CPA2007-00051

"Special Projects"

Seagrass Study and Investigation
Within Hurricane Bay
ADJACENT TO FUTURE DEVELOPMENT PROPERTY
more fully described as
or by STRAP No's: 19-46-24-00-00021.0050;
19-46-24-00-00021.0030; 19-46-24-00-00021.0010;
19-46-24-00-00022.0010

LEE COUNTY
STATE OF FLORIDA

Report Prepared For:

Mr. Robert W. Beasley, Manager
Oyster Bay Land Company & Hanson Marine Properties, Inc.
1711 Main Street
Fort Myers Beach, Florida 33931

Date of Final Seagrass Report:
May 29th, 2008

Seagrass Study and Investigation Report By:

ENVIRONMENTAL LAND SERVICES, INC.
3677 CENTRAL AVENUE
SUITE "G"
FORT MYERS, FLORIDA 33901
(239) 274-8022 OFFICE
(239) 274-8019 FAX

Seagrass Study and Investigation Report Project No.: 2008-1023

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May 29^{th}, 2008

"Seagrass Study Narrative"

On 05/07/2008, a sampling expedition was conducted whereby discovery was made as to the abundant (Blue-Green Algae) found near the Northern shore areas adjacent to our clients future development interests. Understanding the mechanics and dynamics of the land interacting with the effects upon Hurricane Bay are as follows. During the years considerable freshwater runoff has been monitored as if flows freely into Hurricane Bay. This has impact upon the salinity within that marine environment, causing a starvation of the dissolved oxygen within the subject marine environment. Several studies (Sections 5, 7, and 8) have shown, that such impacts slow and/or prevent the re-establishment of seagrass communities in areas with relatively low oxygen and salinity counts as marine areas go. Oddly enough, blue-green algae – a type of algae natural to our area frequently blooms when it finds the climatic and nutrient conditions favorable. Many times when conditions deteriorate further, some individuals identify this algae as "Brown" odiferous algae.

Our work task and project site includes addressing the geological soils and sand features as well. It is important to understand that seagrasses have a rather unique relationship within the soils and sands where they grow. This relationship is one of mutual benefit, whereby the grasses find nutrient content whereby to develop and flourish, plus the added benefit of a sound structure within which to root itself against the punishing wave and fetch actions of Mother nature.

Uniquely enough, past works close to and within this area of focus reveals that sand grain size and content analyses was made of the top three (3) inches of sediments from numerous cores taken across three (3) species – specific Seagrass beds in Estero Bay Aquatic Preserve, southwestern Florida during 1999. This area in fact is just immediate adjacent to our study area to the North. Within that study can be found this interesting information – The seagrass beds contained some algae with abundant Thalassia, Halodule, and Thalassia – Halodule mix, while the sediment was largely composed of varying amounts of quartz sand, silt-sized quartz, and carbonate skeletal particles. Comparison of sediment from different species of Seagrass reveals a difference in terms of pan size characteristics. There is a significantly higher content of silt in Thalassia and Thalassia – Halodule mix sediments than in Halodule beds. This species – specific preference difference may not be due to wave-energy and sediment size alone, but may also be due to freshwater runoff influence. Sediment – trap collections during summer and fall of 1999 and 2000, the wet and dry sessions in southern Florida, give a particle flux ranging from10 to 100 g/diem that increased during periods of high winds, due to the very shallow nature of the bay (<3 feet). During the dry season of 1999/2000 the flux range was lower. It is not known how much of this flux has come from local re-suspension of sediment particles or direct imput from the Gulf of Mexico.

Our findings on May 6th, 2008, were that very small communities of ***Halophila decipiens*** (Paddle-grass) and ***Thalassia testudinum*** (Turtle-grass) are re-establishing themselves in areas mid-bay and further north. These marine plant communities appear very healthy and show robust growth features which gives us some indication as to the ever increasing quality and health of Hurricane Bay itself. To date we have NOT identified any such grass species 500 feet +/- North of the Northern most shore line of our client's real property interests.

Important Considerations:

* As to possible issues relating to the expansion of existing docking facilities and/or maintenance of existing facilities. Per our field work we find NO potential conflict between seagrass growth versus upland future development.

* As to continual use and maintenance of existing channel ingress & egress to the existing docking facilities. Again, per our filed work we find NO potential conflict between seagrass growth versus upland future development.

In closing, no evidence was discovered within Hurricane Bay with the location of those small young-adolescent marine grass communities re-establishing themselves to the North that would impact our client's real estate interest and/or future development needs. Should the subject property (upland) be further developed in the future it is recommended that at least a Phase I, environmental audit be performed and that additional safety measures with regard to toxic and/or hazardous materials be undertaken during construction or development.

Sincerely yours,

R. Al Welch, Sr. V.P.

Richard Alan Welch, Sr. V.P.
Environmental Land Services, Inc.
3677 Central Avenue, Suite "G"
Fort Myers, Florida 33901-8226

May 29, 2008

Mr. Robert W. Beasley
1711 Main Street
Fort Myers Beach, Florida 33931

RE: Seagrass Study and Investigation Report 2008-1023

Dear Sir:

A seagrass study was conducted upon the subject marine property on 05/07/2008.

No soil sampling evidence was discovered during the course of the preliminary soils investigation that would lead to a reasonable conclusion that the subject property might be contaminated to an economically significant degree.

The on-site physical inspection of the seagrass study and investigation did not discover any evidence that would lead to a reasonable conclusion that the subject property might be contaminated to an economically significant degree.

No other warranty, expressed or implied, is made, and any and all other warranties or guarantees are hereby expressly disclaimed.

Please do not hesitate to call if I can help to clarify or be of future professional assistance.

Certified and Sealed this 29th day of May, 2008.

R. Alan Welch
State of Florida
Professional Geologist
Number:PG792

R. Alan Welch
Member: A.I.P.G.
Certified Prof.Geologist
Number:CPG8546

PROFESSIONAL GEOLOGIST CERTIFICATION

This report was prepared or conducted under the direct supervision of Mr. R. Alan Welch, P.G., of Environmental Land Services, Inc.,(E.L.S.). Our Professional Services have been performed using that degree of care and skill ordinarily exercised under similar circumstances by other Professional Geologists and Engineers practicing in this field.

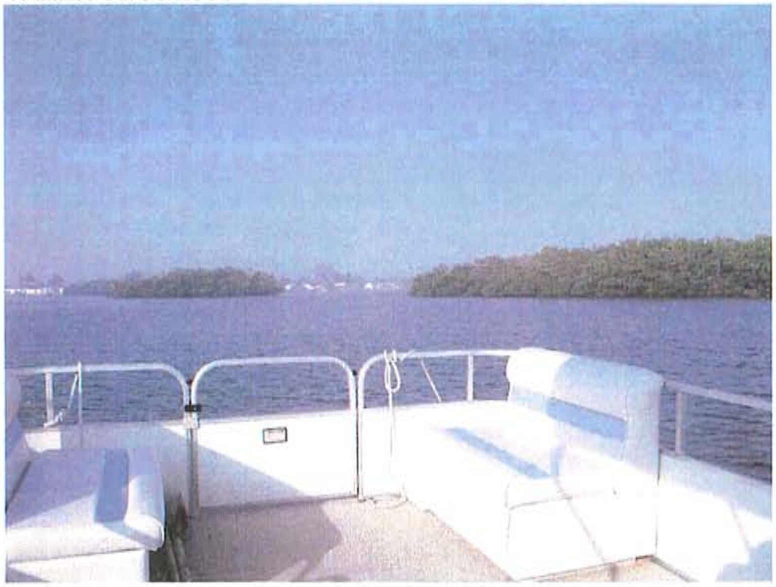
No other warranty, expressed or implied, is made as to the Professional advise in this report.

R. Alan Welch
State of Florida
Professional Geologist
No. PG0000792

Date: May 29, 2008

2008-1023

DATE ALL PHOTOS TAKEN 05/06/2008



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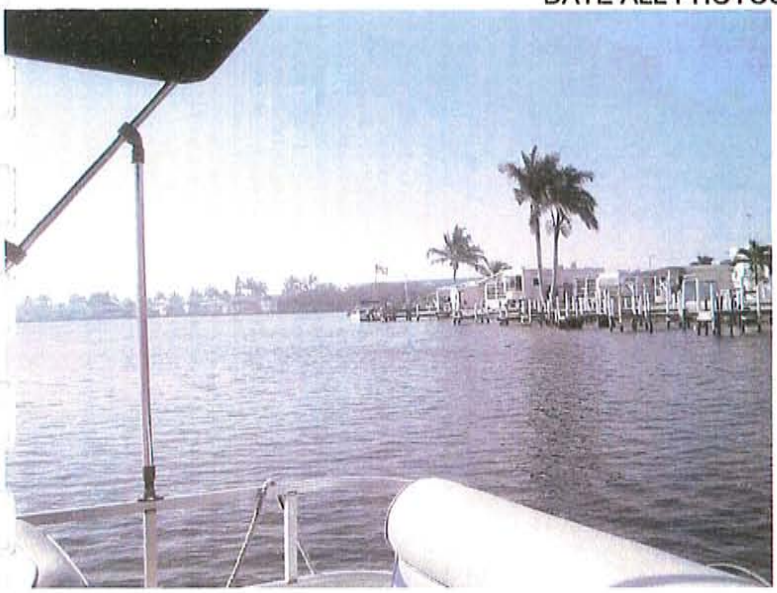

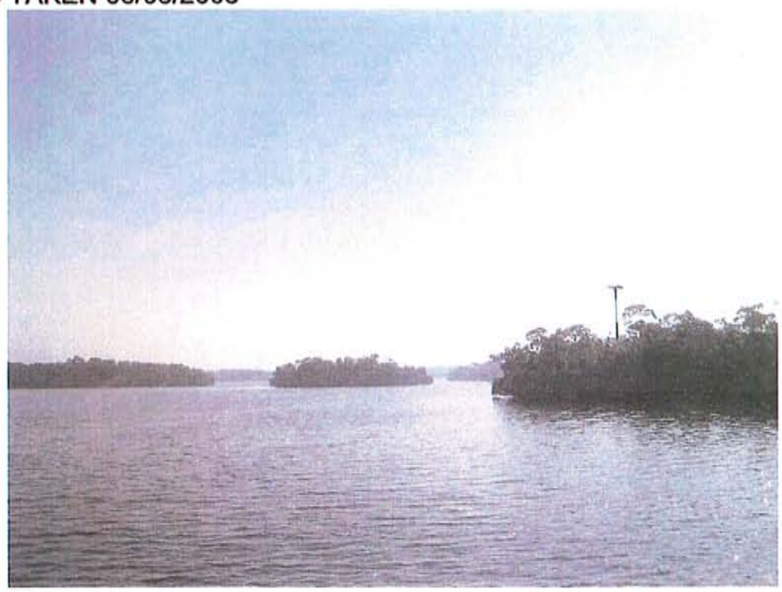

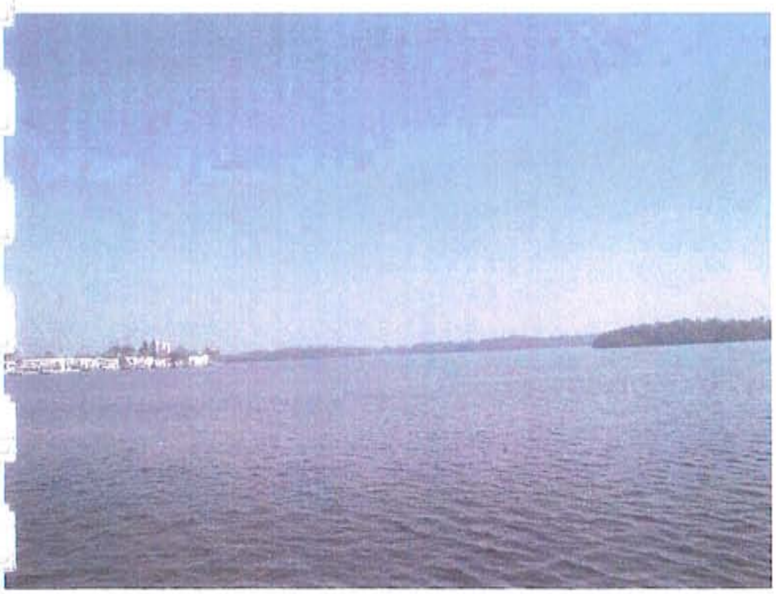

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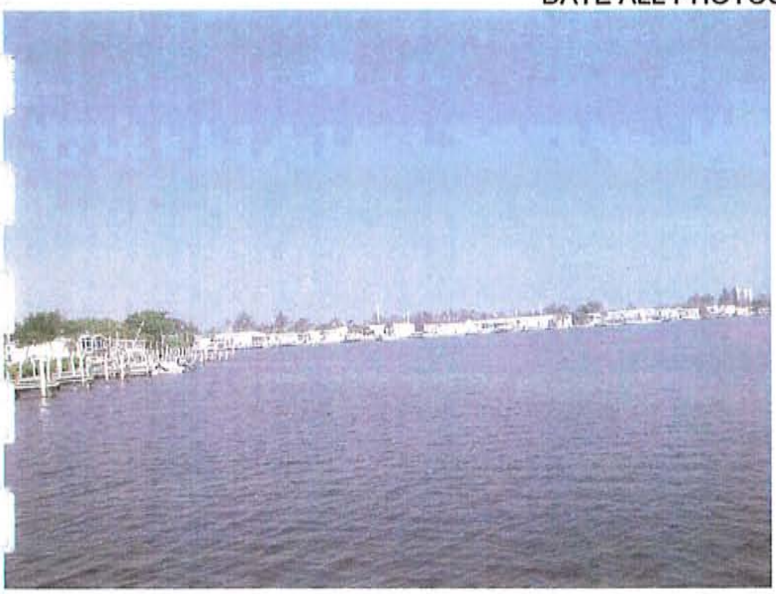

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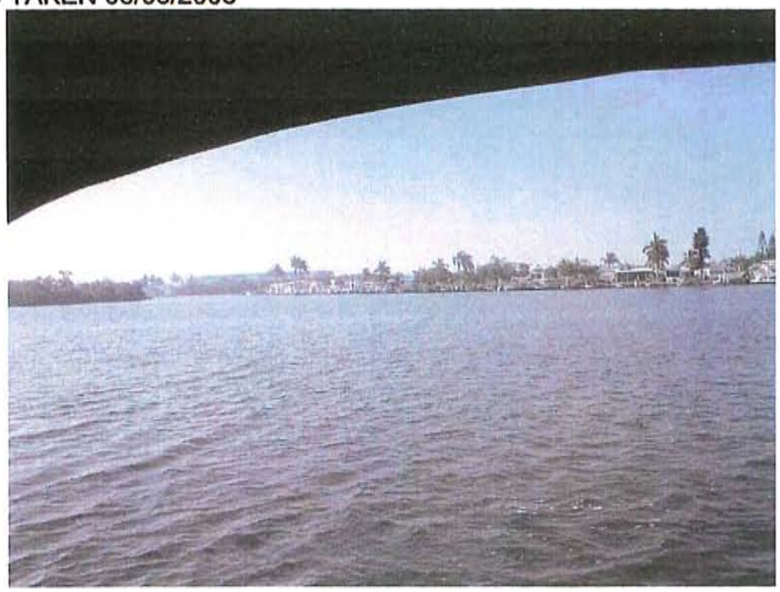

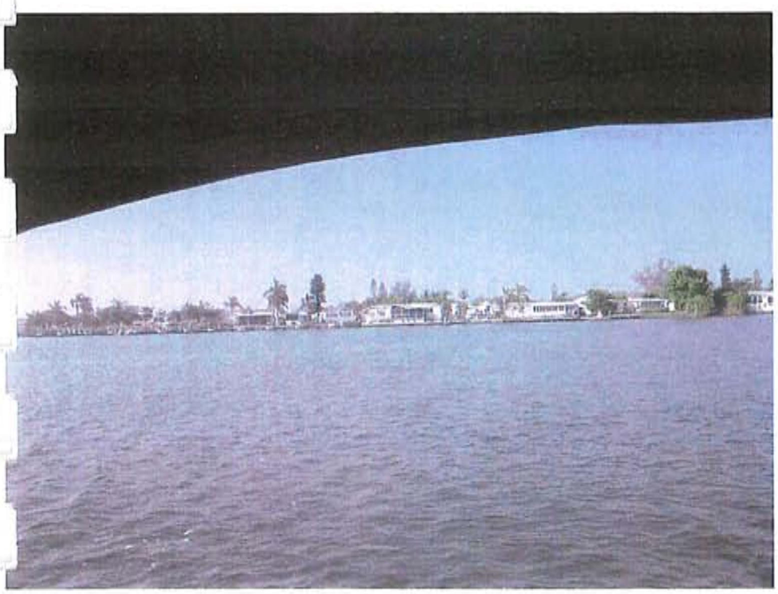

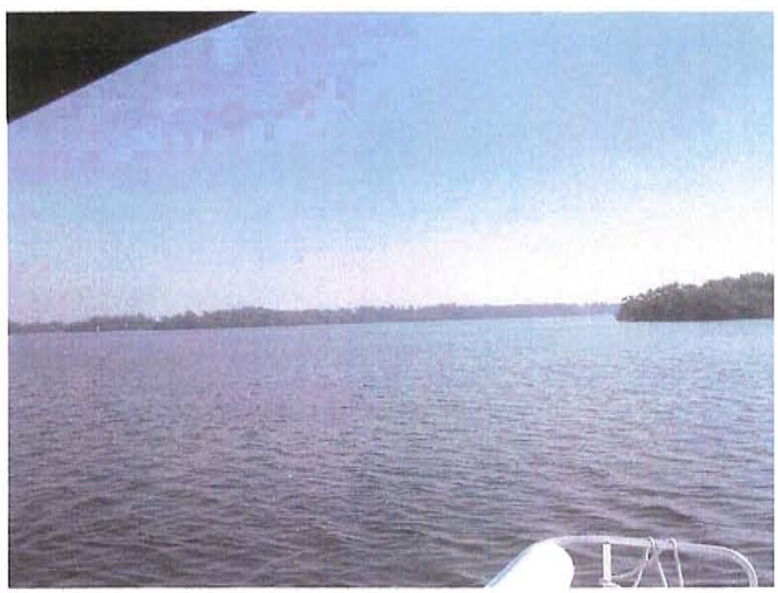

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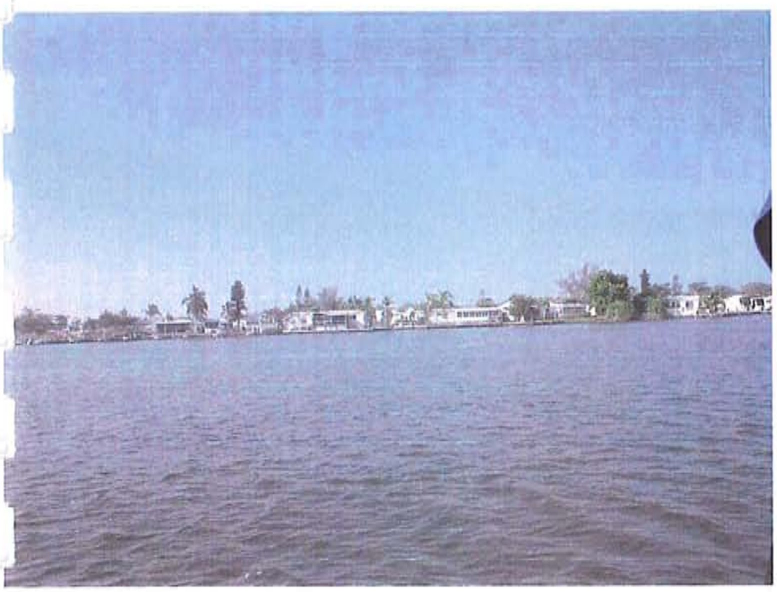

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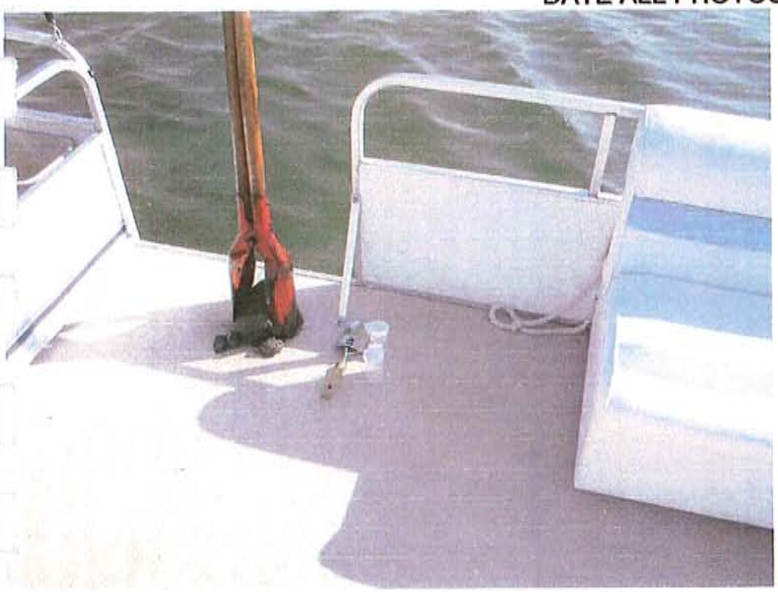

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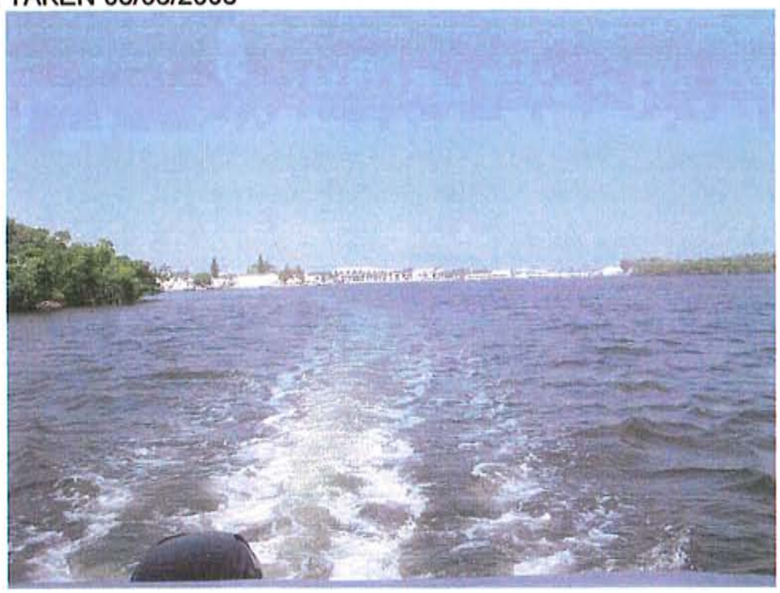

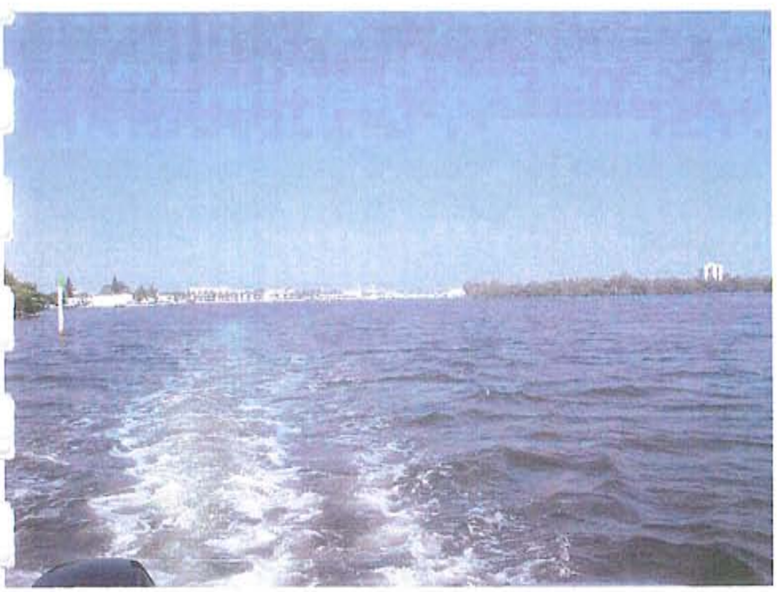

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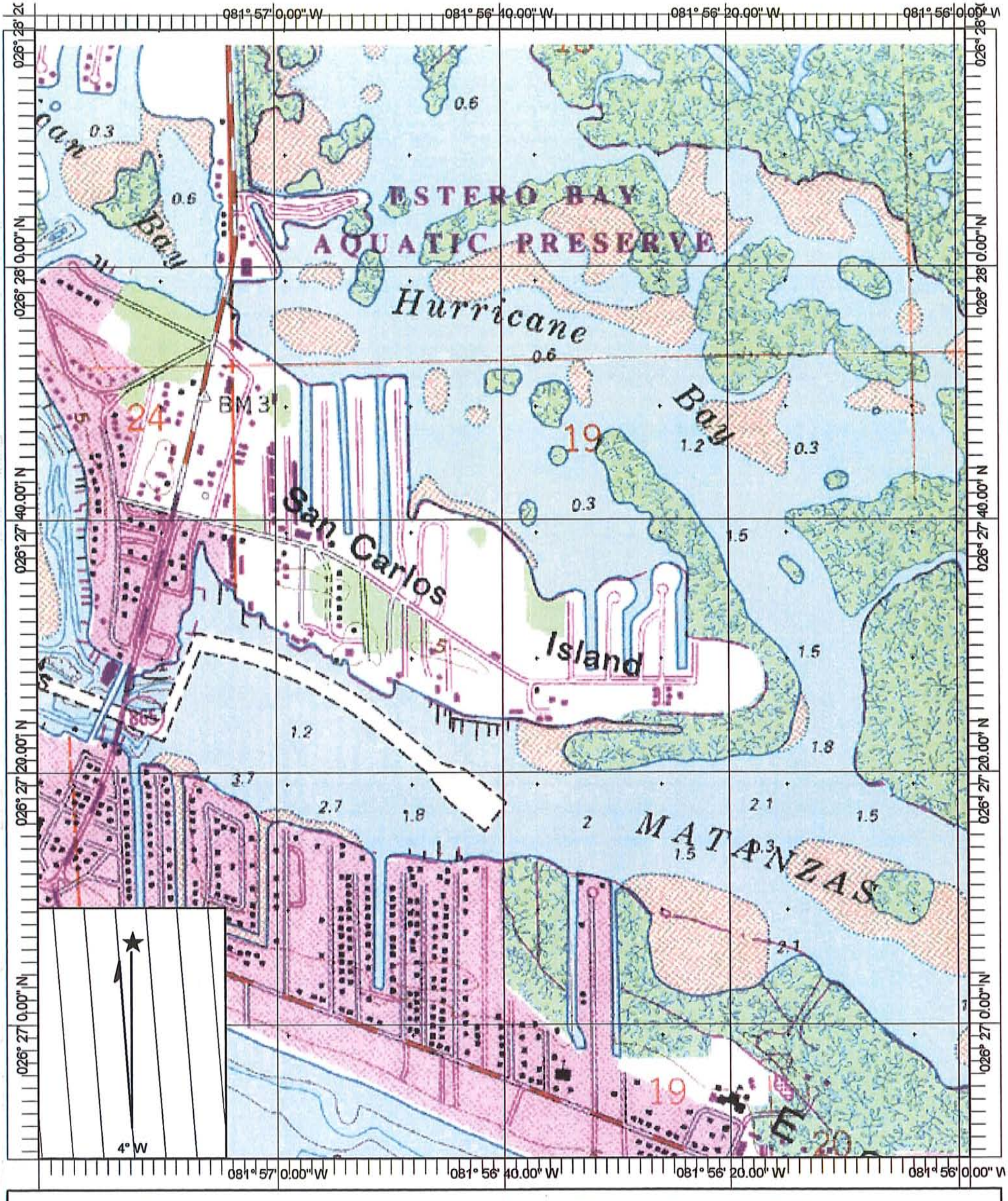
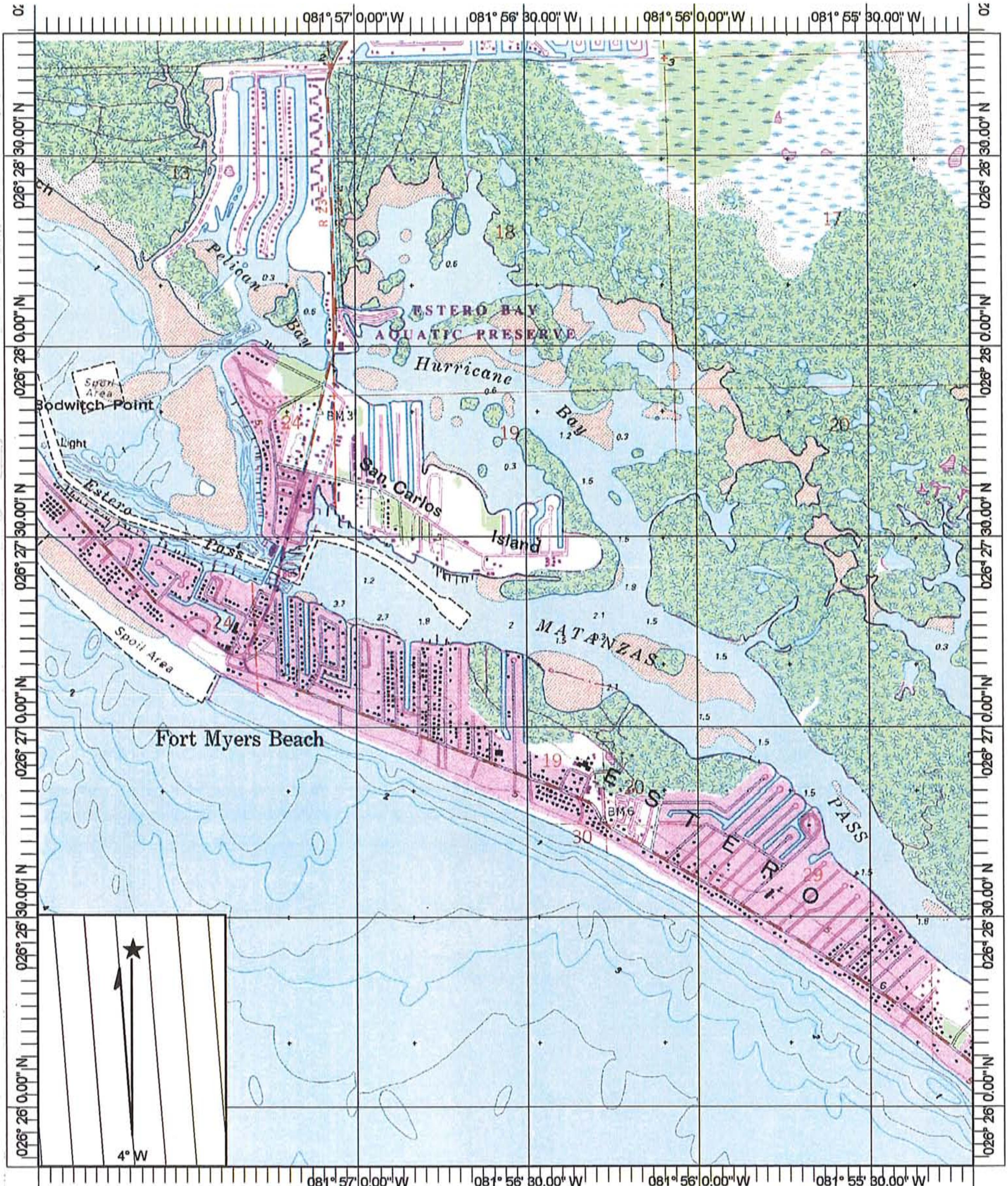


Name: FORT MYERS BEACH
Date: 3/20/2008
Scale: 1 inch equals 1000 feet

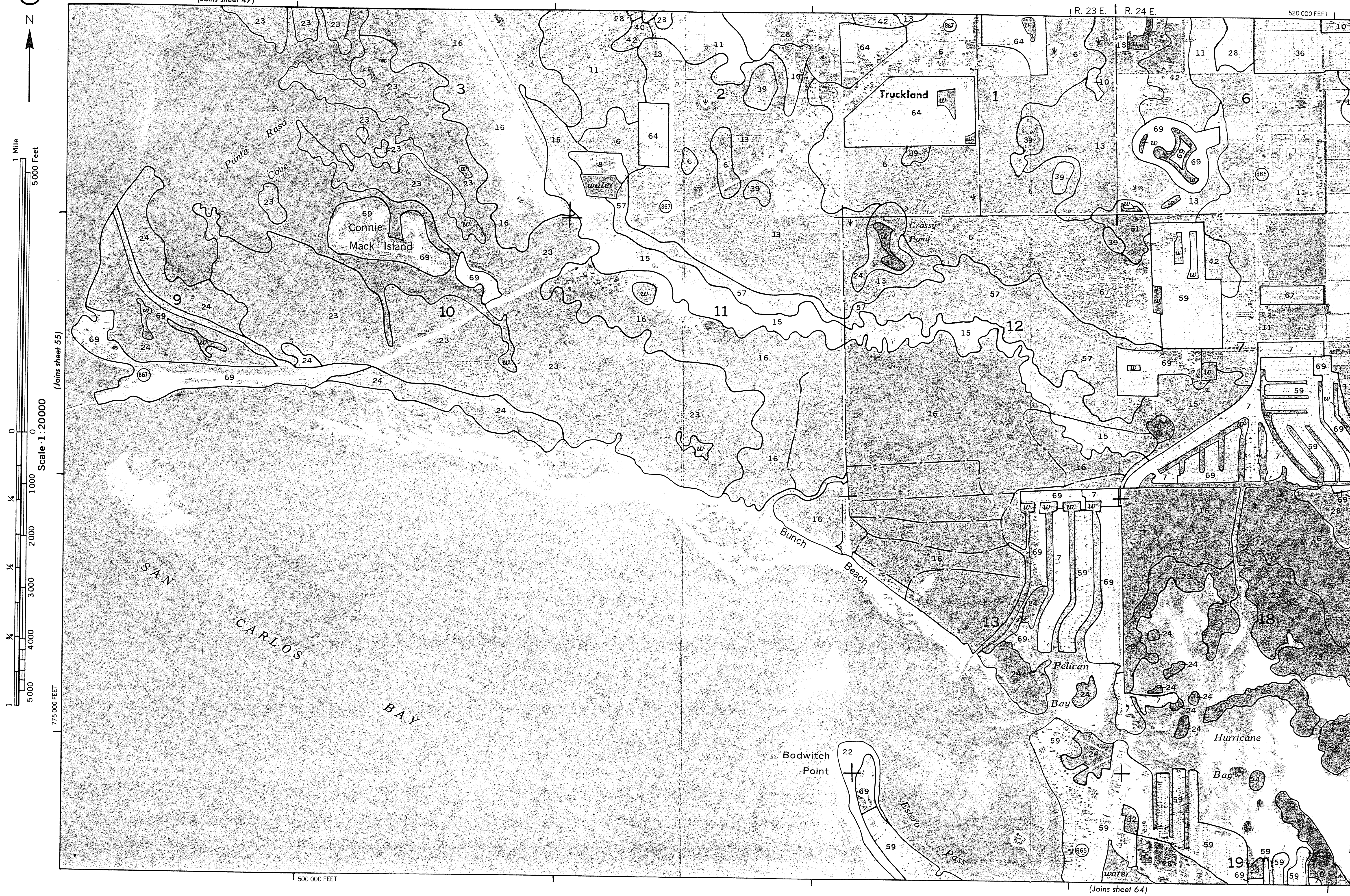
Location: 026° 27' 34.1" N 081° 56' 40.0" W
Caption: SeaGrass Study
2008-1023A

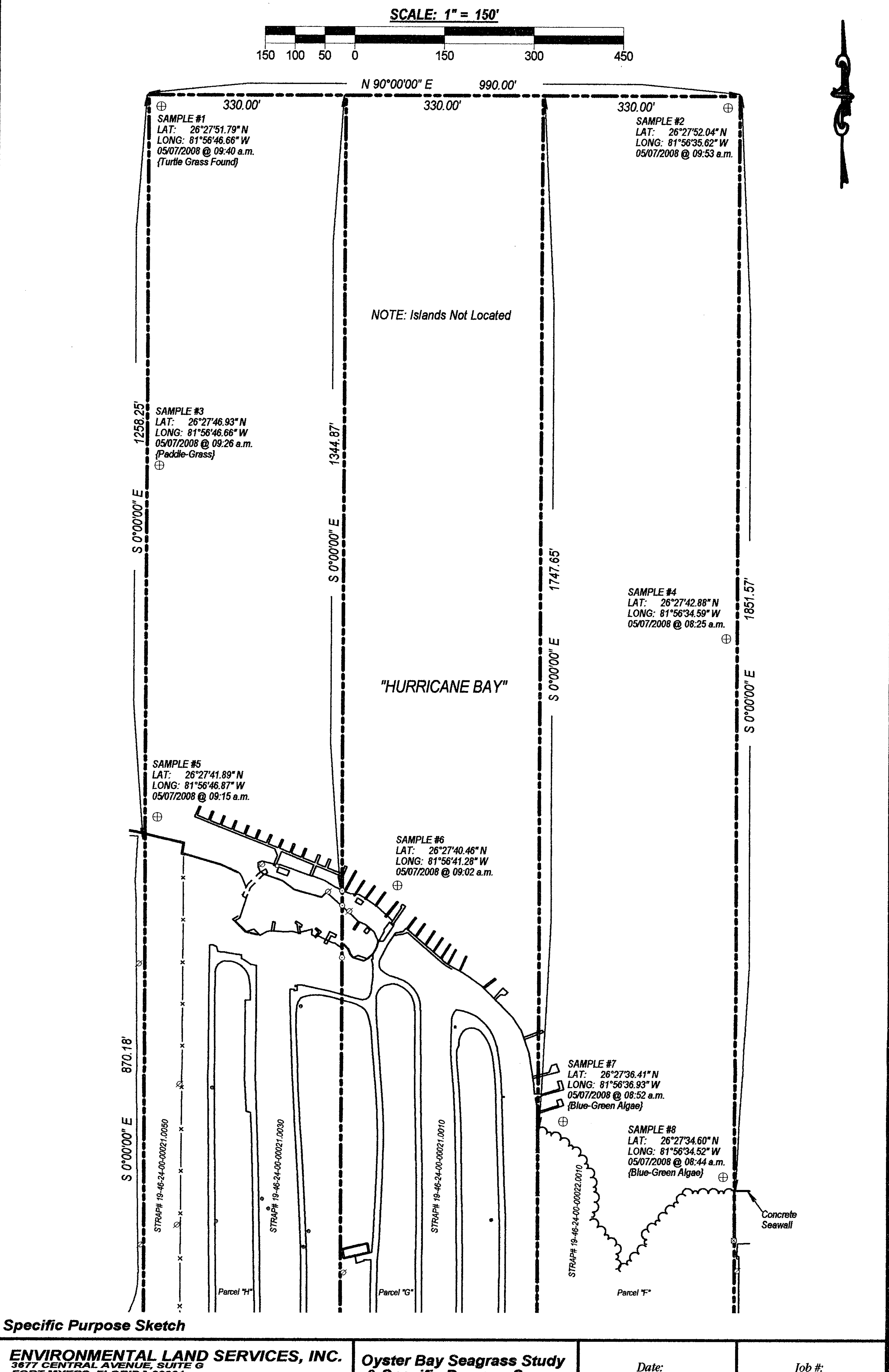


Name: FORT MYERS BEACH
Date: 3/20/2008
Scale: 1 inch equals 2000 feet

Location: 026° 27' 20.0" N 081° 56' 34.1" W
Caption: SeaGrass Study
2008-1023A

LEE COUNTY, FLORIDA — SHEET NUMBER 56





Specific Purpose Sketch

ENVIRONMENTAL LAND SERVICES, INC. 3677 CENTRAL AVENUE, SUITE G FORT MYERS, FLORIDA 33901 PHONE: (239) 274-8022 FAX: (239) 274-8019 ELS	Oyster Bay Seagrass Study & Specific Purpose Survey	Date: 05/07/08	Job #: 2008-1023A

LOCATION KESSON FL

Established Series
Rev. WGH:AGH
12/84

KESSON SERIES

The Kesson series consists of deep, very poorly drained, rapid to moderately rapid permeable soils that formed in thick marine deposits of sand and shell fragments in tidal swamps and marshes along the Gulf Coast of Peninsular Florida. Slopes range from 0 to 1 percent.

TAXONOMIC CLASS: Siliceous, hyperthermic Typic Psammaquents

TYPICAL PEDON: Kesson fine sand in a tidal area.
(Colors are for moist soil unless otherwise stated.)

A--0 to 6 inches; black (10YR 2/1) fine sand; single grained; loose; common fine and medium roots; about 15 percent shell fragments; moderately alkaline; calcareous; clear smooth boundary. (0 to 7 inches thick)

C1--6 to 10 inches; pale brown (10YR 6/3) fine sand; single grained; loose; common fine and medium roots; about 10 percent shell fragments; modrately alkaline; calcareous; clear smooth boundary. (4 to 34 inches thick)

C2--10 to 13 inches; light brownish gray (10YR 6/2) fine sand; single grained; loose; about 10 percent shell fragments; moderately alkaline; calcareous; clear smooth boundary. (3 to 22 inches thick)

C3--13 to 23 inches; light gray (5Y 7/1) and gray (5Y 6/1) fine sand; common medium distinct dark gray (10YR 4/1) streaks; single grained; loose; about 5 percent shell fragments; moderately alkaline; calcareous; gradual wavy boundary. (10 to 18 inches thick)

C4--23 to 38 inches; light gray (5Y 7/1) fine sand; single grained; loose; about 30 percent shell fragments; moderately alkaline; calcareous; gradual wavy boundary. (15 to 18 inches thick)

C5--38 to 80 inches; white (5Y 8/1) fine sand; single grained; loose; about 5 percent shell fragments; moderately alkaline; calcareous.

