaved, evergreen trees (*Coccoloba diversifolia*, *Eugenia foetida*) that are usually not affected by fire or flood. The small tidal amplitude (0.15 to 0.40 m) in the Florida Bay, favors the formation of a freshwater lens and the associated reduction in soil porewater salinity that are necessary for hammock establishment and persistence [7, 8]. A mixture of halophytic prairie (*Batis*, *Salicornia*) and buttonwoods (*Conocarpus erectus*) occur at seasonally wet elevations (0.5-0.8 m above MSL). Black and white mangroves (*Avicennia germinans*, *Laguncularia racemosa*) are typically found at lower elevations surrounding the hammocks (0.4-0.5 m above MSL). The Florida Everglades ecosystem maintains a delicate balance of freshwater and seawater structure that permits the coexistence of glycophytic hardwood hammocks and halophytic buttonwoods and mangroves. Glycophytic hardwood hammocks at higher elevations tend to limit soil salinity by decreasing plant transpiration. On the other hand, mangroves maintain transpiration even at high salinity along the coasts [9]. At intermediate elevations, the dominant buttonwoods, can obtain water from brackish groundwater [10]. Any rapid changes in salinity could result in degradation of wetland habitats, which in turn can affect the species distribution and abundance. Hence, Coot Bay Hammock is a study site appropriate for studying how SLR can impact the dynamics of vegetation competition in the tropical South Florida. The computational setup (Figure 2) of the study site is presented in Section 4 after the following description of the simulation model.

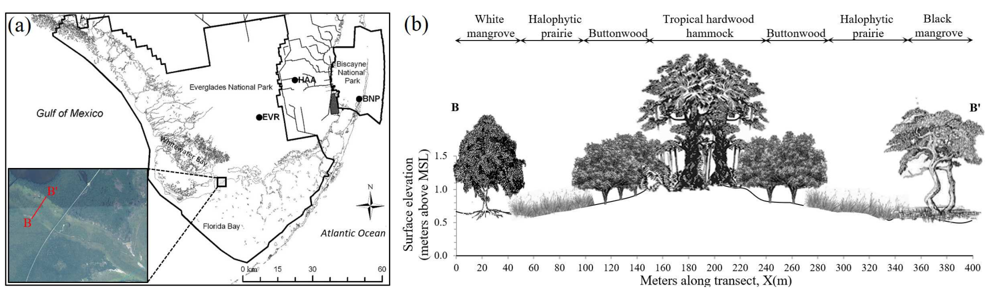

Figure 1: (a) South Florida with study site Coot Bay Hammock shown in black box. Regional study area map showing the location of transect B-B$'$. (b) Elevation and vegetation profile along cross section B-B$'$ [6].

3 MANTRA Model

MANTRA couples two USGS simulation models MANHAM and SUTRA. MANHAM simulates coastal vegetation growth in an environment of changing salinity. SUTRA simulates groundwater flow and transport of solutes including salt [11]. The MANHAM model was originally developed to simulate the long-term vegetation evolution of two vegetations competing along salinity gradients for light and tolerances to salinity [12]. The biomass (B_{Ci})

of the plants depends on the plants gross productivity (U_{Cvi}), respiration (M_{Cvi}) and litterfall (L_{Cvi}).

$$\frac{dB_{Ci}}{dt} = U_{Cvi} - M_{Cvi} - L_{Cvi}. \tag{1}$$

In MANHAM, the underlying groundwater dynamics beyond the vadose zone are not explicitly modeled in MANHAM. To overcome this, MANHAM was dynamically coupled with SUTRA to produce MANTRA (MANham; suTRA). The coupled model MANTRA has the capability to model subsurface hydrology and salinity transport, and their impact on vegetation succession. The main drivers are scenarios of climate change, SLR, coastal hydrology and topography.

The Coot Bay Hammock transect fundamentally divides vegetation into four zones: (i) mangroves, (ii) buttonwoods, (iii) halophytic prairies, and (iv) hardwood hammocks. Therefore, there is a need to expand the number of competing species in MANTRA for this simulation study. It is currently unknown how long the buttonwoods and halophytic grasses can rely on brackish water. Their photosynthetic capacity may be reduced significantly in brackish water to undermine biomass production and plant growth. But due to their similar level of salinity tolerance in the Florida Everglades [13, 14], buttonwoods are aggregated with the halophytic prairies in this study. Hence, MANTRA is enhanced to include a third competing species with the aim to provide a more realistic evaluation of the coastal landscape transformation under future SLR scenarios.

