# **Title**: CLASSIFICATION OF VEGETATION FOR SURFACE-WATER FLOW MODELS IN TAYLOR SLOUGH, EVERGLADES NATIONAL PARK

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**Abstract**: Surface-water flow velocity in the wetlands of Taylor Slough, Everglades National Park, is controlled by factors such as water depth, land-surface gradient, wind effects, and the type and density of vegetation. In order to evaluate the effect of vegetation on this shallow surface-water flow for model development, it is necessary to extrapolate from point measurements of velocity and surface-water slope made concurrently with characterization of vegetation at locations throughout the slough to the entire model area. At these flow measuring locations, vegetation, including periphyton, was harvested in horizontal layers, either 10 cm or 20 cm thick, from the bed through the water column to the top of the plants, in 0.5-m square quadrats. Species composition, density, leaf and(or) culm number and size, biomass, and leaf area index were determined for each layer. The vegetation samples were grouped into classes by species composition and biomass. A geographic information system graphical user interface (DBView) was developed and used to assimilate and interpret the various spatial data, such as a 68-class 1993-94 Landsat vegetation map of southern Florida, a 20-class Landsat Thematic Mapper image, digital orthophoto quadrangles, land-surface elevations, and digital line graphs. Working with both sets of Landsat data, color infrared aerial photographs, and other available maps, we recombined Landsat vegetation classes to delineate the areal extent of basic vegetation types throughout the slough. These vegetation types have different effects on flow velocity and may be associated with different model roughness characteristics. After crosschecking the final vegetation classes on each Landsat map with actual field vegetation samples and specific ground-truth observations, we selected an 8-class vegetation map from Landsat Thematic Mapper images for use with surface-water models in Taylor Slough.

# 2. INTRODUCTION

The south Florida Everglades is a vast, diverse wetland ecosystem characterized by small land-surface slope, slowly moving surface water, and emergent and submersed aquatic vegetation interspersed with tree islands. The Everglades have been greatly altered during the past 100 years (McPherson et al., 1976; McPherson and Halley, 1996). A complex water-management system that includes levees, canals, pumps, and other water-control structures now regulates flooding and provides a steady supply of fresh water to urban areas and agricultural lands. Drainage projects have diverted much of the water that originally flowed southward from Lake Okeechobee through the Everglades. Restoration and management of the Everglades ecosystem requires understanding and manipulating the amount and timing of water flows throughout the system.

U.S. Geological Survey (USGS) scientists have developed a surface-water model of Taylor Slough, located in the southeastern corner of the Florida Everglades (Figure 1), that will assist water managers in planning and conducting restoration efforts. Many complex processes within the slough interact with the hydrologic cycle to influence the way the ecosystem functions. Precipitation, ground-water discharge, and surface-water inflows are sources of fresh water that maintain the constant flow through Taylor Slough toward Florida Bay. Among the many factors that control the velocity, flow direction, water depth, and hydroperiod in Taylor Slough are frictional resistance from vegetation and mats of periphyton, the effects of sheltering from wind of different plant communities, topography, evapotranspiration losses, and tidal stage in Florida Bay. Modeling the surface-water flow requires extrapolation from point measurements of velocity and surface-water slope made concurrently with characterization of vegetation to the entire model area. Vegetative resistance to flow in the model can be expressed by either Manning's n or the Darcy-Weisbach friction factor, but these coefficients must be related to the actual field characteristics of the vegetation through which flow occurs to provide the basis for accurate predictions of flow (Lee and Carter, 1997).

The purpose of the research reported here was to analyze the structure, density, and species composition of the major vegetative communities in Taylor Slough and to use available remotely sensed data to develop a vegetation cover map for the model area. The generalized vegetation cover classes are subsequently related to the frictional resistance of the vegetation in order to provide roughness coefficients for the model. The vegetation cover map also serves as the basis for calculating regional evapotranspiration and for estimating the wind sheltering effects afforded by different vegetation classes.