TYPE LOCATION: Lee County, Florida; about 1 mile west of intersection of Bailey Road and Bay Drive and 14 feet north; NE1/4NE1/4 sec. 19, T. 46 S., R. 23 E.

RANGE IN CHARACTERISTICS: Sulfur content is more than 0.75 percent within depths of 20 inches. The calcium carbonate equivalent is more than three times the sulfur content for some portion. Reaction ranges from mildly alkaline to strongly alkaline and the soil is calcareous. It does not become extremely acid when dry. Texture is sand or fine sand throughout.

The A horizon has hue of 10YR, value of 2 to 6, chroma of 1 to 3. Content of shell fragments ranges

from about 5 to 15 percent. Some pedons have organic horizons less than 8 inches thick above the A horizon.
The C horizon has hue of 10YR to 5GY, value of 2 to 8, chroma 1 to 3. Content of shell fragments ranges from about 5 to 30 percent.

COMPETING SERIES: These are the Dianola, Hallandale, Plantation, Pompano, Sanibel, and Tatton series. Dianola and Tatton soils have more than 10 percent silt and clay in the 10- to 40-inch control section. Hallandale soils are shallow to limestone. Plantation and Sanibel soils have histic epipedons. Pompano soils are not subject to tidal flooding and have very low salinity.

GEOGRAPHIC SETTING: Kesson soils are in tidal swamps and marshes along the Gulf Coast in Peninsular Florida. Slopes are less than 1 percent. The soils formed in thick deposits of sand and shell fragments. Near the type location, the mean annual precipitation is about 55 inches and the mean annual temperature is about 73 degrees F.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Captiva, Myakka, and Wulfert series. Wulfert soils are organic. Captiva and Myakka soils are poorly drained and are on higher elevations. In addition, the Myakka soils have a spodic horizon.

DRAINAGE AND PERMEABILITY: Kesson soils are very poorly drained. Runoff is slow. Permeability is moderately rapid to rapid. Under natural conditions, the soil is flooded during normal high tides.

USE AND VEGETATION: Kesson soils are used mainly for wildlife habitat. Native vegetation is black mangrove, oxeye daisy, batis, and scattered American mangrove.

DISTRIBUTION AND EXTENT: Coastal tidal area of Peninsular Florida. The series is of small known extent.

MLRA OFFICE RESPONSIBLE: Auburn, Alabama

SERIES ESTABLISHED: Manatee County, Florida; 1980.

REMARKS: This series was formerly mapped as tidal swamp.

National Cooperative Soil Survey
U. S. A.

LOCATION WULFERT FL

Established Series
Rev. WGH; AGH; GRB
01/2004

WULFERT SERIES

The Wulfert series consists of very deep, very poorly drained, rapidly permeable soils in tidal areas along the Gulf Coast. They formed in well decomposed organic material and underlying materials. Near the type location, the mean annual temperature is about 72 degrees F., and the mean annual precipitation is about 55 inches. Slopes range from 0 to 1 percent.

TAXONOMIC CLASS: Sandy or sandy-skeletal, siliceous, euic, hyperthermic Terric Sulfisaprists

TYPICAL PEDON: Wulfert muck--in a mangrove swamp. (Colors are for wet soil.)

Oa1--0 to 2 inches; dark reddish brown (5YR 2/2) muck; 15 percent fiber, 3 percent rubbed; massive; friable; many fine roots, common medium roots; about 55 percent mineral material; 0.5 percent sulfur; 318 mmho/cm conductivity; slightly acid; clear smooth boundary.

Oa2--2 to 12 inches; dark reddish brown (5YR 3/2) muck; 75 percent fiber, 3 percent rubbed; massive; friable; common coarse roots; about 56 percent mineral material; 1.5 percent sulfur; 350 mmho/cm conductivity; strongly acid; clear smooth boundary.

Oa3--12 to 36 inches; dark brown (7.5YR 3/2) muck; 95 percent fiber, 16 percent rubbed; massive; friable; common fine and medium roots; about 79 percent mineral material; 2.4 percent sulfur; 245 mmho/cm conductivity; extremely acid; gradual wavy boundary. (Combined thickness of the Oa horizons range from 16 to 51 inches)

Cg--36 to 80 inches; gray (5Y 5/1) fine sand; single grained; loose; about 10 percent, by volume, shell fragments; about 0.3 percent sulfur; 74 mmho/cm conductivity; few medium distinct light gray (5Y 7/1) streaks; extremely acid.

TYPE LOCATION: Lee County, Florida; approximately 0.2 mile north of intersection of the power line and dike and about 75 feet west; SE 1/4, SE 1/4, Sec. 7, T. 46 S., R 22 E.

RANGE IN CHARACTERISTICS: Sulfur content ranges from 0.7 to 2.4 percent in the Oa2 and Oa3 horizons. The organic material in all tiers is dominantly sapric material, but in some pedons, hemic material occurs. Conductivity of the saturation extract above the C ranges from about 200 to 400 mmho/cm. Reaction of the Oa horizons ranges from extremely acid to neutral in the natural state and from extremely acid to slightly acid after drying. Reaction of the Cg horizon in the natural state ranges from extremely acid to slightly alkaline and from extremely acid to moderately acid after drying.

The Oa horizon has hue of 5YR to 10YR, value of 2 or 3, and chroma of 3 or less. Mineral content ranges up to 80 percent. Texture is muck.

The Cg horizon has hue of 10YR to 5Y, value of 3 to 7, and chroma of 1 or 2. Redoximorphic features in shades of yellow, brown, or gray range from none to many. Content of shell fragments range from 0 to 20 percent, by volume. Texture is sand, fine sand, loamy fine sand, loamy sand, their gravelly or mucky analogs.

COMPETING SERIES: The Weekiwachee series is the only known series in the same family. Weekiwachee soils are on similar positions and are moderately deep to limestone bedrock.

GEOGRAPHIC SETTING: Wulfert soils are in tidal swamps and marshes along the Gulf Coast in Peninsular Florida. Slopes are less than 1 percent. They formed in moderately thick deposits of hydrophytic plant remains and sandy marine sediments containing shell fragments. The climate is humid subtropical. The average annual precipitation ranges from 50 to 60 inches, and the average annual temperature ranges from 70 to 74 degrees F.

GEOGRAPHICALLY ASSOCIATED SOILS: These are Captiva and Kesson series. They are both sandy throughout. The poorly drained Captiva soils are on higher positions and have mollic epipedons. Kesson soils are on similar positions.

DRAINAGE AND PERMEABILITY: Very poorly drained; rapid permeability.

USE AND VEGETATION: Wulfert soils are used mainly for wildlife habitat. The native vegetation is dominated by American mangrove, black mangrove, needlegrass rush, seashore saltgrass, marshhay cordgrass, and smooth cordgrass.

DISTRIBUTION AND EXTENT: Gulf Coast tidal area of Peninsular Florida. The series is of small known extent.

MLRA OFFICE RESPONSIBLE: Auburn, Alabama.

SERIES ESTABLISHED: Manatee County, Florida; 1980.

REMARKS: Diagnostic horizons and features in this pedon:

Histic epipedon the zone from 0 to 36 inches (Oa1, Oa2, and Oa3 horizons).

Wulfert soils are flooded during normal daily high tides.

The revision changed the series classification to recognize the 1992 amendments to Soil Taxonomy that introduced changes in classification of Histosols.

ADDITIONAL DATA: Sample number S36-6-(1-4). Soil Characterization Lab., IFAS, University of Florida, Gainesville, FL.

National Cooperative Soil Survey
U.S.A.

LOCATION PECKISH FL

Established Series
Rev. WGH:HFH
9/82

PECKISH SERIES

The Peckish series consists of deep, very poorly drained, rapidly permeable soils that formed in thick beds of sandy marine sediments in tidal swamps along the coast of Peninsular Florida. Slopes range from 0 to 1 percent.

TAXONOMIC CLASS: Sandy, siliceous, hyperthermic Typic Sulfaquents

TYPICAL PEDON: Peckish mucky fine sand in a mangrove tidal swamp.
(Colors are for moist soil unless otherwise stated.)

A11--0 to 4 inches; dark reddish brown (5YR 2/2) mucky fine sand; massive; friable; 45 percent sulfur; 222 mmho/cm conductivity; very strongly acid; abrupt smooth boundary. (4 to 9 inches thick)

A12--4 to 6 inches; dark grayish brown (10YR 4/2) mucky fine sand; massive; friable; 13 percent sulfur; 59 mmho/cm conductivity; very strongly acid; abrupt smooth boundary. (0 to 2 inches thick)

A13--6 to 9 inches; dark reddish brown (5YR 3/2) mucky fine sand; massive; friable; 26 percent sulfur; 105 mmho/cm conductivity; strongly acid; abrupt smooth boundary. (0 to 3 inches thick)

A21--9 to 12 inches; gray (10YR 5/1) fine sand; single grained; loose; many fine roots; 7 percent sulfur; 32 mmho/cm conductivity; strongly acid; clear smooth boundary. (13 to 33 inches thick)

A22--12 to 25 inches; light gray (10YR 6/1) fine sand; few light gray (10YR 7/1) streaks along old root channels; single grained; loose; few fine and medium roots; few pockets of organic material; 2 percent sulfur; 50 mmho/cm conductivity; very strongly acid; gradual wavy boundary. (11 to 18 inches thick)

A23--25 to 36 inches; light gray (10YR 7/1) fine sand; common medium distinct light brownish gray (10YR 6/2) and grayish brown (10YR 4/2) mottles; single grained; loose; 4 percent sulfur; 25 mmho/cm conductivity; neutral; clear wavy boundary. (0 to 11 inches thick)

B2h--36 to 43 inches; dark grayish brown (10YR 4/2) and very dark grayish brown (10YR 3/2) fine sand; single grained; very friable; sand grains thinly coated with organic matter, many uncoated sand grains; 3 percent sulfur; 29 mmho/cm conductivity; extremely acid; clear smooth boundary. (5 to 7 inches thick)

B3&Bh--43 to 48 inches; brown (10YR 5/3) and dark brown (10YR 4/3) fine sand; common medium distinct very dark grayish brown (10YR 3/2) mottles; single grained; very friable; many uncoated sand grains 6 percent sulfur; 30 mmho/cm conductivity; very strongly acid; gradual wavy boundary. (0 to 7 inches thick)

C--48 to 61 inches; pale brown (10YR 6/3) fine sand; few fine distinct very dark grayish brown (10YR 3/2) streaks along old root channels; single grained; loose; 4 percent sulfur; 27 mmho/cm conductivity; very strongly acid.

TYPE LOCATION: Lee County, Florida; about 0.7 mile southeast of intersection of State Highway 867 and Shell Point Blvd. and 150 feet south in the SE1/4NE1/4 sec. 11, T. 46 S., R 23 E.

RANGE IN CHARACTERISTICS: Sulfur content ranges from 2 to 45 percent within depths of 20 inches. Reaction ranges from very strongly acid to moderately alkaline in the natural state, and from extremely acid to neutral after drying.

The A1 horizon has hue of 10YR, value of 2, and chroma of 1 or value of 3 or 4 and chroma of 1 to 3; hue of 7.5YR, value of 3, and chroma of 2; or hue of 5YR, value of 2 or 3, and chroma of 2. It is mucky fine sand or fine sand.

The A2 horizon has hue of 10YR, value of 5 to 7, and chroma of 1 or 2; or hue of 2.5Y, value of 5, and chroma of 2.

The Bh horizon does not meet the requirements of a spodic horizon. It has matrix color in hue of 10YR, value of 3 to 5, and chroma of 2 or 3; or hue of 7.5YR, value of 3, and chroma of 2 or is a mixture of these colors. Some pedons have a B3&BH or B3 horizon, where present, the color is in hue of 10YR, value of 4, and chroma of 2, value of 5 or 6, and chroma of 3; or hue of 7.5YR, value of 5, and chroma of 3.

The C horizon has hue of 10YR, value of 5 to 7, and chroma of 3 or less. Texture is sand or fine sand. Shell fragments are in the C horizon in some pedons.

COMPETING SERIES: These are Homosassa and Kesson series in the same family. Homosassa soils have hard limestone within depths of 20 to 40 inches and lack Bh horizons. Kesson soils lack Bh horizons.

GEOGRAPHIC SETTING: Peckish soils are in tidal swamps and mashes. Slopes are less than 1

percent. The soil formed in thick deposits
of sand. Near the type location, mean annual precipitation is
about 55 inches and mean annual temperature is about 73 degrees F.

GEOGRAPHICALLY ASSOCIATED SOILS: These are Myakka and Hallandale series. Myakka soils lack appreciable amounts of sulfides within 120 inches of the surface and have spodic horizons. Hallandale soils have limestone less than 20 inches below the surface and lack Bh horizons.

DRAINAGE AND PERMEABILITY: Peckish soils are very poorly drained. Runoff is slow. Permeability is rapid. Under natural conditions, the soil is flooded daily during normal high tides.

USE AND VEGETATION: Peckish soils are used mainly for wildlife habitat. Native vegetation is black-mangrove, American mangrove in swamps, and batis, saltwort, bushy sea-oxeye, marshhay cordgrass, and seashore saltgrass in marshes.

DISTRIBUTION AND EXTENT: Coastal tidal area of Peninsular Florida. The series is of small known extent.

MLRA OFFICE RESPONSIBLE: Auburn, Alabama

SERIES ESTABLISHED: Lee County, Florida; 1982.

REMARKS: This series was formerly mapped as tidal swamp, mangrove. This soil would classify as Spodic Sulfaquents if this subgroup were in taxonomy.

National Cooperative Soil Survey
U. S. A.

Lee County GOVERNMENT

Community Development

E-Con
Online Perm

Affordable Housing
Building Services
Code Enforcement
Comprehensive Planning
Data Resources
Environmental Sciences
Historic Preservation
Zoning
Applications-Docs-Maps
Building Permit Reports
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Contact Information
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Wetlands

What is a Wetland?	Wetland Determination	Wetland Permitting	History of Wetland Protection in Lee County	Wetland Permit Agencies	Hydric Soil Clarification

WHAT IS A WETLAND?

TOP

Wetlands are those areas defined by Florida Statutes subsection 373.019(17). These areas are usually inundated or saturated by water long enough to create oxygen poor soils which under normal circumstances support wetland vegetation as defined in Chapter 62-340.450 of the Florida Administrative Code (F.A.C.). There are various natural plant communities typical of wetlands in Florida. Hydric pine flatwoods, cypress domes and strands, hydric hammocks, mangrove swamps, marshes and wet prairies are some of the wetland plant communities found in Lee County.

WETLAND DETERMINATION

TOP

Wetlands are determined using the Florida Unified Wetland Delineation Methodology detailed in Chapter 62-340, F.A.C. Persons trained in using this methodology determine if an area contains wetlands based on the type of vegetation present, hydric indicators in the soil, and evidence of hydrology. The historical Soil Survey of Lee County completed in the early 1980s, serves as guideline for locating potential wetland areas. Frequently flooded, slough (sheet-flow) and depressional (ponding and muck) soil types can indicate areas of wetland formation; however, a site visit needs to be conducted by a person trained in wetland delineation methodology to verify the presence or absence of wetlands. For a listing of prominent hydric soils within Lee County, click here. To obtain a copy of the Soil Survey of Lee County, click here. Please note that just because a parcel does not contain a hydric soil mapping unit number does not automatically mean wetland conditions are not present. And the opposite is true – just because a parcel is mapped with a hydric soil number does mean that a wetland is definitely present. Thus, the need for a site inspection by trained personnel. For more information about wetlands and the Florida Unified Wetland Delineation Methodology, please go to www.dep.state.fl.us/water/wetlands/delineation/index.htm

Lee County no longer conducts independent wetland determinations since the passing of Land Development Code Wetland Protection Amendments. However, if a hydric soil mapping unit, according to the Soil Survey of Lee County, is present on a parcel Lee County requires a wetland determination prior to the approval of applications for single family residence building permits, planned development rezonings, lot splits, and development orders. The Florida Department of Environmental Protection (DEP) provides wetland determinations for single family residence parcels. The South Florida Water Management District (SFWMD) handles parcels zoned for commercial, agriculture and multi-family use. If a wetland determination reveals wetlands are present on a parcel, an Environmental Resource Permit must first be obtained prior to the issuance of Lee County permits and development orders. See Wetland Permitting below.

DEP conducts informal wetland determinations at no cost for single family residence parcels under one acre. To obtain the Request for Informal Wetland Determination form online, go to www.dep.state.fl.us/south. Once completed, the form can be faxed or mailed to DEP. For parcels over one acre or further information on wetland determinations, please contact the DEP South District Office.

To view a copy of Soil Survey of Lee County you can either:

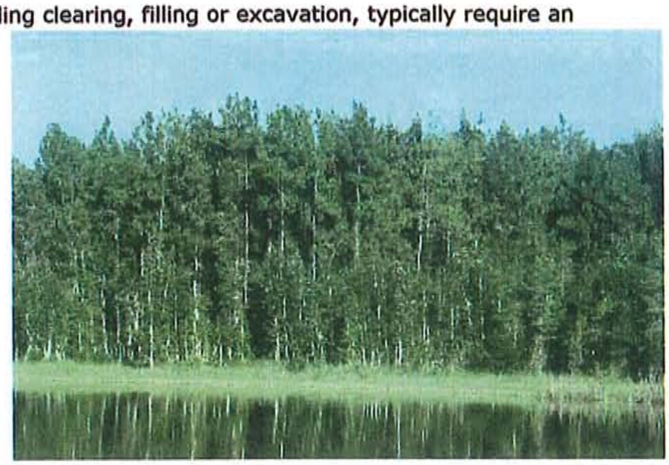
Come to the Lee County Department of Community Development at 1500 Monroe Street, Fort Myers. (get directions here)

OR

Visit the Soil & Water Conservation (Natural Res Conservation) buildings at 3434 Hancock Bridge Parkway, Suite 209-B, 33903 or call 239-995-5678.

WETLAND PERMITTING

TOP



Impacts to wetlands, including clearing, filling or excavation, typically require an Environmental Resource Permit (ERP) from the Florida Department of Environmental Protection (DEP) or the South Florida Water Management District (SFWMD). Generally, parcels zoned for single family residence are handled by DEP. Parcels zoned for multi-family residence, commercial and agriculture are handled by SFWMD. Prior to the release of Lee County development orders and building permits on parcels containing wetlands (see section above for information on Wetland Determinations), an ERP must be obtained and a copy provided to Lee County. Conditions of the DEP or SFWMD Environmental Resource Permit will be incorporated into Lee County development orders and permits. Lee County Environmental Sciences staff will participate in the compliance and enforcement of permit conditions.

HISTORY OF WETLAND PROTECTION IN LEE COUNTY

TOP

On September 18, 1996, the Lee County Board of County Commissioners approved amendments to the Wetland Protection Section in Chapter 14 in the Land Development Code. These amendments change the permit process for parcels of land with wetlands.

WETLAND PERMIT AGENCIES - (Federal, State, Regional and Local Agencies) TOP

U.S. ARMY CORPS OF ENGINEERS - (ACOE)

Fort Myers Regulatory Office
1520 Royal Palm Square Blvd., Suite 310
Fort Myers, FL 33919
Telephone (239) 334-1975
Fax (239) 334-0797
http://www.saj.usace.army.mil

FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION - (DEP)

South Florida District Office
2295 Victoria Avenue, Suite 364
Fort Myers, FL 33901
Telephone (239) 332-6975
Fax (239) 332-6969
http://www.dep.state.fl.us/

SOUTH FLORIDA WATER MANAGEMENT DISTRICT - (SFWMD)

Fort Myers Service Center
2301 McGregor Boulevard
Fort Myers, FL 33901
Telephone (239) 338-2929
Fax (239) 338-2936
http://www.sfwmd.gov/

LEE COUNTY DIVISION OF ENVIRONMENTAL SCIENCES

1500 Monroe Street, 4the Floor
Fort Myers, FL 33901
Telephone (239) 533-8389
Fax (239) 485-8344
http://www.lee-county.com/dcd/Environmental/Environmental.htm

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PROMINENT HYDRIC SOILS OF LEE COUNTY TOP

(ACCORDING TO THE USDA / SOIL CONSERVATION SERVICE SOIL SURVEY OF LEE COUNTY)

Hydric soils are those soils that in their natural conditions are saturated, flooded, or ponded long enough during the growing season (February-December in Lee County) to develop anaerobic conditions that favor the growth and regeneration of hydrophytic (wetland) vegetation.

FLOODING

Soil flooded by moving water from stream overflow, run off or high tides.

Field Symbol	Field Mapping Unit Name
8	Hallandale fine sand, tidal
15	Estero Muck
16	Peckish mucky fine sand
23	Wulfert muck

24	Kesson fine sand
56	Isles muck
57	Boca fine sand, tidal

SLOUGH (SHEET-FLOW)

Broad nearly level, poorly defined drainage way that is subject to sheet-flow in the rainy season.

Field symbol	Field Mapping Unit Name
5	Captiva fine sand
10	Pompano fine sand
12	Felda fine sand
14	Valkaria fine sand
26	Pineda fine sand
34	Malabar fine sand
38	Isles fine sand, slough
74	Boca fine sand, slough
75	Hallandale fine sand, slough
77	Pineda fine sand, limestone substratum

PONDING

Standing water on soils in closed depressions. The water can be removed only by percolation or evapotranspiration.

Field Symbol	Field Mapping Unit Name
19	Gator muck
20	Terra Ceia muck
27	Pompano fine sand, depressional
39	Isles fine sand, depressional
40	Anclote fine sand, depressional
41	Valkaria fine sand, depressional
44	Malabar fine sand, depressional
45	Copeland sandy loam, depressional
49	Felda fine sand, depressional
51	Floridan fine sand, depressional
53	Myakka fine sand, depressional
62	Winder sand, depressional
73	Pineda fine sand, depressional

78	Chobee muck

Note: Soil #6 - Hallendale fine sand and #13 - Boca fine sand have indicated a high percentage of hydric soils within the mapping unit and may also indicate a wetland area.

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IFAS Extension

Lee County: Soil Ratings for Selecting Pesticides[1]

G.W. Hurt and T.A. Obreza[2]

RATINGS FOR LEE COUNTY SOILS FOR PESTICIDE SELECTION

Resource soil scientists with the Florida USDA Natural Resources Conservation Service have rated the soils that are delineated by map units in the Lee County Soil Survey Report[1] for their potential for leaching and runoff of pesticides. The rating criteria are given in a companion publication entitled "Soil Ratings for Selecting Pesticides for Water Quality Goals." These soil ratings have been developed to help pesticide users determine the potential for pesticides to be lost to groundwater or surface water bodies.

As explained in Circular 959[2], factors that determine pesticide leaching ratings in soil are permeability and the occurrence of mucky layers in the upper 80 inches of the soil. Soils rated High have a high potential for pesticides to leach to groundwater, soils rated Medium have a medium potential for pesticides to leach to groundwater, and soils rated Low have a low potential for pesticides to leach to groundwater. Factors that determine pesticide runoff ratings from soils are hydrologic group, permeability, and slope. Soils rated High have a high potential for pesticide runoff, soils rated Medium have a medium potential for pesticide runoff, and soils rated Low have a low potential for pesticide runoff.

NOTE: The user may discover that one or more map unit names in Table 1 have been updated from names given in the legend of the soil survey report[1]. For example, a soil map unit may be listed in the survey report with a single soil series name, whereas the same soil map unit is shown as comprising two or more soil series in Table 1 (sequence numbers 1, 2, 3, ..) Where this occurs, the user should use the multi-named map unit given **here**, and make pesticide selections based on the most limiting condition to be found on the land in question. If necessary, the local Natural Resources Conservation Service office should be contacted to perform an on-site evaluation of the land in question.

REFERENCES

1. Henderson, W.G. Jr. 1984. *Soil Survey of Lee County Area, Florida.* USDA/NRCS in cooperation with University of Florida, Institute of Food and Agricultural Sciences, Agricultural Experiment Stations, Soil and Water Science Department, and the Florida Department of Agriculture and Consumer Services.

1. This document is SL84, a fact sheet of the Soil and Water Science Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication date: April 1991, revised September 2006. Please visit the EDIS Web site at http://edis.ifas.ufl.edu.
2. G.W. Hurt, National Leader for Hydric Soils, Natural Resources Conservation Service, USDA; T.A. Obreza, Professor, Soil and Water Science Department, Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611.

2. Obreza, T.A. and G. W. Hurt. 2006. *Soil Ratings For Selecting Pesticides For Water Quality Goals*. Circular 959, Soil and Water Science Department, Cooperative Extension Service, University of Florida, Gainesville, Florida, 32611. 5pp.

ACKNOWLEDGMENTS

The development of this document was supported by the USDA/ES Water Quality Initiative Project # 89EWQI-1-9134.

Table 1. Soil Ratings for Lee County (see footnotes for explanations of column headings).

MUID	SYS NUM	MUSYM	SOIL NAME	SOIL LEACH	SOIL RUNOFF
71002	1	2	CANAVERAL	High	Medium
71004	1	4	CANAVERAL	High	Medium
71004	2	4	URBAN LAND	High	Medium
71005	1	5	CAPTIVA	High	High
71006	1	6	HALLANDALE	Medium	High
71007	1	7	MATLACHA	Medium	Medium
71007	2	7	URBAN LAND	Medium	High
71008	1	8	HALLANDALE	Medium	High
71009	1	9	EAUGALLIE	Low	High
71010	1	10	POMPANO	High	High
71011	1	11	MYAKKA	Medium	High
71012	1	12	FELDA	Medium	High
71013	1	13	BOCA	Low	High
71014	1	14	VALKARIA	High	High
71015	1	15	ESTERO	Low	High
71016	1	16	PECKISH	High	High
71017	1	17	DAYTONA	Low	Low
71018	1	18	MATLACA	Low	Medium
71019	1	19	GATOR	Low	High
71020	1	20	TERRA CEIA	Low	High
71022	1	22	BEACHES	High	High
71023	1	23	WULFERT	Low	High
71024	1	24	KESSON	Low	High
71025	1	25	ST. AUGUSTINE	High	Low
71025	2	25	URBAN LAND	High	High
71026	1	26	PINEDA	Low	High
71027	1	27	POMPANO	Medium	High
71028	1	28	IMMOKALEE	Medium	High
71029	1	29	PUNTA	Medium	High
71033	1	33	OLDSMAR	Low	High
71034	1	34	MALABAR	Low	High
71035	1	35	WABASSO	Low	High
71036	1	36	IMMOKALEE	Medium	High
71036	2	36	URBAN LAND	Medium	High
71037	1	37	SATELLITE	High	Low
71038	1	38	ISLES	Medium	High
71039	1	39	ISLES	Medium	High
71040	1	40	ANCLOTE	High	High
71041	1	41	VALKARIA	High	High
71042	1	42	WABASSO	Low	High
71043	1	43	SMYRNA	Medium	High
71044	1	44	MALABAR	Low	High
71045	1	45	COPELAND	Medium	High
71048	1	48	ST. AUGUSTINE	High	Medium
71049	1	49	FELDA	Medium	High
71050	1	50	OLDSMAR	Low	High

Table 1. Soil Ratings for Lee County (see footnotes for explanations of column headings).

MUID	SYS NUM	MUSYM	SOIL NAME	SOIL LEACH	SOIL RUNOFF
71051	1	51	FLORIDANA	Low	High
71053	1	53	MYAKKA	Medium	High
71055	1	55	COCOA	High	Low
71056	1	56	ISLES	Medium	High
71057	1	57	BOCA	Low	High
71059	1	59	URBAN LAND	Medium	High
71061	1	61	ORSINO	High	Low
71062	1	62	WINDER	Low	High
71063	1	63	MALABAR	Low	High
71064	1	64	HALLANDALE	Medium	High
71064	2	64	URBAN LAND	Medium	High
71066	1	66	CALOOSA	Low	Medium
71067	1	67	SMYRNA	Medium	High
71067	2	67	URBAN LAND	Medium	High
71069	1	69	MATLACHA	Medium	Medium
71070	1	70	HEIGHTS	Low	High
71072	1	72	BRADENTON	Low	High
71073	1	73	PINEDA	Low	High
71074	1	74	BOCA	Low	High
71075	1	75	HALLANDALE	High	High
71076	1	76	ELECTRA	Low	Medium
71077	1	77	PINEDA	Low	High
71078	1	78	CHOBEE	Low	High
71079	1	79	WATER		

Footnotes:

MUID = Natural Resources Conservation Service's map unit identifier.

SEQ NUM = Sequence Number, indicating a particular soil name among one or more names constituting a map unit name.

MUSYM = Map Unit Symbol from the soil map and legend in the Soil Survey of Lee County, Florida. Note that if a MUSYM appears more than once in this list it signifies that two or more soils are co-dominant that map unit, and each such soil is rated separately here.

SOIL NAME = Name of soil or other landscape component (urban land, beaches, water, etc.).

SOIL LEACH = The rating of the soil for leaching of pesticides through the soil profile.

SOIL RUNOFF = The rating of the soil for runoff of pesticides from the soil surface.

NOTE: See "Soil Ratings for Selecting Pesticides for Water Quality Goals" (IFAS Extension Circular 959) for explanations of the criteria used to develop soil ratings presented in the right-hand four columns of this list.

MATANZAS PASS PRESERVE

198 Bay Road
Fort Myers Beach

LAND STEWARDSHIP PLAN
2006

Commission for Accreditation of Park and Recreation Agencies
CAPRA ACCREDITED

Discover
LEE COUNTY
Parks & Recreation

Approved by Lee County
Board of County Commissioners: 05/02/2006

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A. APPENDICES

Vision Statement

Continued dedication of residents, visitors, and Lee County Parks and Recreation will insure the preservation of the Matanzas Pass Preserve as a tropical island habitat. Guided nature walks, wildlife viewing from the pavilion on the bay, walking trails, and boardwalks will provide educational opportunities in this versatile outdoor classroom. The Matanzas Pass Preserve enhances opportunities for kayaking/canoeing along with bird watching and fishing in the Estero Bay Aquatic Preserve. Through conservation, restoration and maintenance the Matanzas Pass Preserve will remain a peaceful place of rest and tranquility for wildlife and those who visit.

Executive Summary

The Nature Conservancy donated the 58-acre Matanzas Pass Preserve to Lee County in 1994, after twenty years of stewardship. The physical distance of the Nature Conservancy office in Orlando to Fort Myers Beach made long distance management problematic. A volunteer committee, which became the Friends of Matanzas Pass Preserve, was established by The Nature Conservancy to co-manage the preserve and many projects were developed and completed with volunteer staff. When Lee County assumed stewardship of the Preserve, a site analysis was obtained, surveys prepared, and a Restoration Plan, Master Site Plan, and Resource Management Plan were created. This management plan is a revision and update of the 1996 plan. Since 1996, new recycled plastic boardwalks replaced deteriorated wooden boardwalks and interpretive signs were placed in the preserve with support from the Lee County Visitors Convention Bureau and the Tourist Development Council. Exotic removal began and was effective on air potato, Australian pines, and Brazilian peppers.

The Matanzas Pass Preserve is one of a few undeveloped, protected areas in the developed town of Fort Myers Beach on Estero Island. Walking the preserve boardwalk and trails offers a rare opportunity to view the flora and fauna of a mangrove forest and maritime oak hammock from within. The acquisition of the Matanzas Pass Preserve has insured its protection and preservation for present and future generations of residents and visitors.

Land Stewardship Plans are fluid and change through environmental influences, use changes, and population growth. Many of the issues addressed in the 1996 management plan are the same today - maintenance, exotic pest plant control, and restoration. Many issues evolve over time – resource based uses, carrying capacity, and educational programming.

Revisions to the 1996 plan include: updating surveys, plant community maps, and fauna list and creating management units, management goals, and strategies. Implementation timetables and standards to measure the achievements are included in an easy to read table. Incorporating a vision statement and action plan with this revised plan as well as updated aerial photographs, site plan, and management unit map brings the preserve information up to date.

I. Introduction & Purpose

The Matanzas Pass Preserve (MPP) is located in southwestern Lee County on the seven-mile long island of Estero, in the town of Fort Myers Beach. The 58 acre preserve runs along Matanzas Pass which links San Carlos Bay and Estero Bay, the first aquatic preserve in the state of Florida. The preserve is accessible from Bay Road and ends in a small parking area in front of the Historic Cottage. Three natural plant communities make up the preserve: mangrove swamp, maritime hammock and coastal grassland. The natural plant communities and shady hammock support a variety of wildlife on land and in the estuary.

The efforts of many people, both residents and visitors, have played a part in the acquisition of this parcel of property. Calusa Indians, homesteaders Robert Gilbert and George McAuley, Dr. and Mrs. Winkler, Martha Redd, nature photographer John Dunning, The Nature Conservancy and Lee County Government all are responsible for the preservation of the Matanzas Pass Preserve. The Winkler's came to Estero Island in 1912 by boat and bought 50 acres of land from Robert Gilbert and another 25 acres of land from homesteader George McAuley, which gave them the parcel of property from the Gulf of Mexico to Matanzas Pass including the Preserve area. Dr. Winkler built the two-story Beach Hotel and pier on the Gulf of Mexico by barging lumber to Estero Island.

The Winklers hired Martha Redd to care for them as they aged and when they passed on in 1938, she inherited the property on the bay side of Estero Boulevard in its pristine condition. As the development boom was beginning, Martha Redd was under pressure to sell her large parcel of land. For 36 years Martha had lived on the land in the area of the Matanzas Pass Preserve with little improvement and was criticized for living in a jungle. In 1974 Martha Redd's nieces and nephews inherited the land and were interested in selling it for development. Local residents, realizing the importance of acquiring this land, spearheaded grass roots fund raisers to secure the option to buy.

Nature photographer and island residents, John and Harriett Dunning, purchased 43 acres of the then believed to be 55 acres of the Martha Redd estate for $125,000.00 in October 1974. Mr. Dunning donated 22 acres to The Nature Conservancy, keeping one acre for himself, and offered to sell the rest of the property to the residents for $105,000.00. Through tremendous grass-root efforts residents and visitors raised the money to buy the remaining acres and completed the purchase two years later. With this goal achieved, The Nature Conservancy was given possession of the Matanzas Pass Preserve in 1977 to insure that this area would be properly managed and remain in conservation. A local volunteer committee was established to oversee the property.

The Preserve has historically been referred to as a 42-acre site either due to early surveying techniques or to the area being estimated in size. The Preserve now stands at 58 acres due to corrections made with modern technology in surveying and the donation of approximately one acre of land from the School District of Lee County to the Lee County Board of County Commissioners in 1995. These out parcels can be seen in figure 2: Matanzas Pass Preserve 2005 Aerial.

Clearing paths, hauling debris, building an elevated boardwalk with bridges, placing benches, and trimming vegetation began in 1977 with volunteers including students from teacher Bill Hammond's Environmental Education Program - the Monday Group, from Lee County Schools, and Boy Scout Troops. The Fort Myers Beach Rotary Club built the Rotary Pavilion on the bay, Estero Island Garden Club landscaped the entrance and Lois Gressman, an original member of the Friends group, wrote a trail guide. The Nature Conservancy officially opened the Preserve with a ribbon cutting ceremony January 20, 1979 and the title, Matanzas Pass Wilderness Preserve.

In June 1992, vandals destroyed the main bridge causing the closing of the Preserve. The Nature Conservancy held a meeting September 15, 1992 to investigate management alternatives. After exploring possibilities, The Nature Conservancy donated the property to Lee County in 1994 to insure proper future management and protection of the natural resources. The title of the Preserve was changed to reflect the possible discrepancy of the term "wilderness" and that which the site represents.

In 1995, the School District of Lee County donated an acre of land to serve as an entrance for the preserve, provide parking, and to house the Historic Davison Cottage, the fourth house built on Fort Myers Beach, and to serve as an information area for the preserve. This addition of land gave the Preserve a public access. Americorps volunteer Yih-Ming Hsu completed the Matanzas Pass Preserve Restoration Plan, Master Site Plan and Resource Management Plan in 1996 for Lee County Division of Parks and Recreation.

Land stewardship for the preserve continues to be a challenge. The upland area and mosquito control ditch spoil piles are invaded with exotics species in the southeast and southwest sections. Boaters and careless visitors contribute to the constant need for litter control. Human disturbances from bicycles and pets occur as well as unwanted, destructive, and irresponsible behavior. Many wading birds and listed species utilize the preserve. A balance is needed between the natural resources and the resource based recreational opportunities this preserve can provide. Limiting the Preserve to pedestrian traffic on trails only, no bicycles or motorized vehicles, and control of unauthorized use along with education for preservation will go a long way to achieving balance.

The purpose of this stewardship plan is to revise the 1996 plan, and to define the conservation, restoration, and preservation goals for the Matanzas Pass Preserve. It is a guide to support the best management practices for Lee County's Department of Parks and Recreation.

II. Location and Site Description

Matanzas Pass Preserve is located in southwestern Lee County, Sections 19-20, Township 46 South, Range 24 East on the island of Estero, south of Sanibel Island and north of Bonita Beach and consists of 58 acres. The Preserve runs along Matanzas Pass, the body of water connecting San Carlos Bay and Estero Bay. The main entrance to the preserve is located on Bay Road off Estero Boulevard in the Town of Fort Myers Beach, Lee County and is an estimated 1.1 miles southeast of the Matanzas Pass Bridge. The north-northeast boundary of the preserve is Matanzas Pass; the south and southeast boundaries border the subdivisions of Shell Mound Park and Zimmer's Addition to Shell Mound Park, Donora Boulevard. The south and southwest boundary are adjacent to the Red Coconut RV Park, Gulf View Colony, Borton's Subdivision, Nature View Court, Fort Myers Beach Elementary School and Lee County's Bay Oaks Recreation Center; the western boundary is the man-made canal along Tropical Shores Way. (Figures 1 & 2)

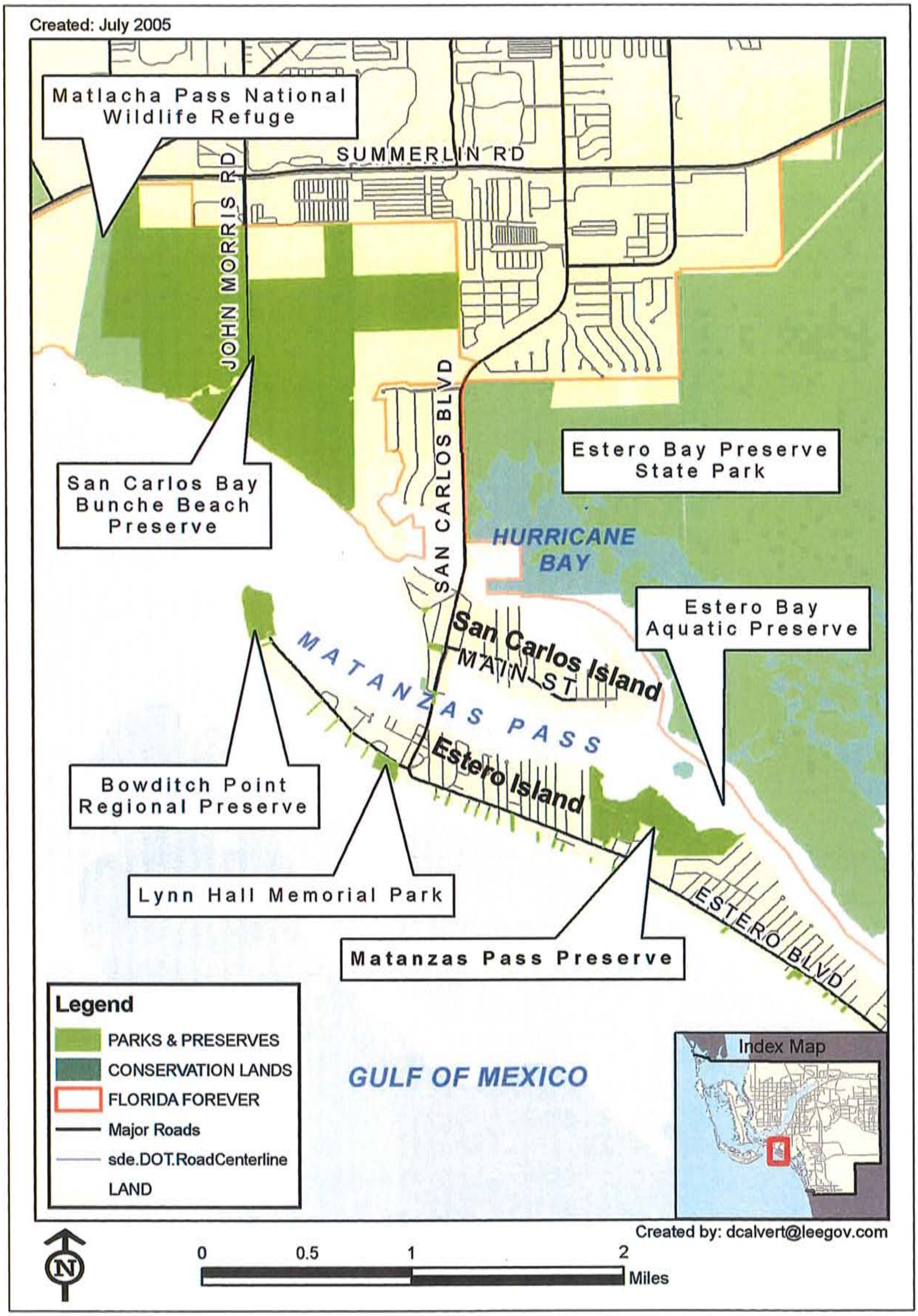
Many preserves and wildlife sanctuaries are located in the region. Little Estero Critical Wildlife Area is located 4.5 miles to the south and Bowditch

Pointe Regional Preserve is located 1.5 miles to the north. On the mainland to the west is San Carlos Bay –Bunche Beach Preserve located on John Morris Road and J.N. "Ding" Darling National Wildlife Refuge is located on Sanibel Island.

The Preserve consists of three native plant communities: tidal swamp, maritime hammock, and coastal grassland. (Figure 6). These community designations are based upon Florida Natural Areas Inventory's Guide to the Natural Communities of Florida (Florida State University 1990) (www.fnai.org).