Equations (2) and (3) show the modified fluid and solute mass balance equations in MANTRA. The vegetation zonation, groundwater salinity and soil saturation profiles in Figure 3 and Figure 4 are obtained from solving Equations (1), (2) and (3). Spatial discretization is performed by standard Galerkin finite quadrilateral elements while temporal discretization is performed by a weighted difference method [11].

$$\begin{aligned} &(S_w \rho S_{op} + \epsilon \rho \frac{\partial S_w}{\partial p})\frac{\partial p}{\partial t} + \epsilon S_w (\frac{\partial \rho}{\partial C})\frac{\partial C}{\partial t} \\ &-\nabla.[(\frac{k k_r \rho}{\mu})(\nabla p - \rho g)] = Q_p - \sum_{i=1}^{3} Q_{plant,i}, \end{aligned} \tag{2}$$

$$\begin{aligned} &\frac{\partial(\epsilon S_w \rho C)}{\partial t} + \nabla.(\epsilon S_w \rho v C) - \nabla.[\epsilon S_w \rho (D_m I + D).\nabla C] = \\ &Q_p C^* - Q_{plant,1}(C^*_{plant,1} - C) + (Q_{plant,2} + Q_{plant,3})C. \end{aligned} \tag{3}$$

Here, $-Q_{plant,i} = -\int \sum_{k=1}^{NS} \frac{Q_{plant,i,k}}{V_k} \phi_k(x,y,z)dV$ are evaluated at surface cells and are approximated cellwise with a basis function,ϕ_k where $Q_{plant,i,k} = \frac{B_{Ci,k}}{\sum_{j=1}^{3} B_{Cj,k}} R_{i,k}\, A_{s,k}\, \rho$. The water uptake rates (mmday^{-1}) by hardwood hammocks (R_1), mangroves (R_2), and buttonwoods (R_3) are given by the empirical relations (4) (6) with S_v (kgkg^{-1}) as the vadose zone salinity [7].

$$R_1(S_v) = 1.0(1 - \frac{S_v}{3.14 + S_v}), \tag{4}$$

$$R_2(S_v) = 1.5(\frac{100 - S_v}{15 + 100 - S_v}), \tag{5}$$

$$R_3(S_v) = \frac{2.83}{2 + e^{0.15(S_v - 10)}}. \tag{6}$$

In this study, soil water deficit effect on plant transpiration is incorporated using a water stress response function [15],

$$\alpha(h) = \frac{1}{1 + (h/h_{50})^2}. \tag{7}$$

In Equation (7), pressure head is represented by h (m). On the other hand, pressure head that induces a 50 % reduction in plant water uptake is represented by h_{50} (m). The effect of water potential at root surface and reduced water flow to root surface on plants water uptake is collectively simulated by the effective parameter $h_{50} = 15$ m [16]. Seawater inundation effect on plant's water uptake is incorporated as an inundation stress response function,

$$\beta(d) = \frac{1}{1 + (d/d_{50})^2}. \tag{8}$$

In Equation (8), d (m) refers to the inundation depth and d_{50} (m) is the inundation depth that induces a 50 % reduction in water uptake by plants. The pneumatophore roots of *Avicennia* mangrove species has been reported to be up to 0.30 m in height [17]. Hence, inundation stress effect on mangrove is modelled using a critical value of $d_{50} = 0.15$ m, indicating a 50 % reduction in plant water uptake at that depth. Mangrove and buttonwood communities share specialized adaptations to thrive in saline and flooded (anaerobic) environments and thus, the same critical value of $d_{50} = 0.15$ m is assumed for buttonwood. A lower value of $d_{50} = 0.075$ m is assumed for hardwood hammock with relatively lower tolerance to inundation. Salinity, water deficit, and inundation stresses were assumed to interact multiplicatively and collectively in Q_i to affect the productivity U_{Cvi} of species i [18].

$$Q_i = \alpha(h)\beta(d)\frac{R_i(S_v)}{R_i(0)}. \tag{9}$$

$$U_{Cvi} = \frac{Q_i g_{Ci} w_{Ci} SI(1 - e^{-k_i S_{CT}})}{\sum_{j=1}^{3} w_{Cj}}. \tag{10}$$

Further details of MANTRA as well as the definition and unit of the parameters in the aforementioned equations can be referred to Voss and Provost [11], Teh et al. [19, 20] and Kh'ng et al. [18].