## 2.1 Taylor Slough

Taylor Slough is the second largest drainage basin within Everglades National Park (Olmsted et al. 1980). It extends from the northeastern edge of the Park near the L-31W canal to Florida Bay; its western and eastern limits are not precisely defined. Olmsted et al. (1980) divide the slough south of its intersection with the L-31W canal into three segments: (1) upper Taylor Slough, a 5.5-km reach between the slough-canal intersection and the Anhinga Trail (located near the Royal Palm Visitor's Center) where the slough is narrow and well defined; (2) middle Taylor Slough, a 7-km reach extending from the Anhinga Trail to the point where the Old Ingraham Highway bends sharply west; and (3) lower Taylor Slough, the 13-km reach extending south of the bend in Old Ingraham Highway to the mangrove zone just north of the Buttonwood Embankment (Craighead, 1969). The model area (Figure 1), referred to as the Southern Coastal and Inland Systems (SICS), includes part of upper Taylor Slough south of the east-west park road to Flamingo and all of middle and lower Taylor Slough, and extends to cover the mangrove zone, the Buttonwood Embankment, and part of northeastern Florida Bay.

Taylor Slough occupies a broad depression in the Miami oolite bedrock—the center of the depression is deeper than the margins and, in lower Taylor Slough, is filled with peat up to 2 m thick. This peaty center is covered with a complex of willow-sawgrass marshes, evergreen shrub islands, and open sparse rush marshes, whereas the margins support sawgrass, rush, or a mixture of both. Peat also is found in bedrock depressions in the lower part of the slough. Otherwise, marl is the predominant soil in the slough; the marl flats are generally covered with a thick mat of periphyton. The periphyton community is an assemblage of microalgae that lives on shallow submersed substrates (Browder et al., 1994). Periphyton is commonly associated with precipitated calcite, thus its generally white to greenish white color; and it may cover the submersed stems of macrophytes as well as forming a layer on the sediment or a floating mat on the water surface. This thick, dense periphyton layer offers resistance to flow in addition to that provided by vegetation, but because of its variable location in the water column and its tendency to dry up and blow away under drought conditions, it is difficult to identify and map with remotely sensed data.

Plant communities of upper, middle, and most of lower Taylor Slough were mapped by Rintz and Loope (1978) using color infrared photographs. Details of the mapping and vegetation survey are found in Olmsted et al. (1980). Vegetation descriptions and elevation measurements were made on three transects across the slough; however, only the southernmost of these transects was actually within the model area. Vegetation was classified into ten communities, six as tree and four as broadly defined graminoid associations (Table 1).

Table 1. Vegetation classes of Taylor Slough and associated hydroperiods illustrated in a Vegetation Map of Taylor Slough, Everglades National Park, (Rintz and Loope 1978)

| Class | Vegetation class | Description | Hydroperiod | Periphyton |
|---|---|---|---|---|
| | Tree communities | | | |
| 1 | Tropical hardwood hammocks | Closed canopy tropical hardwood trees and shrubs | Rarely under water | None |
| 2 | Pinelands | Open stands of pine with an understory of evergreen shrubs and some herbs | Inundation is rare | None |
| 3 | Bayheads | Closed canopy evergreen forest | Mean hydroperiod 1-4 months | None |
| 4 | Former agricultural lands | Now forested with primarily evergreens | Dry | None |
| 5 | Willow heads | Willow stands with margins of sawgrass or Phragmites | Mean hydroperiod 3-10 months | None |
| 6 | Cypress forest | Cypress domes, heads and stands, understory often evergreen (on peat) | Mean hydroperiod <3-4 months | None |
| | Graminoid communities | | | |
| 7 | Muhlenbergia (bunchgrass) prairies | Muhlenbergia mixed with sawgrass and other grasses, herbs, and shrubs, sometimes with dwarf cypress (on marl) | Mean hydroperiod 2-4 months | Periphyton mat usually present |
| 8 | Sawgrass-willow marshes | Tall, dense sawgrass mixed with willow and button bush (on peat) | Mean hydroperiod 8-10 months | Periphyton is absent |
| 9 | Sawgrass and sawgrass-spikerush marshes | Sawgrass with varying proportions of spikerush and sedge (on marl) | 3-8 months | No information |
| 10 | Open marshes | Open water devoid of vegetation or spikerush mixed with a variety of sedges, rushes, and forbs (either peat or marl) | Mean hydroperiod > 9 months | No information |