Figure 2: Matanzas Pass Preserve 2005 Aerial

Figure 1: Matanzas Pass Preserve Location Map



III. Natural Resources Description

A. Physical Resources

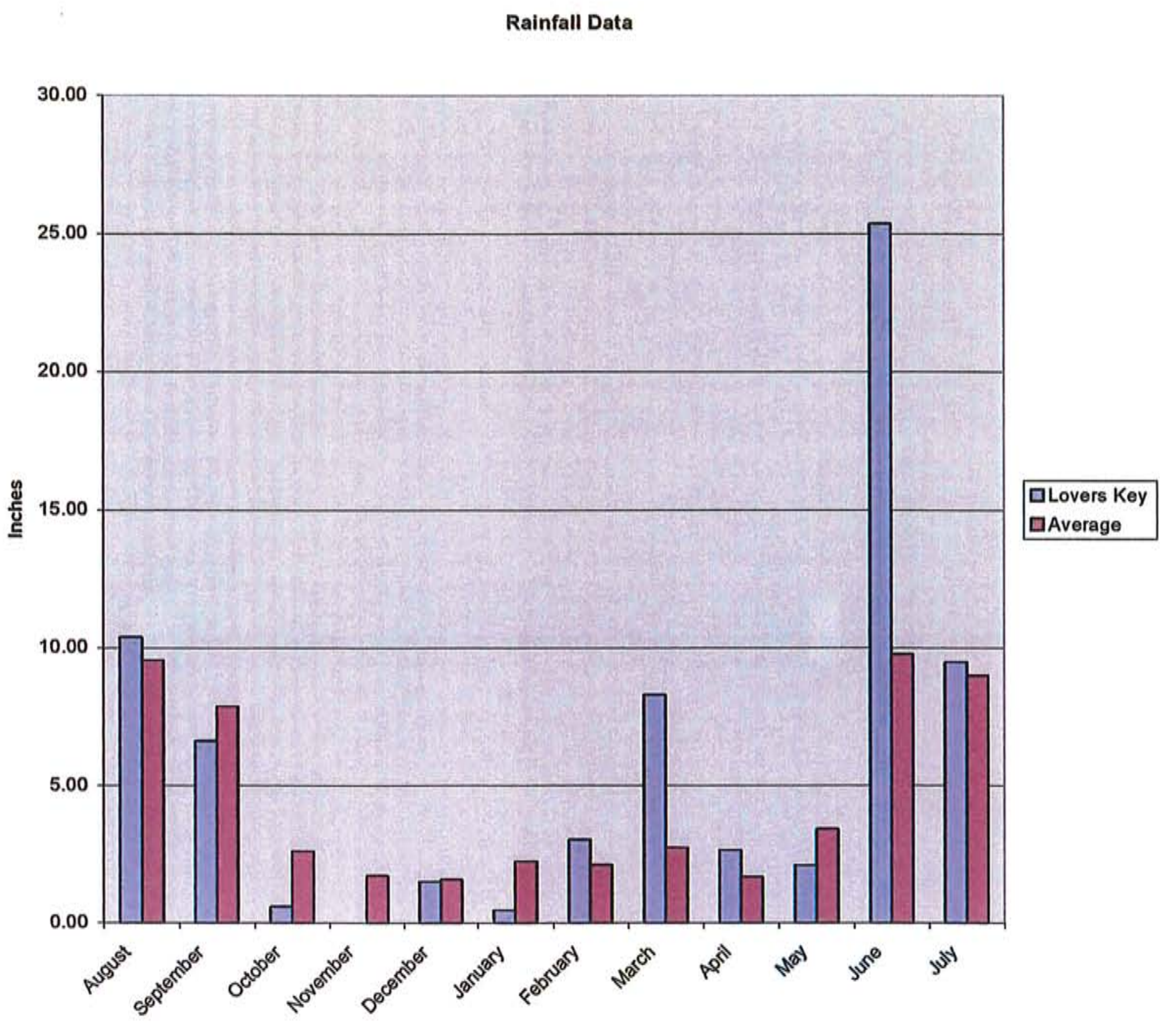
i. Climate

Southwest Florida has a humid, sub-tropical climate due to its maritime influence from the Caribbean Sea and the Gulf of Mexico, with temperature trends linked to its latitude and proximity to these bodies of water. Four seasons occur in Florida if only with slight changes. The seasons influence the weather by length of daylight, precipitation, sea breeze, storm fronts, and extreme events, such as hurricanes and tropical storms. Winters are mild with an average temperature of 65 degrees Fahrenheit, but the jet stream can bring in cool air and freezes. The summer mean monthly temperature is 91 degrees Fahrenheit with high humidity. Average relative humidity in mid - afternoon is about 50 to 60 percent. Humidity is higher at night and the average dawn humidity is about 80 percent.

Rainfall data has not been collected for this Preserve. However, annual rainfall averages 54.7 inches at Lakes Regional Park; a Lee County facility located approximately 5 miles northeast of the Preserve. Additionally, the average annual rainfall at the Sanibel-Captiva Conservation Foundation (SCCF), located on Sanibel Island approximately 7.5 miles west of the Preserve, is 46.59 inches. Total annual rainfall for Lee County is 54.19 inches and in 2004 the average rainfall was 61.92 inches, due to an active hurricane season. 2004 data was collected last year at Lovers Key State Park, five miles south of the Matanzas Pass Preserve and is included in the graph. On average, 60 percent of the rain falls June through September. Afternoon thunderstorms occur during the wet season and help to modify the summer temperature. The entire Preserve lies within Lee County's Coastal High Hazard Area (Appendix C) and is vulnerable to both tropical storms and hurricanes from June to November. The Rainfall Data Graph depicts southwest Florida's typical dry winter and summer rainy season.

Graph 1

Average Lee County rainfall over a 30-year period in inches is depicted with the dark red bars and the August 2004 to July 2005 rainfall data in inches is depicted with blue bars. The 2004-2005 data was collected at Lovers Key State Park, five miles south of the Matanzas Pass Preserve.



ii. Geology

Barrier Island Geology

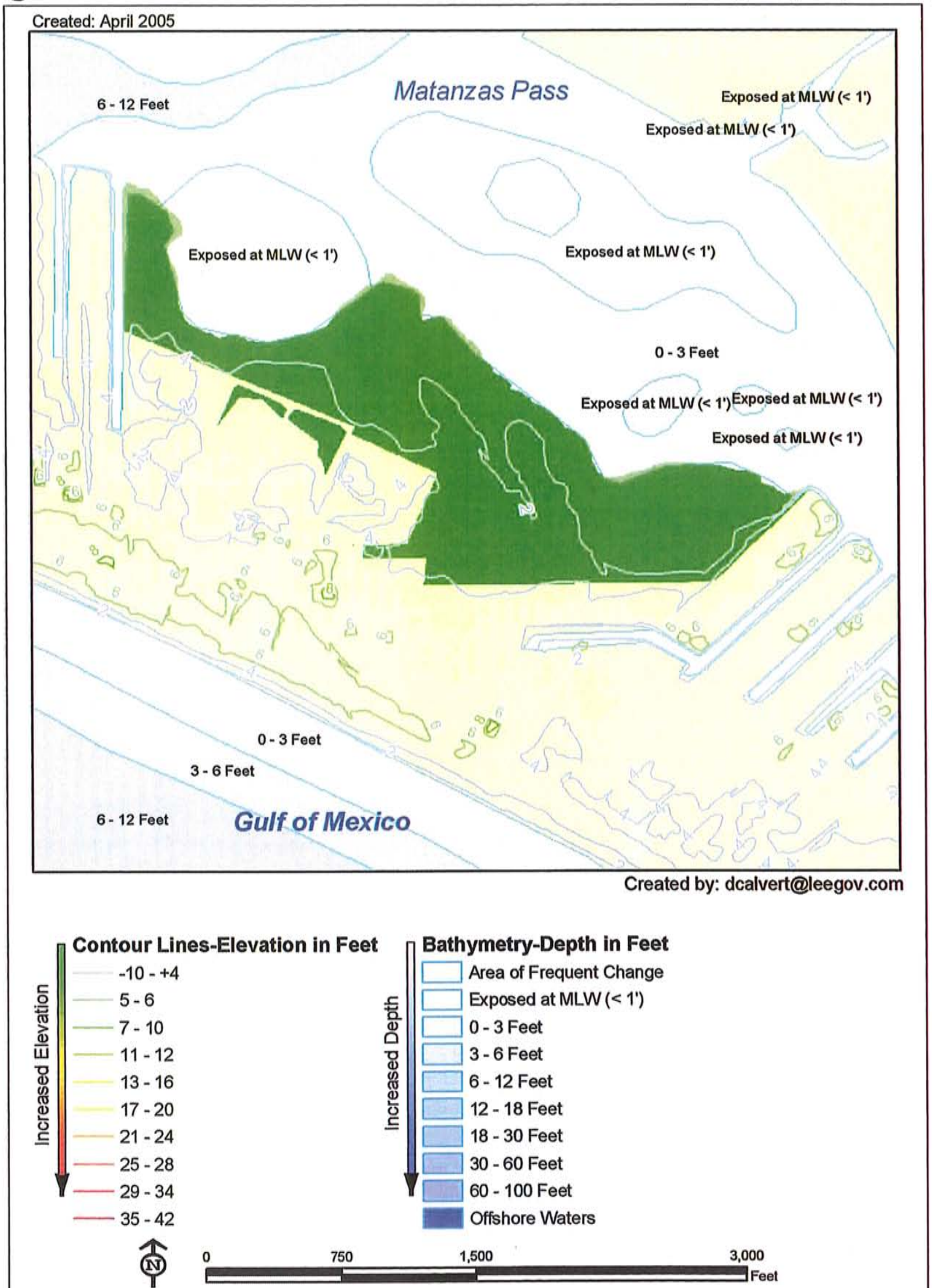
Barrier islands are linear islands of sand that parallel coastlines. They are thought to have been formed in three ways: by the growth of spits from headlands and their subsequent breaching by inlets; by the emergence of underwater shoals; and by the drowning and isolation of mainland dunelines as sea level rose (Schwartz, 1971).

Florida's peninsular Gulf of Mexico barrier islands occur on "highs" in the underlying Pleistocene surface (Johnson and Barbour, 1991). This Pleistocene is of the Anastasia Formation and consists of limestone, sand, and clay (Brown, et al. 1991). The islands bounding Estero Bay are essentially sedimentary deposits that were carried by longshore currents. These deposits originate from sediments deposited at the mouths of rivers and creeks, including the Caloosahatchee River, when rising sea levels flooded this area approximately 5,000 years before present (Johnson and Barbour, 1991).

iii. Topography

The slope of the site ranges from zero to four feet in elevation (Figure 3). A majority of the site falls between zero and two-feet in elevation as the mangrove swamp rises out of Matanzas Pass. When the intertidal zone of Matanzas Pass is exposed at mean low water level, a feeding area is created for resident avian life. Within the Preserve, the elevation reaches four feet as the site approaches the south-southeast and south-southwest boundaries and the land slopes upward. This slight change in elevation makes possible the change in community from a mangrove swamp to a maritime hammock and a small portion of coastal grassland. All elevations are based on the National Geodetic Vertical Datum (NGVD).

Figure 3: Matanzas Pass Preserve Topography Map



iv. Soils

Soils in the Preserve are identified as Entisols and Histosols. Level, poorly drained coastal marshes and swamps of variable-textured mineral and organic materials subject to frequent tidal flooding can dominate these soils. Ecosystems include mangroves, salt marshes, and maritime forests. Primarily used for recreation and wildlife (Ecosystems of Florida, 1990) (Figure 4).

The northern sections of the Preserve consist of Kesson Fine Sand. This is a nearly level, very poorly drained soil in broad tidal swamps, with areas subject to tidal flooding. Slopes are smooth and range from 0 to 1 percent. Natural vegetation consists of black mangrove (*Avicennia germinans*), sea ox-eye daisy (*Borrichia arborescens*), and red mangrove (*Rhizophora mangle*) (USDA/SCS 1984).

Canaveral fine sand, in the southwestern portion of the preserve, includes small areas (less that ten percent) of Captiva and Kesson soils and is described as nearly level, moderately well drained and somewhat poorly drained soil in low ridges. Slopes are smooth to slightly convex, ranging from zero to two percent. Natural vegetation includes cabbage palm (*Sabal palmetto*), seagrape (*Coccoloba uvifera*), wild coffee (*Pyschotria nervosa*) and an understory of vines and herbaceous plants (USDA/SCS 1984).

Captiva fine sand makes up a southeastern central portion of the Preserve. This is nearly level, poorly drained soil in sloughs. Slopes are smooth to concave and range from zero to one percent. Natural vegetation consists of cabbage palm, sand cordgrass (*Spartina bakeri*), leather fern (*Acrostichum danaeifolium*), and wax myrtle (*Myrica cerifera*) (USDA/SCS 1984).

Canaveral-Urban Land Complex soil makes up a limited area of the southern border of the Preserve where homes are located. This complex consists of Canaveral fine sand and areas of Urban land. The Canaveral soil and Urban land are so intermingled that they cannot be separated on the scale used for mapping (SDA/SCS 1984) (Figure 4).

Figure 4: Matanzas Pass Preserve Soils Map

Created: July 2005

1 inch equals 1,000 feet

v. Hydrology and Watershed

Over three quarters of the Preserve consists of mangrove swamp that is influenced by tidal flow and fresh water run off. The tides bring relatively clean water to the mangroves, and in turn, flush out accumulations of hydrogen sulfide and salts. The mangrove swamp also filters nutrients such as phosphorus and nitrogen from terrestrial runoff, which help to buffer the estuary from water pollution.

The construction of mosquito control ditches in the late 1950's has impacted the site. When the ditches were dug the spoil piles were left on the sides of the ditches creating dirt mounds that prevent natural water flow and increased the area of mangrove habitat. The ditches generally run through the site from northeast to southwest and northwest to southeast, an estimated 6,440 feet in length. Approximately half of the ditching occurs in the submerged mangrove areas where hydrological impacts may not be noticeable.

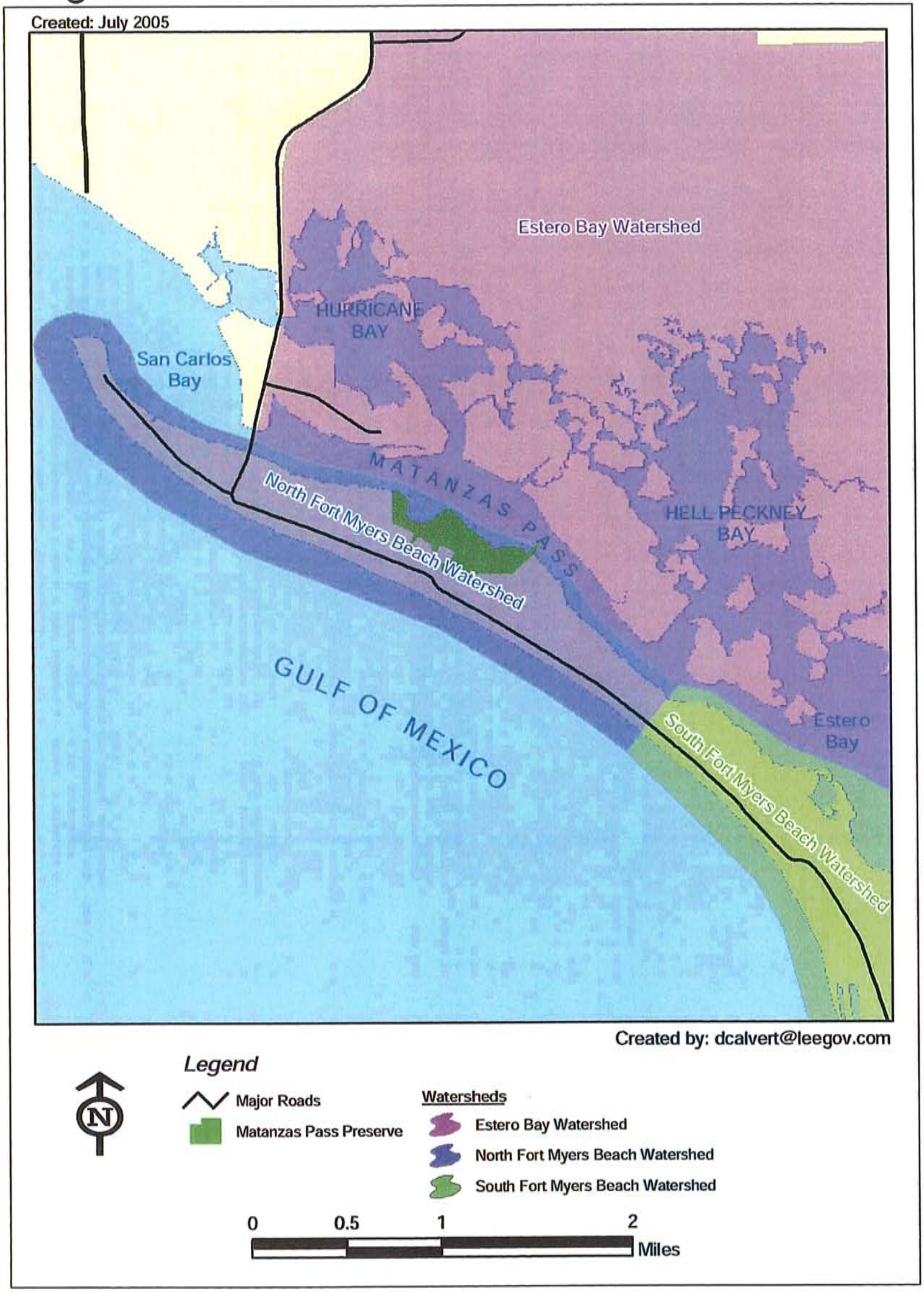
Matanzas Pass Preserve is located with in the Greater Charlotte Harbor Watershed. The Greater Charlotte Harbor Watershed extends over an area of 4,400 square miles. At its northern end, the Peace River basin begins in Polk County near Lakeland with the Myakka River basin starting to the east in Manatee County until it winds and meanders to meet the north side of the Charlotte Harbor. To the south Pine Island Sound and Matlacha Pass connects Charlotte Harbor to the tidal Caloosahatchee River and Estero Bay in Lee County.

The area south of the Caloosahatchee River mouth, including San Carlos Bay and Matanzas Pass forms the northern boundary of the Estero Bay estuary. Protected on the west by a barrier island chain including the Town of Fort Myers Beach and Bonita Beach, the estuary stretches southeast to the mouth of the Imperial River at the county boundary.

The 300 square mile Estero Bay Watershed includes Ten Mile Canal, Hendry Creek, Mullock Creek, Estero River, Spring Creek, Imperial River, Estero Bay, Hurricane Bay, Hell Peckney Bay, and the waterway know as Matanzas Pass.

This watershed divides near central Fort Myers Beach to become the North Fort Myers Beach Watershed and the South Fort Myers Beach Watershed with the Matanzas Pass Preserve being located in the former. This watershed is subject to storm water runoff, tidal, and storm surge influences that affect the island (Figure 5).

Figure 5: Matanzas Pass Preserve Watershed



B. Biological Resources

i. Ecosystems Function

Flood storage and desynchronization is the process by which wetland basins store and gradually release peak water flows from precipitation or upland runoff. Wetlands that perform this function may provide significant flood control services to nearby communities. Coastal wetlands also store flood waters, thus reducing the flood impact of major storms (Scodari, 1990). The 17.4 acres of maritime hammock and 2.9 acres of coastal grasslands in the Preserve have a lower elevation than that of the immediate surrounding community. This enhances the ability of the Preserve to retain and dissipate runoff from rain and small storms. Storm magnitude and duration are factors that will affect this function.

Shoreline anchoring is the process by which the root system of wetland vegetation stabilizes soil at the water's edge and enhances the accretion of soil and/or peat at the shoreline. Dissipation of erosive forces is the process by which wetland vegetation diminishes the erosive impact on soil by waves, currents, and general water level fluctuations. These wetland functions protect both natural resources and man-made structures by inhibiting shoreline erosion and the creation of eroded sediments that can cause siltation of navigable waterway. Larger wetlands with extensive, persistent vegetation (e.g., forested wetlands) are probably the most effective at dissipating erosive forces
(Scodari, 1990). The 37.7 acre of tidal swamp community provides this function with a forest of red, black, and white mangroves (*Laguncularia racemosa*), and buttonwoods (*Conocarpus erectus*) which dissipate wave energy and anchor soil with their intertwined root system.

Nutrient retention is the process by which wetlands store nutrient waste, such as phosphorus and nitrogen, within their soil and vegetation. Nutrient removal is the process by which wetlands release these retained wastes. More study is necessary to determine the exact role that wetlands play in improving water quality. For example, no literature suggests general criteria for measuring levels of wetland nutrient retention (Scodari, 1990). It is believed that all wetlands serve as nutrient traps to varying degrees. The Preserve is a 58 - acre nutrient trap, serving the Estero Bay Watershed.

The aquatic food chain support function refers to the direct and indirect use of the wetland-derived nutrients by fish and shellfish. This function is known to be important to the production of commercial and sport estuarine fish and shellfish (Scodari, 1990). The detritus material that is produced from the 37.7 acres of tidal swamp community is flushed to areas where fish and aquatic invertebrates can consume it directly or indirectly, or it can be consumed by organisms present near the point of production.

Fisheries habitat support function refers to the "physical and chemical factors, which affect the metabolism, attachment, and predator avoidance of the adult or larval forms" (P. Adamus & L. Stockwell). This function is widely recognized as important; wetlands provide both nursery grounds and food for many species of freshwater and saltwater fish. Most commercial saltwater fish and shellfish depend on coastal estuaries and their wetlands for spawning grounds and nurseries (Scodari, 1990). A total of 37.7 acres of mangrove root systems in the Preserve provide cover, food, and water quality through sediment settlement (turbidity) for larval, juvenile, and adult fish.

Wildlife habitat support is the provision of environmental features that supply food and shelter needs of birds, mammals, and other wildlife. This function gives people the opportunity to engage in bird watching, hunting and other wildlife-oriented recreational activities. Factors affecting a wetland's wildlife support function include availability of cover and freedom from disturbance; availability of food; and availability of specialized habitat needs (Scodari, 1990).

The 58 acres of the Matanzas Pass Preserve is devoted to creating wildlife habitat that provides cover and food availability as well as specialized habitat needs such as coastal grass lands, standing snags, and fruit bearing vegetation for the wildlife population. To prevent disturbances to wildlife no bikes, motorized vehicles, or pets are allowed in the Preserve.

ii. Natural Plant Communities

Florida Natural Areas Inventory's Guide to the Natural Communities of Florida (Florida State University, 1990)(Figure 6) ranks natural areas as significant on a Global (G) or State (S) basis and numerically from 1 to 5 including an uncertain rank marked by a question mark (?). A rank of 1 designates an area as critically imperiled (G1-S1) and a rank of 5, (G5 –S5) as demonstrably secure, although it may be quite rare in part of its range. The three native plant communities of the Matanzas Pass Preserve are ranked as follows:

G3 S3 Tidal Swamp

G4 S3 Maritime Hammock

G3 S2 Coastal Grassland

Definitions of Global (G) element ranks:

G3 = Either very rare and local throughout its range or found locally (even abundantly at some of its locations) in a restricted range or because of other factors making it vulnerable to extinction throughout its range, 21 to 100 occurrences;

G4 = Apparently secure globally, though it may be quite rare in parts of its range, especially at the periphery;

Definition of State (S) element ranks:

S2 = Imperiled in state because of rarity (6-20 occurrences or little remaining area) or because of some factor(s) making it very vulnerable to extinction throughout its range;

S3 = Rare or uncommon in state (on the order of 21 to 100 occurrences). Plant species list can be found in Appendix A.

Tidal Swamp Community - 37.7 acres, 65 % of MPP

The northern boundary along Matanzas Pass is vegetated with red mangrove, black mangrove, white mangrove and buttonwood. Typically these species occur in zones defined by varying water level determined by land elevation. Exceptions are seen in the Matanzas Pass Preserve. Red mangroves usually occupy the lowest zone along the shoreline and in the water, black mangrove the intermediate zone a slight increase in land elevation, and white mangrove and buttonwood share the highest zone. On the mangrove boardwalk, observing red and black mangroves in the same area is not unusual and at times white mangroves, black mangroves and buttonwood occur in the same area.

Other plants associated with Tidal Swamps and seen in the preserve are glasswort (*Salicornia spp.*), sea purslane (*Sesuvium portulacastrum*), saltwort (*Batis maritima*), and sea oxeye. Unconsolidated substrates are usually found in the sub tidal regions surrounding tidal swamps. The Matanzas Pass Preserve supports healthy areas of subtidal, intertidal, and supratidal zones which make up the unconsolidated substrate. The Preserve helps to protect other inland communities by absorbing the brunt of tropical storms and hurricanes.

The condition of this community is good. Invasive exotic plants were treated in December 2004, and are limited to the mosquito ditch berms dug in the 1950's. This area will continue to be monitored and treated as needed in the future for exotic pest plants. Volunteer workdays and designated coastal clean up dates will target this area of the Preserve to have litter removed as trash washes in with the tides and storms.

Maritime Oak Hammock Community - 17.4 acres, 30 % of MPP

Upland parts along the south border and central area of the Preserve are vegetated with live oak (*Quercus virginiana*), cabbage palm, sea grape, strangler fig (*Ficus aurea*), saw palmetto (*Serenoa repens*), beauty berry (*Callicarpa americana*), poison ivy (*Toxicodendron radicans*), coral bean (*Erythrina herbacea*), coontie (*Zamia integrifolia*), and rouge-plant (*Rivina humilis*). Maritime hammocks occur on old coastal dunes that have been stabilized long enough for the growth of a forest as seen in the 1944 aerial.(Figure 7). The oaks and palms of the Preserve support a variety of epiphytes such as golden polypody (*Polypodium aureum*), resurrection fern (*Polypodium polypodioides*), ball moss (*Tillandsia recurvata*), Spanish moss (*Tillandsia usneoides*), and shoestring fern (*Vittaria lineata*). Nutrient recycling is generally accomplished by detrital organisms instead of by fire. Maritime hammocks are used by migrating birds for food and shelter following trans-oceanic or trans-gulf migrations. Maritime hammocks originally occurred in continuous bands on barrier islands but are now dissected into short strips by development and are rapidly disappearing. The Matanzas Pass Preserve is surrounded by development. (Figure 6)

This community is at maintenance level for invasive exotic vegetation since Lee County took possession. Clean up events, Lee County Staff, and the Friends of the Matanzas Pass Preserve keep this area litter and exotic plant free.

Coastal Grassland Community – 2.9 acres, 5 % of MPP

In the very southern portion of the Preserve is a section called the restoration area because it is in the process of being restored to its former community. Here the elevation increases slightly and a small coastal grassland exists. Characterized by the gently undulating land scattered with small clumps of trees and shrubs. Typical plants include beach morning glory (*Ipomoea stolonifera*), sea oxeye, sand spurs (*Cenchrus spp.*), crowfoot grass (*Dactyloctenium aegyptium*), prickly pear cactus (*Opuntia spp.*), wax myrtle (*Myrica cerifera*), and groundsel bush (*Baccharis spp.*). Coastal grassland is a low flat area behind fore dunes that is found on broader barrier islands, capes, spits, and is best developed along the Gulf Coast. The old fore dune line on Fort Myers Beach lies to the north of present day Estero Boulevard just to the south of the Preserve boundary. It may be flooded by saltwater and covered with sand and debris during major storms. With time, these areas become vegetated with pioneer species, eventually taking on characteristics similar to prairie.

If no major storms occur to renew the process, coastal grasslands will often be colonized by shrubs and trees and eventually may succeed to coastal strand or flatwoods (Figure 6).

Invasive exotics are being removed in this area and the Friends of Matanzas Pass Preserve have obtained funding from the Charlotte Harbor National Estuary Program to restore this area with wax myrtle, sea oxeye, beautyberry (*Callicarpa americana*) and white indigoberry (*Randia aculeata*).

Figure 6: Matanzas Pass Preserve Natural Plant Communities

iii. Wildlife Species

The two types of tidal swamps in the Preserve are over wash swamps, found on islands that are frequently inundated by tides, and narrow fringe swamps, located along waterways. These communities are significant because they function as nursery grounds for most of the state's commercially and recreationally important fish and shellfish. This natural area is also the breeding grounds for a substantial population of wading birds, shorebirds, and other animals. The continuous shedding of mangrove leaves and other plant components produce as much as 80% of the total organic material available in the aquatic food web.

Typical animals that rest, forage, or nest in the Preserve are mangrove water snake (*Nerodia clarkia compressicauda*), brown pelican (*Pelecanus occidentalis*), osprey (*Pandion haliaetus*), bald eagle (*Haliaeetus leucocephalus*), herons *(Ardea)*, egrets (*Egretta*), and raccoons (*Procyon lotor*).

Tidal swamp grades into the maritime hammock with hardwood forest and dense understory. This area of the Preserve is centrally located and at a slightly higher elevation from the tidal swamp area, providing good habitat and foraging area for yellow rat snakes (*Elaphe obsoleta quadrivittata*), gray squirrel (*Sciurus carolinensis*), raccoon, opossum (*Didelphis virginiana*), blue jay (*Cyaocitta cristata*), northern cardinal (*Cardinalis cardinalis*), and pileated woodpecker (*Dryocopus pileatus*).

The smallest area in the preserve is the coastal grassland and has the largest number of private residences for neighbors, the highest natural elevation, and the most open space. Habitat for marsh rabbit (*Sylvilagus palustris*), butterflies, red-shouldered hawk (*Buteo lineatus*), American kestrel (*Falco sparverius*), and box turtle (*Terrapene carolina*) is unique to this area.

A Wildlife Species List can be found in Appendix B. As staff explores the preserve monthly the FNAI field reports for rare animal and plant species will be consulted and filled out if applicable. These can be found in the Land Stewardship Operations Manual

iv. Listed Species and their Designation

Providing habitat for a wide range of animals may protect designated species included on Florida's Endangered Species, Threatened Species, and Species of Special Concern document maintained by Florida Fish and Wildlife Conservation Commission in accordance with Rules 68A-27.003, 68A-27.004 and 68A-27.005 respectively Florida Administrative Code (F.A.C.) as well as those listed by the federal government in the Endangered Species Act.

Maintaining the native biological communities will benefit all species and proper stewardship practices in the Preserve will ensure protection of designated species. Management practices in the Preserve include the control of exotic plants and litter, wildlife monitoring, restoring native plants to areas cleared of exotic plants, and enforcement of unacceptable behavior in the Preserve such as camping, biking, motorized vehicles, weapons, and pets.

Table 1 documents designated species that occur in the Preserve. Many other species inhabit the Preserve as well (Appendix B). Following the list and key to abbreviations and notations is a brief summary of a few of the species, why they are in decline and management measures that will take place to protect them in the Matanzas Pass Preserve.

Table 1

Listed Species Found at Matanzas Pass Preserve and their designated status

Common Name	Scientific Name	FWC	USFWS	Occurrence
Reptiles				
American alligator	*Alligator mississippiensis*	SSC (1,3)	T (S/A)*	confirmed
Gopher tortoise	*Gopherus polyphemus*	SSC (1,2,3)		confirmed
Birds				
Brown pelican	*Pelecanus occidentalis*	SSC (1)		confirmed
Reddish egret	*Egretta rufescens*	SSC (1,4)		confirmed
Snowy egret	*Egretta thula*	SSC (1)		confirmed
Little blue heron	*Egretta caerulea*	SSC (1,4)		confirmed
Tricolored heron	*Egretta tricolor*	SSC (1,4)		confirmed
White ibis	*Eudocimus albus*	SSC (2)		confirmed
Osprey	*Pandion haliaetus*	SSC (1,2)		confirmed
Roseate spoonbill	*Platalea ajaja*	SSC (1,4)		expected
Bald eagle	*Haliaeetus leucocephalus*	T	T	expected
Peregrine falcon	*Falco peregrinus*	E		expected
Mammals				
Florida manatee	*Trichechus manatus latirostris*	E	E	confirmed
Plants		**FDA**	**FWS**	
Golden leather fern	*Acrostichum aureum*	T	E	confirmed
Joe wood	*Jacquinia keyensismez*	T		confirmed
Wild cotton	*Gossypium hirsutum*	E		confirmed

Key to Abbreviation and Notations

FDA	= Florida Department of Agriculture & Consumer Services
FWC	= Florida Fish and Wildlife Conservation Commission
USFWS	= United States Fish and Wildlife Service
E	= Endangered
T	= Threatened
SSC	= Species of Special Concern
T (S/A)*	= Threatened/Similarity of Appearance to a Threatened Taxon in the Entire Range

Below is a brief description of a few of the species listed in Table 1, as well as management recommendations for the Matanzas Pass Preserve in regard to the needs of these species.

American Alligator

The best know reptile in Florida was once on the way to extinction due to habitat destruction and a market for hunting hides. Laws protecting the alligator have enabled this species to make a remarkable recovery.
Occasionally an alligator is sited at the preserve. Alligators can co-exist with man as long as care is taken not to feed the alligators.

The major threat to the American alligator existence is the destruction of suitable habitat. Matanzas Pass Preserve does not provide habitat for the alligator, yet they have been sited using the pond.

Gopher Tortoise

Gopher tortoises were last sited in the preserve in 1999. The habitat is not typical of sand hills, scrub, upland pine flatwoods, or pastures but increased growth in the area may have forced them into the Preserve or they may have been released by people.

Little can be done in the Matanzas Pass Preserve to enhance habitat for gopher tortoise due to the low elevation and lack of upland habitat.

Brown Pelican

The brown pelican is perhaps Florida's most distinctive and recognized bird. It wanders inland upon occasion; pelicans are grace in the air as they flap and glide over the water. Endangered at one time by effects of pesticides, the pelican has made a good come back since the use of DDT was outlawed. Food shortages, human disturbance, increased turbidity from dredging and pollution (especially entanglement in fishing gear) are all factors that led to their decline between the 1970's through the mid 90's (Hipes et.al. 2000).

Education about the importance of proper disposal of monofilament, litter, and keeping a distance from the pelicans will protect this bird and it's habitat. Continued use of trash receptacles and scheduled volunteer clean up days will concentrate on monofilament and debris that can endanger pelicans and other wildlife.

Reddish Egret

The reddish egret is Florida's least common heron. Still suffering the effects of century past plume hunting, this wading bird's rate of recovery following protection has been much slower than that of other species. Red mangroves appear to be a favored nest site (Kale & Maehr 1990) and it is not unusual to observe this egret in the preserve feeding.

Continued protection of red mangroves, a litter free preserve, maintain the "no dog" policy, and teaching visitors to observe wildlife from a distance will be beneficial to the reddish egret.

Snowy Egret

Long filmy feathers (aigrettes), prominent head, neck, and back plumes of breeding adults made snowy egrets a prime target for plume hunters during the last century. This wading bird has made a remarkable come back from drastically low numbers and nest in multi-species colonies located in shrub-covered wetlands or islands in lakes and coastal lagoons (Kale & Maehr 1990).

Management for this species will include education in the proper behavior of people and their domesticated animals and the importance of habitat preservation and restoration.

Little Blue Heron

The general population trend for this species is in decreasing. This may be related to wetland losses and there is speculation that competition with cattle egrets for nest sites may be contributing to this decline (Kale & Maehr 1990).

Management issues for the little blue heron species will be the same as the snowy egret.

Osprey

Drastic declines in osprey population in the 1950s and 60s were due to environmental contaminants. Banning of chlorinated hydrocarbon pesticides has helped this species recover. The birds will nest readily on tall manufactured platforms and other structures. (Kale & Maehr 1990).

Ospreys are seen frequently using the snags in the Preserve for hunting and eating. Preservation of the Matanzas Pass Preserve will provide a foraging area as well as a future nesting site if tall man-made platforms are constructed (Kale & Maehr 1990).

Peregrine Falcon

Peregrine Falcons also suffered decline due to habitat destruction and environmental contamination. It has made a fairly good come back since the use of DDT has stopped (Kaufman 2000). As one of the wintering areas for the falcon, the Preserve provides good hunting grounds and an area with little human disturbance

Management will be the same as for the osprey.

Florida Manatee

The manatee has been documented by Lee County Parks and Recreation staff swimming in Matanzas Pass adjacent to the preserve. Increased boat traffic in the area is the main concern for this species, as frequent scaring and some deaths due to boat encounters are documented. Sea grass beds just off the coast of the preserve provide food for manatees and a channel provides a waterway for this mammal.

Signage for a manatee zone would be appropriate for the pavilion in the Preserve, as well as education for residents and visitors.

v. Biological Diversity

Many species of birds, reptiles, invertebrates, fish, and mammals inhabit, forage, nest, or rest in the Matanzas Pass Preserve. At low tide, wading and shore birds take advantage of the mud flats and ditches that are teeming with food. The mangroves provide nesting and roosting area for birds. Many species of fish either breed or spend some part of their juvenile life in the protection of the mangroves. The integrity and diversity of the Matanzas Pass Preserve and its associated waters must be protected when and where possible. Management staff will perform the following actions in this regard:

- Control of invasive exotic vegetation and annual follow-up maintenance will provide suitable habitat for native wetland and terrestrial species.
- Removal of any debris and prevention of future dumping on site will improve and protect water quality.
- Removal of hazardous debris such monofilament line and other potential entrapment debris will also contribute to the quality of surrounding waters and protect wildlife species that utilize this area.
- On-going species surveys conducted by volunteers and staff will confirm and protect the diversity that is present.
- Provide educational opportunities for visitors through both interpretive signs and programs.

C. Cultural Resources

i. Archaeology

Human disturbance in the Matanzas Pass Preserve consists of the mosquito ditching that took place in the 1950's and the original boardwalk constructed in the 1970's through the mangrove swamp. This all occurred prior to 1987 when Piper Archaeological Research, Inc. conducted an archaeological site inventory of Lee County.

Although the Preserve is not likely to contain archaeological material due to its wet nature, it is located less than one mile from the Florida Master Site File number 8LL 1101, which is locally known as the Mound House. This site is an archaeologically significant Calusa shell mound. The shell mound was altered first in 1906 with the construction of a home that was enlarged through the years and again in the 1950's with the dredging of canals surrounding the property in order to create the Shell Mound Park subdivision. The most western canal dug to fill the Shell Mound Park subdivision is the east boundary of the Preserve.

ii. Land use History

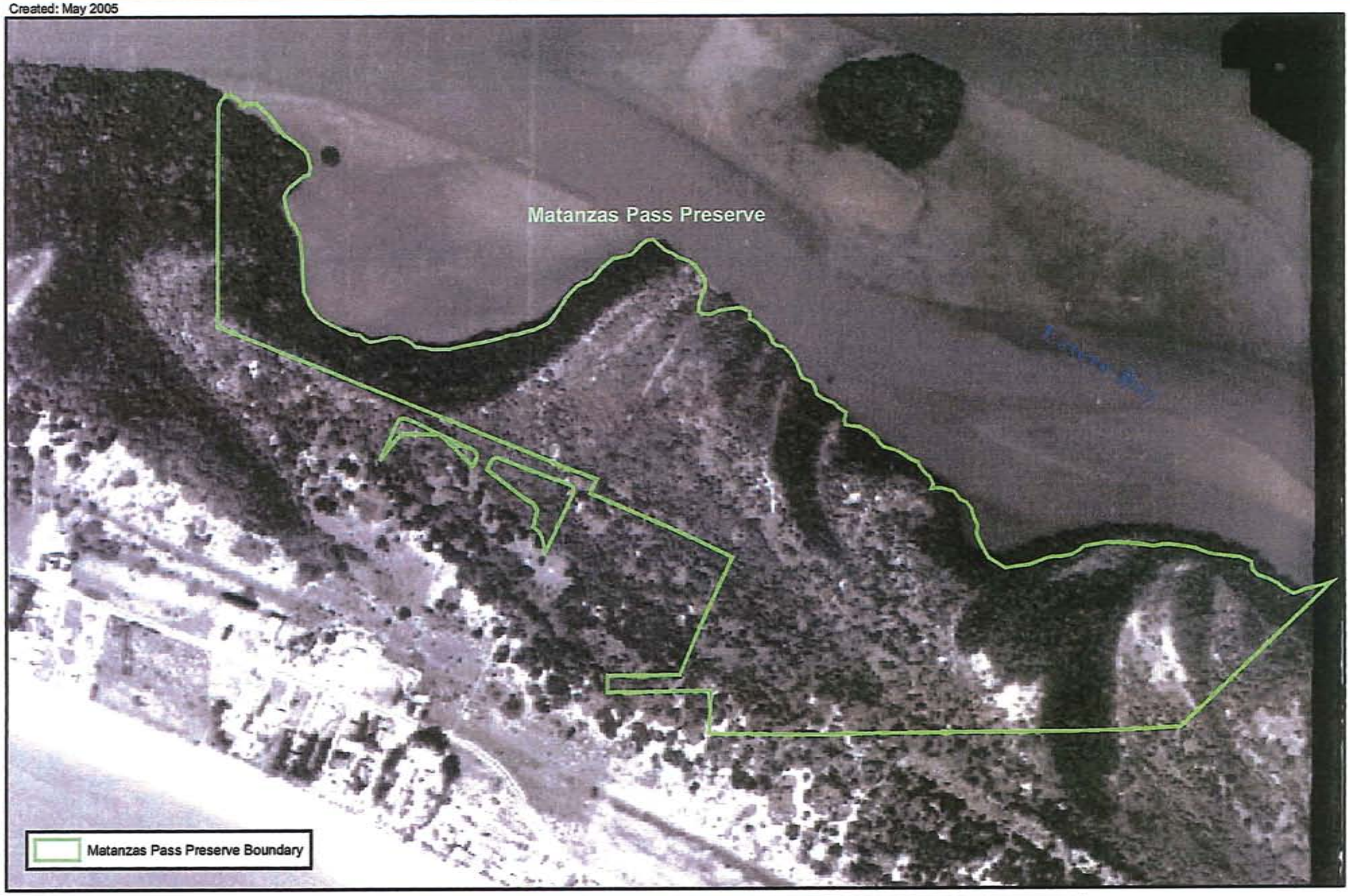
Prior to 1958, the Preserve was virtually undisturbed by man except for a few foot trails and a jeep trail, seen in the 1944 and 1953 aerials (Figures 7&8). Since 1958, the Matanzas Pass Preserve and the surrounding areas have gone through great changes, as seen in the aerial photo taken in 1958 (Figure 9). Land adjacent to the Matanzas Pass Preserve has been developed with roadways, home sites, a school, and canals visible in the aerials. Mosquito control ditches were excavated in the central and eastern section of the Preserve with a 750 foot unpaved mosquito control service road, visible in the 1958 aerial. These ditches were used frequently in Florida to drain wetlands and reduce mosquito-breeding habitat. Spoil piles were left in place and can be seen as white spots along the ditches in the 1958 aerial.