4 Coot Bay Hammock Simulation

MANTRA is applied to assess the consequences of SLR on coastal saltwater intrusion and their associated impacts on the coastal vegetation in Coot Bay Hammock, Florida Everglades. The 400-m transect B-B$'$ is modelled as a two-dimensional domain, with distance along the transect on the x-axis and elevation on the y-axis. Figure 2(a) depicts the cross section of the coastal aquifer from southwest to northeast along the transect B-B$'$. In the model simulation, tidal and precipitation values are imposed daily. The means and standard deviations are used appropriately for representing the observed tidal and precipitation data in Florida [6, 7, 8]. Figure 2(b) illustrates the 2-D computational setup for Coot Bay Hammock simulation, along with the finite-element mesh discretization and assigned boundary conditions. The model domain is discretized into 1,620 nodes and 1,520 quadrilateral elements, with 19 vertical layers from ground surface to 9-m below MSL. The horizontal element size is 5 m while vertical elements vary between 0.05 m and 1 m. The tidal oscillations are imposed as specified pressure boundaries for all nodes below inundation level and along the seaward vertical boundary where the concentration of the inflowing fluids is that of seawater ($C = 0.03$ kgkg^{-1}). Freshwater recharge via precipitation is imposed over the surface of land. For the bottom boundary, a specified concentration of 0.03 kgkg^{-1} is imposed.

The simulation reaches steady-state after 100 years of simulation with a time step of 1 day. The spatial and temporal discretization used satisfied the Peclet (Pe) and Courant (Cr) number criteria for numerical stability. The cross-sectional views of the simulated steady-state distribution of vegetation, salinity, and saturation before SLR (existing condition) along the transect B-B$'$ is shown in Figure 3. Simulation results depict that hardwood hammocks

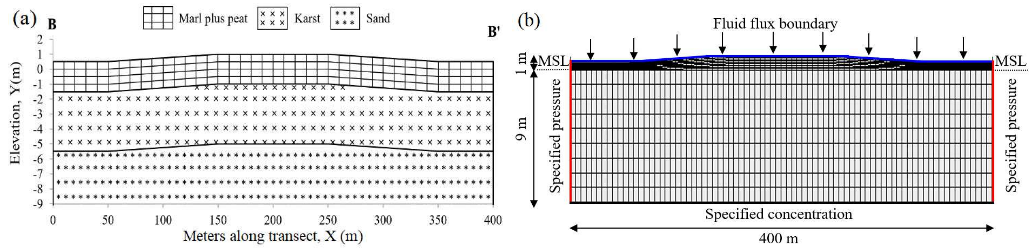

Figure 2: (a) Schematic hydrogeological cross-section of the coastal aquifer from southwest to northeast along the Coot Bay Hammock transect B-B$'$. (b) Finite-element grid used in MANTRA to simulate SLR scenario at the Coot Bay Hammock, along with assigned boundary conditions.

occupy the higher elevation areas with low salinity ($C < 0.005$ kgkg^{-1}) while buttonwoods occupy the intermediate elevations with intermediate salinity ($0.005 \leq C < 0.010$ kgkg^{-1}). Finally, mangroves occupy the lower elevation areas with high salinity ($0.010 \leq C < 0.03$ kgkg^{-1}), as shown in Figure 3(a). The model successfully reproduces the observed vegetation zonation pattern in Coot Bay Hammock, as shown in Figure 1(b). The coastal aquifer is mainly recharged through precipitation that infiltrates the ground surface and percolates downwards until it reaches the saturated zone. Figures 3(b) and 3(c) show the formation of a 1-m thick freshwater lens sustained by precipitation and self-reinforcing positive feedback from glycophytic hardwood hammocks.