Figure 1. Location of Taylor Slough, south Florida Everglades, and outline of Southern Inland and Coastal Systems (SICS) model area. The land within the model area is shown in yellow. ( • shows location of vegetation sampling quadrats)

# 3. METHODS

## 3.1 Vegetation characterization

Measurements of flow velocity and surface-water slope were made on four different dates on three west-to-east transects across Taylor Slough. Global Positioning System (GPS) coordinates were used to establish the location of sampling points so that measurements could be repeated at the same site as desired. On three of these sampling dates, vegetation, including periphyton, was harvested from 0.5-$m^2$ quadrats in horizontal layers, either 10 or 20 cm thick, from the bed through the water column to the top of the plants (Figure 1). The plant material was sorted and measured and both plant material and periphyton were oven-dried at 105 °C for 12 hours or more to determine biomass of the individual components in grams dry weight per square meter (gdw/$m^2$). Species composition, density, leaf and(or) culm number and size, leaf area index (LAI), and biomass were determined for each layer. In addition, total biomass, total biomass minus periphyton biomass, and total LAI were calculated for each individual quadrat.

The quadrats were grouped according to species composition and subsequently into density classes based on total biomass minus periphyton: sparse = 0-500 gdw/$m^2$, medium = 500-1000 gdw/$m^2$, dense = 1000-2000 gdw/$m^2$, and very dense = >2000 gdw/$m^2$.

## 3.2 Development of vegetation map

A variety of remotely sensed products were available for developing the vegetation cover maps, including 1:12,000-scale color digital orthophoto quadrangles and the color infrared (IR) aerial photographs from which these were made, a 68-class 1993-94 Landsat vegetation cover classification map of southern Florida developed by the former National Biological Service and the University of Florida, and several vegetation maps of parts of the Taylor Slough model area (Rintz and Loope, 1978; Olmsted et al., 1980; Olmsted et al., 1981). In addition, we acquired a set of 1997 Landsat Thematic Mapper (TM) images that covered the model area.

A geographic information system graphical user interface (DBView), which was developed specifically to assimilate and interpret spatial data (Stewart, 1997), was used to manipulate and recombine the 68 classes in the south Florida Landsat map into six vegetation cover classes plus water using the color IR photographs, digital orthophoto quadrangles, and vegetation maps for guidance. Following a detailed examination of this vegetation map and correlation of the map with ground-truth information, a second vegetation cover map was developed using a January 1997 TM image. The Landsat TM instrument records both reflected (six bands) and emitted (thermal band) energy, respectively, for each ground area sampled. The ground spacing of reflected light measurements is nominally 30 m,while each thermal measurement represents an area 120 m on a side. Typically, the reflected and thermal data are processed separately.

However, for this effort, the thermal data were oversampled to the 30-m resolution of the reflected bands. All data points within the resulting 7-band image were statistically grouped into 20 land-cover classes. The result of this process was then geometrically rectified to match the coordinate system used for all other field and remote sensing data collection. Using DBView, vegetation data collected in the field, and field observations, the 20 land-cover classes were further grouped into the seven vegetation classes and one water class.

Evaluation of these two vegetation cover maps required field trips to many sites within or on the periphery of Taylor Slough, including the area to the east that includes the C-111 canal area criss-crossed by drainage canals and the area to the west along the main park road to Flamingo and the Old Ingraham Highway (Figure 1). A special field reconnaissance was made to northern Florida Bay to check the map classes along the Buttonwood Embankment (Craighead, 1969) and the edges of the tidal embayments where Taylor Slough flows into Florida Bay (Figure 1). In addition, the GPS locations of the samples were plotted directly on the vegetation cover maps using DBView to identify the vegetation class from which each sample came.

## 4. RESULTS AND DISCUSSION

Figure 2 is the 8-class vegetation cover map developed from TM data; classes 1-7 are vegetation classes, and class 8 is open water (Table 2). This map provides an improved classification over the recombined Landsat 68-class map, particularly with regard to the separation of mangrove classes. The TM map, which may be refined further, divides the model area into classes that in turn may be linked with roughness characteristics associated with vegetation.