The higher elevations of the spoil piles and the disturbed land made these areas susceptible to invasion by exotic vegetation. In 1996, shortly after Lee County took possession of the Preserve from The Nature Conservancy, control of invasive exotic vegetation began. By removing Brazilian pepper (*Schinus terebinthifolius*) and Australian pines (*Casuarina* *equisetifolia*) at the end of Bay Road, an entrance and parking area for the Preserve and Historic Cottage were created.

Lee County Tourist Development Council funding was used to replace and expand an elevated boardwalk and pavilion, which were in dire need of repair, and added a kayak /canoe landing dock. The foot trails are in good condition and have resting benches and trash receptacles placed in quiet areas along the trail.

Figure 7: Matanzas Pass Preserve 1944 Aerial

Created: May 2005



NOT TO SCALE

Rec	Flight FIPS	Year	Flight#	Tile#	Latitude	Longitude	County	Quad Name	Zipcode	Place Name	Township Range
1	12071	1944	3C	13	26.47228	-81.93127	LEE	FORT MYERS BEACH	33908		46S24E

Created by: dcalvert@leegov.com
Source: web.uflib.ufl.edu/digital/collections/FLAP

Figure 8: Matanzas Pass Preserve 1953 Aerial

Created: May 2005

NOT TO SCALE

Rec	Flight FIPS	Year	Flight#	Tile#	Latitude	Longitude	County	Quad Name	Zipcode	Place Name
1	12071	1953	3H	95	26.45688	-81.9329	LEE	FORT MYERS BEACH	33908	

Created by: dcalvert@leegov.com
Source: web.uflib.ufl.edu/digital/collections/FLAP

Figure 9: Matanzas Pass Preserve 1958 Aerial

Created: May 2005

NOT TO SCALE

Rec	Flight FIPS	Year	Flight#	Tile#	Latitude	Longitude	County	Quad Name	Zipcode	Place Name	Township Range
1	12071	1958	4V	89	26.45867	-81.93538	LEE	FORT MYERS BEACH			
1	12071	1958	4V	88	26.44496	-81.94011	LEE	FORT MYERS BEACH		FORT MYERS BEACH	

Created by: dcalvert@leegov.com
Source: web.uflib.ufl.edu/digital/collections/FLAP

iii. Public Interest

The entrance to Matanzas Pass Preserve is anchored by two cottages. The *We're Here* cottage, which was the fourth home built on Fort Myers Beach in the early 1900's, and a 1950's style cottage. Both are the present day home of the Estero Island Historic Society and host the display information for the Preserve. One block west is the Fort Myers Beach Elementary School and Fort Myers Beach Library. One block north of the Preserve is Bay Oaks Recreation Complex and Town Pool. Two blocks west is the beach and Gulf of Mexico. A grocery store, church, restaurants, homes, offices, and fire station are within walking distance. Florida Gulf Coast University is located thirty minutes away by car.

Florida Gulf Coast University, public and private school groups, private and non-profit organizations use the Preserve as an outdoor classroom due to the close location. Coastal geomorphology and ecology can be experienced at its best in this rare 58-acre area of coastal grassland, mangrove swamp, and maritime hammock on Estero Island.

IV. Factors Influencing Management

A. Natural Trends and Disturbances

Natural trends influencing stewardship include hurricanes, drought, tropical storms, tidal flooding, patterns of wet and dry seasons, bird migration and nesting seasons. Coastal grassland communities depend on occasional saltwater flooding to keep from transforming into a coastal strand community. High intensity wind and long durations of standing salt water from tidal flooding or storm surge effects even salt tolerant plant species by weaking or eventually killing them. Bird nesting and migration will be considered when work is conducted in the Preserve to minimize disturbance to the foraging birds resting, feeding, and raising young.

Significant storms can and have caused damage to the vegetation in the Preserve with mortality and dieback of slash pines, buttonwood, strangler figs, and live oaks. Only the maritime hammock area of the preserve can support heavy equipment to remove large vegetation from the Donora Street access after a storm and this is not recommended. If restoration needs to take place after a significant storm, plant community and site elevation will be taken into consideration. After flooding, low-lying areas of the Preserve are prone to hold saltwater for a period of time. It is not unusual to have a storm tide wash over a barrier island and no precautions other than the removal of hazard trees needs to be taken.

B. Internal Influences

There are varieties of human influences as mentioned in previous sections of the plan that impact the Matanzas Pass Preserve.
In the past visitors became accustomed to a lack of enforcement of county regulations relating to littering, motorized vehicles, camping, biking, and walking pets. The following will help to explain these issues further and specify stewardship measures to reduce or eliminate these problems.

Several mosquito ditches are located in the central and east-southeast portion of the Preserve. The associated berms and mounds have had invasive exotics plants on them in the past and will need continued monitoring and treatment. When applying any chemicals for invasive exotic plant removal Land Stewardship Staff will follow the procedures described in the Land Stewardship Operations Manual. (see management action plan Table 2, units 1, 2, 3, 4)

The coastal grassland community, in the southeast section, has had a great deal of human disturbance from dumping and motorized vehicles. There is also scattered trash spread in portions of this area. Much of the trash washed up during storms, but most is from visitors and neighbors of the Preserve. This area was the target area for exotic removal in 1995 and is part of the restoration area.

Since staff has been hired, organized trash removal is a goal with volunteers and the Friends group. This problem will continue to decrease over time as the trash is regularly picked up.
(management action plan, Table 2, Units 1, 2, 3, 4).

A live aboard boating community anchors just off shore and a heavily used boating channel is adjacent to the Preserve. Continual clean up of debris that washes up on the shore, including containers of cleaning solutions, oil, and paint, collected before the pollutants leak into the waters will improve water quality (see management action plan, Table 2, Units 1-4).

Fishing is allowed at the Matanzas Pass Preserve, which could lead to a problem with monofilament line litter. Monofilament line can cause injury and death to birds and other wildlife when tangled or ingested. Coordination with the Monofilament Recovery and Recycling Program (http://fishinglinerecycling.org/) to organize volunteer clean-up days and set up recycling bins will help alleviate this problem (see management action plan Table 2, Unit 2).

Because the Preserve is in a secluded area, enforcing the regulations that apply to all county parks and preserves has been difficult. It will take time for visitors to the Preserve to learn that these and other practices will no longer be tolerated and that there will be a regular staff presence to enforce these regulations.

Visits by the Lee County Park Rangers staff, Lee County Maintenance staff, Lee County Parks and Recreation staff, and the Lee County Sheriffs Office has improved the behavior by visitors in the Preserve.

C. External Influences

There are forty-four existing single-family residences and two mobile home/ recreational vehicle parks that directly abut the south-southeast and south-southwest property boundaries. These are the sources of two major problems.

First, illegal dumping of both garbage and vegetation waste into the Preserve has littered the area and continues to occur on some boundaries. Second, there exist structural encroachments, which include a fence and tool sheds. The Preserve has been used as a campsite by vagrants and for illicit activities such as drug and alcohol use. The level of this type of use has decreased greatly. Problems prevalent today are the use of motorized vehicles (mopeds and scooters) and bicycles, vandalism to the boardwalk and pavilion, and littering throughout the area.

The mobile home communities and residential homes to the south and southeast section of the Preserve are possible areas for horticultural dumping and encroachment concerns. The situation should be monitored and if necessary, the use of signage and presentations/public workshops incorporating "When Nature is your Neighbor" and "Florida Yards and

Neighborhoods" will be used to alleviate any problems. (see management action plan, Table 2, Unit 3).

D. Legal Obligations and Constraint

i. Permitting and Mitigation Issues

Because the Preserve is comprised mainly of wetland plant communities, should any construction be considered, required permits would need to be obtained from various agencies, including the U. S. Army Corps of Engineers, Florida Department of Environmental Protection and the South Florida Water Management District.

Since the entire area of the Preserve is located within the Coastal High Hazard Area any construction considered will need to take this into consideration. (Appendix C)

Lee County's Local Mitigation Strategy supports the efforts of the County to purchase environmentally sensitive areas in high hazard flood zones through Conservation 20/20 funds. It also supports natural resource protection activities that preserve or maintain natural areas through restoration and renourishment. The management of this Preserve implements this strategy.

ii. Relationship to Other Plans

The Lee Plan, 2004 Codification, is used as a vision for the future. In the first chapter of the Lee Plan, entitled Lee County – A vision for 2020, the three broad purposes of the plan are listed:

"First of all, certain day-to-day public and private activities within each jurisdiction must be consistent with the goals, objectives, and policies in the adopted plan. Second, the plan is a source of authority for the local government's land development regulations and for a wide range of official discretionary actions, including, but not limited to, the capital improvement program. Finally, the plan represents the community's vision of what it will or should look like by the end of the planning horizon."

The entire Lee Plan is found on the Internet at: http://www.leecounty.com/dcd1/Leeplan/Leeplan.pdf. The two chapters of the Lee Plan that affect the management of the Matanzas Pass Preserve are Chapter V Parks, Recreation and Open Space and Chapter VII Conservation and Coastal Management.

Chapter V, provides that Land Stewardship staff ensure that any public use facilities constructed at the Matanzas Pass Preserve complies with Goal 85: Park Planning and Design. Staff will also work to provide, whenever staffing and funding permit, appropriate environmental programs to the public in order to meet Goal 86: Environmental and Historic Programs.

Under Chapter VII, Goal 107: Resource Protection within Objective 107.1: Environmentally Critical Areas, Lee County Land Stewardship Staff has the responsibility to conserve and enhance the natural functions of environmentally critical lands such as the wetland habitats found at the Matanzas Pass Preserve.

Objective 107.2: Plant Communities, states Lee County will protect, maintain and routinely update an inventory of native plant communities.

Objective 107.3: Wildlife, states that Lee County has a responsibility to maintain and enhance the fish and wildlife diversity for the benefit of a balanced ecological system.

Within Objective 106.1: Coastal High Hazard Area Expenditures,
Policy 106.1.1 describes the need to seek approval from the county commission for the use of public funds in a Coastal High Hazard Area, in which the entire Matanzas Pass Preserve is located, for the development of public use facilities.

E. Management Constraints and Coordination

The main constraints to management of the Preserve are funding and staffing. The Matanzas Pass Preserve has received a grant for assistance with exotic plant removal and native plant restoration from The Charlotte Harbor National Estuary Program. The Friends of the Matanzas Pass Preserve wrote and provided the in kind match for this grant. Obtaining funds through grants and other sources will continue.

Coordination with other agencies and adjacent landowners will also be an important part of managing the Preserve. Bowditch Point Regional Preserve

is located 1.5 miles west on Estero Boulevard and staff will coordinate activities that would affect both Preserves when necessary.
Environmental education relating to the dynamics of barrier islands would be productive for both preserves.

F. Public Access and Resource Based Recreation

The public has used the Matanzas Pass Preserve for at least 60 years, as evident in the 1944 aerial (Figure 7). For more information on the historic use of the Preserve see the Land Use History section. There is presently no parking fee at Matanzas Pass Preserve due to the lack of facilities and limited parking.

Public use of this Preserve will always need to be monitored and controlled to ensure that it does not interfere with the health of the ecosystem or the wildlife that utilize it. There will be at least one staff person on site that will play a very important role with interacting with the public. Staff will make sure that the public is complying with Lee County Parks and Recreation's rules as well as educating visitors about the Preserve and what makes it such a unique and important area. The environmental education programs offered each year will also be important for educating visitors and instilling respect for the resources while enjoying the Preserve.

This Preserve is Highlight number 4 on the Estero Bay portion of The Great Calusa Blueway, Lee County's paddling trail that provides an ecological tour of the bays, rivers, backwaters and shorelines of southwest Florida. Information on this canoe trail can be found at www.thegreatcalusablueway.com and a map of the Estero Bay portion of this trail is located in Appendix D.

Existing improvements to the property are the 7,091 feet of trail system that includes 2,986 feet of elevated boardwalk, which meanders down to the pavilion over looking the bay. The elevated boardwalk, along with the estimated 4,105 feet of foot hiking trails provide an enjoyable hiking area, as well as wildlife viewing, fishing, and photography. The elevated boardwalk includes a landing area for visitors arriving by canoe and kayak (Figure 10).

The Master Site Plan for the Preserve (Figure 10) displays other existing improvements such as the teaching amphitheater, pavilion on the bay, resting areas, and the Historic Cottage.

The challenge of providing a positive experience for visitors, while protecting the fragile ecosystem of the Preserve, will always be a focus for county staff.

Figure 10: Matanzas Pass Preserve Site Plan

G. Future Acquisition

Adjacent lands to the Preserve will be considered for acquisition. Conservation 20/20 nominations number 283 and 284 are adjacent to the preserve and have recently been acquired. This estimated acre of land consists of maritime oak hammock and will be added to management unit 2 goals and strategies.

V. Management Action Plan

A. Management Units

The Matanzas Pass Preserve has been divided into management units to better organize and achieve management goals. Figure 11 delineates the four management units, which were created based on community habitat type, management needs, and restoration required.

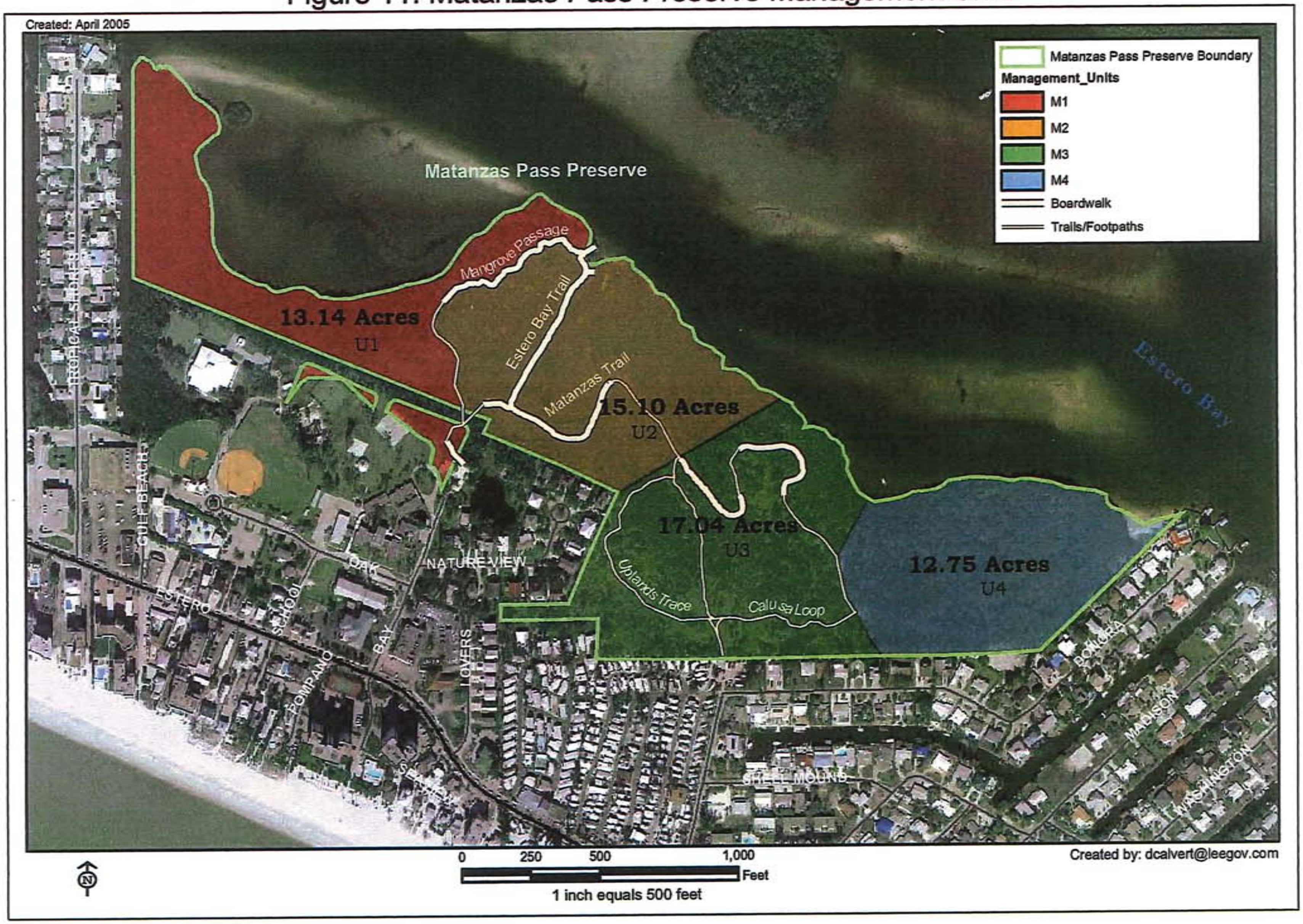
Management unit #1 is 13.14 acres and located in the western portion of the Preserve and consists of a mangrove swamp community which extends north to Matanzas Pass and west to the canal off Tropical Shores Way, east to the elevated boardwalk and south to the boundary lines of a roadway easement belonging to the Town of Fort Myers Beach.

Management unit #2 is the 15.10 acres tract east of the Mangrove Passage boardwalk and extends north to Matanzas Pass, east to a boundary line where the single foot trail ends and splits into three trails, and south to residential home boundaries. It is comprised of maritime hammock and mangrove swamp.

Management unit #3 is 17.04 acres and is located south of unit #2 and consists of coastal grasslands, maritime hammock and mangrove swamp. This area is know as the restoration area and is the target area for exotic pest plant control and future native plant restoration.

Management unit #4 consists of 12.75 acres of the east section of the preserve and is entirely mangrove swamp with east and west boundaries being mosquito ditches, the south property line behind residential homes on Donora Avenue and the north boundary is Matanzas Pass.

Figure 11: Matanzas Pass Preserve Management Units



B. Goals, Strategies and Projected Timetable

The Matanzas Pass Preserve is part of a countywide quarterly site inspection program for all preserves. A copy of the site inspection form is available in the Land Stewardship Operations Manual. The inspection allows staff to monitor any impacts and/or changes to each preserve and includes listing all animal sightings and new plants found. If during these inspections at the Preserve staff finds FNAI listed species, staff will report those findings to FNAI using the appropriate form located in the Land Stewardship Operations Manual.

The Florida Exotic Pest Plant Council's List of Invasive Species (www.fleppc.org) will be consulted in determining the invasive exotic plants to be controlled in every management unit. The invasive exotic plant control will be conducted with the least amount of impact to the preserve possible and with appropriate herbicides (as per the Land Stewardship Operations Manual).

Table 2 outlines the goals, strategies and projected timetable for projects in the Preserve.

A. Goals, Strategies and Projected Timetable for Implementation

The table below outlines the goals for each management unit and strategies for achieving the goals.

Table 2: Goals, Strategies, Implementation Timetable and standards for success in all Management units in the MPP.

Management units	***Goals***	***Strategies***	***Projected Timetable for Implementation***	***Performance Measures***
All	1. Develop a self guided walk	Develop a self-guided trail to coincide with markers sensitively placed throughout the trail.	This project may be funded by grants and completed by November 30, 2010.	Placing of markers
	2. Establish photo points to monitor changes	A panoramic view taken from GIS points at designated times of the year.	The photos will be taken annually under similar conditions.	Photos will provide staff with visual documentation of changes in the preserve
U1 12.99 acres	1. Invasive exotic plant control, keep unit at maintenance level	Monitor and maintain invasive exotic plants on the existing mosquito control ditches with hand clearing methods using appropriate herbicide mix for each exotic plant species.	Ongoing project. Monitor unit one for exotics during quarterly inspections.	All target invasive exotic vegetation treated. Seed sprouts and re-sprouts will be treated annually
	2. West boundary on Tropical Shore Lagoon canal and North boundary along Matanzas Pass kept free of debris	Work with volunteer groups, such as the Friends of Matanzas Pass Preserve, Annual Coastal Clean Up, and Monofilament Madness to keep this area free from debris.	At least four-scheduled debris pick up days annually.	The coastline boundary of U1 kept free from debris
U2 14.99 acres	1. Invasive exotic plant control, keep unit at maintenance level.	Control Brazilian pepper, Australian pine, and air potato, in the southeast area and along spoil piles created from mosquito ditching. Cut stump and foliar applications of appropriate herbicide mix for each exotic plant species and removal of air potato tubers.	Treatment of Brazilian pepper, Australian pines and air potato to be completed by July 30, 2006. This project is funded by a grant from Lee County Visitor & Convention Bureau, Beach and Shoreline Project.	All target invasive exotic vegetation controlled to a 95% level
	2. Planting native plants in restoration area	Appropriate native plants will be selected to re-vegetate the restoration area.	Plantings will be installed by September 30, 2005. This project will be funded by a grant from the Charlotte Harbor National Estuary Program.	Natural recruitment of native plants has occurred and plantings achieved a 90% survival rate.

Table 2: Goals, Strategies, Implementation Timetable and Standards for success for all management Units in the MPP.

Management units	***Goals***	***Strategies***	***Projected Timetable for Implementation***	***Performance Measures***
U2	3. Contact adjacent neighbors about controlling invasive exotic vegetation.	Work with neighbors to control invasive exotic vegetation that is a seed source to Management Unit 2	Ongoing project	Staff will work with appropriate entity to control off-site invasive exotic plant seed source
	4. Monitor coastal and upland areas, keep free of debris.	Target volunteer groups and special events such as Coastal Clean up to aid in debris removal	Staff will work with volunteer groups to keep the area clean on a monthly basis or as needed	Coastal and upland areas of unit 2 will be kept free of debris
	5. Develop and implementation of environmental education programs.	Continue to support guided walks through the preserve	Weekly guided walks through the preserve will be provide by Bay Oaks programming staff and volunteers	Program staff to offer environmental education programs ranging from plant and animal identification to barrier island dynamics will be available to the public
U3 17.09 acres	1. Goals #1, 2, 3, 4, and 5 or Unit 2 also apply to Unit 3.			
	6. Prevent inappropriate use of the preserve	Install signs with clearly stated rules and regulation. Implement stepped up surveillance by Lee County Park Rangers, staff at Bay Oaks, and the Lee County Sheriff's department	Replace old and install new signs and increase surveillance by January 30, 2006	Inappropriate behavior in the preserve will be controlled
	7. Prevent dumping and encroachments from adjacent neighbors	Preserve boundary/no-dumping signage. Maybe required to control encroachments and dumping, such as yard waste. Meeting with neighbors to educate about living next to nature	Ongoing project as neighbors change	Encroachments and dumping will be prevented

Table 2: Goals, Strategies, Implementation Timetable and standards for success in all management units in the MPP

U4 12.96 acres	1. Invasive exotic plant control, keep unit at maintenance level	Control Australian pine, Brazilian pepper, and air potato along spoil piles created from mosquito ditching. Cut stump and foliar applications of appropriate herbicide mix for each exotic plant species and remove air potato tubers.	On going project	All targeted invasive exotic vegetation controlled to a 95% level
U4	2. Research and create enhancement of trail system	Discover possibilities of extending trail system to include access off of Donora Street for local population.	Staff will determine if this project is possible and can be accomplished by December 30, 2008	If this goal can be accomplished there will be a new trail system with an access off Donora Street for public use

VI. Financial Consideration

A. Funding

Funding sources will be researched and applications will be made for appropriate grants or other sources of funding such as Florida Department of Environmental Protection Bureau of Invasive Plant Management for the exotic control projects.
Project cost and funding sources are listed in Appendix E.

B. Staffing

Maintenance for the Matanzas Pass Preserve is divided into operations and land stewardship; both are located in the Department of Parks and Recreation. The land stewardship section is responsible for the management of all preserves, and consists of a manager, supervisor, coordinators, contracts coordinator, and field technician. A land steward's job consists of conservation and restoration of biological communities, which includes exotic plant removal and monitoring, debris removal, forming contacts with other groups and agencies to share the latest data on similar land management activities, establishing volunteer programs for the sites, protecting water resources, establishing opportunities for multiple uses and compatibility, providing public access and response to public use. Land Stewardship staff from other preserves are available to assist with management from time to time.

Partnerships with the Fort Myers Beach Historic Society, Town of Fort Myers Beach, Fort Myers Beach Elementary School, Florida Gulf Coast University, Lee County Master Gardeners, and the Department of Environmental Protection have created educational opportunities for thousands of people to explore the mangrove and maritime forest of a barrier island, learning the importance of native vegetation and conservation.

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Appendices

Appendix A

Plant sightings at Matanzas Pass Preserve

Appendix A: Plant Sightings at Matanzas Pass Preserve

Scientific names for this list were obtained from Wunderlin & Hansen, 2003

Scientific Name	Common Name	Native Status
Family: Surianaceae (*BayCedar*)		
Suriana maritima	Bay cedar	native
Family: Convolvulaceae (Morning –Glory)		
Ipomoea alba	Moonflower	native
Ipomoea pes-caprae	Railroad Vine	native
Ipomoea sagittata	Saltmarsh Morning Glory	native
Family: Callicarpa		
Callicarpa americana	Beautyberry	native
Family: Rhizophoraceae		
Rhizophora mangle	Red mangrove	native
Family: Avicenniaceae		
Avicennia germinans	Black mangrove	native
Family: Combretaceae		
Laguncularia racemosa	White mangrove	native
Conocarpus erectus	Buttonwood	native
Family: Lentibulariaceae		
Utricularia amethystina	.Bladderwort	native
Family: Rhamnaceae		
Rhamnus caroliniana	Buckthorn	native
Family: Fabaceae		
Pithecellobium unquis-cati	Catclaw Blackbead	native
Sophora tomentosa	Necklacepod	native
Dalbergia ecastophyllum	Coinvine	native
Caesalpinia bonduc	Nickerbean	native
Abrus precatorius	Rosary pea	exotic
Family: Zamiaceae		
Zamia intergrifolia	Coontie	native
Family: Poaceae		
Dactyloctenium aegyptium	Crowfoot grass	native
Spartina bakeri	Sand cord grass	native
Panicum maximum	Guineagrass	exotic
Family: Ruppiaceae		
Sansevieria hyacinthoides	Bowstring hemp	exotic
Family: Anacardiaceae		
Schinus terebinthifolius	Brazillian pepper	exotic
Toxicodendron radicans	Eastern poison ivy	native
Family: Asteraceae		
Eupatorium capillifolium	Dogfennel	native
Ambrosia artemisiifolia	Common ragweed	native
Borrichia frutescens	Seaside oxeye	native
Pluchea camphorata	Camphorweed	native
Solidago sempervirens	Seaside goldenrod	native
Baccaharis angustifolia	Saltwater falsewillow	native
Bidens bipinnata	Spanish needle	native
Family: Anacardiaceae		
Salicornia bigelovii	Glasswort	native
Family: Bataceae		
Batis maritima	Saltwort	native

Appendix A: Plant Sightings at Matanzas Pass Preserve (continued)

Scientific Name	Common Name	Native Status
Family: Fagaceae		
Quercus virginiana	Live oak	native
Family: Burseraceae		
Bursera simaruba	Gumbo limbo	native
Family: Cactaceae		
Opuntia humifusa.	Prickly pear cactus	native
Family: Apocynaceae		
Asclepias tuberosa	Milkweed	native
Family: Annonaceae		
Toxicodendron radicans	Poison ivy	native
Family: Phytolaccaceae (pokeweed)		
Rivina humilis	Rouge-plant	native
Family: Polypodiaceae (polypody)		
Phlebodium aureum	Golden polypody	native
Family: Pteridaceae		
Acrostichum danaeifolium	Giant leather fern	native
Family: Vittariaceae		
Vittaria lineata	Shoestring fern	native
Family: Pinaceae		
Pinus elliottii	Slash pine	native
Family: Arecaceae (palm)		
Sabal palmetto	Cabbage palm	native
Serenoa repens	Saw palmetto	native
Family: Agavaceae		
Yucca aloifolia	Spanish bayonet	native
Family: Bromeliaceae		
Tillandsia *flexuosa*	Twisted airplant	native
Tillandsia *recurvata*	Ball moss	native
Tillandsia usneoides	Spanish moss	native
Family: Musaceae		
Musa acuminata	Dwarf banana	exotic
Family: Orchidaceae		
Encyclia tampenisi	Florida butterfly orchid	native
Family: Moraceae		
Ficus aurea	Strangler fig	native
Family: Polygonaceae		
Coccoloba uvifera	Seagrape	native
Family: Rubiaceae		
Psychotria nervosa	Wild coffee	native
Randia aculeata	White indigoberry	native
Family: Sapindaceae		
Cupaniopsos anacardioides	Carrotwood	exotic
Family: Solanaceae		
Lycium carolinianum	Christmasberry	native
Family: Vitaceae		
Parthenocissus quinquefolia	Virginia creeper	native
Family:Myricaceae		
Myrica cerifera	Wax myrtle; southern bayberry	native

Appendix A: Plant Sightings at Matanzas Pass Preserve (continued)

Scientific Name	Common Name	Native Status
Family: Myrtaceae		
Eugenia axillaris	White stopper	native
Eugenia uniflora	Surinam cherry	exotic
Family: Theophrastaceae		
Jacquinia keyensis	Joewood	native
Family: Malvaceae		
Gossypium hirsutum	Wild cotton	native

Appendix B

Wildlife Sightings at Matanzas Pass Preserve

Appendix B: Wildlife Sightings at Matanzas Pass Preserve

Scientific Name	Common Name	Designated Status FWC	Designated Status USFWS	Occurrence
Crustaceans				
Family: Grapsidae				
Aratus pisoni	Mangrove tree crab			confirmed
Butterflies				
Family: Pieridae (whites and sulphurs)				
Ascia monuste	Great southern white			confirmed
Phoebis philea	Orange –barred sulpher			confirmed
Family: Danaidae				
Danaus plexippus	Monarch			confirmed
Family: Nymphalidae				
Junonia coenia	Buckeye			confirmed
Agraulis vanille	Gulf fritillary			confirmed
Reptiles				
Family: Alligatoridae				
Alligator mississippiensis	American alligator	SSC	T	confirmed
Family: Colubrids				
Elaphe obsoleta quadrivittata	Yellow rat snake			confirmed
Nerodia clarkii compressicauda	Mangrove water snake			confirmed
Coluber constrictor priapus	Southern black racer			confirmed
Family: Emydidae				
Terrapene arolina bauri	Florida box turtle			
Family: Testudinids				
Gopherus polyphemus	Gopher tortoise	SSC		confirmed
Family: Polychridae				
Anolis sagrei	Brown anole			confirmed
Family: Scincids				
Eumeces fasciatus	Five lined skink			confirmed
Birds				
Brown pelican	*Pelecanus occidentalis*	SSC		confirmed
Blue jay	*Cyanocitta cristata*			confirmed
Family: Ardeidae				
Ardea alba	Great egret			confirmed
Ardea herodias	Great blue heron			confirmed
Bubulcus ibis	Cattle egret			confirmed
Butorides virescens	Green heron			confirmed
Egretta caerulea	Little blue heron	SSC		confirmed
Egretta thula	Snowy egret	SSC		confirmed

Appendix B: Wildlife Sightings at Matanzas Pass Preserve

Scientific Name	Common Name	Designated Status FWC	Designated Status USFWS	Occurrence
Family: Ardeidae-continued				
Egretta tricolor	Tricolored heron	SSC		confirmed
Nycticorax nyticorax	Black-crowned night heron			confirmed
Egretta rufescens	Reddish egret	SSC		confirmed
Nyctanassa violacea	Yellow-crowned night heron			confirmed
Family: Threskiornithidae				
Platalea ajaja	Roseate spoonbill	SSC		expected
Eudocimus albus	White ibis	SSC		confirmed
Plegadis falcinellus	Glossy ibis			expected
Family: Cathartidae				
Coragyps atratus	Black vulture			expected
Cathartes aura	Turkey vulture			confirmed
Family: Accipitridae				
Subfamily: Buteoninae				
Buteo lineatus	Red-shoulder hawk			confirmed
Haliaeetus leucocephalus	Bald eagle	T	T	expected
Family: Pandionidae				
Pandion haliaetus	Osprey			confirmed
Family: Falconidae				
Falco sparverius	American Kestrel			expected
Family: Columbidae				
Zenaida macroura	Mourning dove			confirmed
Family: Picidae				
Picoides pubescens	Downy woodpecker			confirmed
Dryocopus pileatus	Pileated woodpecker			confirmed
Melanerpes carolinus	Red-bellied woodpecker			expected
Family: Sylviidae				
Subfamily: Polioptilinae				
Polioptila caerulea	Blue-grey gnatcather			confirmed
Family: Mimidae				
Dumetella carolinensis	Grey catbird			confirmed
Mimus polyglottos	Northern mockingbird			expected
Family: Corvidae				
Corvus brachyrhynchos	American crow			expected
Corvus ossifragus	Fish crow			expected
Cyanocitta cristata	Blue jay			confirmed
Family: Laniidae				
Lanius ludovicianus	Loggerhead shrike			confirmed
Family: Cardinalidae				
Cardinalis cardinalis	Northern cardinal			confirmed

Appendix B: Wildlife Sightings at Matanzas Pass Preserve

Scientific Name	Common Name	Designated Status FWC	Designated Status USFWS	Occurrence
Family: Strigidae				
Bubo virginianus	Great horned owl			confirmed
Family: Icteridae				
Agelaius phoeniceus	Red-winged blackbird			confirmed
Mammals				
Family: Trichechidae				
Trichechus manatus latirostris	Florida manatee	E	E	confirmed
Family: Dildelphidae				
Didelphis virginiana	Opossum			confirmed
Family: Procyonidae				
Procyon lotor	Raccoon			confirmed
Family: Sciuridae				
Sciurus carolinensis	Gray squirrel			confirmed
Family: Leporidae				
Sylvilagus palustris	Marsh rabbit			confirmed
Family:Musteildae				
Lutra canadensis	River otter			confirmed

Key

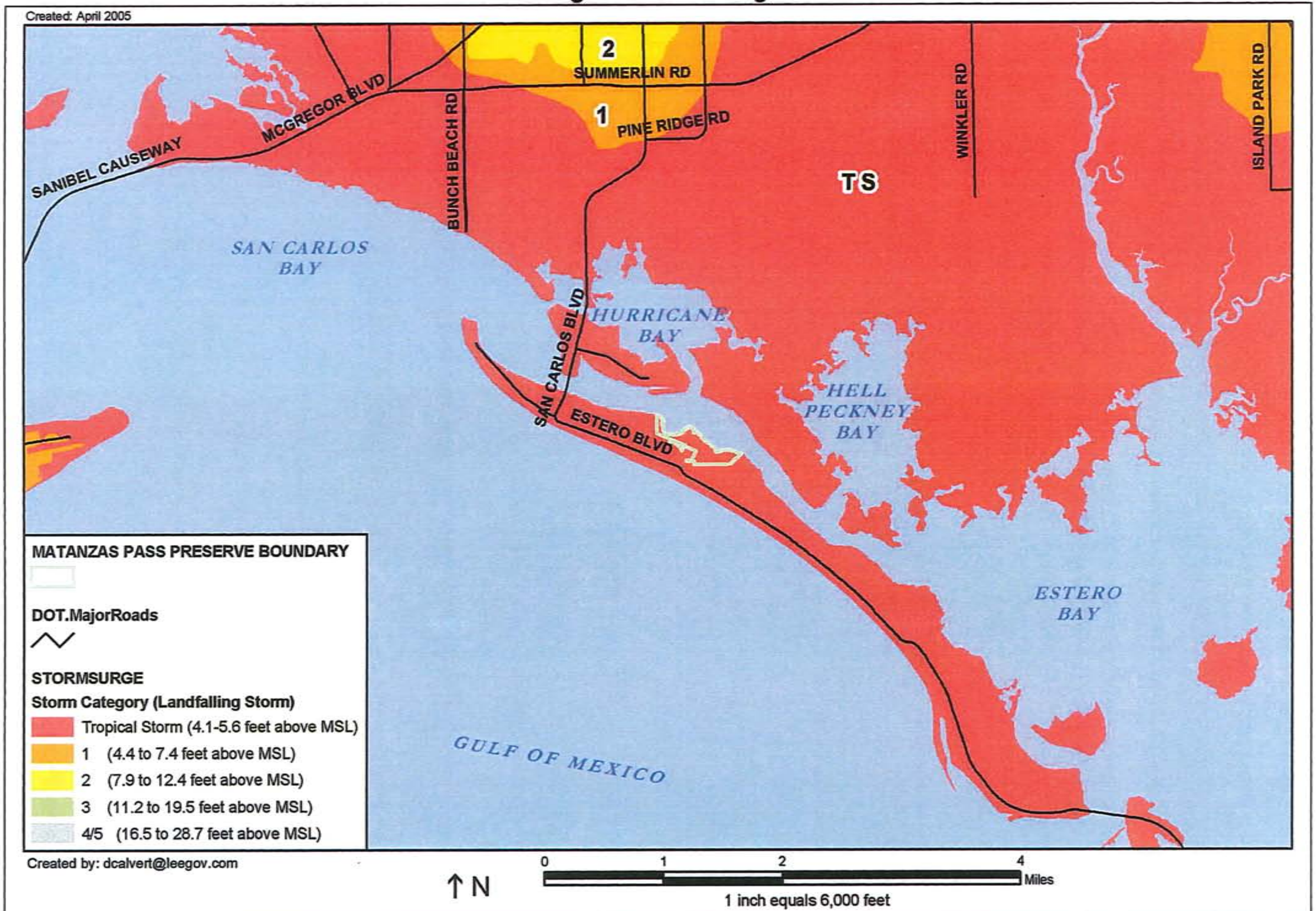
FWC: Florida Fish & Wildlife Conservation Commission
USFWS: U.S. Fish and Wildlife Service

SSC: Species of Special Concern
T: Threatened
E: Endangered

Appendix C

Strom surge-Coastal High Hazard

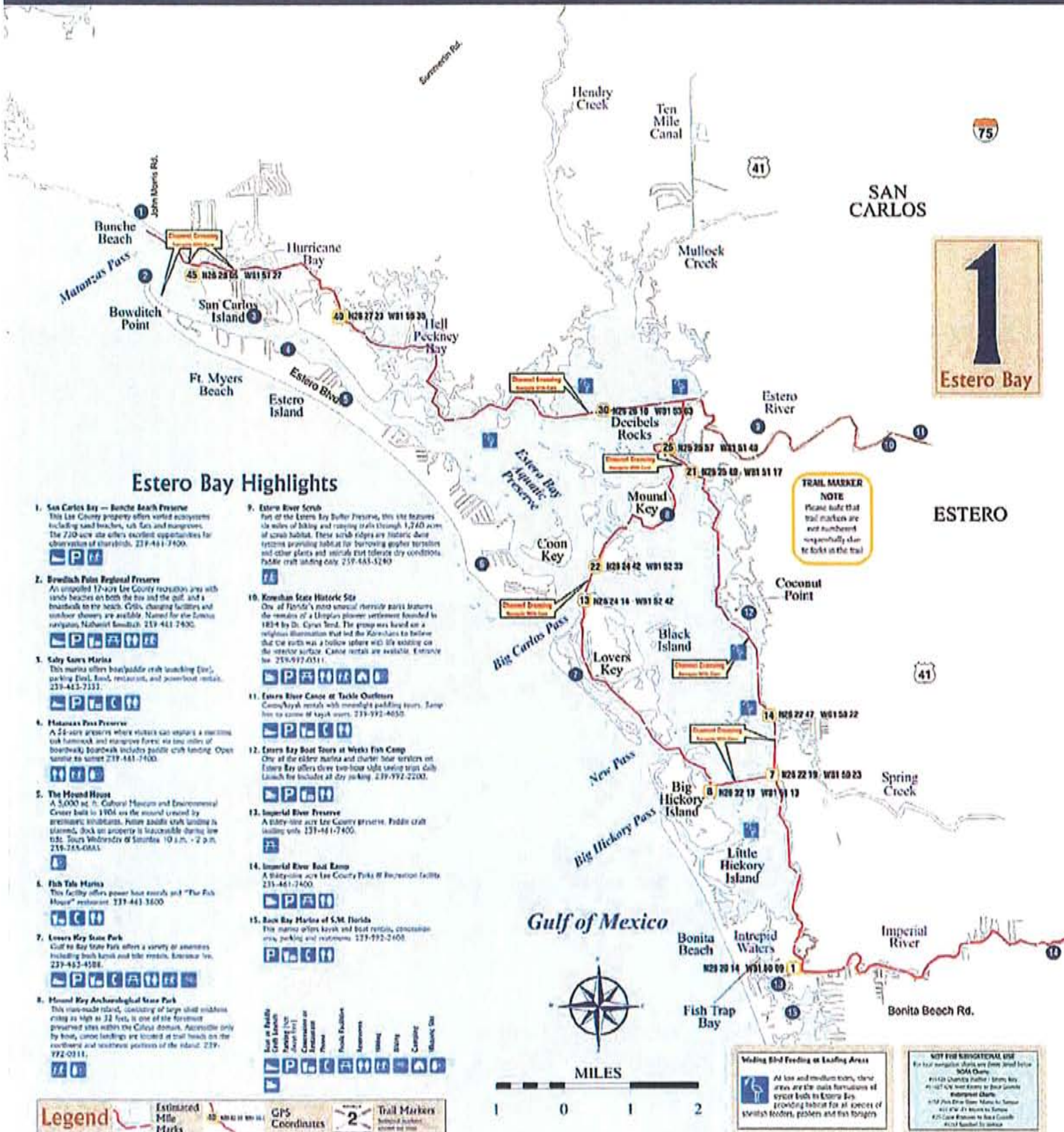
Storm Surge-Coastal High Hazard



Appendix D

The Great Calusa Blueway Map

The Great Calusa Blueway • Estero Bay



Appendix E

Projected Cost and Funding Sources Table

Projected Cost and Funding Sources Table

Structures and Improvements

Item	Possible Funding source	Estimated cost
Trail improvement Picnic tables Boundary markers Fencing installed New foot trails	Tourist Development Council (TDC) and or Program (FERDAP) Grants	$ 4,000.00 $ 800.00 $ 1,000.00 $ 8,000.00 $ 1,000.00
		$14,800.00

Resource Enhancement & Protection

Item	Possible Funding Source	Estimated Cost
Invasive Exotic Plant Removal	Lee County Visitor & Convention Bureau (VCB)	$25,000.00
Native Planting	Charlotte Harbor National Estuary Program	$40,500.00
		$65,000.00

Education Programs

Item	Possible Funding	Estimated Cost
Information Kiosk and Educational markers	Lee County Parks and Recreation	$20,000.00
Education Program Material including trail guides		$ 5,000.00
		$25,000.00

Total Cost Estimate

Site Management & Maintenance

Item	Possible Funding Sources	Estimated Cost
Exotic Plant Control	VCB	$ 6,000.00 per year
Trail Maintenance	Lee County Parks and Recreation	$ 5,000.00 per year
Upkeep		$ 3,000.00 per year
Staff	Tourist Development Council (TDC)	$40,000.00 - $60,000.00 per year
		$54,000.00-$74,000.00

FLORIDA FISH AND WILDLIFE CONSERVATION COMMISSION
FISH AND WILDLIFE RESEARCH INSTITUTE

Glossary of Aquatic Vegetation Terms

Do you need a definition? Try our glossary of aquatic vegetation-related terms.