To investigate the effects of SLR, MSL is assumed to increase at a global SLR rate of 3.2 mmyr^{-1} [21] until it permanently inundates the slightly elevated ridge in the Coot Bay Hammock area. Figure 4 shows the simulated vegetation and salinity profiles at the Coot Bay Hammock transect subject to SLR of 3.2 mmyr^{-1} over a period of 250 years. As observed in Figures 4(a)(i)(a)(ii) and 4(b)(i)(b)(ii), with increasing brackishness of plant-available water, the mangrove plants with higher salinity tolerance have expanded into areas of higher elevation and displaced the adjacent buttonwood and halophytic communities. The upland salinity-intolerant hardwood hammocks remain relatively intact, probably due to their ability to regulate soil salinity by controlling water uptake. This self-reinforcing positive feedback helps to restrict infiltration of saline groundwater and to resist the invasion of buttonwoods. Consequently, the buttonwoods and halophytic prairie are being squeezed into smaller and smaller transition areas between saltwater and freshwater environments. The increasing sea level will begin to inun-

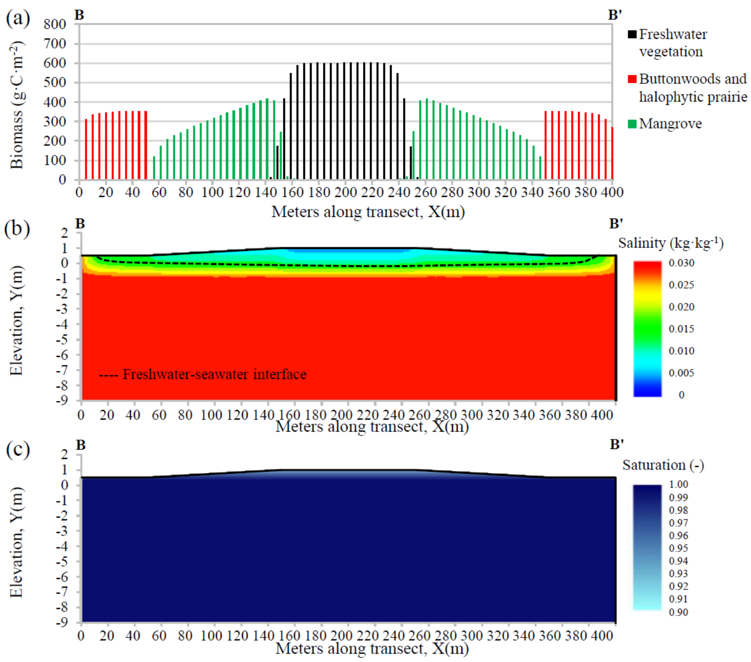

Figure 3: Existing pre-SLR (a) vegetation zonation, (b) groundwater salinity, and (c) soil saturation profiles along the transect B-B$'$ simulated by MANTRA.

date the lower portion of the ridge where precipitation formerly recharged the sites freshwater aquifer, and will subsequently affect the natural replenishment of groundwater. The anticipated reduction in aquifer recharge has resulted in decreased freshwater hydraulic head and more landward shift of the freshwater-seawater interface, thereby exacerbating saltwater intrusion. It is also notable that both the buttonwoods and halophytic prairie as well as hardwood hammocks show declines in aboveground biomass in response to shifts in salinity (Figures 4(a)(iii) and 4(b)(iii)). Additionally, the photosynthetic ability of intertidal mangrove species is negatively affected by the increasing salinity and flooding stresses imposed by SLR, thus reducing the plants growth and modifying their biomass allocation patterns and accumulation. When the mangrove species cannot survive the interplay of these abiotic stressors, their distributions appear to contract at the seaward edge, or their populations will gradually decline in aboveground biomass with increasing salinity and disappear from the Coot Bay landscape [22]. These mangrove losses along the seaward fringe are balanced by gains associated with inland encroachment of mangroves [23]. The invasion of hammock