The vegetation map produced by Rintz and Loope (1978) (Table 1) was based on 1973 high altitude color IR aerial photographs; and although it does not include all of the model area, it was useful to compare vegetation classes on that map with those shown on the map developed from the TM data (Table 2). The Rintz and Loope (1978) estimates of hydroperiod were based on regression analysis of precipitation and water levels measured at a network of 57 staff gages located in Taylor Slough (Olmsted et al., 1980). Twenty-four years have elapsed between the aerial photographs used by Rintz and Loope (1978) and the 1997 TM data, and it is probable that the vegetation communities have changed during this period. Changes in the vegetation of the Florida Everglades from the early 1900’s to 1974 as a result of natural succession and human activities were documented by Alexander and Crook (1974), but changes in the graminoid communities in the National Park were not as great as those further north, where canals and levees had immediate impact. Additionally, differences in water level and seasonal differences in the timing of the imagery can affect map classes. Two of the Olmsted et al. (1980) classes, willow heads and cypress forest, do not have any counterparts in our classification; the former are seldom encountered in the model area, and the latter is classified according to the understory in our map, because cypress is deciduous and would lack a distinct signature in January. The TM evergreen class includes open pine forests and former

Table 2. Vegetation classes of the Taylor Slough Southern and Inland Coastal Systems model area as illustrated in the Landsat TM map and their relationship to the vegetation classes of Rintz and Loope (1978)

| Vegetation class—TM data | Description | Hydroperiod | Peri-phyton | Rintz and Loope (1978) class |
|---|---|---|---|---|
| Evergreen | Open stands of pine with understory of evergreen shrubs and(or) herbs. Also may include areas of sparse mangrove with a herbaceous understory | Upland stands not inundated/hydroperiod of mangrove areas in unknown | none | 2, 4 |
| Mangrove/ buttonwood | Dense mangrove and(or) buttonwood along Florida Bay or embayments. | Stand edges may be inundated year round, but interiors are rarely to occasionally inundated | none | 1, 3 |
| Mangrove/ water | Short mangrove stands in a matrix of water | Stand edges are inundated year round; stand interiors may be flooded, but water is shallow | none | none |
| Rush/ (Other) | Open water with sparse rush or spikerush mixed with a variety of sedges, and forbs | Probably >9 months as in Olmsted et al. (1980) | Mats present | 10 |
| Mixed sawgrass/ rush | Sawgrass and(or) spikerush dominate—proportions vary | Probably 3-8 months as per Olmsted et al. (1980) | Variable | 8, 9 |
| Sawgrass/ bunchgrass | Sawgrass mixed with bunchgrass and other grasses, herbs, and shrubs—sometimes with dwarf cypress | Dryer than other sawgrass classes | | 7, 9 |
| Sawgrass | Sawgrass dominates, but may be mixed with a variety of rushes, sedges, and forbs | Wetter than sawgrass/ bunchgrass class-- includes areas where inundation is 8-10 months (Olmsted et al. (1980)) | | 7, 9 |
| Open water | Tidal embayments of northeastern Florida Bay and open water bodies | | | |