Anthropogenic:
Conditions that result from human activities. "Anthropo-" meaning human and "-genic" meaning produced from.

Ascidian:
A small, sedentary, marine invertebrate (chordate) having a saclike body and a siphon through which water enters and leaves; commonly known as sea squirts.

Axenically:
Not contaminated by or associated with any other living organisms. Usually used in reference to pure cultures of microorganisms that are completely free of the presence of other organisms.

Bryozoan:
Group of suspension-feeding organisms that usually live in branching colonies and obtain food by using tentacles to collect particles suspended in the water column. Bryozoans can use seagrasses for support and in turn provide habitat for juvenile fish and various invertebrates.

Crustaceans:
A class of invertebrates including shrimps, crabs, barnacles, and lobsters that usually live in water and breathe through gills. They have hard outer shells and jointed appendages and bodies.

Detritus:
Dead or decaying animal or plant matter.

Diffusion:
The process where solids, liquids, or gases are transported (sometimes through a membrane) from a region of higher concentration to an area of lower concentration.

Dredging:
Dragging something along the ocean bottom, inadvertently or intentionally removing and redistributing the sediment and other materials found there. There are several specific definitions for dredges:

1. To deepen waters to form channels or improve navigation, boats or barges with dredges attached remove sediment from the bottom of the area.
2. To collect shellfish, an implement consisting of a net on a frame, called a dredge, is used.
3. When a boat drags its propeller through seagrass beds or other bottom types, it is called prop dredging.

Echinoderm:
Any animal belonging to the phylum Echinodermata, which features radially symmetrical (radiating from a common center) bodies; this includes starfishes, sea urchins, sea cucumbers, etc.

Epiphyte:
A non-parasitic plant that uses other plants as anchors.

Flux rate:

A change in the rate of flow. In reference to seagrasses, the term refers to the rate of nutrient exchange between the sea floor sediments and the overlying water column.

Forams (Foraminifera):
Single cellular organisms (protists) with a hard shell or test; may be benthic or planktonic.

GIS (Geographic Information System):
GIS is a sophisticated computer-based tool that allows users to produce simple maps from complex spatial data. Researchers can overlay multiple data layers to perform a variety of tasks, including generating a detailed view of the ecosystem, determining changes over time, and predicting various scenarios in the future. See the Geographic Information System and Mapping Web page for more information.

Hyperthermia:
A state of higher-than-normal temperatures

in situ:
A Latin term meaning, "in its original position." In biology, it refers to experiments or observations gathered in the natural habitat, as opposed to those gathered in a laboratory.

Infauna:
Organisms that live in the substrate of a body of water and obtain their nutrients through digestion of ingested detritus or by filtering particles out of the surrounding water. Common examples include species such as clams, crabs, shrimp, sea cucumbers, and polychaete worms.

Light attenuation:
Describes how light intensity decreases with distance from the water surface. As water depth increases, less light is available to organisms living on the ocean bottom. Light attenuation increases with increased amounts of phytoplankton, dissolved organic matter, and macroalgae and epiphytic microalgae.

Macroalgae:
Algae species that can be seen without a microscope. In the marine environment, this usually refers to seaweed.

Meristem:
A specialized area within a plant where rapid cell division occurs. Apical meristems allow for vertical growth.

Microalgae:
Algae species that cannot be seen without a microscope (phytoplankton).

Micropropagation:
Use of tissue culturing methods to grow large numbers of plants from very small pieces of plants, often single cells. Mudbank: A shallow bottom area of shifting mud.

Pathogen:
An organism that can cause diseases in other organisms Photosynthesis: The formation of carbohydrates in plants from water and carbon dioxide—caused by the action of sunlight on the chlorophyll pigments.

Phytoplankton:
Microscopic plants that float in water and are transported by the currents; often used as a food source by marine animals

Phytoplankton bloom:
An event in which the density of phytoplankton in the water drastically increases.

Productivity:
The rate of production of biomass (which is the amount of living matter in an area); primary productivity refers to the biomass produced by the photosynthesizing plant components of an ecosystem.

Propagation:
Increasing the number of plants through cuttings, seeds, or divisions.

Protists:
A diverse taxonomic kingdom that includes plant-like forms such as algae (including seaweed); fungus-like forms such as slime molds and water molds; and animal-like forms such as protozoans (Amoeba, Euglena, Paramecium, etc.)

Rhizome:
An underground stem that can grow horizontally or vertically and from which roots grow to provide anchorage for seagrasses. A vertical rhizome is sometimes referred to as a short shoot; horizontal rhizomes have longer internodes, or rhizome fragments. For more details, see illustration in Seagrasses and Land Plants.

Runoff:
The flow of water, usually from precipitation, which is not absorbed into the ground. It flows across the land and eventually runs into stream channels, lakes, oceans, and depressions or lowpoints in the Earth's surface. Runoff can pick up pollutants from the air and land, carrying them into the water body and affecting the species that live there.

Sediment porosity:
The ability of water to flow through sediment. The degree of water movement through sediment depends on sediment characteristics such as type, grain size, and degree of compaction.

Sediment resuspension:
The remixing of sediment particles and pollutants back into the water by storms, currents, organisms, and human activities such as dredging or shipping.

Shellfish:
Aquatic animals with shells, such as oysters and clams.

Subculture:
A culture that is derived from a culture.

Transport:
An exchange of molecules (and their kinetic energy and momentum) across the boundary between adjacent layers of a fluid or across cell membranes.

Turbidity:
In water bodies, the condition of having suspended particles that reduce the ability of light to penetrate beneath the surface. Soil erosion, runoff, and phytoplankton blooms can increase turbidity.

Florida Fish and Wildlife Conservation Commission
FISH AND WILDLIFE RESEARCH INSTITUTE

Conserving Florida's Seagrass Resources: Developing a Coordinated Statewide Management Program (2003)

This non-technical planning document is intended to provide a conceptual framework for the development of a coordinated, statewide seagrass management initiative, while recognizing, supporting, and building on the accomplishments of local programs.

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This article is excerpted from the introduction of Florida Seagrass Management Plan: "Effective local seagrass management programs are currently underway in several areas of Florida, primarily in subtropical portions of the peninsula (e.g., Indian River Lagoon, Florida Bay, Sarasota Bay, and Tampa Bay). In addition, a number of federal, state, and local government agencies conduct regularly scheduled mapping and monitoring of seagrass habitats within their jurisdictions. However, the state of Florida does not yet have a coordinated statewide program for managing its seagrass resources. This report recommends a series of steps that could be taken to initiate a coordinated, cooperative, multi-agency program. The plan outlined herein provides a framework for quantitative management goals for the five distinct regions of the state that currently possess extensive seagrass resources. It also provides recommendations regarding the state's potential role in developing the following:

- Consensus-based seagrass management strategies at the regional and statewide level
- A methodologically consistent, statewide seagrass mapping and monitoring program
- A schedule for reporting regional and statewide status and trends information
- A schedule for assessing the state's management strategies and the progress made toward achieving the adopted management goals
- A management-oriented, statewide seagrass research program
- A statewide, public outreach program focused on seagrass management and conservation

The process of developing a statewide seagrass management program should not be allowed to impede or delay progress in the local areas where effective community-based programs are already in place. The statewide program should review and, if appropriate, adopt existing seagrass management goals and strategies developed by local stakeholder groups. A primary purpose of the statewide program should be to provide increased support for—and greater statewide consistency in the implementation of—the various components of seagrass management. To avoid unnecessary duplication of effort, the program should build on accomplishments at the local level and work cooperatively with local management programs. It is assumed that the statewide management program will be guided by a statewide management plan. The plan should be a "living document" that is revisited every 4 to 6 years, as statewide summaries of seagrass status and trends are updated and reported to the public. Of necessity, this initial planning document focuses on basic procedural issues, providing a brief overview of Florida's existing seagrass resources and a list of recommendations for the participating organizations to consider as they work to initiate a consistent, coordinated statewide management effort."

CONSERVING FLORIDA'S SEAGRASS RESOURCES:Ç DEVELOPING A COORDINATEDÇ STATEWIDE MANAGEMENT PROGRAMÇ

Florida Fish and Wildlife Conservation CommissionÇ
Florida Marine Research InstituteÇ
100 Eighth Avenue SEÇ
St. Petersburg, FL 33701-5095Ç

September 2003

CONSERVING FLORIDA'S SEAGRASS RESOURCES:Ç DEVELOPING A COORDINATEDÇ STATEWIDE MANAGEMENT PROGRAMÇ

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September 2003

SUMMARY OF KEY RECOMMENDATIONS

Effective seagrass management programs are currently active at the local level in several of Florida's coastal areas, and a number of federal, state, and local government agencies are performing regularly scheduled mapping and monitoring of seagrass habitats within their jurisdictions. However, the state of Florida does not yet have a coordinated, statewide program for managing its seagrass resources. The following steps are recommended to develop and initiate such a program:

A Development of Regionally-Based Statewide Goals
1. With coordination and logistical support provided by the Florida Coastal Management Program, a combination of state and federal agencies and local governments should work cooperatively to identify quantitative, consensus-based, seagrass coverage goals for each of Florida's five seagrass regions.
2. These goals should be specific, measurable, technically defensible, ecologically appropriate, and achievable within a specified time period.
3. The regional goals should be developed by a statewide technical advisory committee (TAC) and should be based on input from a wide range of local stakeholders.
4. In local areas where seagrass management goals have already been developed, such as Tampa Bay and the Indian River Lagoon, those goals should be reviewed and—if found appropriate—adopted by the TAC as a component of a larger regional goal.
5. The sum of these regional goals will represent the statewide seagrass management goal.

B Development of Management Strategies
1. The TAC assembled to develop the regional and statewide coverage goals should also be tasked with developing clear strategies for achieving those goals.
2. The strategies should include a list of agency responsibilities and timelines for achieving the regional and statewide goals.

C Implementing the Strategies
1. Following approval of the strategies, an interagency memorandum of understanding (MOU) should be drafted to guide their implementation.
2. Participation in the MOU should be open to the participating agencies and to other public or private organizations that wish to make a significant commitment to statewide seagrass management.
3. The MOU should specify the steps each participating organization proposes to take to implement the agreed-upon strategies, the time frame within which those steps are proposed to occur, and an estimate of the resources that need to be budgeted to accomplish the work.

D Evaluating and Reporting Progress Toward Goals
1. The state should develop a methodologically consistent statewide program for mapping and monitoring seagrass coverage and condition.

2. The results of the mapping and monitoring program should be summarized and reported to the public in a timely manner (e.g., every 2–3 years) and should be made available to managers, scientists, and other interested parties through a relational database that is publicly accessible via the Internet.
3. The 2–3 year summary reports should be used by the state to evaluate the progress made toward meeting its seagrass management goals.
4. On a less frequent basis (e.g., every 4–6 years), the results should be used to assess, and if necessary, refine and improve the state's seagrass management goals and strategies.

E Management-Related Research

1. The state should identify and prioritize existing management-related research needs with respect to seagrass conservation.
2. The annual and long-term costs of carrying out the necessary research should be estimated.
3. Adequate funding should be budgeted to carry out the work.

F Public Outreach

1. The state should support existing outreach efforts by assisting in the distribution of accurate information about the status of Florida's seagrasses and stressors affecting them.
2. A "Citizens' Report on the Status of Florida's Seagrasses" should be prepared and distributed on a regular basis (e.g., every 2–3 years).
3. A statewide teaching curriculum introducing students to Florida's seagrasses, the environmental and economic value of seagrasses, and the state's seagrass conservation goals should be developed and implemented.

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ACKNOWLEDGMENTS

Information and data used in this report were gleaned from a variety of sources including technical reports; federal, state, and local seagrass monitoring and management programs; and historical documents. Source materials and other suggested readings are listed in Section 11.

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1. INTRODUCTION

Report Purpose and Scope

This report is intended to serve as a non-technical planning document; it provides a conceptual framework for the development of a coordinated, statewide seagrass management initiative, while recognizing, supporting, and building on the accomplishments of local, community-based programs.

Effective local seagrass management programs are currently underway in several areas of Florida, primarily in subtropical portions of the peninsula (e.g., Indian River Lagoon, Florida Bay, Sarasota Bay, and Tampa Bay). In addition, a number of federal, state, and local government agencies conduct regularly scheduled mapping and monitoring of seagrass habitats within their jurisdictions. However, the state of Florida does not yet have a coordinated statewide program for managing its seagrass resources. This report recommends a series of steps that could be taken to initiate a coordinated, cooperative, multi-agency program.

The plan outlined herein provides a framework for quantitative management goals for the five distinct regions of the state (Fig. 1) that currently have extensive seagrass resources. It also provides recommendations regarding the state's potential role in developing the following:

- Consensus-based seagrass management strategies at the regional and statewide level
- A methodologically consistent, statewide seagrass mapping and monitoring program
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It is assumed that the statewide management program will be guided by a statewide management plan. The plan should be a "living document" that is revisited every 4 to 6 years, as statewide summaries of seagrass status and trends are updated and reported to the public. Of necessity, this initial planning document focuses on basic procedural issues, providing a brief overview of Florida's existing seagrass resources and a list of recommendations for the participating organizations to consider as they work to initiate a consistent, coordinated statewide management effort.

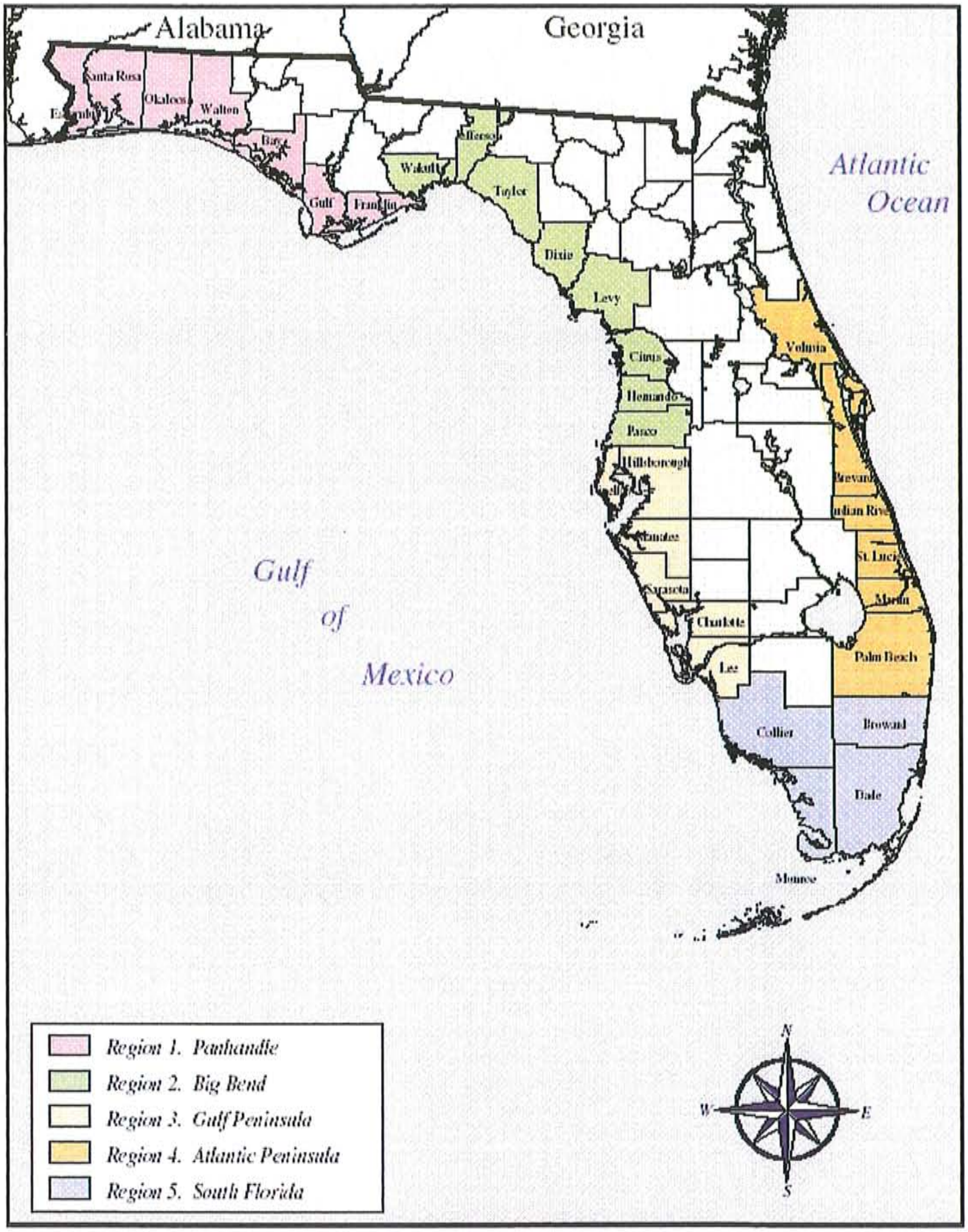

Figure 1. Regions of Florida containing significant seagrass resources.

Background

The need for a statewide seagrass management program was formally explored during a facilitated workshop held in June 2000 at the Florida Marine Research Institute (FMRI) in St. Petersburg. FMRI Director Ken Haddad, now Executive Director of the Florida Fish and Wildlife Conservation Commission, convened the session.

The one-day workshop brought together representatives of key organizations to discuss Florida's approach to seagrass management, focus on the existing roles and activities of state and federal agencies, and identify areas in which coordination and oversight could be improved. Various regulatory and non-regulatory management issues were discussed. Workshop participants also addressed existing seagrass management and monitoring activities, areas in which improved collaboration would be beneficial, and "missing links" in data or information that would enable them to perform their duties more effectively.

In general, participants supported the concept of a statewide seagrass management program that would serve as an overall blueprint for guiding long-term protection and enhancement of the state's more than 2.7 million acres of seagrass meadows.

In 2000, Workshop participants identified the following key seagrass management issues:

- Attention to and understanding of the status of seagrass resources throughout the state is uneven. Highly focused management and monitoring programs are underway in some areas—such as Florida Bay, Indian River Lagoon, Sarasota Bay, and Tampa Bay—where sufficient resources are available to support these activities. Mapping and monitoring projects in other portions of the state are conducted on a less frequent and less consistent basis, due, in part, to a lack of funding and other resources in those areas.
- No central database exists for the storage and retrieval of mapping and monitoring data.
- No strategic plan exists to identify priority management, monitoring, or research activities.
- Standardized statewide mapping or monitoring techniques have not yet been developed.
- Regulatory activities by federal, state, regional, and local government agencies often emphasize a piecemeal, case-by-case view of impacts to individual seagrass habitats, rather than a broader, more comprehensive approach capable of preserving the integrity of seagrass-based ecosystems.

Participants offered the following key recommendations:

- Specific, quantitative targets for seagrass recovery or preservation are important tools.
- The state has a critical role to play as a facilitator in guiding long-term management of seagrass resources.
- Monitoring and mapping efforts should be coordinated statewide, and standard protocols for monitoring and mapping should be developed.
- Any strategic plan developed by the state should recognize regional differences in seagrass resources, impacts, and research and monitoring priorities, as well as successful local and regional management activities.
- Efforts to inform the public about the economic and environmental value of seagrass should be expanded and coordinated on a statewide level.

- A central clearinghouse for data related to seagrass coverage, trends, and impacts is needed..
- Linking science and management is crucial to the success of seagrass conservation efforts and to achieving public support for conservation initiatives.
- Collaboration at all levels of government, including the regulatory and law enforcement arenas, should be improved. Additionally, collaboration is desirable among agencies and non-profit or private organizations promoting seagrass protection.

Another State's Experience: Some Lessons from Texas

Texas, like Florida, is a large coastal state with significant seagrass resources. Like Florida, legal and regulatory authority for seagrass management in Texas waters is divided among a number of state and federal agencies and local governments. No single agency has the authority, the funding, or the staff resources to develop and implement a coordinated, statewide seagrass management program. Recognizing the environmental and economic importance of seagrass habitats and the fragmented nature of the state's regulatory authority and management resources, the Texas Parks and Wildlife Department (TPWD), in partnership with the Texas Natural Resource Conservation Commission, the Texas General Land Office (TGLO), and several federal resource management organizations, initiated a multi-stakeholder planning effort in 1995. That effort produced a plan for the development and implementation of a statewide program to coordinate seagrass research, conservation, and management. The plan is available via the Internet: www.tpwd.state.tx.us/texaswater/coastal/seagrass/plan/navbar.htm

The planning process underway in Texas offers a number of lessons that can be used during the development of a comparable statewide management program for Florida. The following extended excerpts from the current Texas plan highlight several of those lessons:

> "The development of this planning document started with work by the Resource Protection Division, TPW, when evidence of boat propeller scarring was extensively noted in many seagrass beds of Texas bays."
>
> "A decision was made to initiate a conservation planning effort to identify resource management problems, enumerate planning objectives, and develop long and short range strategies and actions to protect and preserve Texas seagrasses."
>
> "A planning team was organized to draft a conceptual planning document, conduct a Seagrass Symposium and Workshop, and then compile and prepare this published document. These activities have taken place over the last three years (since 1995). Because of statutory management authority over coastal public waters or biological resources therein, three state agencies (Texas Parks and Wildlife, Texas General Land Office, and Texas Natural resource Conservation Commission) have taken the lead in guiding plan development. In addition, the two National Estuary Programs, Corpus Christi Bay and Galveston Bay, were actively involved. This multiuser/multistakeholder approach provides a good model for resource management and conservation that can be implemented at a local level through such a Seagrass Plan."

Management/Policy Issues

"A sound management process that coordinates agency policies, public awareness, and existing research knowledge is needed to achieve effective seagrass conservation, while allowing for economic development. Management objectives were identified that address four problem areas: (1) seagrass beds are being lost or degraded, and/or species composition is changing; (2) agency coordination may prevent adequate management; (3) data synthesis and monitoring are insufficient for management decisions and need to be focused on management needs; and (4) public outreach is too limited to achieve the goal of public awareness. Objectives addressing these problems fall into three primary categories – regulatory, management, and educational policies."

Regulations

"Regulatory policies for effective management involve ensuring water and sediment quality and coordinating and strengthening the mitigation sequence and guidelines. Beneficial water and sediment quality for seagrass communities involves establishing seagrass habitat as a specific aquatic life use in the Texas Surface Water Quality Standards. Additional evaluation would be needed to develop criteria or screening levels, such as suspended sediment, nutrient concentrations, turbidity, and salinity, for seagrass protection. Watershed management programs can protect water and sediment quality by promoting non-regulatory management activities. Implementation of Best Management Practices (BMPs), especially water-based BMPs, are needed to address impacts from runoff."

"Federal and state regulations and programs that help protect seagrasses are primarily the Section 404 and 401 Permits of the Clean Water Act and the Texas Coastal Management Program (CMP). The mitigation sequence of avoidance, minimization, and compensation is in the Section 404(b)(1) Guidelines and is the substantive environmental standard by which all Section 404 permit applications are evaluated. The Texas Natural Resource Conservation Commission rules for Section 401 Certification and the CMP policies have incorporated key components of the Section 404 (b)(1) Guidelines. However, improvement is needed in coordinating the permitting process. In addition, the mitigation sequence needs to be strengthened and guidelines for avoidance of seagrass impacts emphasized."

Management Programs

"Management programs focus on 1) seagrass restoration, enhancement, and creation; 2) dredging and shoreline development; 3) policy consistency; and 4) research, data acquisition, and monitoring. Restoring and enhancing seagrasses was originally reported as being largely unsuccessful. Recently, many seagrass restoration projects have been successful, especially the restoration of shoalgrass (*Halodule wrightii*). In order to increase the success rate of restoration projects, management efforts need to be directed toward strengthening current restoration guidelines and providing increased research on successful planting techniques."

"Dredging of new canals and maintenance dredging of channels may cause mortality of seagrasses from burial or inhibit growth from turbidity and light reduction. Development along shorelines may affect conditions of water depth and currents and cause loss of seagrasses. Best Management Practices are needed to protect seagrasses while allowing for development of coastal resources."

"Consensus among user groups over controversial issues involving natural resource use is difficult to achieve. The 1994 Beneficial Uses Group Plan for the Houston Ship Channel deep-draft navigation project is an example of a model plan or consensus agreement that minimized the ecological and sociological impacts of dredging by maximizing the beneficial uses of dredged material."

"Policies affecting seagrasses are present in many agencies and may be written with only one agency and its specific regulatory authority in mind. Future policies should be prepared in a holistic framework and existing policies examined for flexibility and to ensure that goals are achieved."

"Research, data acquisition, and monitoring need to be focused on management needs, i.e., on the water quality requirements of seagrasses. Management efforts will depend upon the development of new approaches that utilize a watershed approach to using water quality parameters to control import of nutrients into estuaries. Monitoring programs are needed for status and trends information and to help evaluate management actions. Ecological studies are needed to develop dependable restoration techniques. Sound, scientific data are needed to provide reliable information for application to management."

Education and Outreach Issues

"Education, not regulation, has the greatest potential for conservation and restoration of seagrass ecosystems in Texas estuaries. A diverse group of stakeholders in Texas' coastal ecosystems developed a vision and plan for education and outreach in support of seagrass conservation. We envision a Texas where awareness, knowledge, concern, and skills will result in responsible behavior that conserves the seagrasses of our state. Conservation education programs can take citizens from ignorance of seagrass ecosystems through awareness, understanding, and concern to practicing responsible behavior in regard to this ecosystem."

"Education and outreach objectives should assist in developing a sense of community stewardship and individual responsibility for seagrass conservation.

Relevant information should be presented clearly, accurately, and with common-sense ideas for the public. State and federal agencies should strengthen their commitment to outreach programs."

Plan Implementation

"The final section deals with implementation of immediate, high priority strategies and identifies appropriate participants in the process. TPW, TGLO, and TNRCC have targeted and committed to a number of these high priority objectives as part of their agency programs. In addition, the roles of the State Wetlands Conservation Program, the two Texas National Estuary Programs, and public education and outreach programs are clarified and outlined as implementation mechanisms."

Florida's seagrass management effort is in a position to learn from and build on the Texas experience. Many elements of the Texas program have been incorporated in the planning framework described in Sections 2–10. Florida should move from this initial planning stage to implementation of a coordinated, statewide seagrass management program as expeditiously as possible.

2. FLORIDA'S SEAGRASSES

Seagrasses are flowering marine plants that live submerged in Florida's lagoons, bays, and other coastal waters. Because seagrasses require sunlight to flourish, the densest and most luxuriant beds are usually found in shallow, clear waters at depths of three meters or less. Seagrass health is inextricably linked to water quality: the clearer the water, the deeper seagrasses can grow. Activities that affect water quality and clarity, such as dredging and filling or excessive nutrient loading from urban, industrial, and agricultural land uses, may severely restrict the growth of seagrasses or caus e them to disappear altogether.

Seven species of seagrass are found in Florida waters (Fig. 2). Florida's largest seagrass species, *Thalassia testudinum* (turtle grass), has long strap-shaped leaves and robust rhizomes. In the marine environment, extensive meadows are usually dominated by this species, in combination with *Syringodium filiforme. Syringodium* (manatee grass) can be distinguished by its cylindrical leaves, which, because they are brittle and buoyant, are frequently broken off from the parent plant, and widely dispersed by winds and currents. *Halodule wrightii* (shoal grass) has flat, narrow leaves and a shallow root system. It is thought to be an early successional species in the development of seagrass beds in the gulf and Caribbean and is a dominant species in many estuarine environments. *Halodule* is able to survive more frequent and prolonged exposure during periods of low tide; it is often the predominant species at the shallow-water fringe of large meadows. In some areas, *Halodule* also dominates the deep-water edge of many meadows.

Three additional species (*Halophila engelmannii, Halophila decipiens*, and *Halophila johnsonii)* are also found in Florida's coastal waters. *Halophila engelmannii* is often present in meadows dominated by *Thalassia* and *Syringodium*, but it also occurs in deeper areas where these species are absent. *Halophila decipiens* is found in both inshore and offshore areas. Reported from depths of up to 90 m near the Dry Tortugas, it forms single-species stands (to depths of 20 m or more) beyond the deep edge of the extensive *Thalassia/Syringodium* meadows in the Big Bend region. *Halophila johnsonii* is a relatively newly described species that is morphologically similar to *H. decipiens*. Because of its highly restricted geographic range (northern Biscayne Bay to Sebastian Inlet, on Florida's east coast) and potential vulnerability to extinction due to chance disturbance events, the U.S. Fish and Wildlife Service recently listed *Halophila johnsonii* as a threatened species.

A seventh species, *Ruppia maritima* (widgeon grass), tolerates a wide range of salinities. It is often encountered on Florida's west coast, particularly in estuaries such as Homosassa Bay. The species can form dense beds, such as those found in upper Tampa Bay. In recognition of its broad salinity tolerance, some researchers have suggested that *Ruppia maritima* might be thought of as a freshwater plant that is also capable of living in saline environments.

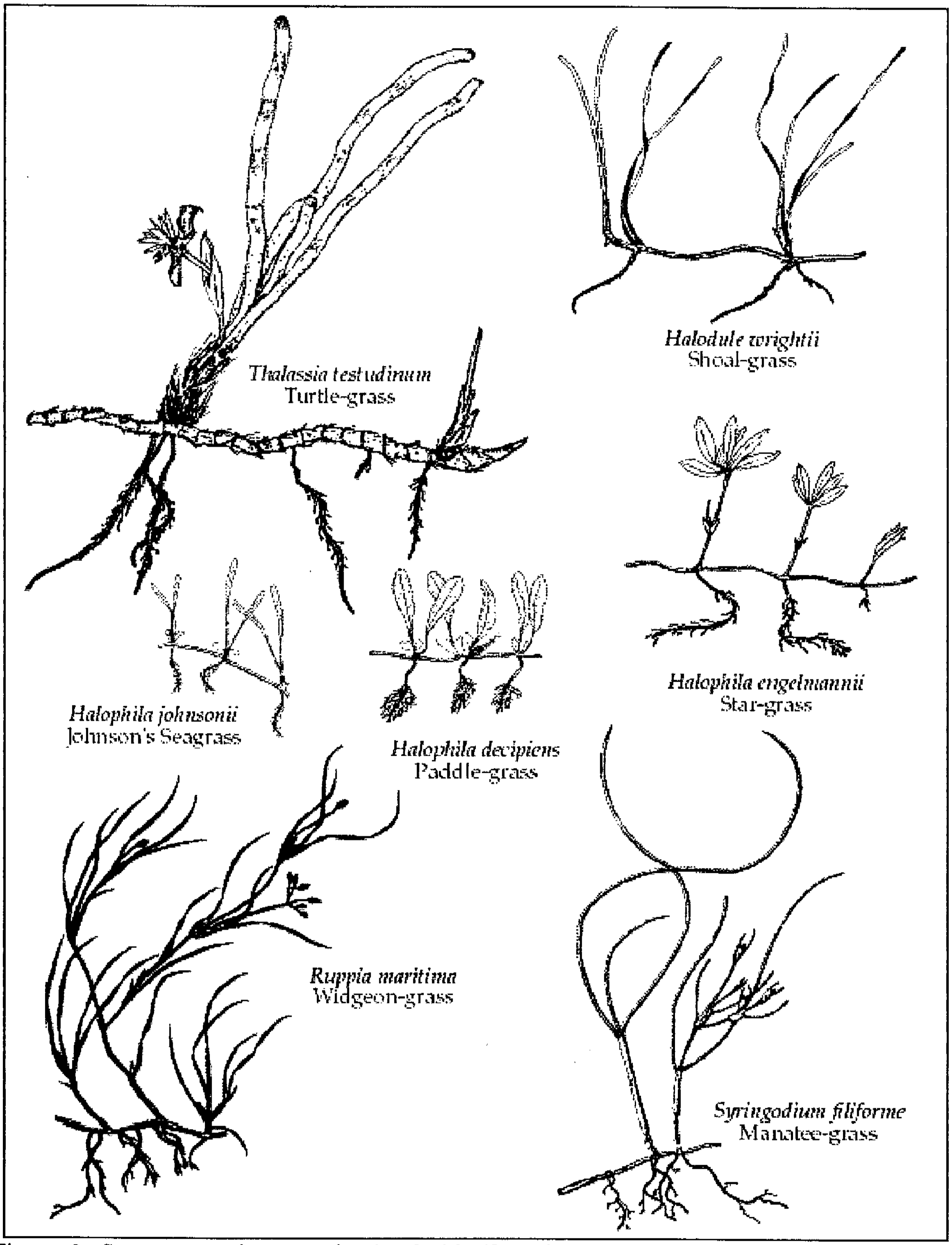

Figure 2. Seagrass species occurring in Florida (from Sargent et al. 1995, based on drawings by Mark D. Moffler).

3. ENVIRONMENTAL AND ECONOMIC VALUE OF SEAGRASS HABITATS

The approximately 2.7 million acres of seagrass beds that occur in Florida's coastal waters represent key components of the state's marine environment and economy. They help to maintain water clarity by trapping fine sediments and particles with their leaves and stabilizing bottom sediments with their root systems and rhizomes. They provide food and shelter for numerous marine organisms, including the endangered West Indian manatee. More than 70% of Florida's recreational and commercial fish, shellfish and crustacean species spend part of their lives in seagrass beds. As a result, the environmental and economic values provided by Florida's seagrasses are substantial. The Smithsonian Marine Station at Fort Pierce has provided the following summary:

> "A single acre of seagrass can produce over 10 tons of leaves per year. This vast biomass provides food, habitat, and nursery areas for a myriad of adult and juvenile vertebrates and invertebrates. Further, a single acre of seagrass may support as many as 40,00 fish, and 50 million small invertebrates."
>
> "Because seagrasses support such high biodiversity, and because of their sensitivity to changes in water quality, they have become recognized as important indicator species that reflect the overall health of coastal ecosystems."
>
> "Seagrasses perform a variety of functions within ecosystems, and have both economic and ecological value. The high level of productivity, structural complexity, and biodiversity in seagrass beds has led some researchers to describe seagrass communities as the marine equivalent of tropical rainforests. While nutrient cycling and primary production in seagrasses tends to be seasonal, annual production in seagrass communities rivals or exceeds that of terrestrially cultivated areas."
>
> "As habitat, seagrasses offer food, shelter, and essential nursery areas to commercial and recreational fishery species, and to the countless invertebrates that are produced within, or migrate to seagrasses. The complexity of seagrass habitat is increased when several species of seagrasses grow together, their leaves concealing juvenile fish, smaller finfish, and benthic invertebrates such as crustaceans, bivalves, echinoderms, and other groups. Juvenile stages of many fish species spend their early days in the relative safety and protection of seagrasses. Additionally, seagrasses provide both habitat and protection to the infaunal organisms living within the substratum as seagrass rhizomes intermingle to form dense networks of underground runners that deter predators from digging infaunal prey from the substratum. Seagrass meadows also help dampen the effects of strong currents, providing protection to fish and invertebrates, while also preventing the scouring of bottom areas. Finally, seagrasses provide attachment sites to small macroalgae and epiphytic organisms such as sponges, bryozoans, forams, and other taxa that use seagrasses as habitat."

> "Economically, Florida's 2.7 million acres of seagrass supports both commercial and recreational fisheries that provide a wealth of benefits to the state's economy. Florida's Department of Environmental Protection (FDEP) reported that in 2000, Florida's seagrass communities supported commercial harvests of fish and shellfish valued at over 124 billion dollars. Adding the economic value of the nutrient cycling function of seagrasses, and the value of recreational fisheries to this number, FDEP has estimated that each acre of seagrass in Florida has an economic value of approximately $20,500 per year, which translates into a statewide economic benefit of 55.4 billion dollars annually. In Fort Pierce, Florida alone, the 40 acres of seagrass in the vicinity of Fort Pierce Inlet are valued at over $800,000 annually. When projected across St. Lucie County's estimated 80,000 acres of seagrass, this figure increases to 1.6 billion dollars per year."

Comparable estimates of the economic value of seagrass habitats have been developed in other parts of the state. In 2001, the estimated total value of six seagrass-dependent species (including pink shrimp and stone crabs) in Florida was $117 million. The estimated value of the Florida shrimp industry in 2001 was $27 million. In Monroe County alone, more than $200 million is spent yearly on eco-tourism activities such as wildlife viewing and diving. Seagrass meadows in the Indian River Lagoon serve as the backbone of a recreational and commercial fishing industry that has an estimated economic impact of about $1 billion per year.

4. SEAGRASS STATUS AND TRENDS

Background

Currently in Florida, the only organizations that regularly map seagrasses are the three largest water management districts (the Southwest Florida, St. Johns River, and South Florida districts). These mapping programs are performed at a regional level. The maps are typically updated every two to three years.

In more localized areas, a variety of state and federal agencies conducted mapping sporadically or on a one-time basis. These agencies included the Florida Department of Environmental Protection, Florida Fish and Wildlife Conservation Commission-Marine Research Institute, National Oceanic and Atmospheric Administration, U.S. Army Corps of Engineers, U.S. Geological Survey, and the U.S. Minerals Management Service.

A review of available information on seagrass status and trends suggests that long-term coverage losses have occurred in each of the five regions addressed by this plan. In several regions, the most pronounced coverage losses have occurred in highly urbanized estuaries. A regional breakdown of seagrass coverage and trends is as follows.

Region 1: Panhandle

The Panhandle region includes the coastal waters of Franklin, Gulf, Bay, Walton, Okaloosa, Santa Rosa, and Escambia counties. Based on 1992 aerial photography provided by the USGS, this region contains about 42,000 acres of seagrasses, or 2% of the statewide total.

From the 1940s to the early 1970s, a substantial decline in overall submerged aquatic vegetation (SAV) was reported in the Escambia-Pensacola Bay system, including Santa Rosa Sound, Pensacola Bay, Escambia Bay, and Big Lagoon. In recent years, however, improved water quality in three of these four water bodies has led to seagrass expansion. In Santa Rosa Sound and Pensacola Bay, SAV showed significant increased growth; horizontal growth rates of some beds averaging more than 18 inches over one year. In Escambia Bay, most of the earlier SAV losses have been recovered. The most recent study showed continued declines in Big Lagoon.

Region 2: Big Bend

The Big Bend region includes the coastal waters of Pasco, Hernando, Citrus, Levy, Dixie, Taylor, Jefferson, and Wakulla counties. The region, bounded on the landward side by freshwater inflows from 14 river systems and extensive groundwater influx and on the seaward side by the Gulf of Mexico, is a unique "low-energy" coastline that could be considered one vast estuarine area. The most recent estimate of seagrass coverage in this region (based on 1992 USGS aerial photography) was 797,000 acres, which represents 27% of the total seagrass coverage in the state. This is the second largest contiguous area ofseagrass habitat in the eastern Gulf of Mexico, making it an important resource not only to Florida but nationally and internationally as well. With the exception of some intensive studies carried out by Florida State University staff, little research or monitoring has been conducted in the region. Recently, cooperative mapping and monitoring efforts have been initiated by the Southwest Florida Water Management District, the Suwannee River Water Management District, the University of Florida, the Florida Marine Research Institute, and the Gulf of Mexico Program.

Currently, the remoteness of the seagrasses in the Big Bend, combined with the low density of the region's human population, have apparently served to keep seagrass coverage stable. The estuary of the Fenholloway River is the only area where an historical loss of seagrass coverage has been documented; the loss is due to water quality impacts from an upstream pulp mill discharge. Recent improvements in the quality of the mill effluent appear to be permitting some seagrass recovery in that area. Anecdotal references in the scientific literature suggest that historical seagrass coverage may have been higher than the currently observed levels in Suwannee Sound and Waccasassa Bay, but this possibility has not yet been thoroughly investigated.

Based on our understanding of seagrass loss and recovery in other Florida estuaries, maintaining adequate water quality and water clarity will be the major emphasis for conserving seagrass resources in the Big Bend region. The following management activities need to be implemented in the region:

- Continue the mapping and monitoring work recently begun by the Southwest Florida and Suwannee River water management districts. In particular, the Suwannee River Water Management District's work in the northern Big Bend is currently supported by a short-term grant from the Gulf of Mexico Program; this effort needs a dedicated long-term funding source. Long-term programs tracking water clarity and seagrass coverage and condition will be key components of a regional management strategy.

- Conduct the research needed to identify the water quality conditions—including nutrient loadings, turbidity levels, and water clarity—that must be maintained to permit adequate light to penetrate to the deepest seagrass meadows. These will be important management targets, which will be needed to assess the effectiveness of other land use and water quality management efforts.