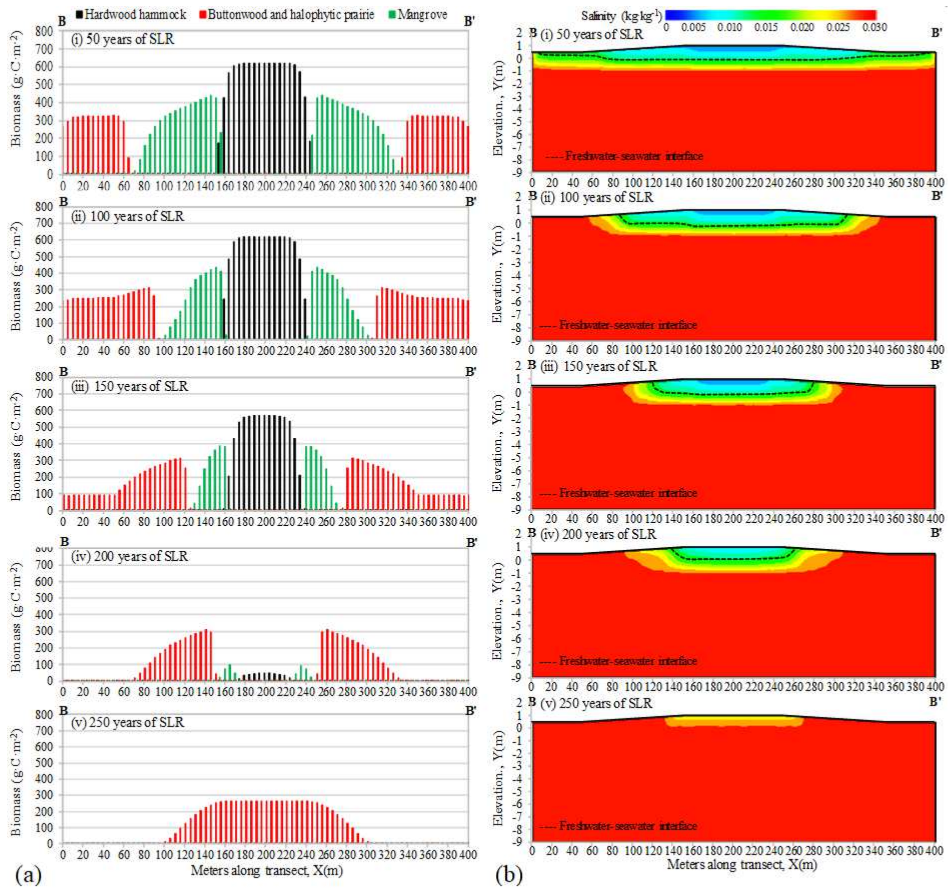

Figure 4: Simulated (a) vegetation and (b) salinity profiles along the Coot Bay Hammock transect B-B$'$ subject to SLR of 3.2 mmyr^{-1} over a 250-year period.

stands by buttonwoods is noticeable, whereas significant areas of buttonwoods and halophytic prairie are lost on the lower sides of the ridge due to mangrove encroachment. Induced by saltwater intrusion due to SLR, the biomasses of hardwood hammocks and buttonwood forests decline significantly at higher salinity (Figures 4(a)(iv) and 4(b)(iv)). The slightly elevated coastal ridge will be permanently inundated by 0.80 m rise in sea level after 250 years, allowing seawater to flow freely inland accompanied by rapid landward replacement of freshwater hammocks by mangrove communities (Figures 4(a)(v) and 4(b)(v)). Simulation results imply that in 250 years, 50 percent of the vegetated area of the Coot Bay Hammock could be converted to open water with mangroves being the only plant community left.

5 Conclusion

To investigate how SLR may impact plant community at Coot Bay Hammock, Florida Everglades, the coupled hydrology-salinity-vegetation model MANTRA was further enhanced to include a third competing species.
MANTRA simulation results are consistent with the field observation of vegetation zonation pattern. Further simulation reveals a potential decrease in coastal hardwood hammocks and buttonwood forests due to the elevated groundwater salinity induced by SLR. With their ability to thrive in saline and inundated environments, mangroves ultimately take over the areas previously occupied by upland buttonwood, halophytic prairie, and hardwood hammock. Climate change and SLR will increase vulnerability of freshwater resources in southern Florida and the associated ecosystems. Reduction in freshwater flows through the Florida Everglades coupled with SLR will accelerate the loss of freshwater wetland habitats. This mandates immediate management attention to conserve and sustain the South Florida ecosystem in the face of GCC and SLR.

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References

[1] S. M. Davis, J. C. Ogden, Everglades: the ecosystem and its restoration, CRC Press, Boca Raton, Florida, 1994.

[2] L. Berry, F. Bloetscher, H. N. Hammer, M. Koch-Rose, D. Mitsova-Boneva, J. Restrepo, T. Root, R. Teegavarapu, Florida water management and adaptation in the face of climate change, Florida Climate Change Task Force, Florida, (2011).

[3] M. S. Ross, J. F. Meeder, J. P. Sah, P. L. Ruiz, G. J. Telesnicki, The southeast saline Everglades revisited: 50 years of coastal vegetation change, J. Veg. Sci., **11,** (2000), 101–112.

[4] M. Simard, K. Q. Zhang, V. H. Rivera-Monroy, M. S. Ross, P. L. Ruiz, E. Castañeda-Moya, R. R. Twilley, E. Rodriguez, Mapping height and biomass of mangrove forests in Everglades National Park with SRTM elevation data, Photogramm. Eng. Rem. S., **72,** (2006), 299–311.