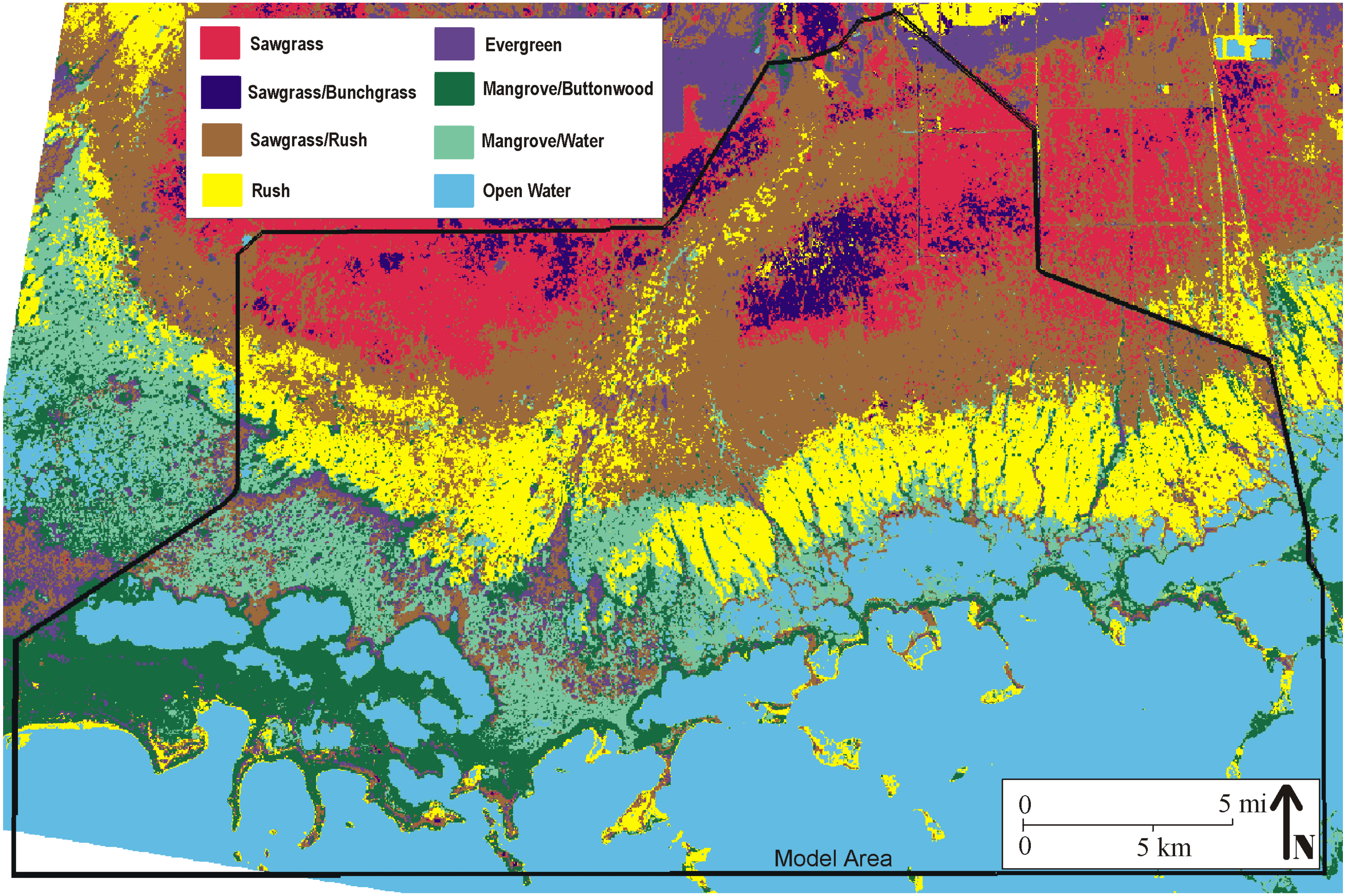

Figure 2. Eight-class vegetation cover map developed from January 1997 Landsat Thematic Mapper images. Outline of the Southern Inland and Costal Systems (SICS) model area is also shown.

agricultural lands, neither of which is present in the model area to any degree. However, the TM evergreen class also includes some evergreen mangrove or other tree/shrub communities along the mangrove fringe to the south. The mangrove/buttonwood class includes bayheads and tropical hardwood hammocks, both dense evergreen cover. The mangrove/water class appears only in our classification and provides a distinction that is real and important from the viewpoint of flow. In this class, a matrix of slowly flowing open water is dotted with short mangrove islands and stands, which are often quite thickly packed together, but sometimes with small scattered bodies of open water. The 68-class Landsat vegetation classification confused this class with rush.

Figure 3 shows the percentage of each class in the total model land area. Evergreen trees and shrubs, including mangrove, occupy 33.7 percent, sawgrass and sawgrass/bunchgrass cover 16.3 percent, rush covers 19.1 percent, and mixed sawgrass/rush covers an additional 30.9 percent of the area. A small amount of open water is included in the land area but is not counted in this tally.