Region 3: Gulf Peninsula

The Gulf Peninsula region includes the coastal waters of Pinellas, Hillsborough, Manatee, Sarasota, Charlotte, and Lee counties. Based on 1999 aerial photography provided by the South Florida and Southwest Florida water management districts, this region contains approximately 107,000 acres of seagrass, or about 5% of the statewide total.

Due to reductions in pollutant loads and improvements in water quality, some estuarine areas of this region have demonstrated modest to dramatic seagrass coverage gains over the past 25 years.. In Tampa Bay, for example, 40% of seagrasses were lost between about 1950 and 1982. However, from 1982 to 1996, more than 5,000 acres were recovered thanks to improved treatment of wastewater and stormwater, as well as restrictions on dredging and filling. Tampa Bay seagrasses suffered a recent setback during the El Niño event of 1998–1999, when 2,000 acres were lost.This was the first decline in bay-wide coverage since 1982. Recent aerial mapping shows an expansion of about 1,200 acres by 2002, indicating that the system appears to be rebounding from that setback.

Currently, there are about 26,000 acres of seagrass throughout Tampa Bay. Local partners have developed a consensus-based goal of restoring more than 12,000 additional acres, which would bring total coverage back to the levels that occurred in the early 1950s.

In Sarasota Bay, seagrass losses during the 1940s to the 1980s are estimated at approximately 30%. In 1988, the total seagrass coverage was estimated at 8,651 acres. However, changes in seagrass coverage in Sarasota Bay have been dramatic since then. Between 1989 and 1990, nutrient loadings from wastewater treatment plants were reduced by as much as 25%, substantially improving water clarity. Between 1988 and 1996, seagrass coverage in the Manatee County portion of the bay increased by roughly 800 acres; in the Sarasota County portion, seagrass coverage increased by an estimated 670 acres. Most of these increases occurred along the deep edges of existing seagrass beds, suggesting that improved water clarity and light availability were important factors contributing to increased seagrass coverage.

Currently, there are about 9,110 acres of seagrass in Sarasota Bay. The Sarasota Bay National Estuary Program has adopted a restoration approach that seeks to control nitrogen loadings through the use of "best available technologies" to reduce discharges from point and nonpoint sources.

The greater Charlotte Harbor area—which includes Charlotte Harbor proper, along with Lemon Bay, Gasparilla Sound, Pine Island Sound, Matlacha Pass, Estero Bay, and the Caloosahatchee River estuary—is generally less urbanized than either Tampa Bay or Sarasota Bay. As a result of large-scale dredge and fill projects, a portion of the area, primarily in southern Pine Island Sound, lost an estimated 30% of its seagrasses prior to the 1980s. Elsewhere in the area, long-term seagrass coverage appears to be relatively stable.

In 1992, the Southwest Florida Water Management District initiated a biennial mapping project to assess seagrass coverage trends in the portion of the area that falls within its jurisdiction. Currently this area, which includes Charlotte Harbor proper, Lemon Bay, and Gasparilla Sound, contains about 18,000 acres of seagrass.

Region 4: Atlantic Peninsula

The Atlantic Peninsula region includes the coastal waters of Volusia, Brevard, Indian River, St. Lucie, Martin, and Palm Beach counties. This region contains about 3%, or 74,456 acres, of the state's total seagrasses.

Seagrasses in this region occur primarily within the Indian River Lagoon system, an estuary that spans about 160 miles of coastline and includes portions of six counties. All seven of Florida's seagrass species are found in the area. This region displays the highest seagrass diversity of any estuary in the Western Hemisphere. One rare species found only in the southern reaches of the lagoon, Johnson's seagrass (*Halophila johnsonii*), was designated as federally threatened species in 1998. Conservation of this scarce and ephemeral species presents unique management challenges.

Based on 1943 coverage estimates, potential seagrass coverage in the lagoon is estimated at 91,570 acres. The Indian River Lagoon National Estuary Program has developed specific recovery or preservation targets for each segment of the lagoon based on the depths at which seagrasses can be expected grow under adequate water quality conditions.

The Indian River Lagoon Surface Water Improvement and Management (SWIM) Plan, updated in 2002 and available on the South Florida Water Management District Web site (www.sfwmd.gov), provides the following overview of seagrass distribution and trends:

> "Lagoon areas containing the largest seagrass coverages are around N. Merritt Island in the federally protected bottomlands of NASA/Kennedy Space Center (North IRL and northern Banana River) and the Canaveral National Seashore (southern Mosquito Lagoon). These areas experienced little change between 1943 and 1999."
>
> "The largest area with the least seagrass coverage, and with the greatest loss since 1943 (70% loss), extends from Cocoa to just south of Turkey Creek"
>
> "Within the SJRWMD portion of the IRL (Mosquito Lagoon, Banana River, North and Central IRL), the current (1999) 61,884 acres of seagrass is 63% of the potential 98,274 acres of coverage (based on 1.7 m depth). The 1943 seagrass coverage was 63,238 acres; 64% of the potential acreage."
>
> "Within the SFWMD portion (South IRL), the current (1999) seagrass cover is 7,808 acres or 39% of the potential 19,799 acres. The early 1940s seagrass coverage was nearly the same – 7,668 acres or 39% of the potential acreage."
>
> "For the entire IRL, the potential coverage area for seagrass is 118,000 acres; but only 59% of that is currently covered in seagrass (69,692 acres in 1999). In general, "healthy" seagrass areas are adjacent to relatively undeveloped watersheds or in proximity to inlets, whereas areas of extensive losses are adjacent to highly developed watersheds and shorelines."

Region 5: South Florida

The South Florida region includes the coastal waters of Collier, Monroe, and Dade counties. This area contains approximately 63%, or more than 1.4 million acres, of the total seagrasses in Florida. The extensive Florida Bay seagrass meadow is among the largest contiguous seagrass beds on earth. On the Atlantic side of the Florida Keys, seagrasses are closely associated with coral patch reefs.

Though sparse, long-term coverage data for this region indicate a significant decline in seagrasses in urbanized portions such as the Miami-Dade area, where an estimated 43% percent of seagrasses in the north section of Biscayne Bay have been lost since the 1940s. Seagrasses in Dade and Monroe counties also exhibit some of the highest rates of propeller scarring in Florida. Seagrass managers have recommended the implementation of a four-point approach (education, channel marking, enforcement, and limited-motoring zones) to reduce propeller scarring in these counties and other portions of the state where significant scarring occurs. In addition, the Florida Keys National Marine Sanctuary is currently implementing its detailed 10-point program addressing channel and reef marking, education and outreach, enforcement, mooring buoys, regulation, research and monitoring, submerged cultural resources, volunteers, water quality, and zoning issues for the management of seagrasses and other resources in the area under its jurisdiction.

Beginning in 1987, Florida Bay experienced a dramatic bay-wide seagrass decline, substantially reducing coverage and biomass. The unexpected and incompletely understood die-off has been attributed to a combination of factors, including widespread and persistent microalgae blooms, sediment sulfide toxicity, hypersalinity due to multi-year drought, and infection of grasses by the slime mold *Labyrinthula*. Between 1984 and 1994, the estimated biomass of three seagrasses declined sharply: turtle grass by 28%; manatee grass by 88%, and shoal grass in Florida Bay declined by 92%. Although the rate of decline has slowed considerably in recent years, seagrass coverage losses have continued in parts of the bay, possibly jeopardizing their long-term viability. Chronic light reductions and increased water turbidity are thought to be important factors in the ongoing decline.

5. ORGANIZATIONS INVOLVED IN SEAGRASS MANAGEMENT

A variety of agencies in all branches of government and many non-governmental organizations are involved in seagrass management in Florida. A brief overview of these potential partners and their roles is provided in the tables that follow. More extended summaries of legal authorizations and agency roles and responsibilities are provided in Appendix A.

As the experience in Texas has shown, successful development of a coordinated statewide management program will require the active participation of the full range of agencies and stakeholder groups that have an interest in seagrass resources.

FEDERAL AGENCIES

Agency	Authority	Primary Responsibility
All Federal Agencies	National Environmental Policy Act (NEPA)	Provides for consultation among applicable agencies, through preparation and review of environmental assessments (EA) and environmental impact statements (EIS) regarding proposed federal actions
U.S Army Corps of Engineers	Section 404 of the Federal Water Pollution Control Act (Clean Water Act)	Regulates dredging and discharges of fill material
U.S. Environmental Protection Agency	National Pollution Discharge Elimination System (NPDES) of the Clean Water Act	Regulates domestic and industrial wastewater discharges and certain municipal stormwater discharges
	Non Point Source Program (NPS) of the Clean Water Act	Oversees development of state management programs to address non-point source runoff; provides Section 319 grant funds
	Section 320 of the Clean Water Act	Administers National Estuary Programs and Gulf of Mexico Program
	Florida Keys National Marine Sanctuary (FKNMS) and Protection Act, under the National Marine Sanctuaries Act	Develops and implements water quality and resource protection programs for the FKNMS

FEDERAL AGENCIES (Cont.)		
Organization	**Authority**	**Primary Responsibility**
National Oceanic and Atmospheric Administration	Coastal Zone Management Act	Approves and oversees state Coastal Management Programs
	Section 315 of the CZMA	Administers National Estuarine Research Reserves (NERR)
	Magnuson-Stevens Fisheries Conservation and Management Act	Establishes national standards for fishery conservation and develops fishery management plans
	Sustainable Fisheries Act; Amendment to MSFCMA	Designates essential fish habitat (EFH) areas and develops appropriate conservation measures for those areas
	Endangered Species Act	NOAA's National Marine Fisheries Service implements the ESA for sea turtles and Johnson's seagrass, including management of critical habitats
	Florida Keys National Marine Sanctuary (FKNMS) and Protection Act of the National Marine Sanctuaries Act	Develops and implements comprehensive management plans and accompanying regulations for management of FKNMS
	No-Net-Loss Policy	NOAA's National Marine Fisheries Service oversees this policy for wetlands protection and mitigation in marine waters
	Submerged Aquatic Vegetation Policy of NOAA's Atlantic State Fisheries Commission	Provides for the conservation, preservation and restoration of SAV along the Atlantic Coast of the U.S.
U.S. Coast Guard		Develops regional oil spill response plans; enforces federal fisheries and marine mammal protection laws
US Department of the Interior Mineral Management Service		Conducts surveys of nearshore coastal waters
US Department of the Interior National Park Service		Manages National Park lands, including those with submerged lands and seagrasses

FEDERAL AGENCIES (Cont.)		
Organization	**Authority**	**Primary Responsibility**
U.S. Fish and Wildlife Service	Endangered Species Act (ESA)	Requires federal agencies to consult on activities that affect listed species
	Fish and Wildlife Coordination Act	Requires federal agencies to consult with USFWS on development activities in order to conserve resources, including seagrasses and other submerged aquatic vegetation
	USFWS Mitigation Policy	Establishes policies to mitigate for resource losses, including seagrasses and other submerged aquatic vegetation
	Refuge Administration Act	Establishes and manages National Wildlife Refuges
	Coastal Grants Program	Provides funding for restoration of coastal habitats, including seagrasses and other submerged aquatic vegetation

NON-FEDERAL ORGANIZATIONS
(STATE AND REGIONAL AGENCIES, LOCAL GOVERNMENTS, NGOs)

Organization	Authority	Primary Responsibility
Board of Trustees of the Internal Trust Fund for the State of Florida	Chapter 253 FS; Chapter 18 FAC (state lands)	Holds title to the natural resources located within three miles of the Atlantic coast and nine miles of the gulf coast
	Chapter 18-21, FAC sovereign submerged lands management	Manages and protects sovereign lands, especially those important to public drinking water supply, shellfish harvesting, public recreation, and fish and wildlife propagation and management
	Chapter 18-18, FAC (Florida Bay Aquatic Preserve) and Chapter 18-20, FAC (other aquatic preserves)	Develops and implements comprehensive management programs to preserve, protect, and enhance designated aquatic preserves
Florida Department of Environmental Protection	Chapter 62-302, FAC Surface Water Quality Standards	Conserves waters of the state to protect, maintain, and improve water quality for public water supplies, propagation of fish and wildlife, and other uses; includes nutrient enrichment management specifically to protect seagrasses
	Chapter 62 FAC	Serves as permitting authority for waterfront developments, marinas, wastewater treatment plants, and industrial wastewater discharges Manages state parks and aquatic preserves Coordinates emergency response programs for oil spills Administers non-regulatory stewardship programs such as Clean Marina Program Guides implementation of the state's Coastal Management Program

NON-FEDERAL ORGANIZATIONS (Cont.)		
Organization	**Authority**	**Primary Responsibility**
Florida Department of Agriculture and Consumer Services	Chapter 5 FAC	Ensures safety of shellfish harvesting areas Protects the state's agricultural and natural resources by promoting environmentally safe agricultural practices, including aquaculture
Florida Fish and Wildlife Conservation Commission	Chapter 68 FAC	Creates and enforces fish and boating laws Oversees the Florida Marine Research Institute, which conducts research in seagrass biology, status and trends, and impacts Provides regulatory review of water-based development Establishes state manatee protection sanctuaries and speed zones
Florida Department of Community Affairs	Chapter 9 FAC	Coordinates reviews of developments of regional impact (DRI) Oversees implementation of local comprehensive land use plans as specified by Florida statutes Oversees implementation of land use plans for state Areas of Critical Concern
Water Management Districts	Chapter 40 FAC	Regulate projects related to water quality and quantity Implement the state's Surface Water Improvement and Management (SWIM) program

NON-FEDERAL ORGANIZATIONS (Cont.)		
Organization	**Authority**	**Primary Responsibility**
Port Authorities	Laws of Florida (separate chapter for each authority)	Regulate docks and other structures within their sovereign land ownership Develop emergency response plans for oil or chemical spills
National Estuary Programs	Clean Water Act Section 320	Develop and coordinate implementation of watershed management plans Coordinate data collection and distribution Develop and distribute outreach materials
Regional Planning Councils	Chapter 29 FAC	Coordinate local review of DRIs Assist communities in long-range planning, including natural resource protection
Local Governments	Local ordinances, delegated permitting authority	Wide range of responsibilities, including: • Delegated permitting of wetland and shoreline impacts, point and non-point source discharges • Managing parks and aquatic preserves • Regulating (by ordinance) boating speeds and manatee and seagrass protection zones
Non-Governmental Organizations		Many activities, including: • Lobbying for coastal resource use and protection • Environmental education, public outreach and involvement

6. SETTING SEAGRASS MANAGEMENT GOALS

Importance of Quantitative Goals

In recent decades, natural resource managers have made increasing use of quantitative planning methods that are based on the adoption of numeric, science-based goals and regular assessment of progress toward those goals. The approach of adopting and measuring progress toward quantitative goals offers a number of benefits:

- Increased accountability
- Clearer identification of monitoring priorities
- Improved efficiency in the allocation of funding and manpower
- More rapid identification of management actions that are most cost-effective and environmentally beneficial

Setting quantitative, science-based seagrass management goals and regularly measuring and reporting progress in achieving them is also critically important for securing support from the citizens of Florida and their elected officials.

Existing (Local) Goals

Indian River Lagoon and Tampa Bay currently have quantitative, consensus-based seagrass coverage goals.

In the Indian River Lagoon, the Indian River Lagoon National Estuary Program has developed coverage goals for various lagoon segments based on the 1943 total estimated seagrass coverage of 91,570 acres. The goals assume sufficient water quality and light attenuation to allow seagrasses to grow to approximately 5.6 feet in depth. Achieving coverage targets will be accomplished by the adoption of specific pollutant load reduction goals (PLRGs) for each segment. The goals, based on the difference between the 1943 estimates and present-day coverage, will be updated every 2–3 years through aerial mapping and digitization conducted by the St. Johns River Water Management District.

For Tampa Bay, the Tampa Bay Estuary Program (TBEP) has adopted a long-term goal of recovering 12,350 acres of seagrasses bay-wide, which would increase seagrass coverage to about 38,000 acres. This is the estimated coverage present in the bay in the early 1950s, excluding areas permanently altered by dredging and filling activities. Water clarity in the bay has improved dramatically since 1985, and water quality models developed by TBEP indicate that clarity is now sufficient to allow achievement of the seagrass recovery goal, over time, through natural regrowth. To maintain existing water clarity and sustain the seagrass recovery process, TBEP has adopted a nutrient management goal of capping the nitrogen loads entering the bay at the average levels observed during 1992–1994.

Between 1996 and 2010, nitrogen loadings to Tampa Bay are projected to increase by 7 percent because of population growth and related development. This equates to an estimated increase in annual nitrogen loads of slightly less than 17 tons per year; to maintain the bay's current nitrogen levels, local governments and industries need to reduce or prevent cumulative increased loadings to the bay by this amount.

The Tampa Bay Nitrogen Management Consortium, a public-private partnership, has agreed to collectively reach this goal by conducting a variety of nitrogen load reduction projects, including land acquisition, habitat restoration, construction of upgraded stormwater treatment systems, and reductions in domestic and industrial point source discharges and air emissions. Consortium partners report their pollution-control projects to TBEP, which has developed a database to track progress by calculating reductions in nitrogen loads for various types of projects.

Monthly bay-wide water quality monitoring provides an overall measure of the success of these efforts. The monitoring, conducted by local governments, is combined with aerial photography and digitized mapping of Tampa Bay's seagrass beds. The Southwest Florida Water Management District conducts monitoring every 2–3 years.

Recommendations for the Development of Statewide Goals

The state of Florida, through its existing resource management agencies, should take the lead in developing quantitative, consensus-based seagrass coverage goals for each of the five regions shown in Fig. 1. These goals should be specific, measurable, realistic, and environmentally and technically sound. Ideally, they should be achievable within a specified time (e.g., 25 years). Goals should be developed based on input from a wide range of stakeholders, including resource managers; scientists; resource user-groups; environmental organizations; trade associations; agricultural, development and industrial interests, and the public and elected officials. The sum of these regional goals will represent the statewide seagrass management goal.

To develop these goals, a statewide seagrass management technical advisory committee (TAC) should be assembled. The group could be modeled after the committee DEP recently used in the development of the state's "Impaired Waters Rule" (Chap. 62-302 FAC). TAC members, who should be familiar with regional and statewide seagrass management issues and methods, should be appointed by the heads of the Department of Environmental Protection, the Fish and Wildlife Conservation Commission, the Department of Community Affairs, the Department of Agriculture and Consumer Services, and the five water management districts. Each agency should also designate one or more senior administrative staff members to review draft recommendations developed by the TAC. The Florida Coastal Management Program should fund, organize, coordinate, and provide logistical support to the TAC.

The TAC should hold one or more public meetings in each of the state's five seagrass regions. The meetings should be well-advertised, and provide an opportunity for input from stakeholders who are not committee members. Technical staff from organizations involved in seagrass management at the regional level should be invited to participate in the regional meetings. These organizations could include the estuary programs, estuarine research reserves, other preserves, parks and wildlife refuges, local governments, colleges and universities, and relevant NGOs. Federal agencies with regulatory responsibilities that affect seagrasses within the regions should also be invited to participate in the goal-setting process.

7. DEVELOPING AND IMPLEMENTING A STATEWIDE STRATEGY

Background

If the statewide seagrass management effort is to be successful, it must be practical, adaptable, and forward-looking. It should allow for flexibility, and revision of goals as conditions change and new information becomes available. It should provide clear, concise regional and statewide strategies that can be implemented across jurisdictional boundaries. It should serve as a blueprint guiding efforts at all levels of government and should also include the private sector, civic organizations, and other NGOs. It should recognize, support, and incorporate successful existing management programs, building on the accomplishments of local programs rather than duplicating their efforts. Moreover, it should promote new policies to fill identified gaps and ensure that adequate management attention is paid to seagrasses in all regions of the state. A cooperative, coordinated statewide approach of this type will provide managers in each region with consistent direction and a means of linking their efforts to the larger goal of protecting and enhancing all seagrass resources.

Once appropriate seagrass coverage goals are identified at the regional level, a logical sequence of steps can be used to develop and implement management strategies for individual regions and water bodies. A recommended approach, based on a logical framework developed by the National Research Council for estuarine water quality management, is shown in flowchart form in Figure 3.

Identifying Potential Conservation and Restoration Areas

The threats to and health of seagrass communities vary substantially within and between the five regions shown in Fig. 1. While some areas need restoration efforts to re-establish seagrasses to ideal levels, other areas primarily need conservation to maintain current seagrass abundance and health levels. Techniques for managing these areas will necessarily differ. Management efforts in restoration areas will focus primarily on *reducing* and eventually *reversing* water quality degradation, propeller scarring, or other causes of seagrass losses, and *restoring* seagrass habitats. Management efforts in conservation areas will focus primarily on *preserving* robust seagrass resources by *preventing* potential problems that could lead to future declines in coverage or habitat quality.

Panhandle: Seagrasses in the Panhandle region occur primarily in shallow nearshore areas. The limited amount of seagrass present in the region is potentially at risk from inappropriately conducted shoreline development, dock construction, and boat operation. In general, seagrasses in Panhandle estuaries apparently remain at or near historic levels; although, some areas, such as Pensacola Bay, Choctawhatchee Bay, West Bay, and St. Andrew Bay, have experienced losses. The recommended regional strategy is a combination of conservation and, in areas where losses have occurred, restoration projects.

Big Bend: Throughout the Big Bend region, large expanses of seagrasses occur. Some of the world's largest low-density, deepwater seagrass meadows exist offshore from the state's nine-mile natural resource boundary. In the near future, the main emphasis of this region's seagrass management will presumably focus on conservation rather than restoration. Human population growth and associated development pressures are just beginning to occur. To prevent water quality degradation, a full range of management practices, including stormwater management, centralized wastewater systems, land use BMPs, and public education and outreach will be needed.

Gulf Peninsula: The northern portion of this region, including St. Joseph Sound, Clearwater Harbor, Boca Ciega Bay, Tampa Bay, and Sarasota Bay, has a long history of urbanization and corresponding reductions in seagrass coverage. Recent assessments by Pinellas County indicate that substantial seagrass coverage, which approaches 60% of the coverage currently present in Tampa Bay, remains in the Clearwater Harbor and St. Joseph Sound area. The county will seek implementation of a combined restoration and conservation effort in those areas in the near future. The Tampa Bay Estuary Program and the Sarasota Bay National Estuary Program have both identified restoration as the primary management strategy for their water bodies. The Charlotte Harbor National Estuary Program has identified the southern portion of the region, which includes Lemon Bay, Gasparilla Sound, Charlotte Harbor, Pine Island Sound, Matlacha Pass, Estero Bay, and the Caloosahatchee River estuary, as a seagrass conservation area.

South Florida: Although it contains most of the state's nearshore seagrass coverage, much of this region appears to be a restoration area. Boat groundings and propeller scarring damage seagrasses in the shallow waters of the Florida Keys, Florida Bay, and Biscayne Bay. The cumulative effects of these individually localized physical perturbations are so severe that the Florida Keys National Marine Sanctuary (FKNMS) developed a judicially-based damage assessment and restoration process to facilitate the recovery of damaged sites. In addition to these clearly anthropogenic seagrass losses, by 1994, the incompletely-understood "die-off" that began in Florida Bay in 1987 caused dramatic reductions in the biomass of three seagrasses: *Thalassia* by an estimated 28%; *Syringodium* by 88%, and *Halodule* by 92%. Although the loss rate from "die-off" has slowed considerably in recent years, researchers have described the long-term future of seagrasses in Florida Bay as "uncertain."

Atlantic Peninsula: Assessments conducted by the Indian River Lagoon National Estuary Program, in cooperation with the St. Johns River Water Management District and the South Florida Water Management District, indicate that the northernmost portion of the Indian River Lagoon and adjacent areas of the Mosquito Lagoon and Banana River have experienced relatively small amounts of seagrass loss. An emphasis on conservation appears to be the most appropriate management approach for these waters. More urbanized areas have reportedly experienced significant amounts of seagrass loss due to physical removal through dredging and filling and reduced water quality. An emphasis on restoration appears needed in these areas.

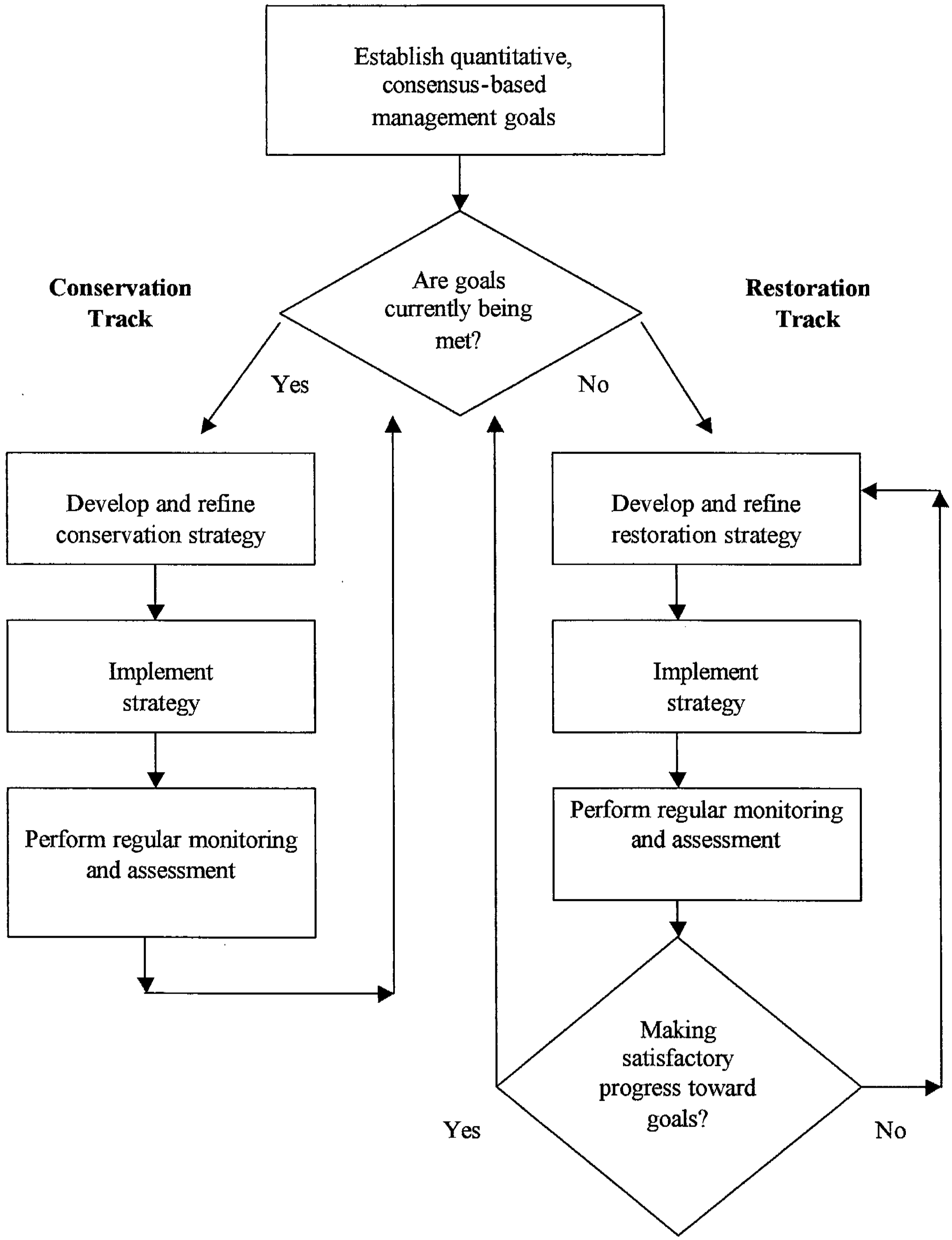

Figure 3. Recommended seagrass management process in conservation and restoration areas

Developing Management Strategies

The TAC assembled to develop the regional and statewide seagrass coverage goals should also develop clear strategies for achieving those goals.

As in the goal-development process, the TAC should hold one or more public meetings in each of the state's five seagrass regions. The meetings should be well advertised, and provide an opportunity for input from stakeholders who are not committee members. Invited participants should include technical staff members from the estuary programs, parks and preserves, local governments, colleges and universities, non-governmental organizations, and other stakeholders with an interest in seagrass management at the regional level.. Federal agencies with regulatory or resource management responsibilities within each region should also be brought into the process.

For each region, the TAC should develop specific conservation and restoration strategies based on the approach shown in Fig. 3. These strategies may involve both regulatory and non-regulatory elements and should include agency responsibilities and timelines for achieving the regional and statewide seagrass coverage goals described in Section 2. A summary of these regional strategies should be published, in draft form, to provide an additional opportunity for review and comment from stakeholders who are not members of the committee. A draft-form statewide strategy document, revised in response to stakeholder input, should be provided for the review and approval of the heads of the sponsoring agencies.

Implementing the Strategies

Following approval of the strategy document by the agency heads, an interagency memorandum of understanding (MOU) should be drafted to guide its implementation. Participation in the MOU should be open to each sponsoring agency. To the extent possible given the complications that arise in the development of multi-party agreements, — participation should also be open to other public or private organizations that wish to make a significant commitment to statewide seagrass management. The MOU should specify the steps each participating organization proposes to take to implement the agreed-upon regional strategies, the timeline on which those steps are proposed to occur, and the resources that will need to be budgeted to accomplish the work. A multi-party, interlocal agreement developed in the Tampa Bay region in 1998 to guide the implementation of a community-based Tampa Bay management plan, could serve as a template for the statewide MOU.

8. EVALUATION AND REPORTING

Importance of Tracking Progress Toward Goals

Regular evaluations of status and trends in seagrass coverage and condition are essential for proper management of the resource. Methodologically consistent long-term mapping and monitoring programs, providing information on areal coverage, species composition, health, and spatial and temporal fluctuations in the distribution of seagrass communities are particularly helpful in assessing progress toward meeting the state's management goals. This type of assessment alerts managers to new problems or issues in a timely fashion and assures Floridians of the state's commitment to protecting seagrass habitats.

The localized influences of human activities such as dock construction or vessel grounding and propeller scarring incidents need to be evaluated. It is important to estimate the ecological and economic costs associated with those influences and to assess the success of habitat restoration projects that are carried out as mitigation.

Mapping

Several local and regional mapping programs have been conducted or are currently underway in Florida. These efforts are sponsored by a variety of agencies and organizations.

Traditionally, assessments of coverage and condition used a combination of aerial photography and on-site monitoring While these continue to be the primary methods available to managers, research is currently underway on a variety of remote sensing techniques that may become available for use by seagrass management programs in the near future.

Recent and historical mapping data are available from several internet-based sources:

- NOAA Coastal Services Center, Benthic Habitat Mapping program (http://www.csc.noaa.gov/crs/bhm)

  This Web site provides benthic habitat maps of Apalachicola Bay, Estero Bay, Florida Bay, Florida Keys, Indian River Lagoon, and deep seagrass beds on Florida's west continental shelf. Data are georeferenced and validated. The files are provided to the user in ARC/INFO® Export or ArcView® Shapefile format. All files are zipped, using PKZIP®, for quicker downloading. Each zip file contains the polygon files and the Federal Geodetic Data Committee (FGDC) compliant metadata file. Projection and datum information, as well as classification system, are included in the metadata records.

- USGS National Wetlands Research Center
  (http://sdms.nwrc.gov/pub.metrec.html)

  This Web site contains downloadable GIS maps of Apalachee Bay SAV (1992), Choctawhatchee Bay SAV (1992), Florida Panhandle coastal habitats (1996), Pensacola Bay SAV (1960s, 1992), Saint Andrew Bay, and Tampa Bay habitats (1956, 1972, 1982).

- Florida Marine Research Institute (FMRI)
  (http://floridamarine.org/seagrass)

  This Web site contains GIS maps, data, technical reports, and public education and outreach products.

- Southwest Florida Water Management District (SWFWMD)
  (http://www.swfwmd.state.fl.us/data/dataonline.htm)

  This Web site provides downloadable GIS maps showing assorted 1988–1999 seagrass coverages in Clearwater Harbor, Tampa Bay, Sarasota Bay, Lemon Bay, and Charlotte Harbor .

- Florida Institute of Technology
  (http://probe.ocn.fit.edu/SAVproject/SAV.html)

  The Web site provides the description of the development of a protocol to use hyperspectral imagery to map seagrass.

- Florida International University
  (http://serc.fiu.edu/seagrass/!CDreport/DataHome.htm)

  This Web site provides seagrass mapping and monitoring data from the Florida Keys.

- University of Miami
  (http://library.miami.edu/netguides/environ_fla.html)

  This Web site offers links to sites that provide maps, data, and background information on Florida habitats and resource management issues.

- ESRI Conservation Program Resources
  (http://www.conservationgis.org/links/marine2.html)

  This Web site offers links to sites that provide maps, data, and background information on national resource management issues.

Additionally, private entities have also funded seagrass mapping efforts from time to time. These entities are primarily utilities and other companies operating industrial facilities with permitted discharges to nearshore waters. Depending on company policies and the purpose and scope of the mapping effort, the resulting images and maps may be available to researchers and resource managers on a case-by-case basis.

Monitoring

In Florida, monitoring of seagrass condition has been done in relatively localized areas, such as individual bays, estuaries, parks, or other management units, rather than on a regional or statewide scale. Local governments, water management districts, or state or federal resource management and agencies typically carry out the projects. Information on monitoring program design is available from a number of sources (see Section 10).

Most recent seagrass monitoring programs have included one or more of the following components:

- Species composition
- Short-shoot density and morphology
- Standing crop
- Epiphyte loads
- Water quality
- Water clarity
- Light attenuation/PAR
- Water depth (with emphasis on the deep edges of seagrass beds)
- Primary productivity

In addition to these frequently monitored parameters, topics of emerging interest have included the presence and absence of plant pathogens and the potential effects of sediment chemistry on the distribution and abundance of individual seagrass species.

An overview of monitoring programs is provided in the in the Florida Seagrass Manager's Toolkit developed in 2003 for the FWC-Florida Marine Research Institute. The institute also maintains a seagrass research and conservation projects database on its Web site at http://www.floridamarine.org

Reporting

Presently, only a handful of local initiatives exist to provide regular and timely reports on seagrass coverage or condition in Florida; no statewide programs provide this information. Perhaps the most extensive local program is that implemented by the Southwest Florida Water Management District to support its SWIM program and the National Estuary Programs in Tampa Bay, Sarasota Bay, and Charlotte Harbor. In addition to those estuaries, the SWFWMD program also includes the waters of Clearwater Harbor and St. Joseph Sound. Aerial photography of seagrass beds in these areas is performed every 2–3 years, and the results are ground-truthed and digitized on GIS maps. Results are disseminated through regular reports to the TACs associated with the SWIM and National Estuary programs, and through occasional SWFWMD publications. The Indian River Lagoon National Estuary Program, the South Florida Water Management District, and St. Johns River Water Management District are conducting a similar program for the Indian River Lagoon .

Recommended State Role

With support from the Department of Environmental Protection, the five regional water management districts, and other appropriate agencies, the Florida Fish and Wildlife Conservation Commission should take the lead in developing a methodologically consistent statewide program for mapping and monitoring seagrass coverage and condition.

The results of this mapping and monitoring program should be summarized and reported to the public in a timely manner (e.g., every 2–3 years) and should be made available to managers, scientists, and interested citizens through a relational database that is publicly accessible via the Internet. The state should use the 2–3 year summary reports to evaluate progress toward meeting its regional and statewide seagrass management goals. On a less frequent basis (e.g., every 4–6 years), the results should be used to assess, and if necessary refine and improve, the state's regional conservation and restoration strategies, following the NRC-recommended process shown in Fig. 3.

9. MANAGEMENT-RELATED RESEARCH

Background

Successful resource management is based on solid technical understanding of the target resource and the natural and man-made stressors that affect it. There is a general consensus that Florida's previous and current seagrass research efforts are not uniform in all regions and do not systematically address some key issues and concerns.

Managers and scientists participating in various seagrass symposia or workshops in the past decade have identified key research needs:

- Identification of critical water quality conditions for successful seagrass conservation and restoration
- Evaluation of factors, other than water quality, which may influence seagrass recruitment and survival (factors include epiphyte coverage, macroalgal density and distribution, disease, sediment quality, current velocity, and wave energy)
- Effects of propeller scarring on seagrass coverage and the habitat value provided by scarred beds
- Improved forecasting of seagrass population trends
- "Micro" (patch-size) dynamics, related to factors such as sediment deposition rates and nutrient availability
- More detailed evaluation of the economic value of seagrass habitats
- Additional assessment of seagrass transplanting methods, to determine methods' effectiveness in relation to one another and to natural recruitment
- Development of an online database documenting the outcomes of seagrass restoration and transplant projects
- Scientific assessment of factors affecting the success of seagrass restoration projects
- Assessment of the resilience of restored sites in the presence of natural disturbances
- Additional research on the biology and ecology of native seagrass species (e.g., effects of sexual vs. asexual reproduction on regional populations)

Recommended State Role

The FWC-Florida Marine Research Institute should take the lead in identifying and prioritizing the state's management-related seagrass conservation and restoration research needs. The institute should estimate the costs of carrying out the necessary research and—working in cooperation with researchers in the state university system, management agencies, and private organizations—seek funding to carry out the work. Potential funding sources include the state budget, federal grant programs, private foundations, public-private partnerships, and cooperative funding efforts carried out with local governments, water management districts, and public and private colleges and universities.

10. PUBLIC OUTREACH

Background

Since education can lead to behavioral changes that significantly reduce human impacts to seagrasses, fostering public awareness of the importance of seagrass habitats is an integral part of a successful statewide management plan Many current local initiatives target boaters and other waterway users as well as waterfront residents whose landscaping practices or septic disposal systems may pose a threat to water quality and seagrass health.

The Florida Seagrass Alliance is a consortium of environmental educators representing key government and non-government organizations concerned with seagrass management. The alliance recently initiated a statewide public awareness program that led to the Governor's proclamation designating March as Florida's annual Seagrass Awareness Month. To facilitate promotion of Seagrass Awareness Month, alliance members developed and distributed a "Seagrass Toolbox" that contains fact sheets, press releases, and radio, print, and television public service advertisements. Similar programs could be initiated on a statewide basis.

Recommended State Role

The state of Florida should take the following steps to improve public awareness of the value of seagrasses:

- Support existing outreach efforts by assisting in the distribution of accurate information about the status of Florida's seagrasses and stressors affecting them.
- Prepare and distribute a "Citizens' Report on the Status of Florida's Seagrasses" every two to three years.
- Develop a statewide teaching curriculum introducing Florida students to seagrasses, their environmental and economic value, and the state's seagrass conservation goals.

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Appendix A

Federal and Non-Federal Agency
Legal Authority, Roles, and Responsibilities

FEDERAL AGENCIES

Legal Authority

Federal authority addressing protection of submerged aquatic vegetation, including seagrasses, is found in the following legislation and executive orders:

National Environmental Policy Act (NEPA)(42 U.S.C § 321)
This act requires the preparation of an environmental impact statement (EIS) for every major federal action that will significantly affect the environment. The EIS must address the following:

- The environmental effects of the action
- Alternatives to the proposed action
- The relationship between local short-term uses of humans' environment and the maintenance and enhancement of long-term productivity
- Any irreversible and irretrievable commitments of resources that would be involved in the proposed action should it be implemented

NEPA provides a framework for seeking consultation from applicable federal or state agencies with an interest in the environment potentially affected by the project.

Federal Water Pollution Control Act ("Clean Water Act")(33 U.S.C. § 1251)
The Clean Water Act (CWA) establishes the basic parameters for restoring and maintaining the chemical, physical, and biological integrity of the nation's waters. The primary mechanism regulating discharge of pollutants into waterways is the National Pollutant Discharge Elimination System (NPDES), administered by the U.S. Environmental Protection Agency. Under the NPDES program, a permit is required from EPA or an authorized state for the discharge of any pollutant from a point source into the waters of the U.S.

In 1987, the CWA was amended to include the current non-point sources (NPS) program addressing stormwater runoff. Under this program, states must develop management programs to address non-point runoff, including the identification of best management practices and measures. In addition, section 319 authorizes grants to assist states implementing approved management programs.

The section 404 permit program of the CWA is implemented by the U.S. Army Corps of Engineers. Section 404 requires a permit for the discharge of dredged or fill materials into waters of the U.S. that lie inside of the baseline for the territorial sea and of fill materials into the territorial sea within three miles of shore. Although the COE has the permitting responsibility under the section 404 program, in Florida and almost all other states, EPA has the right to review and comment on the effects of proposed dredge and fill activities. EPA also has the right to prohibit discharges that would have an unacceptable effect on municipal water supplies, shellfish beds, fishery areas, wildlife, and recreational areas.

Submerged Lands Act (43 U.S.C. § 1301)
The Submerged Lands Act grants states title to the natural resources located within three miles of their coastlines (nine miles for Texas and the gulf coast of Florida). For purposes of the SLA, the term "natural resources" includes oil, gas, and all other minerals.

More than one state entity may implement state management authority for oil and gas exploration and production on submerged state lands.

Coastal Zone Management Act (CZMA) (16 U.S.C. § 1451)
CZMA strives to protect and preserve coastal resources. Through the CZMA, states are encouraged to develop their own coastal zone management programs (CZMPs) to allow economic growth that is compatible with the protection of natural resources, the reduction of coastal hazards, the improvement of water quality, and sensible coastal development. CZMA provides financial and technical assistance for coastal states to manage their coastal zones in a manner consistent with CZMA standards and goals.

For federal approval, a state CZMP must meet certain criteria:

- Identify the coastal zone boundaries
- Define the permissible land and water uses within the coastal zone that have a direct and significant impact on the coastal zone and identify the state's legal authority to manage these uses
- Inventory and designate areas of particular concern
- Provide a planning process for energy facilities siting
- Establish a planning process to assess the effects of shoreline erosion and to decrease those effects
- Facilitate effective coordination and consultation between regional, state, and local agencies.

The National Oceanic and Atmospheric Administration (NOAA) provides the requisite federal approvals for CZMPs and oversees the programs.