[5] D. Peterson, Four Florida environmental priorities for the legislature in 2018, 2018.

[6] S. Y. Teh, M. Turtora, D. L. DeAngelis, J. Jiang, L. Pearlstine, T. J. Smith, H. L. Koh, Application of a coupled vegetation competition and groundwater simulation model to study effects of sea level rise and storm surges on coastal vegetation, J. Mar. Sci. Eng., **3** (2015), 1149–1177.

[7] A. K. Saha, S. Saha, J. Sadle, J. Jiang, M. S. Ross, R. M. Price, L. S. L. O. Sternberg, K. S. Wendelberger, Sea level rise and South Florida coastal forests, Clim. Change, **107,** (2011), 81–108.

[8] J. Park, E. Stabenau, K. Kotun, Sea-level rise and inundation scenarios for national parks in South Florida, Park Sci., **33,** (2017), 63–73.

[9] L. D. L. Sternberg, S. Y. Teh, S. M. L. Ewe, F. Miralles-Wilhelm, D. L. DeAngelis, Competition between hardwood hammocks and mangroves, Ecosyst., **10,** no. 4, (2007), 648–660.

[10] N. Ish-Shalom, L. D. L. Sternberg, M. Ross, J. O'Brien, L. Flynn, Water utilization of tropical hardwood hammocks of the lower Florida Keys, Oecol., **92,** (1992), 108–112.

[11] C. I. Voss, A. M. Provost, SUTRA: a model for 2D or 3D saturated-unsaturated, variable-density ground-water flow with solute or energy transport, U.S. Geological Survey, Reston (2002).

[12] S. Y. Teh, D. L. DeAngelis, L. D. L. Sternberg, F. R. Miralles-Wilhelm, T. J. Smith, H. L. Koh, A simulation model for projecting changes in salinity concentrations and species dominance in the coastal margin habitats of the Everglades, Ecol. Model., **213,** (2008), 245–256.

[13] K. S. Wendelberger, D. Gann, J. H. Richards, Using bi-seasonal worldview-2 multi-spectral data and supervised random forest classification to map coastal plant communities in Everglades National Park, Sens., **18,** (2018), 829.

[14] C. M. Schaefer, Halophytes and their potential as landscape plants, M.Sc. Thesis, The University of Arizona, (1959).

[15] M. Th. van Genuchten, A numerical model for water and solute movement in and below the root zone, U.S. Salinity Laboratory, Riverside, (2005).

[16] T. H. Skaggs, P. J. Shouse, J. A. Poss, Irrigating forage crops with saline waters: 2. modeling root uptake and drainage, Vadose Zone J., **5,** (2006), 824–837.

[17] P. Hogarth, The biology of mangroves and seagrasses, Oxford University Press, Oxford, 2017.

[18] X. Y. Khng, S. Y. Teh, H. L. Koh, S. Shuib, Sea level rise undermines SDG2 and SDG6 in Pantai Acheh, Penang, Malaysia, J. Coast. Conserv., **25,** (2021), 9.

[19] S. Y. Teh, H. L. Koh, D. L. DeAngelis, C. I. Voss, L. D. L. Sternberg, Modeling δ^{18}O as an early indicator of regime shift arising from salinity stress in coastal vegetation, Hydrogeol. J., **27,** (2019), 1257–1276.

[20] S. Y. Teh, D. L. DeAngelis, C. I. Voss, L. D. L. Sternberg, H. L. Koh, MANTRA-O18: An Extended Version of SUTRA Modified to Simulate Salt and δ^{18}O Transport amid Water Uptake by Plants, E3S Web of Conferences, **54,** (2019), 00039.

[21] IPCC, Climate change 2013: the physical science basis, working group 1 contribution to the fifth assessment report of the International Panel on Climate Change, Cambridge University Press, New York, (2013).

[22] C. Craft, J. Clough, J. Ehman, S. Joye, D. Park, S. Pennings, H. Guo, M. Machmuller, Forecasting the effects of accelerated sea level rise on tidal marsh ecosystem services, Front. Ecol. Environ., **7,** (2009), 73–78.

[23] F. E. Egler, Southeast saline Everglades vegetation, Florida, and its management, Vegetation, **3,** (1952), 213–265.