The 68-class 1993-94 Landsat vegetation cover map was not suitable for our modeling purposes when we recombined the 68 existing classes in the Taylor Slough model area to form a 6-class vegetation map, mainly because the rush class was confused with the mangrove/water class in the lower part of Taylor Slough. In addition, classes in the upper slough did not match well with those on the map by Rintz and Loope (1978).

Detailed analysis of the vegetation showed differences that would be reflected by the vegetation cover map as well as the difficulty of accounting for the influence of periphyton on flow. Figure 4 compares a sampling quadrat containing medium sawgrass with one containing rush. Distribution of biomass in the water column is quite different in the two classes, and it can be seen that periphyton could strongly influence the resistance to flow in both quadrats. Table 3 shows the vegetation cover class (from the final TM 8-class vegetation map) of the individual vegetation quadrats as classified on the basis of density and species composition. We sampled only one dwarf mangrove quadrat to get some idea of the amount of biomass below the water surface. The single quadrat assigned to the mangrove/buttonwood class was sampled at an open spot among clumps of dwarf mangrove. The greatest variety of vegetation/density classes occurred in the mixed sawgrass/rush map class, characterized by a wide hydroperiod range (Table 2) and including most of the center corridor of the slough. Relatively few samples are in the sawgrass/bunchgrass class because it lies in a dryer part of Taylor Slough, considerably less accessible by airboat.

The surface-water model of Taylor Slough is composed of 305-m square grid cells, whereas the Landsat TM pixels are 30 m on a side. It is desirable to have fewer, well-generalized classes in this situation so that the vegetation characteristics can be more directly linked with defined roughness coefficients. The map is also being used to generalize the evapotranspiration data being collected at widely spaced sites in the south Florida Everglades for modeling water flows. Additionally, we intend to use this map as a base on which to overlay salinity contours and surface elevations to establish linkages among vegetation, water quality, and hydroperiod.

Table 3. Comparison of field classes of Taylor Slough vegetation based on species composition and density with Landsat TM classes. Numbers represent the number of quadrats of each field class that fell into each Landsat TM class

| Landsat TM class | Field Classes | | | | |
|---|---|---|---|---|---|
| | Dense to very dense sawgrass | Sparse to medium sawgrass | Sparse to medium mixed sawgrass/rush | Sparse to medium rush | Man-grove |
| Sawgrass | | 4 | 1 | | |
| Sawgrass/ Bunchgrass | | | 2 | | |
| Mixed sawgrass/ Rush | 5 | 6 | 8 | 9 | |
| Rush/ (other) | | | | 5 | |
| Mangrove/ Buttonwood | | | | 1 | |
| Mangrove/ water | | | | | 1 |
| Evergreen | | | | | |