States with approved CZMPs are eligible for financial assistance and are able to review federal permits and activities that affect their own coastal zone. The Secretary of Commerce may override a state's objection to a project or activity if the Secretary finds that that the federal license or permit is consistent with the objectives of the CZMA or is necessary in the interest of national security.

Among several amendments to the CZMA is Section 315, which establishes the National Estuarine Research Reserve System. States may seek NERR designation for areas suitable for long-term research and conservation that qualify as biogeographic and typological representations of estuarine ecosystems. .

Magnuson-Stevens Fisheries Conservation and Management Act (16 U.S.C. § 1801)
This Act assigns to the U.S. sovereign and exclusive fishery management rights over all fish and all continental shelf fishery resources within the Exclusive Economic Zone.

The MSFCMA establishes national standards for fishery conservation and management within the EEZ. These standards are created through the efforts of eight regional fisheries management councils composed of state officials with fishery management responsibility, the regional administrators of the National Marine Fisheries Service, and individuals appointed by the Secretary of Commerce. The councils are responsible for developing fisheries management plans for each fishery under their authority that warrants conservation and management. The plans describe the fisheries and establish conservation and management measures applicable to both U.S. and foreign fishing vessels.

Sustainable Fisheries Act: Amendments to MSFCMA (P.L. 104-297)
Enacted in 1996, the SFA establishes guidelines for development of fisheries management plans that expand on previously adopted national standards. One of the key guidelines calls for designation of Essential Fish Habitat (EFH), identifying and describing these areas, and evaluating adverse effects and appropriate conservation and enhancement measures.

Endangered Species Act
The Endangered Species Act of 1973 establishes a process for identifying, protecting, and restoring declining plant and animal populations.. The Act authorizes the use of all methods and procedures necessary to bring any endangered or threatened species to the point at which those measures are no longer necessary. Such methods and procedures include, but are not limited to, all activities associated with scientific resources management. To protect habitats essential to the conservation of a listed species and which may require special management considerations or protection, the act also authorizes the designation of "critical habitat" for a threatened or endangered species..

The primary federal agencies responsible for implementation of the ESA are the U.S. Fish and Wildlife Service (i.e. Florida manatee) and NOAA's National Marine Fisheries Service (i.e. sea turtles, Johnson's seagrass).

Protection of Wetlands (Executive Order 11990, 1974)
This executive order establishes federal policy to "minimize the destruction, loss or degradation of wetlands, and to preserve and enhance the natural and beneficial values of wetlands" when carrying out federal activities.

No-Net-Loss Policy (White House Office on Environmental Policy, 1993)
This presidential policy, which applies to all federal agencies, states that wetlands should be conserved however possible and that acres of wetlands transformed for other uses must be mitigated through restoration and creation of wetlands elsewhere.

Submerged Aquatic Vegetation Policy (Atlantic States Marine Fisheries Commission)
This policy provides for the conservation, preservation, and restoration of seagrasses and other submerged aquatic vegetation along the Atlantic coast of the U.S.

FEDERAL AGENCY ROLES AND RESPONSIBILITIES

U.S. Army Corps of Engineers

Responsible for maintaining navigational channels; responsible for permitting of projects specified in Section 404 requirements; responsible for coordinating Environmental Impact Statement reviews and interagency consultations for above projects

U.S. Coast Guard

Develops regional oil spill response plans and is the primary responder when oil spills occur; enforces federal fisheries and marine mammal protection laws

U.S. Department of Commerce/National Oceanic and Atmospheric Administration/National Marine Fisheries Service

Responsible for permit reviews of applicable projects under consultation agreement with the COE and other federal agencies; responsible for identifying and designating essential fish habitat (EFH); responsible for protection of federally listed species, including Johnson's seagrass; responsible for management of National Marine Sanctuaries and associated education and enforcement efforts; oversees management of National Estuarine Research Reserves; conducts damage assessments related to groundings or oil spills

U.S. Department of Interior/Minerals Management Service

Conducts surveys of nearshore coastal waters to identify and map deposits of commercially valuable minerals; oversees mineral extraction leases to private entities

U.S. Department of Interior/U.S. Geological Survey

Conducts extensive research, mapping and monitoring programs of coastal habitats, including seagrass beds

U.S. Department of Interior/National Park Service

Responsible for management of National Parks, including those with submerged lands supporting seagrass beds (Biscayne Bay), and associated education and enforcement efforts

U.S. Environmental Protection Agency

Responsible for permitting of large-scale projects under the purview of the Clean Water Act, including industrial and wastewater facilities, and including NPDES permits; oversees regional non-regulatory waterway management programs such as the National Estuary Programs and the Gulf of Mexico Program; provides grant funding for upgrades to municipal treatment facilities and for innovative technology solution to pollution problems

U.S. Fish and Wildlife Service

The USFWS conducts permit review of applicable water-related developments (dredge/fill activities) and federally funded and licensed projects (water diversions and impoundments) under the Fish and Wildlife Coordination Act (FWCA) of 1958, as amended (48 Stat. 401; 16 U.S.C. 661 *et seq.*). The FWCA requires federal agencies to consult with the USFWS for the purpose of conserving fish and wildlife resources and their habitats during the planning of these projects.

The USFWS conducts consultations under section 7 of the Endangered Species Act of 1973, as amended (87 Stat. 884; 16 U.S.C. 1531 *et seq.*) to ensure that the existence of federally listed species is not jeopardized, and that adverse effects to such species and their habitat are minimized and/or avoided to the extent practicable. The ESA implementing regulations also authorize the USFWS to establish Florida manatee refuges and sanctuaries.

The USFWS also manages National Wildlife Refuges under the authority of the Refuge Administration Act (16 U.S.C. 668dd-668jj), including those submerged lands supporting seagrasses and other submerged aquatic vegetation.

STATE, REGIONAL AND LOCAL AGENCIES

Legal Authority

The Florida legislature has summarized the state's authority to manage seagrasses and their habitats and regulate human activities affecting those habitats in Chap. 253 (sovereign submerged lands), Chap. 258 (maintenance of aquatic preserves), Chap. 373 (activities in surface waters and wetlands), and Chap. 403 (pollution harming animal, plant, or aquatic life) of Florida Statutes (FS).

The Florida Administrative Code (FAC) summarizes agency rules implementing these and other laws relevant to seagrass management in Chap. 18-18 (the Florida Bay Aquatic Preserve), Chap. 18-20 (other aquatic preserves), Chap. 18-21 (sovereign submerged lands management), Chap. 62-302 (surface water quality standards), and Chap. 68C-22 (manatee sanctuary act).

"Sovereign submerged lands" are lands that lie beneath tidal or non-tidal waters held by the government by virtue of its sovereignty rather than through a grant, sale, or other conveyance. The state of Florida was admitted to the union in 1845. As a state, Florida was given title to all sovereign lands previously held by the federal government within the Florida Territory. Subsequent legal treatment of the sovereign lands issue in Florida has been quite complex, producing an inconsistent body of case law that is still under development. For the purposes of this document, however, sovereign submerged lands can be thought of as lands lying beneath tidal waters up to the mean high water line.

Existing statutes and rules addressing management of sovereign submerged lands call on the state and its agencies to, "manage and provide maximum protection for all sovereignty lands, especially those important to public drinking water supply, shellfish harvesting, public recreation, and fish and wildlife propagation and management." Moreover, the state and its agencies are to, "manage, protect, and enhance sovereignty lands so that the public may continue to enjoy traditional uses including, but not limited to, navigation, fishing and swimming" (Chap. 18-21.001 FAC).

The state may sell submerged tidal lands to which it holds title, but prior to doing so it must determine the extent to which the action would create the following issues:

> "interfere with the conservation of fish, marine and other wildlife, or other natural resources... and would result in destruction of oyster beds, clam beds, or marine productivity, including, but not limited to, destruction of marine habitats, grass flats suitable as nursery or feeding grounds for marine life, and established marine soils suitable for producing plant growth of a type useful as nursery or feeding grounds for marine life, and if so, in what respect and to what extent, and it shall consider any other factors affecting the public interests" (Chap. 253.12, FS).

Aquatic preserves are a subset of state-owned submerged lands, of "exceptional biological, aesthetic, and scientific value," which the Florida legislature has "set aside forever as... sanctuaries for the benefit of future generations"(Ch. 258 FS). State rules addressing the management of aquatic preserves, which are summarized in Chap. 18-20 FAC, discuss several aspects of seagrass conservation. The intent of the aquatic preserve management rules (Chap. 18-20.001 FAC) is summarized in Box 1.

A number of human activities are regulated within aquatic preserves, including shoreline hardening, aquaculture, maintenance of navigational channels, construction of pipelines and other linear infrastructure, and placement of public and private docking facilities. The highest levels of protection are provided in areas designated as "Resource Protection Area 1" (RPA 1), which are defined as areas that contain "resources of the highest quality and condition." These resources include corals, marine grass beds, mangrove swamps, saltwater marsh, oyster bars, archaeological and historical sites, endangered or threatened species habitat, and colonial water bird nesting sites (Ch. 18-20.003 FAC).

Chapter 62-302 FAC outlines an additional policy-level mandate for seagrass management in all state waters. "Public policy of the State is to conserve the waters of the State to protect, maintain, and improve the quality thereof for public water supplies, for the propagation of wildlife, fish and other aquatic life, and for domestic, agricultural, industrial, recreational, and other beneficial uses." Because seagrass beds are sensitive to light attenuation due to nutrient enrichment, state policy regarding excessive nutrient enrichment is particularly relevant to seagrass management efforts:

> "excessive nutrients... constitute one of the most severe water quality problems facing the State. It shall be the [State's] policy to limit the introduction of man-induced nutrients into waters of the State. Particular consideration shall be given to the protection from further nutrient enrichment of waters which are presently high in nutrient concentrations or sensitive to further nutrient concentrations and sensitive to further nutrient loadings. Also, particular consideration shall be given to the protection from nutrient enrichment of those waters presently containing very low nutrient concentrations." (Chapter 62-302)

Under Chap. 62-302.400 FAC, all surface waters of the state have been classified according to their designated uses:

- Class I—Potable Water Supplies
- Class II—Shellfish Propagation or Harvesting
- Class III—Recreation, Propagation, and Maintenance of a Healthy, Well Balanced Population of Fish and Wildlife
- Class IV—Agricultural Water Supplies
- Class V—Navigation, Utility, and Industrial Use

Water quality classifications are arranged in order of the degree of protection required. Class I water generally has the most stringent water quality criteria and Class V the least. However, Class I, II, and III surface waters share a set of water quality criteria that have been established to protect "recreation and the propagation and maintenance of a healthy, well-balanced population of fish and wildlife." Seagrass habitats are usually found in Class II (shellfish harvesting) or Class III (recreation and wildlife) waters.

"Impaired waters" are defined in subsection 303(d) of the federal Clean Water Act, and Sect. 403.067 FS, as waters that do not meet their designated uses or applicable water quality standards due to discharges of pollutants from point or non-point sources. Under Sect. 62-303.350 FS, a "decrease in the distribution (either in density or areal coverage) of seagrasses or other submerged aquatic vegetation" provides potential evidence of impairment due to excessive nutrient enrichment. Other potential evidence of excessive nutrient levels include "algal blooms, excessive macrophyte growth…, changes in algal species richness, and excessive diel oxygen swings" (Sect. 62-303.350 FS). Waters that are designated as "impaired" by the state of Florida and the U.S. Environmental Protection Agency are subject to the development of Total Maximum Daily Loads (TMDLs), pursuant to paragraph 303(d)(1) of the federal Clean Water Act.

Box 1. Summary of legislative intent in the establishment of Florida's aquatic preserves

CHAPTER 18-20 FAC (FLORIDA AQUATIC PRESERVES)

18-20.001 Intent.
(1) All sovereignty lands within a preserve shall be managed primarily for the maintenance of essentially natural conditions, the propagation of fish and wildlife, and public recreation, including hunting and fishing where deemed appropriate by the [Board of Trustees of the Internal Improvement Trust Fund], and the managing agency.

(2) Aquatic preserves which are described in Part II of Chapter 258, Florida Statutes, were established for the purpose of being preserved in an essentially natural or existing condition so that their aesthetic, biological and scientific values may endure for the enjoyment of future generations.

(3) The preserves shall be administered and managed in accordance with the following goals:

(a) To preserve, protect, and enhance these exceptional areas of sovereignty submerged lands by reasonable regulation of human activity within the preserves through the development and implementation of a comprehensive management program;

(b) To protect and enhance the waters of the preserves so that the public may continue to enjoy the traditional recreational uses of those waters such as swimming, boating, and fishing;

(c) To coordinate with federal, state, and local agencies to aid in carrying out the intent of the Legislature in creating the preserves;

(d) To use applicable federal, state, and local management programs, which are compatible with the intent and provisions of the act and these rules, and to assist in managing the preserves;

(e) To encourage the protection, enhancement or restoration of the biological, aesthetic, or scientific values of the preserves, including but not limited to the modification of existing manmade conditions toward their natural condition, and discourage activities which would degrade the aesthetic, biological, or scientific values, or the quality, or utility of a preserve, when reviewing applications, or when developing and implementing management plans for the preserves;

(f) To preserve, promote, and utilize indigenous life forms and habitats, including but not limited to: sponges, soft coral, hard corals, submerged grasses, mangroves, salt water marshes, fresh water marshes, mud flats, estuarine, aquatic, and marine reptiles, game and non-game fish species, estuarine, aquatic and marine invertebrates, estuarine, aquatic and marine mammals, birds, shellfish and mollusks;

(g) To acquire additional title interests in lands wherever such acquisitions would serve to protect or enhance the biological, aesthetic, or scientific values of the preserves;

(h) To maintain those beneficial hydrologic and biologic functions, the benefits of which accrue to the public at large.

(4) Nothing in these rules shall serve to eliminate or alter the requirements or authority of other governmental agencies, including counties and municipalities, to protect or enhance the preserves provided that such requirements or authority are not inconsistent with the act and this chapter.

Specific Authority 120.53, 258.43(1) FS. Law Implemented 258.35, 258.36, 258.37, 258.39, 258.393 FS., Chapter 80-280, Laws of Florida. History-New 2-23-81, Amended 8-7-85, Formerly 16Q-20.01, 16Q-20.001, Amended 9-29-97.

AGENCY ROLES AND RESPONSIBILITIES

STATE AGENCIES

Florida Department of Agriculture and Consumer Services
Responsible for safeguarding the public and supporting Florida's agricultural economy by: ensuring the safety and wholesomeness of foods (including shellfish and shellfish harvesting areas) through inspection and testing programs; assisting Florida's agriculture and aquaculture industries by supporting the production and promotion of agricultural products; and conserving and protecting the state's agricultural and natural resources by promoting environmentally safe agricultural practices and managing public lands.

Florida Department of Environmental Protection
Serves as the state's primary environmental regulatory agency, with permitting authority over a wide range of activities, including large waterfront residential developments, marinas, municipal and private wastewater treatment plants, and industrial wastewater discharges. Manages the state's network of parks and aquatic preserves. Provides administrative oversight of regulatory programs that have been delegated to regional water management districts and local governments. Implements non-regulatory stewardship initiatives such as the Clean Marina Program. Coordinates emergency response programs for oil spills. Oversees operation and management of state parks. Guides implementation of the state's Coastal Management Program.

Florida Fish and Wildlife Conservation Commission
Responsible for creation and enforcement of fishing and boating laws. Oversees the state's marine research laboratory (Florida Marine Research Institute), which conducts research in seagrass biology, status and trends, and impacts. Provides regulatory review of marinas, piers and other water-based development activities in consultation with appropriate state and federal agencies. Establishes state manatee protection sanctuaries and speed zones;

Florida Department of Community Affairs
Coordinates reviews of developments of regional impact (DRI); oversees implementation of local comprehensive land use plans as specified by Florida Statutes; oversees implementation of land use plans for state "areas of critical concern."

Regional Agencies

Water Management Districts
The state's five water management districts have responsibility for permitting of projects related to both water quality and quantity (i.e. regulation of water withdrawals for both the public and private sector; regulation of stormwater management systems). They also oversee the state's Surface Water Improvement and Management (SWIM) program to restore and protect key water bodies, including the state's largest estuaries, and develop and implement environmental education programs.

Port Authorities
Responsible for permitting of docks and other structures within their sovereign submerged land ownership; responsible for developing emergency response plans for oil or chemical spills

National Estuary Programs
Implement community-based, non-regulatory management plans for specific estuaries designated by Congress, including Indian River Lagoon, Tampa Bay, Sarasota Bay and Charlotte Harbor; conduct research into problems affecting those estuaries and innovative management solutions; coordinate data collection and distribution; develop and implement educational outreach programs highlighting the importance of estuaries

Regional Planning Councils
Coordinate local reviews of Developments of Regional Impacts; assist communities in long-range planning, including natural resource protection

Local Governments

Local governments' planning, environmental management, and park departments have wide-ranging responsibilities over a variety of small- and large-scale development activities in and adjacent to wetlands and seagrass beds. Local agencies are also responsible for managing and maintaining local parks and aquatic preserves and regulating (by ordinance) boating speeds for both public safety and environmental protection. Additionally, local entities often maintain their own marine law enforcement units.

Non-Governmental Organizations (NGOs)

In Florida, a variety of nonprofit organizations and other NGOs carry out activities that affect seagrass conservation efforts, either directly or indirectly. Environmental organizations, such as the Ocean Conservancy, National Wildlife Federation, and Save the Manatee Club, lobby at the state and national levels in support of laws and government programs supporting the organizations' objectives. Similar lobbying efforts are conducted by trade organizations supporting specific occupational (e.g., commercial fishing), industrial (e.g., marine construction, shipping), and recreational and commercial (e.g., saltwater fishing and boating) interests. A number of NGOs are also involved in environmental education (e.g., the Florida Aquarium) and public involvement and outreach efforts (e.g., Tampa BayWatch) that address certain aspects of seagrass management.

Florida Fish and Wildlife Conservation Commission
FISH AND WILDLIFE RESEARCH INSTITUTE

Seagrass Communities of the Gulf Coast of Florida: Status and Ecology (2004)

This document provides an up-to-date synthesis of research involving the ecology, biology, and management of gulf coast seagrasses.

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This article is excerpted from the foreword of Seagrass Communities of the Gulf Coast of Florida. "The waters along Florida's Gulf of Mexico coastline, which stretches from the tropical Florida Keys in the south to the temperate Panhandle in the north, contain the most extensive and diverse seagrass meadows in the United States. Seagrass meadows rival or exceed most kinds of agriculture in their productivity and also provide unique aesthetic and recreational opportunities. The importance of seagrasses as food, shelter, and essential nursery habitats for commercial- and recreational-fishery species and for the many other organisms that live and feed in seagrass beds is well known. A single acre of seagrass can produce over 10 tons of leaves per year and can support as many as 40 thousand fish and 50 million invertebrates. This high level of production and biodiversity has led to the view that seagrass communities are the marine equivalent of tropical rainforests. The importance of seagrasses to society has become fully recognized by government agencies. Seagrasses are now receiving focused attention from environmental managers, who require integrated science to aid in developing seagrass-protection programs. Studies concerning the ecology, biology, and management of Gulf-coast seagrasses are increasingly diverse and complex; yet a synthesis of this research has not been prepared since the late 1980s. The need for an up-to-date synthesis has resulted in the production of this document, which compiles and organizes the many diverse research efforts that have been accomplished for this region since that time."


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FLORIDA:
STATUS
ECOLOGY
August 2004
CLINTON J. DAWES
RONALD C. PHILLIPS
GEROLD MORRISON


FLORIDA FISH AND WILDLIFE ★ CONSERVATION COMMISSION ★
GULF OF MEXICO PROGRAM
TAMPA
Estuary Program
USGS
science for a changing world

SEAGRASS COMMUNITIES of the GULF COAST of FLORIDA: *STATUS and ECOLOGY*

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FOREWORD

The waters along Florida's Gulf of Mexico coastline, which stretches from the tropical Florida Keys in the south to the temperate Panhandle in the north, contain the most extensive and diverse seagrass meadows in the United States. Seagrass meadows rival or exceed most kinds of agriculture in their productivity and also provide unique aesthetic and recreational opportunities. The importance of seagrasses as food, shelter, and essential nursery habitats for commercial- and recreational-fishery species and for the many other organisms that live and feed in seagrass beds is well known. A single acre of seagrass can produce over 10 tons of leaves per year and can support as many as 40 thousand fish and 50 million invertebrates. This high level of production and biodiversity has led to the view that seagrass communities are the marine equivalent of tropical rainforests.

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August 2004

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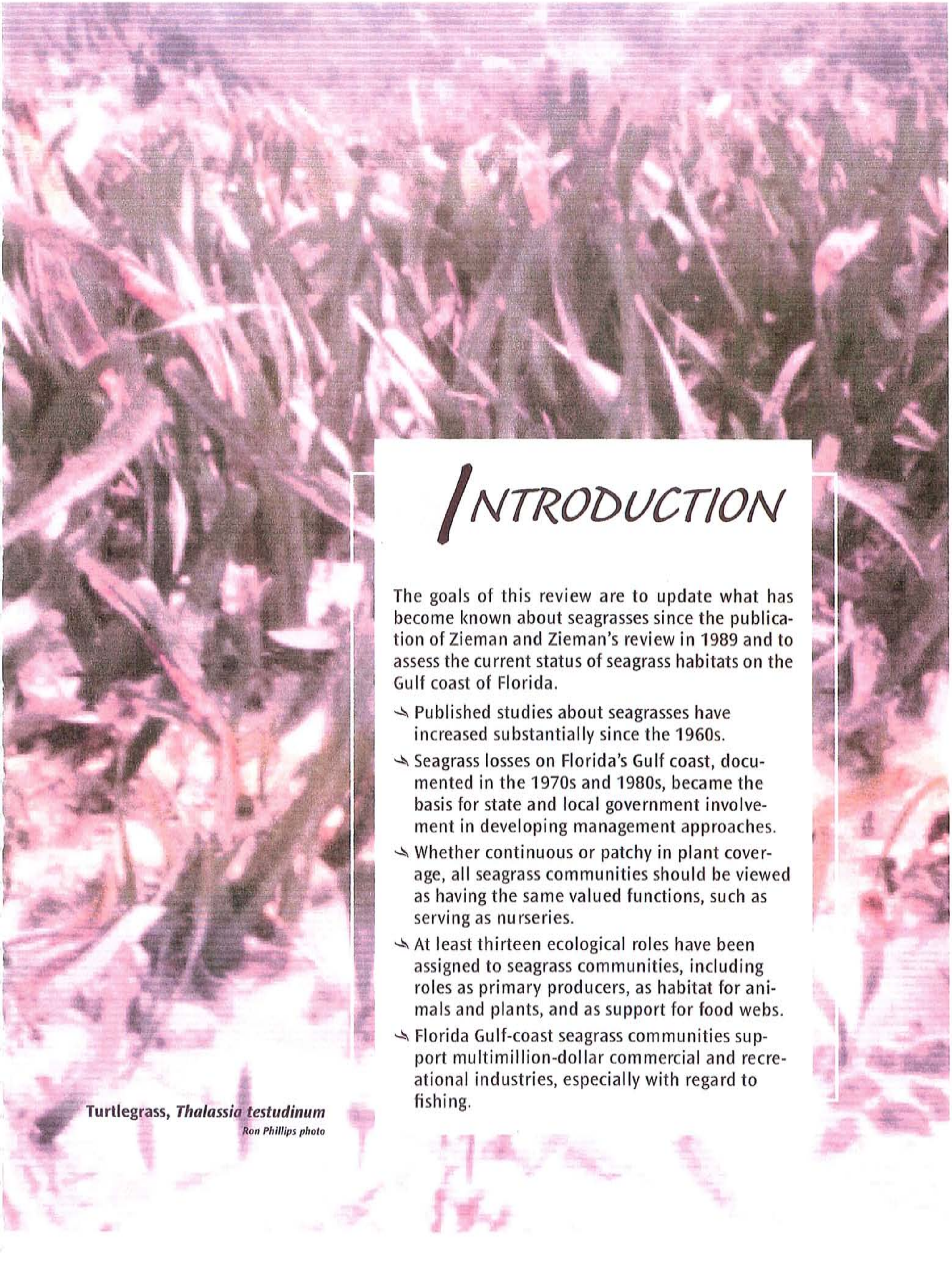
A dedicated group of seagrass scientists and resource managers located throughout the Gulf coast of Florida and elsewhere provided documentation (published and unpublished) and helpful comments on earlier drafts of this document. We appreciate the comments provided by Diane Altsman, Walt Avery, Seth Blitch, Catherine Corbett, Frank Courtney, Mike Crane, Tom Cuba, Kellie Dixon, Mark Flock, Mark Fonseca, Tom Frazer, Roger Johansson, Alice Ketron, George Kish, Eric Lesnett, Jeannine Lessman, Graham Lewis, Robin Lewis, Kevin Madley, Rob Mattson, Gary Raulerson, Bill Sargent, Andy Squires, Betty Staugler, Larinda Tervelt, Dave Tomasko, Tom Ries, Bob Virnstein, and Kim Yates. Llyn French (FWC–FWRI) provided an invaluable service by designing and composing the document for publication.

This document is a joint product of the Gulf of Mexico Program (Larinda Tervelt, project lead), the Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute ([formerly the Florida Marine Research Institute] Kevin Madley, project lead), the United States Geological Survey (Jimmy Johnson, project lead), and the Tampa Bay Estuary Program (Holly Greening, project manager).



Introduction

The goals of this review are to update what has become known about seagrasses since the publication of Zieman and Zieman's review in 1989 and to assess the current status of seagrass habitats on the Gulf coast of Florida.

- Published studies about seagrasses have increased substantially since the 1960s.
- Seagrass losses on Florida's Gulf coast, documented in the 1970s and 1980s, became the basis for state and local government involvement in developing management approaches.
- Whether continuous or patchy in plant coverage, all seagrass communities should be viewed as having the same valued functions, such as serving as nurseries.
- At least thirteen ecological roles have been assigned to seagrass communities, including roles as primary producers, as habitat for animals and plants, and as support for food webs.
- Florida Gulf-coast seagrass communities support multimillion-dollar commercial and recreational industries, especially with regard to fishing.

Turtlegrass, *Thalassia testudinum*
Ron Phillips photo

VISION and SCOPE

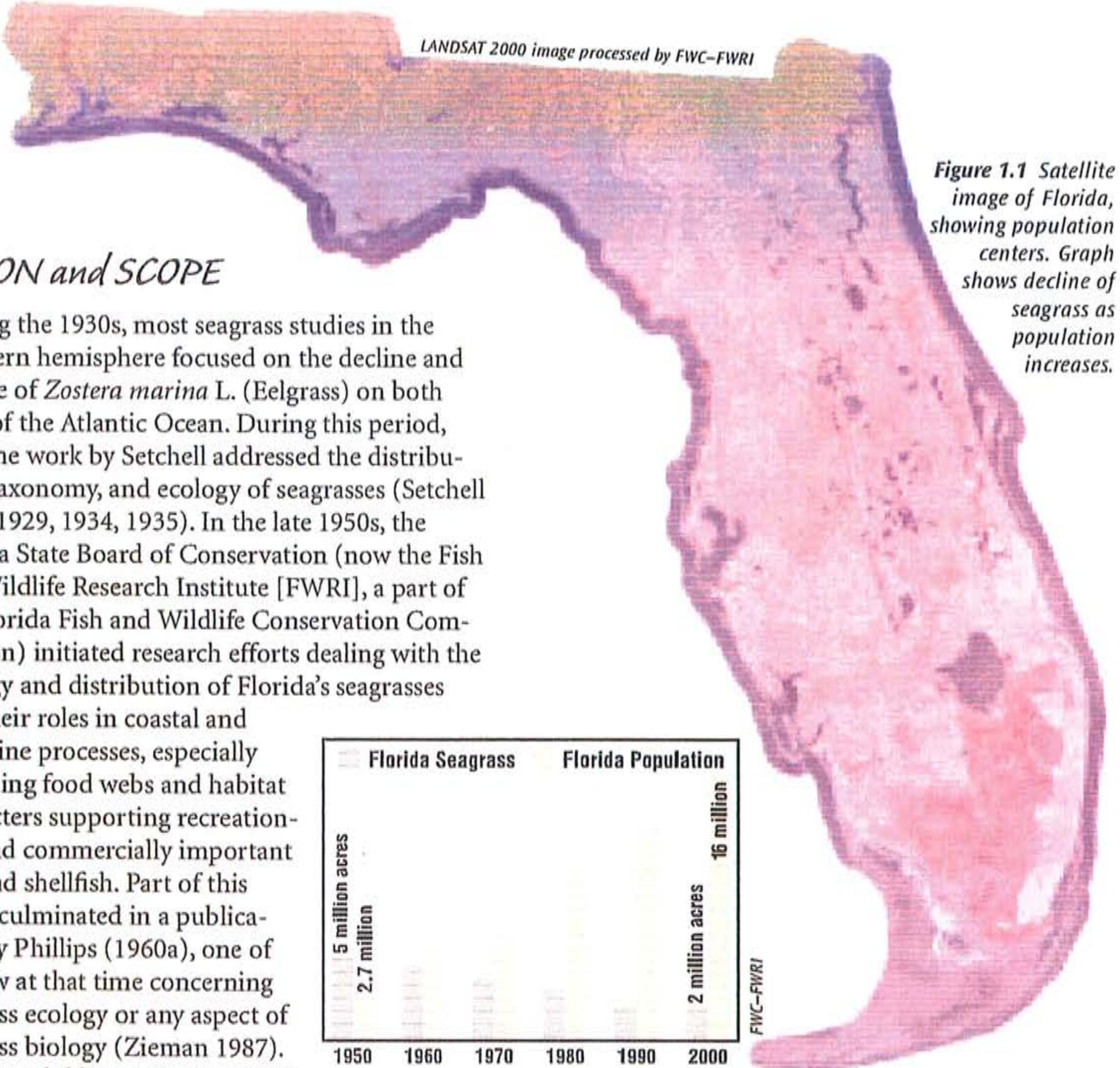


Figure 1.1 Satellite image of Florida, showing population centers. Graph shows decline of seagrass as population increases.

During the 1930s, most seagrass studies in the northern hemisphere focused on the decline and demise of *Zostera marina* L. (Eelgrass) on both sides of the Atlantic Ocean. During this period, only the work by Setchell addressed the distribution, taxonomy, and ecology of seagrasses (Setchell 1920, 1929, 1934, 1935). In the late 1950s, the Florida State Board of Conservation (now the Fish and Wildlife Research Institute [FWRI], a part of the Florida Fish and Wildlife Conservation Commission) initiated research efforts dealing with the ecology and distribution of Florida's seagrasses and their roles in coastal and estuarine processes, especially regarding food webs and habitat characters supporting recreationally and commercially important fish and shellfish. Part of this effort culminated in a publication by Phillips (1960a), one of the few at that time concerning seagrass ecology or any aspect of seagrass biology (Zieman 1987). In 1978, a bibliography compiled by the Seagrass Ecosystem Study listed over 1,400 titles worldwide (Bridges *et al.* 1978), and by 1982, a community profile of south Florida seagrasses contained over 550 references (Zieman 1982).

In a summary of seagrass studies published over a period of 25 years, Zieman (1987) found that initially nearly all seagrass literature was descriptive and qualitative. By 1970, most published works were quantitative, and development of conceptual models had begun. By 1980, increasingly robust models of the mechanisms by which seagrass systems develop and maintain their productivity were being proposed and used as guides for developing proposed research (*e.g.,* McMillan 1978, 1980).

By 1982, scientists, resource managers, and agency personnel monitoring and managing bays and estuaries on the Atlantic and Gulf of Mexico coastlines of Florida, such as for the Indian River Lagoon, Charlotte Harbor, Sarasota Bay, Tampa Bay, and Pensacola Bay, noted dramatic seagrass losses. Starting around 1950, those areas experiencing large population increases also experienced seagrass losses, probably as a result of increasing development pressure (Figure 1.1). To address seagrass losses in the State of Florida, management programs were initiated between 1985 and 1995 to conserve and restore seagrass communities. The State's Surface Water Improvement and Management (SWIM) programs, within the Water Management Districts, address seagrass conservation issues statewide. Federally sponsored National Estuary Programs (NEPs) were designated for four specific estuaries: Tampa Bay National Estuary Program (TBNEP, now TBEP), Sarasota Bay National Estuary Program (SBNEP), Charlotte Harbor National Estuary Program (CHNEP), and Indian River Lagoon Program (IRLP). Since that time, considerable research, particularly regarding the light requirements of different seagrass species, has been conducted. This work was stimulated by the development of goals and targets established by the SWIM Districts and NEPs with respect to reducing eutrophication and nutrient loadings in

Graphic by FWC–FWRI adapted from NOAA Coastal Assessment Framework

Figure 1.2 Demarcated watersheds of Florida's Gulf coast.

the major bays and estuaries. In several of these estuaries, the large seagrass losses observed in the early 1980s have halted, and moderate gains in seagrass extents have been occurring since about 1988 in some areas.

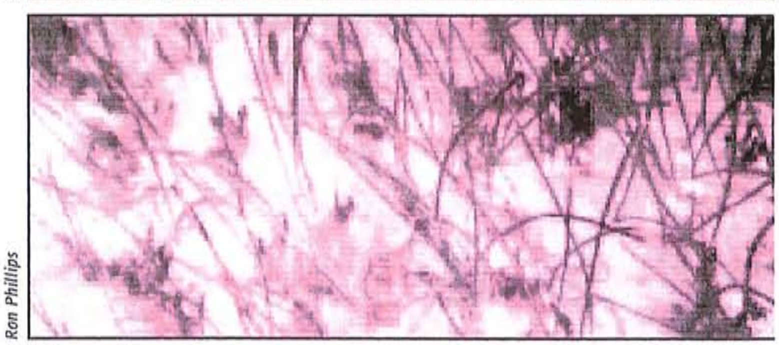
Although many recent studies concerning seagrass ecology and biology along Florida's Gulf coast have been and are being conducted, a synthesis of this information has not been compiled since the 1989 publication of "Ecology of the Seagrass Meadows of the West Coast of Florida: A Community Profile" by Zieman and Zieman. Several resource-management and science programs have identified the need for an updated synthesis of seagrass information:

- The FWC Fish and Wildlife Research Institute has developed a framework for a statewide Seagrass Conservation Plan (Morrison *et al.* 2003a).
- In August 2000, over 70 seagrass scientists and managers attended a Seagrass Management Symposium convened by the Tampa Bay Estuary Program (Greening 2002a). Workshop participants identified, as a first and critical step in seagrass management, the need for a compilation of scientific information on Florida's seagrasses published since the review by Zieman and Zieman (1989).
- The US Geological Survey's (USGS) Coastal and Marine Geology Program initiated a "Gulf of Mexico Estuaries Assessment" in 2001, using Tampa Bay as the subject of a pilot study. An initial element of the study is to develop a "synthesis report" and web-based information bank that would link directly to the USGS National Estuaries Assessment.
- The Gulf of Mexico Program (GMP) made a commitment that "By 2004, the GMP will complete development of an updated gulf-wide characterization of the status and trends of seagrasses and coastal wetlands" (Gulf of Mexico Program 2003).

Knowledge of seagrass ecology and distribution within Florida has progressed substantially in the last 20 years. The objective of this publication is to summarize available data and information about seagrass research performed along the Gulf coast of Florida since 1985. Literature and studies published prior to 1985 are summarized in Zieman and Zieman (1989), which is available from the FWC Fish and Wildlife Research Institute Web site (www.floridamarine.org). The geographical scope of this document extends from Florida Bay and the Florida Keys at the southern extreme northward and westward through the Florida Panhandle to the Alabama border (Figure 1.2). Although the distance is only about 700 km (435 miles) from Florida Bay to Apalachicola Bay (extending over 6.5° of latitude), the aquatic climate changes dramatically. In Florida Bay, conditions are tropical, whereas in the Panhandle region, conditions are temperate and delimit the northern distribution in the Gulf for several Florida seagrass species, including *Thalassia testudinum* (Turtlegrass; Figure 1.3) and *Syringodium filiforme* (Manateegrass; Figure 1.4).

Figure 1.3 Thalassia testudinum *(Turtlegrass)*

Ron Phillips



Ron Phillips

Figure 1.4 Syringodium filiforme *(Manateegrass)*

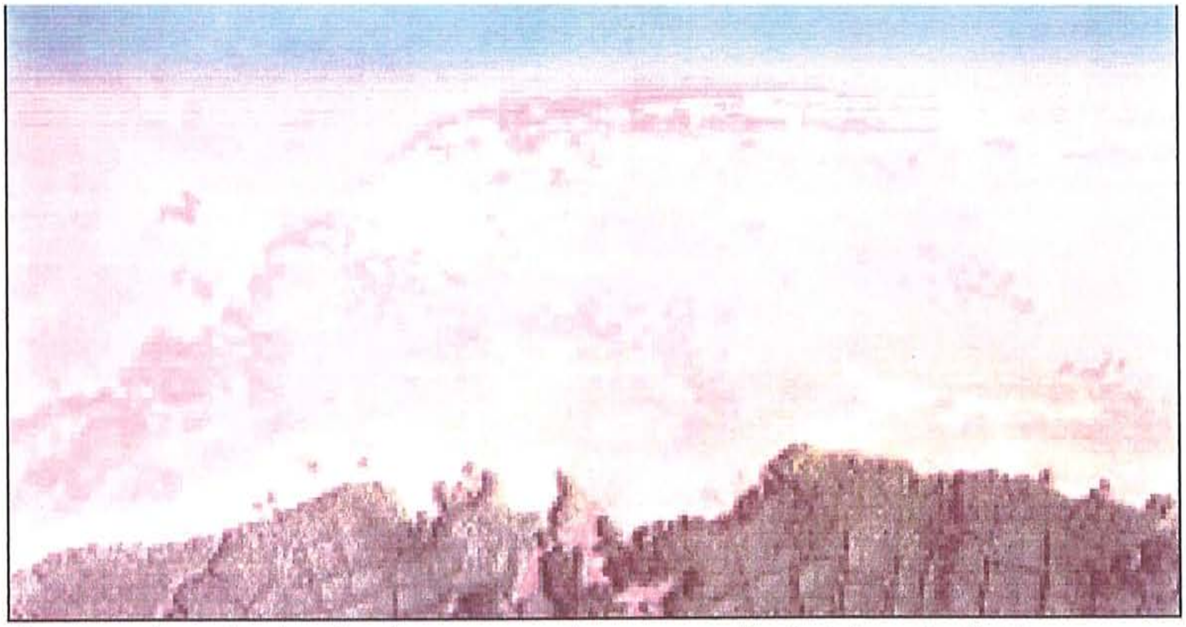


Figure 1.5 *A mixture of patchy and continuous seagrasses along a mangrove shoreline in Tampa Bay, Florida.*

DEFINITION *of* SEAGRASS HABITAT

Simply put, habitat is where an organism resides. Nevertheless, habitat is not only where organisms live but also includes how they live there. Seagrass habitat is an ecological function provided by seagrasses. It is the location where certain organisms can thrive (survive, grow, and reproduce).

Seagrass habitat is defined in this document as a physical space containing seagrasses in sufficient quantity and pattern to produce the appropriate structural and physiological characteristics to support organisms typical of seagrass communities. These characteristics include food webs based on organic-matter production, nutrient cycling, detritus production, shelter, and sediment formation.

Continuous-coverage beds as well as patchy beds of seagrasses provide critical and valued habitat functions. Fonseca *et al.* (1998) found that scattered or patchy *Z. marina* beds covered many thousands of acres of estuarine seafloor in North Carolina, had shoot densities and primary production equivalent to those of continuous-coverage beds, had significantly greater below-ground biomass than did continuous-coverage beds, and often supported densities of economically valuable animal species, *e.g.*, pink shrimp, similar to those of continuous-coverage seagrass beds. They concluded that seagrass habitat must be recognized as indicating not only continuous-coverage seagrass beds, but also chronically patchy areas, therein considering the unvegetated spaces between vegetation as seagrass habitat as well (Figure 1.5).

Thus, the value of seagrass habitat should not be judged on the basis of seagrass densities or patterns, but upon the provided functions. In this document, any reference to areas covered by seagrass means seagrass habitat, as long as valued functions are present and measurable. One should consider that patchy seagrass beds perhaps represent areas in the process of recovering from past disturbances, or they may be areas held in a patchy pattern because of the characteristics of the present physical environment. In any event, patchy seagrasses support valued animals and plants and display typical seagrass functions.

ECOLOGICAL *and* ECONOMIC IMPORTANCE *of* SEAGRASS COMMUNITIES

Seagrasses are a vital component of Florida's coastal ecology and economy. They provide nutrition and shelter to animals that are important to marine fisheries, provide critical habitat for many other animals (*e.g.*, wading birds, manatees, and sea turtles), and improve water quality (Thayer *et al.* 1997,1999; Livingston 1990; Kenworthy *et al.* 1988b; McMichael and Peters 1989; Stedman and Hanson 1997; Valentine *et al.* 1997). For example, Heck *et al.* (2003) found a strong link between seagrass abundance and those of juvenile finfish and shellfish that was related to habitat structure.

In systems where seagrasses occur, nearly all of the commercially and recreationally valuable estuarine and marine animals depend on seagrass beds as refuge or habitat for parts or all of their life cycles (Kikuchi and Peres 1977; Thayer *et al.* 1978, 1984; Kikuchi 1980; Ogden 1980; Thayer and

Ustach 1981; Phillips 1984). As reported by Wingrove (1999) in the Florida Keys, hundreds of fish species, including many of commercial value, rely on seagrass habitats during some parts of their life cycles. Seagrasses help support a thriving, multimillion-dollar recreational fishery including, as an example, the shallow-water seagrass flats fishery seeking bonefish and tarpon. In addition, over 30 species of tropical invertebrates that depend on seagrasses are collected in the Florida Keys annually for the marine aquarium industry.