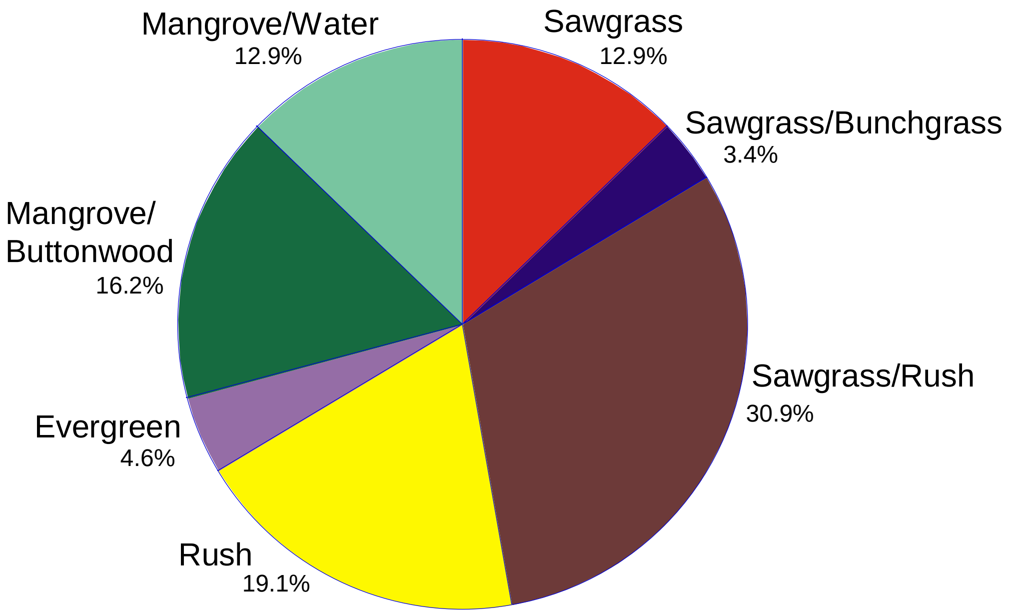

Figure 3. Percent cover of land surface within Southern and Inland Coastal Systems model area by vegetation type as classified on Landsat Thematic Mapper vegetation cover map.

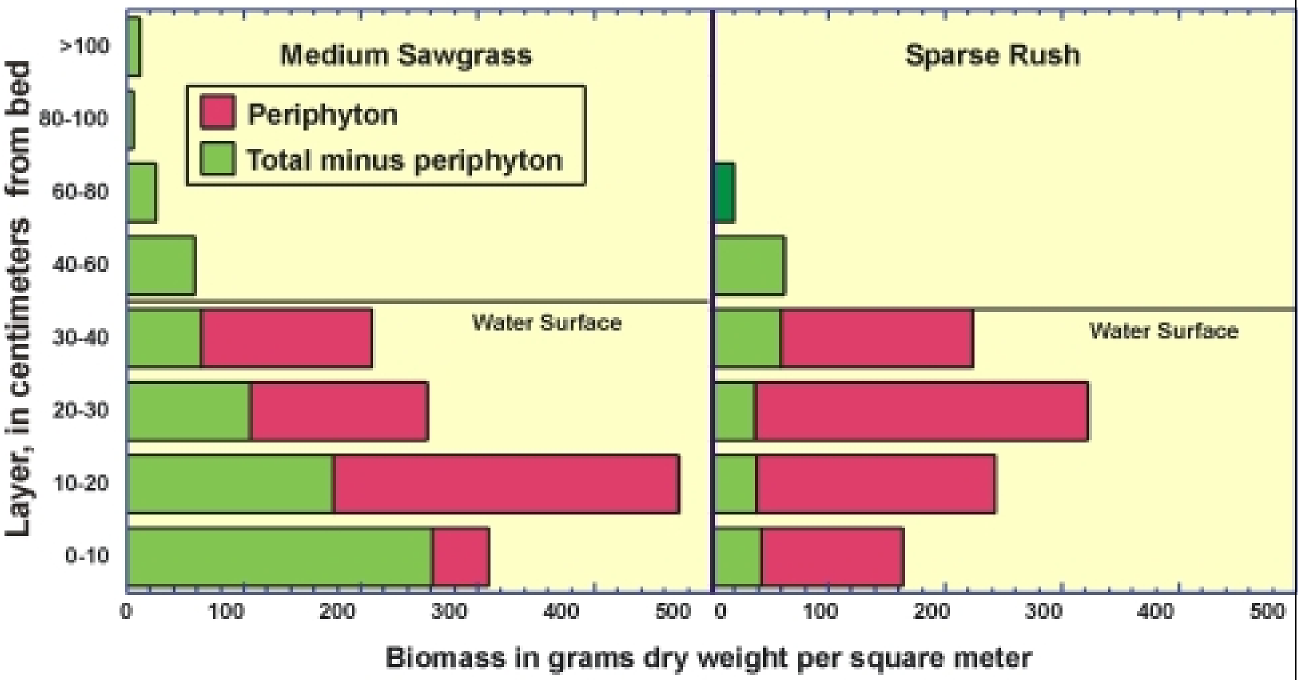

Figure 4. Biomass of a medium sawgrass quadrat and a sparse rush quadrat sampled in Taylor Slough, Everglades National Park, Florida.

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