Short *et al.* (2000) list ecological services provided by seagrasses (modified here):

- Primary production (food for animals and support for fisheries and wildlife)
- Canopy structure (habitat, refuge, nursery, settlement and support of fisheries)
- Epibenthic and benthic production (support of food webs and fishery support)
- Nutrient and contaminant filtration (improved water quality, support of adjacent habitats, support of fisheries)
- Sediment filtration and trapping (improved water quality, countered sea-level rise, support of adjacent habitats)
- Epiphytic substratum (support of secondary production, production of carbonate sediment, support of fisheries)
- Oxygen production (improved water quality, support of adjacent habitats, support of fisheries)
- Organic-matter production and export (support of estuarine and offshore food webs, support of adjacent habitats, support of fisheries)
- Nutrient regeneration and recycling (support of primary production, support of adjacent habitats, support of fisheries)
- Organic-matter accumulation (support of food webs, countered sea-level rise, support of fisheries)
- Dampening of waves and currents (prevention of erosion/resuspension, support of adjacent habitats, increased sedimentation)
- Seed production/vegetative expansion (self-maintenance of habitat, support of wildlife)
- Self-sustaining ecosystem (recreation, education, landscape-level biodiversity)

Costanza *et al.* (1997) and Costanza (1999) stated that, for the entire biosphere, the economic value of all ecosystem services for 16 biomes is in the range of 16 to 54 trillion US \$ y^{-1}, with an average of 33 trillion US \$ y^{-1}. They considered this to be a minimum estimate. The value of coastal environments, including estuaries, coastal wetlands (mangroves and salt marshes), seagrass beds and algae, coral reefs, and continental shelves, is of a disproportionately high value. These communities cover only 6.4% of the world's surface, but they are responsible for 43% of the estimated value of the world's ecological services.

In Florida, seagrass beds are directly responsible for bringing in millions of dollars annually from out-of-state and resident recreational boaters and fishermen and commercial fishermen (Bell 1993; Milon and Thunberg 1993; Virnstein and Morris 1996; Virnstein 1999; Wingrove 1999; Thomas and Stratis 2001). Seagrass beds on the Gulf coast of Florida are important not only for the ecological services they provide, but for the economic health of the state and region.

DOCUMENT CONTENT

The focus of this review is the biology and ecology of seagrasses and of seagrass communities on Florida's Gulf coast.

Chapter 2 considers distribution of the Florida Gulf coast seagrasses and reports the trends in areal extents of seagrass beds, as recorded by monitoring efforts of various local and regional programs. Chapter 3 synthesizes new information regarding autecology and presents what is known regarding genetic analyses of Florida seagrasses. These genetic techniques were not applied to seagrasses prior to the 1990s. Chapter 4 addresses the ecological roles of seagrass communities, of their macroalgal components (epiphytic and drift), and of adjacent coastal communities (mangroves and salt marshes). Chapter 5 focuses on the natural and anthropogenic effects on Florida seagrasses. The Appendix presents keys to the Florida seagrass species and presents brief taxonomic descriptions for the families, genera, and species (includes figures).

A companion document entitled "The Florida Seagrass Manager's Toolkit" (Morrison *et al.* 2003b) addresses seagrass management in Florida and is available at www.floridamarine.org.

DISTRIBUTION, STATUS, and TRENDS

- Florida's Gulf coast can be divided into four regions—South Florida, Gulf Peninsula, Big Bend, and Panhandle—for the purpose of assessing near-shore seagrass community status and trends.
- Aerial photography taken during the 1990s revealed that the South Florida region contained the majority (65%) of the Gulf coast's seagrass coverage, followed by the Big Bend (28%), Gulf Peninsula (5%), and Panhandle (2%) regions.
- The most abundant seagrass species on the Florida Gulf coast are *Thalassia testudinum, Syringodium filiforme,* and *Halodule wrightii,* each of which principally has a tropical to subtropical distribution. Two other species (*Halophila engelmannii* and *H. decipiens*) also occur in the area, in near-shore meadows dominated by *T. testudinum* and *S. filiforme* and in deeper waters where the latter two species are absent.
- A substantial decline in seagrass coverage has occurred in the South Florida region over the past 15 years, following a dramatic "die-off" that began in Florida Bay during 1987.
- In the Gulf Peninsula region between *ca.* 1959 and 1982, mapping efforts in Tampa Bay, Sarasota Bay and Greater Charlotte Harbor revealed reductions in seagrass coverage. However, difficulty in obtaining accurate coverage estimates from the 1950s-era maps has complicated attempts to quantify these declines, particularly in the Greater Charlotte Harbor area.
- Increasing coverage trends have occurred in Tampa Bay and Sarasota Bay since 1982 in response to improved management of nitrogen loadings and increasing water clarity. Increased rainfall, stormwater runoff, and nutrient loadings associated with the 1997–1998 *El Niño* event interrupted the trends in seagrass coverage gains, but they appear to have resumed in recent years.
- Several other areas within the Gulf Peninsula region—including Charlotte Harbor Proper and Lemon Bay—have been mapped approximately biennially since 1988. No significant seagrass coverage trends have been reported from these recent mapping efforts.
- The Big Bend region is a unique "zero-energy" coastline and contains Florida's second-largest near-shore seagrass bed. The region has received relatively little research and management attention. The only long-term seagrass coverage changes reported have been localized losses attributed to the effects of an industrial facility that discharges to the Fenholloway River and Apalachee Bay.
- In portions of the Panhandle region, which is also poorly studied, seagrass coverage may be increasing in some low-salinity areas and declining in some areas of higher salinity.
- In addition to these near-shore seagrass resources, recent work on the West Florida Shelf indicates the presence of extensive, seasonal, deep-water *Halophila* beds, which may exceed four hundred thousand hectares (one million acres).

DISTRIBUTION

Seagrasses are a relatively small group of flowering plants that have adapted to survive and reproduce in the marine environment. They are present in all coastal states of the U.S., with the exception of Georgia and South Carolina, where a combination of freshwater inflows, high turbidity, and large tidal amplitude restricts their occurrence (Thayer *et al.* 1997).

The most abundant taxa in Florida's near-shore waters are *T. testudinum, S. filiforme,* and *H. wrightii,* each of which principally has a tropical to subtropical distribution (Zieman and Zieman 1989). *Thalassia testudinum* (Turtlegrass) is the largest of these species, with long strap-shaped leaves and robust rhizomes (see Appendix for taxonomic keys, descriptions, and illustrations). Extensive seagrass beds are usually dominated by this species, either alone or in combination with other species, such as *Syringodium filiforme. Syringodium filiforme* (Manateegrass) can be distinguished by its cylindrical (terete) leaves that, because they are brittle and buoyant, are frequently broken off from the parent plant and dispersed widely by winds and currents. *Halodule wrightii* (Shoalgrass) has flat, narrow leaves and a shallow root system. It is thought to be an early successional species in the development of seagrass beds in the Gulf of Mexico and Caribbean Sea.

Three other species, *Halophila engelmannii* (Stargrass), *H. decipiens* (Paddlegrass), and *H. johnsonii* (Johnson's Seagrass), are also found in Florida's coastal waters. In the Big Bend region, *H. engelmannii* and *H. decipiens* are scattered throughout beds dominated by *T. testudinum* and *S. filiforme* but also occur in deeper water where these latter two species are absent (Iverson and Bittaker 1986). *Halophila decipiens* has been found in the Big Bend and Tampa Bay regions and at depths to 90 m near the Dry Tortugas (Zieman 1982), and it forms single-species stands in depths of 20 m or more, beyond the deep edge of the extensive *T. testudinum/S. filiforme* beds (Zieman and Zieman 1989, Dawes and Lawrence 1990). *Halophila johnsonii* is a relatively newly described species and is morphologically similar to *H. decipiens* (Eiseman and McMillan 1980). *Halophila johnsonii* is now listed as a threatened species by the National Marine Fisheries Service (NMFS; 2002) and is apparently an endemic whose range is restricted to the lagoon systems of Florida's southeastern (Atlantic) coast. It has not been documented to occur on the Gulf coast (NMFS 2002), and recent evidence suggests it is genetically indistinguishable from *H. ovalis,* a species of the Indo-Pacific region (Waycott *et al.* 2002).

A seventh species, *Ruppia maritima* (Widgeongrass), is a euryhaline plant that is often encountered in the waters of Florida's Gulf coast, particularly in estuaries such as Homosassa Bay (Koch and Dawes 1991a, b) and Tampa Bay (Lazar and Dawes 1991). This species can form dense beds, as found in upper Tampa Bay (Lazar and Dawes 1991). In recognition of its broad salinity tolerance, some authors have suggested that *R. maritima* may be thought of as a freshwater species that is also capable of living in saline environments, rather than a seagrass in the strictest sense (*e.g.,* Zieman 1982, Kuo and den Hartog 2001).

In addition to seagrasses, drift and attached seaweeds also make up an important component of the total submerged aquatic vegetation (SAV) in many areas of Florida (Dawes *et al.* 1987, Dawes 1986). In the Big Bend region, for example, benthic green algae in the order Caulerpales— including *Halimeda incrassata,* seven species of *Caulerpa,* and two species each of *Udotea, Penicillus,* and *Codium*—are important associates in the region's seagrass beds, with standing crops exceeding those of seagrasses in some areas (Mattson 2000).

Depth-related zonation patterns of Gulf-coast seagrass beds (Figure 2.1) have been described by Lewis *et al.* (1985a), Iverson and Bittaker (1986), Zieman and Zieman (1989), and Mattson (2000). As a general rule, *H. wrightii* and *R. maritima* tend to be more abundant in shallow inshore areas because they tolerate frequent tidal exposure and low salinities. *Thalassia testudinum* and *S. filiforme*

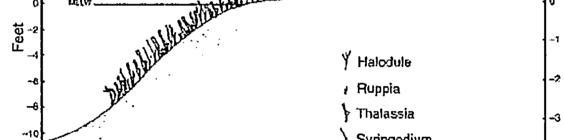


Fig 2.1 An example of an inshore-offshore seagrass zonation profile on Florida's Gulf coast (from McNulty et al. *1972).*

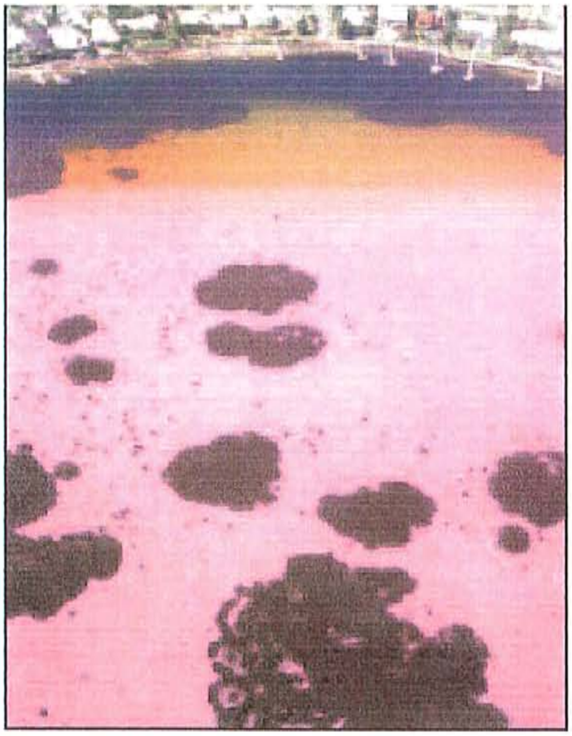


Fig 2.2 Dense seagrass beds begin as patches that coalesce into a larger, more genetically diverse meadow.

reach their highest abundance and biomass in slightly deeper areas, often forming dense single- or mixed-species stands (Figure 2.2). In some areas, *H. wrightii* exhibits a second abundance peak along the deep-water edge of *T. testudinum/S. filiforme* meadows (Iverson and Bittaker 1986, Zieman and Zieman 1989). *Halophila* spp. form sparse beds in deeper waters outside these meadows (Zieman and Zieman 1989, Fonseca *et al.* 2001). In the Big Bend region and Tampa Bay, *H. engelmannii* also occurs in low-salinity areas (<5 ppt) within 1–2 km of river mouths, where an ability to tolerate low light levels in waters of relatively high color may be an important factor explaining its persistence (Dawes 1967, Zimmerman and Livingston 1976, Mattson 2000).

When considering the distribution of seagrasses on Florida's Gulf coast, dividing the area into four regions is helpful. Regions defined by Sargent *et al.* (1995) are summarized in Table 2.1 and Figure 2.3:

- South Florida (Florida Keys and Florida Bay to Estero Bay)
- Gulf Peninsula (Estero Bay to Anclote Key)
- Big Bend (Anclote Key to Ochlockonee Point)
- Panhandle (Ochlockonee Point to the Florida-Alabama border)

The spatial distribution and areal extent of seagrasses vary substantially between these regions (Zieman 1982, Iverson and Bittaker 1986, Sargent *et al.* 1995). Recent status and trends in seagrass coverage at this geographic scale are summarized in the following section.

REGIONAL STATUS and TRENDS

Sargent *et al.* (1995) estimated that, on a statewide basis, Florida's near-shore coastal waters support approximately 1.1 million ha (2.7 million acres) of seagrass. This statewide estimate includes 0.8 million ha (1.9 million acres) of dense and relatively easily mapped seagrasses in state waters where visibility allowed interpretation of bottom communities (within 14.4 km [9 miles] of shore along the Gulf coast). It also includes, in portions of the South Florida region, an estimated 0.3 million ha (0.8 million acres) of sparse and incompletely mapped seagrass beds that are interspersed with hard-bottom communities and are thus difficult to map accurately. This estimate does not include the sparse beds that occur in deeper waters on portions of the West Florida Shelf (Sargent *et al.* 1995).

Along the state's Gulf coast, the coverage of the sparse deep-water beds of the West Florida Shelf and the small, patchy mixed-species beds that occur intermixed with hard bottom outside the main seagrass beds in Florida Bay remain the largest question marks in the effort to develop accurate estimates of overall seagrass coverage. For example, recent assessments indicate that the total area of deep-water beds in the Gulf-coast region may be on the order of 0.4 million ha (1 million acres), which would place them, on a worldwide basis, among the most extensive seagrass habitats currently known (Fonseca *et al.* 2001).

During the 1990s, aerial photographs were used to produce digitized maps of seagrass coverage for

Table 2.1 Extent of seagrass coverage and aerial photography dates in four regions of Florida's Gulf coast (Madley *et al.* 2003).

Region	Seagrass (hectares)	Seagrass (acres)
Panhandle (1992)	17,474	43,178
Big Bend (1992)	247,598	611,815
Gulf Peninsula (1999)	43,323	107,051
South Florida (1992, 1995)	574,875	1,420,517
Gulf coast total	883,270	2,182,561

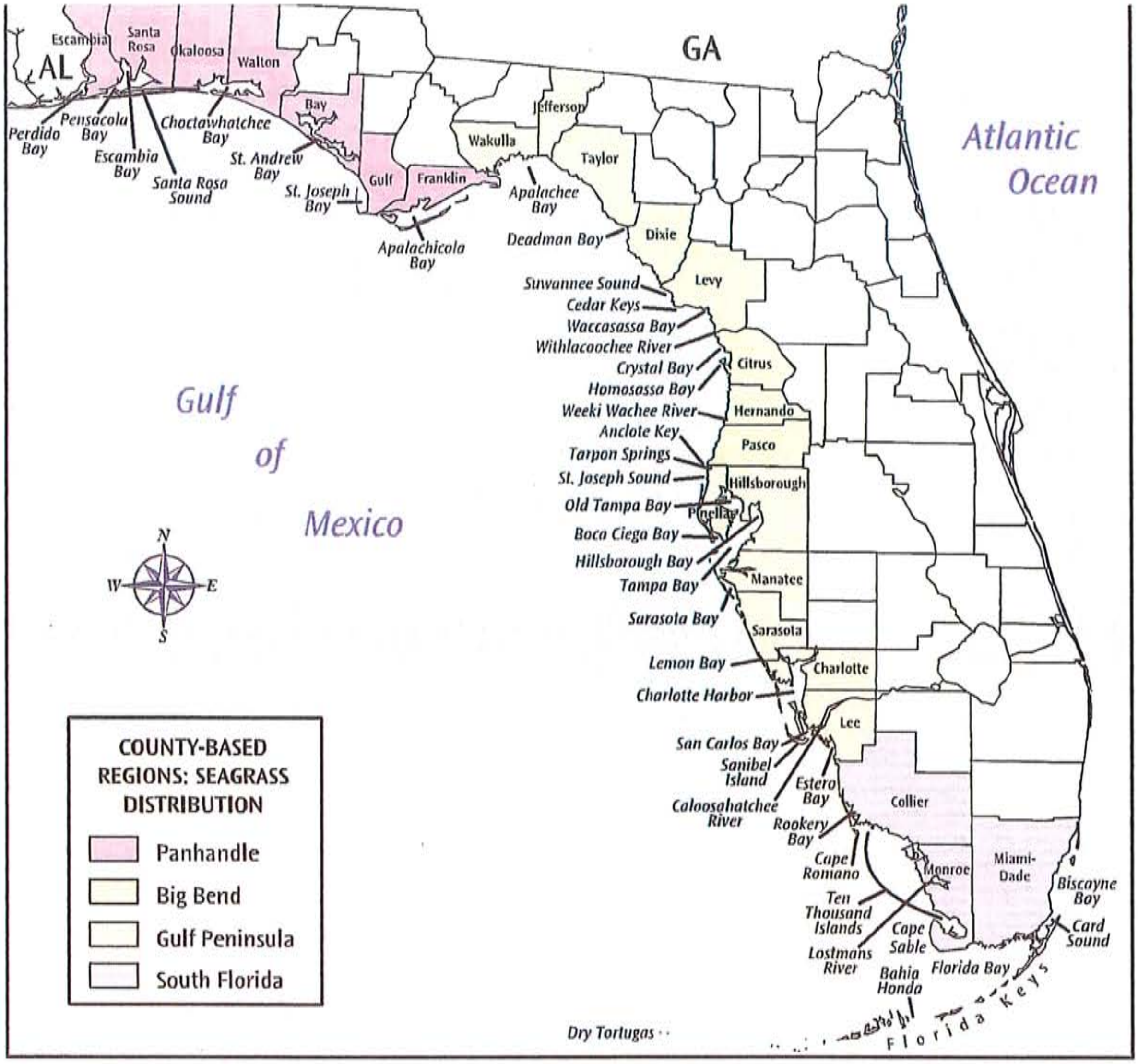


Fig 2.3 County-based regions used to describe seagrass distributions along the Gulf coast of Florida (after Sargent et al. *1995) and containing locations referred to in the text.*

each of the regions shown in Figure 2.3. The dates of these mapping efforts and their results are summarized in Table 2.1. The South Florida region contained the majority (65%) of the Gulf coast's seagrass coverage, followed by the Big Bend (28%), Gulf Peninsula (5%), and Panhandle (2%) regions.

SOUTH FLORIDA

The South Florida region (Figure 2.3) includes the coastal waters of Collier, Monroe, and Miami-Dade counties (Table 2.1). The portion that lies immediately south of Cape Romano includes the Ten Thousand Islands, an area that is dominated by mangrove islands and tidal channels but that also contains patches of seagrasses and some large seagrass beds (*e.g.*, as reported from the Lostmans River area by Dawes *et al.* 1995). The Florida Bay portion, which lies south of Cape Sable and west of the Florida Keys, is a carbonate-sediment-based system that supports extensive seagrass beds.

Based on monitoring data collected annually from 1974 through 1980, Iverson and Bittaker (1986) noted that, in addition to their greater extent, the 0.5 million-ha (1.4 million-acre) Florida Bay seagrass meadows also had about two to four times the short-shoot densities of *T. testudinum* and *S. filiforme* as occurred in the 0.3 million ha (741,000 acre) Big Bend meadows. They hypothesized that the density differences observed in the two areas may be a consequence of greater seasonal variations in solar radiation and water temperature in the Big Bend, which is at the northern limits of tropical American seagrasses (Iverson and Bittaker 1986).

Seagrass coverage and condition in the South

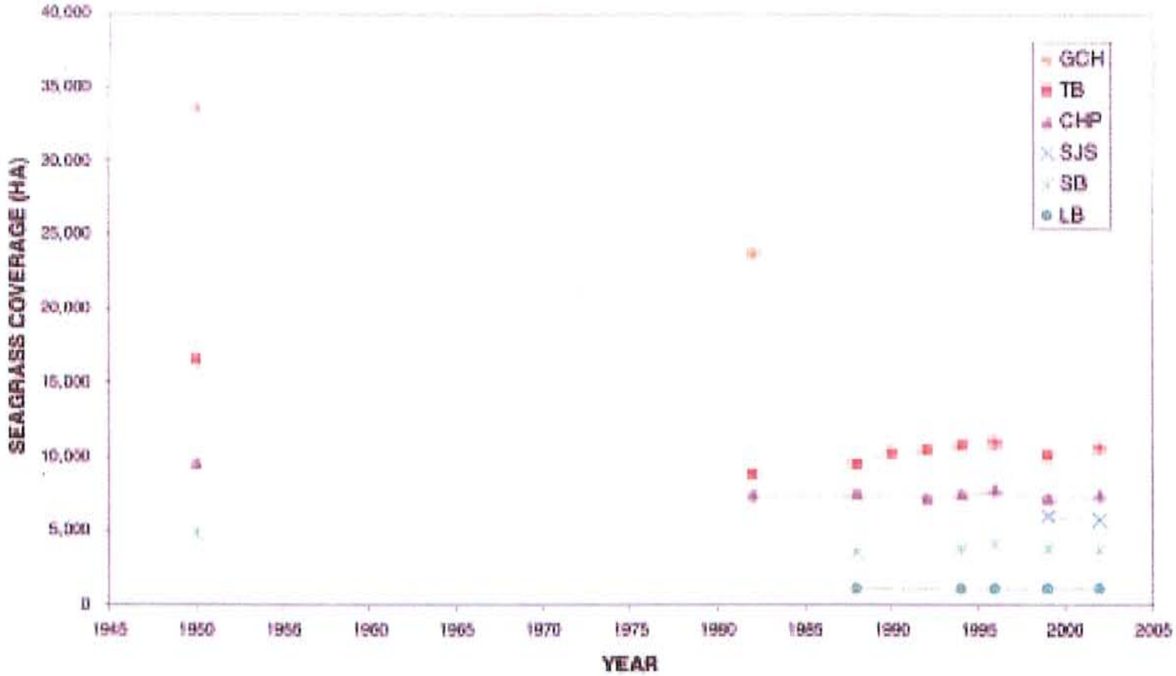


***Figure 2.4** Time series of mapped seagrass coverage within major coastal water bodies of the Gulf Peninsula region (GCH = Greater Charlotte Harbor; TB = Tampa Bay; CHP = Charlotte Harbor Proper; SJS = St. Joseph Sound; SB = Sarasota Bay; LB = Lemon Bay) from* ca. *1950 through 2002. The 1950 values were developed using mapping methods that differ from those currently in use and should be viewed as approximations. (Data sources: FWRI, SWFWMD)*

Florida region have changed since the 1974–1980 period documented by Iverson and Bittaker (1986). A dramatic decline in coverage began in western Florida Bay during the summer of 1987 (Hall *et al.* 1999). Seagrasses in the bay were apparently subjected to decreased light availability resulting from resuspended sediments and widespread, persistent microalgal and cyanobacterial blooms. Bay-wide surveys in 1984 and 1994 indicated that the biomass of *T. testudinum*, *S. filiforme*, and *H. wrightii* declined by 28%, 88%, and 92%, respectively, during that 10-year period. The spatial patterns of seagrass losses suggested that chronic light reductions, which affected all species, and "die-off" (rapid, unexplained plant mortality), which also affected *T. testudinum*, most likely caused the overall decline. Although the loss rate has slowed considerably in recent years, die-off and regression of seagrasses are still occurring in parts of the bay (see also Chapter 5).

GULF PENINSULA

The Gulf Peninsula region lies between Estero Bay and Anclote Key (Figure 2.3) and includes the coastal waters of Lee, Charlotte, Sarasota, Manatee, Hillsborough and Pinellas counties. This region is a moderate-energy coastline, with extensive sand beaches and barrier islands that enclose two large estuarine embayments (Tampa Bay and Charlotte Harbor) and many smaller lagoons (*e.g.*, Estero Bay, San Carlos Bay, Matlacha Pass, Pine Island Sound, Lemon Bay, Sarasota Bay, and St. Joseph Sound) containing the majority of the region's seagrass beds. Recent seagrass-coverage trends in this region appear somewhat irregular, apparently responding to site-specific situations within the different estuary and lagoon systems.

For Tampa Bay, Sarasota Bay, and the Greater Charlotte Harbor system, the earliest photography-based seagrass coverage maps for the region were developed by the FWRI, using aerial photographs taken in the late 1940s and early 1950s and again in 1982 (Harris *et al.* 1983, Tampa Bay Regional Planning Council [TBRPC] 1984, Janicki *et al.* 1994). Maps were subsequently prepared by the Southwest Florida Water Management District (SWFWMD) for Tampa Bay (for the years 1988, 1990, 1992, 1994, 1996, 1999, and 2002), Charlotte Harbor (1988, 1992, 1994, 1996, 1999, and 2002), Sarasota Bay (1988, 1994, 1996, 1999, and 2002), Lemon Bay (1988, 1994, 1996, 1999, and 2002), and St. Joseph Sound (1999 and 2002) (TBNEP 1996, Kurz *et al.* 2000, D. Tomasko *pers. comm.*). Time series of seagrass coverages based on these maps are shown in Figure 2.4.

In Tampa Bay, approximately 46% (7,452 ha or 18,400 acres) of the existing seagrass coverage was lost between *ca.* 1950 and 1982 (Figure 2.4) from the combined effects of dredging and reductions in water clarity (Haddad 1989). Coverage losses in Tampa Bay over longer time periods are difficult to estimate with any accuracy, because of the sparseness of data and absence of aerial photography prior to *ca.* 1950. Indirect methods suggest, however, that as much as 81% of predevelopment coverage may have been lost during the years 1879 through 1982 (Lewis *et al.* 1991).

Between 1982 and 1996 Tampa Bay regained approximately 2,090 ha (5,160 acres) of seagrass, apparently in response to management efforts that led to reduced nutrient loadings and increased water clarity. Reduced nutrient loadings and increased seagrass coverage were also observed in Sarasota Bay during the same period (Tomasko *et al.* 1996). Seagrass coverage then declined in both estuaries, apparently in response to the heavy rainfall and increased stormwater runoff that occurred during the 1997–1998 *El Niño* event (Johansson 2002a).

Seagrass coverage increased once again in Tampa Bay during the 1999–2002 mapping period, as water clarity improved during the relatively dry years that occurred following the cessation of the 1997–1998 *El Niño* event. During this period the total mapped coverage in the bay increased by 501 ha (1,237 acres), to 10,561 ha (26,078 acres). In Sarasota Bay, on the other hand, the total mapped coverage declined slightly between 1999 and 2002, from 4,799 ha (11,850 acres) to 4,740 ha (11,703 acres). Seagrass coalescence occurred in both estuaries during the 1999–2002 mapping period, through a net increase in the coverage of continuous (as opposed to patchy) seagrass beds (D. Tomasko *pers. comm.*).

The documented increases in seagrass coverage in Tampa Bay and the slight increase in Sarasota Bay between 1982 and 2002 apparently occurred in response to improved management of anthropogenic nitrogen loads to both estuaries (Tomasko *et al.* 1996). Through the Grizzle-Figg Act (403.086 Florida Statutes), the Florida Legislature required that all sewage treatment plants discharging to the two estuaries and their tributaries must provide advanced wastewater treatment (AWT) prior to discharge. The City of Tampa upgraded its sewage treatment plant to AWT in 1979, greatly reducing the amount of nitrogen entering Tampa Bay from that source. The City of St. Petersburg implemented a wastewater reuse program which almost eliminated its direct wastewater discharges to Tampa Bay. Similar improvements to sewage treatment plants in Pinellas, Hillsborough, Manatee, and Sarasota counties also helped improve water quality in the receiving estuaries. By the early 1990s, water clarity in some of the most degraded portions of Tampa Bay had already begun to improve (Johansson 1991, TBNEP 1996).

Improved management of seagrass communities has been identified as a priority issue in Tampa Bay and Sarasota Bay and is being addressed through broad-based stakeholder groups. Both systems are part of the U.S. EPA's National Estuary Program, which helps to coordinate the management activities of local, state, and federal agencies and the private sector. The Tampa Bay Estuary Program is pursuing a resource-based management strategy that seeks to limit anthropogenic nitrogen loadings at levels needed to achieve its seagrass-coverage goal of 15,400 ha (38,000 acre), representing 95% of the seagrass coverage that was mapped in the Bay in 1950 (TBNEP 1996, Johansson and Greening 2000). The Sarasota Bay National Estuary Program has adopted a technology-based strategy that seeks to control nitrogen loadings through the adoption of "best available technology" for anthropogenic nitrogen sources in the contributing watershed (SBNEP 1995).

Nitrogen-management strategies are effective seagrass restoration tools in Tampa Bay and Sarasota Bay. Because phytoplankton are important sources of light attenuation in both estuaries, by controlling nitrogen inputs, managers can reduce phytoplankton biomass, increase water clarity, and increase the bay-bottom area that receives sufficient sunlight to support seagrasses (*e.g.*, Johansson and Greening 2000). A similar situation appears to exist in Lemon Bay, where phytoplankton are also a major source of light attenuation (Tomasko *et al.* 2001). In Charlotte Harbor, however, light attenuation is affected more by water "color"—naturally elevated levels of dissolved organic matter discharged from extensive wetlands in the Peace and Myakka river systems—than by phytoplankton abundance (McPherson and Miller 1994). Because of its large watershed, Charlotte Harbor also experiences large seasonal and annual variations in fresh-water inflow, producing large fluctuations in salinity that can be stressful to seagrasses (Tomasko and Hall 1999). The nitrogen-based management strategies developed for Tampa Bay and Sarasota Bay may thus have limited applicability for Charlotte Harbor (D. Tomasko *pers. comm.*).

The time series of mapped seagrass coverage in portions of the Charlotte Harbor system is shown in Figure 2.4. Much of the reduction in coverage in Greater Charlotte Harbor (which includes San Carlos Bay, Matlacha Pass, and Pine Island Sound, in addition to Charlotte Harbor Proper) between *ca.* 1950 and 1982 occurred in the southern portion of the system, particularly in Pine Island Sound and San Carlos Bay. This reduction has been linked, circumstantially, to a series of large-scale anthropogenic activities that occurred in the area during the 1960s, including dredging of the Intracoastal Waterway, construction of the Sanibel causeway, and installation of dam and lock structures in the lower Caloosahatchee River (Harris *et al.* 1983). In addition to direct destruction of seagrass habitats, these projects have been postulated to have indirectly altered the water clarity, salinity, hydrodynamics and flushing characteristics of the area in ways that made it less conducive to seagrass growth and survival (Harris *et al.* 1983). Due to difficulties encountered in interpreting and digitizing the aerial photographs that were taken in the area during the *ca.* 1950 period, however, the coverage values shown for the Greater Charlotte Harbor system in that period in Figure 2.4 should be viewed as rough approximations (Harris *et al.* 1983).

No geographically and technically consistent mapping of seagrass coverage throughout the Greater Charlotte Harbor system has been conducted since 1982. The northern portion of the system—which falls largely within the SWFWMD and is referred to locally as Charlotte Harbor Proper—has been mapped approximately biennially since 1988 by the SWFWMD (Kurz *et al.* 2000). From 1988 through 2002, seagrass coverage in this area fluctuated between 7,200 ha (17,800 acres) and 7,800 ha (19,300 acres), with no apparent upward or downward trends (Figure 2.4). Lemon Bay has been mapped over the same time period and has shown relatively small fluctuations around an average value of 1,058 ha (2,600 acres), with no apparent trends (Figure 2.4).

Mapping data from St. Joseph Sound near Clearwater are available only for the years 1999 and 2002, when an average of 5,840 ha (14,400 acres) were recorded (Figure 2.4).

BIG BEND

The Big Bend region extends from Anclote Key northwestward to Ochlockonee Point in the Panhandle region (Figure 2.3) and includes the coastal waters of Pasco, Hernando, Citrus, Levy, Dixie, Taylor, Jefferson, and Wakulla counties. Zieman and Zieman (1989) note that this portion of the coast is unique in that it is an extensive area, with no offshore barrier islands, where a number of rivers, creeks, and marshes discharge directly into the Gulf of Mexico. It is also one of the few examples of a "zero-energy" coastline, with average breaker heights of 3–4 cm or less and little littoral transport of sand (Murali 1982). Factors contributing to the low-energy characteristics of the area include a wide and gently sloping shelf, divergence of approaching wave trains into a large coastal concavity, the location of the coast in a generally upwind direction, and the wave dampening effects of old submerged beaches and seagrass meadows (Murali 1982).

The region is an environmentally diverse area that can be divided into five subregions (Mattson 2000). The Springs Coast subregion, which extends from Anclote Key northward to the mouth of the Withlacoochee River, is dominated by flows from a series of short, spring-fed river systems: the Weeki Wachee, Chassahowitzka, Homosassa, and Crystal rivers. Concentrations of nitrate nitrogen have been increasing steadily in these rivers in recent decades, due to increasing anthropogenic nitrogen discharges in their highly karstic watersheds and spring recharge areas (Katz *et al.* 1997). The limestone bedrock and sediments of this portion of the coast are rich in carbonates, however, and tend to bind inorganic phosphorus from the water column. Because inorganic phosphorus is less available in the water column, primary production of near-shore aquatic ecosystems are tilted from N-limitation toward P-limitation (Hauxwell *et al.* 2001).

The four subregions north of the Springs Coast subregion are Waccasassa Bay, Suwannee Sound and adjacent coastal waters, Deadman Bay, and Apalachee Bay (Mattson 2000). Discharges from river systems in these subregions tend to be high in color during periods of high flow, a factor that apparently contributes to relatively low seagrass coverage in the vicinity of the river mouths (Mattson 2000).

Although the inshore and offshore seagrass beds of the Big Bend are among the largest in the eastern Gulf of Mexico (Iverson and Bittaker 1986), the region has received relatively little management attention (Mattson 2000). Several mapping surveys have been conducted, but most have covered only a limited portion of the region and have produced highly variable coverage estimates (Mattson 2000). The most extensive, region-wide mapping efforts have been carried out by Iverson and Bittaker (1986) and Sargent *et al.* (1995), producing coverage estimates of 300,000 ha (741,000 acres) and 334,842 ha (827,000 acres), respectively. Neither of these estimates includes the sparse, deep-water seagrass beds that are located offshore. For the entire West Florida Shelf, Fonseca *et al.* (2001) estimated the areal coverage of deep-water *H. decipiens* beds at 0.4 million ha (1 million acres), which would place them among the largest seagrass communities in the world.

In a general sense, the Big Bend area has been described as one of the least polluted coastal regions of the continental United States (Livingston 1990). However, the Fenholloway River—a tributary to Apalachee Bay—is an exception to this generalization, receiving discharges from an industrial facility that are high in color and contain elevated levels of sulfate, BOD, suspended solids and nutrients (Mattson 2000). These discharges have apparently caused localized reductions in water clarity and seagrass coverage in portions of Apalachee Bay (Livingston 1993, Livingston *et al.* 1998).

PANHANDLE

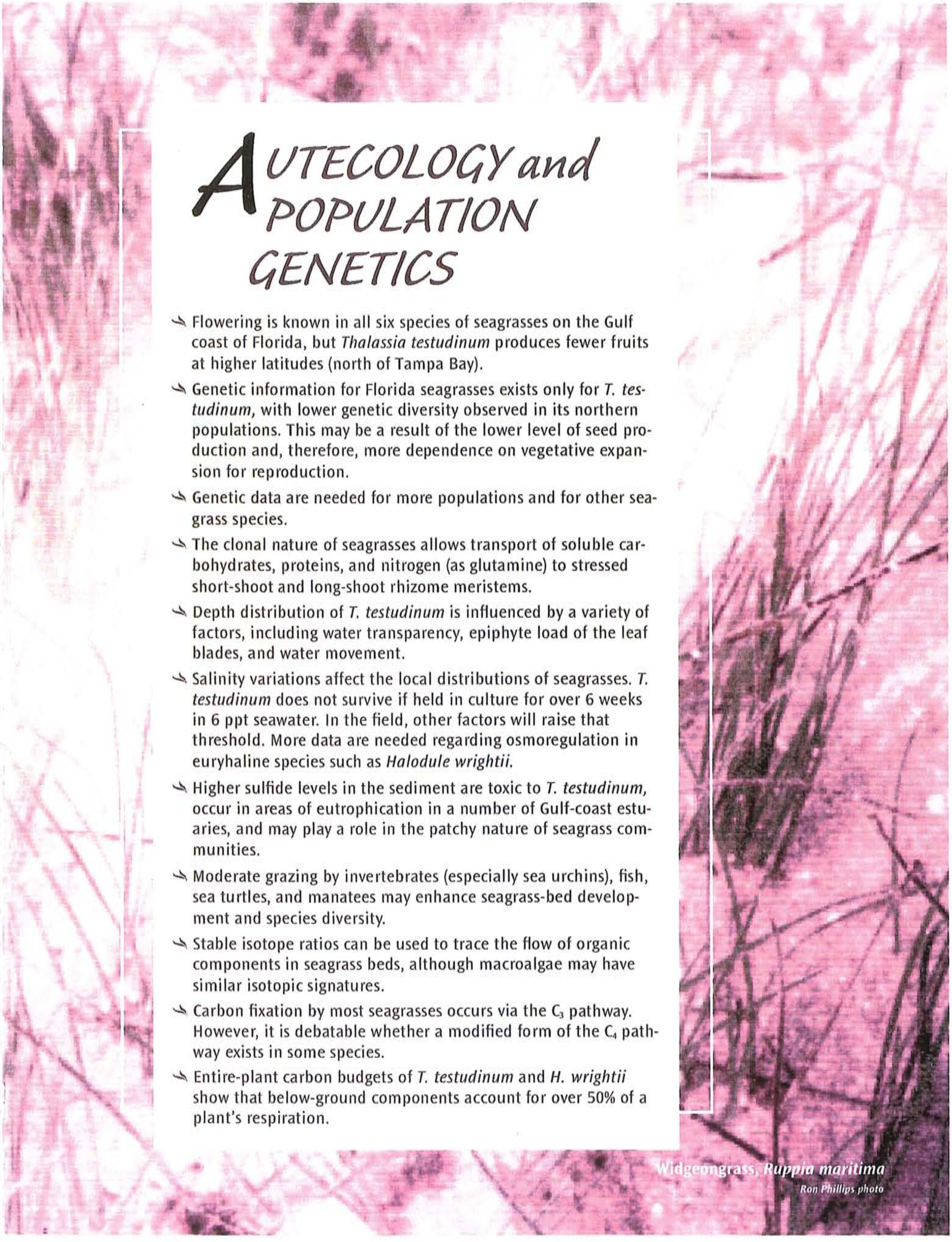
The Panhandle region extends from Ochlockonee Point westward to the Florida-Alabama border (Figure 2.3) and includes the coastal waters of Franklin, Gulf, Bay, Walton, Okaloosa, Santa Rosa, and Escambia counties. It resembles the Gulf Peninsula region in being a moderate-energy coastline with extensive sand beaches and barrier islands enclosing protected estuaries and lagoons (*e.g.*, Apalachicola Bay, St. Joseph Bay, St. Andrew Bay, Choctawhatchee Bay, Santa Rosa Sound, Escambia Bay, and Pensacola Bay) that contain the region's seagrass beds. Like the Big Bend region, it is the subject of limited recent research and management activity.

Based on aerial photography taken in 1992–1993, Sargent *et al.* (1995) estimated that 19,509 ha (48,170 acres) of seagrasses were present in the coastal waters of the Panhandle region. No region-wide coverage estimates have apparently been produced since that time. Lores *et al.* (2000) assessed recent coverage trends in seagrasses and other SAV in the Escambia-Pensacola Bay portion of the region, and provided the following summary:

- SAV in the Escambia-Pensacola Bay System underwent a substantial decline in the late 1940s through the early 1970s;
- Although scientific documentation of SAV distribution since that time is lacking, some observations suggest SAV growth in the oligohaline regions of estuaries in northwestern Florida has shown recent improvements (*e.g.*, in Mobile Bay [Alabama], Escambia Bay, and Perdido Bay);
- Evidence suggests these same areas are also losing SAV in the euryhaline regions;
- Improvements in water quality of the upper bay regions is thought to be leading to recovery of low-salinity seagrasses; and
- Continuing increases in coastal development in the lower bay region, with resulting increased nutrient input and sediment loading/resuspension, may be having an adverse impact on the health and productivity of high-salinity seagrasses such as *T. testudinum*.

AUTECOLOGY and POPULATION GENETICS

- Flowering is known in all six species of seagrasses on the Gulf coast of Florida, but *Thalassia testudinum* produces fewer fruits at higher latitudes (north of Tampa Bay).
- Genetic information for Florida seagrasses exists only for *T. testudinum,* with lower genetic diversity observed in its northern populations. This may be a result of the lower level of seed production and, therefore, more dependence on vegetative expansion for reproduction.
- Genetic data are needed for more populations and for other seagrass species.
- The clonal nature of seagrasses allows transport of soluble carbohydrates, proteins, and nitrogen (as glutamine) to stressed short-shoot and long-shoot rhizome meristems.
- Depth distribution of *T. testudinum* is influenced by a variety of factors, including water transparency, epiphyte load of the leaf blades, and water movement.
- Salinity variations affect the local distributions of seagrasses. *T. testudinum* does not survive if held in culture for over 6 weeks in 6 ppt seawater. In the field, other factors will raise that threshold. More data are needed regarding osmoregulation in euryhaline species such as *Halodule wrightii.*
- Higher sulfide levels in the sediment are toxic to *T. testudinum,* occur in areas of eutrophication in a number of Gulf-coast estuaries, and may play a role in the patchy nature of seagrass communities.
- Moderate grazing by invertebrates (especially sea urchins), fish, sea turtles, and manatees may enhance seagrass-bed development and species diversity.
- Stable isotope ratios can be used to trace the flow of organic components in seagrass beds, although macroalgae may have similar isotopic signatures.
- Carbon fixation by most seagrasses occurs via the C_3 pathway. However, it is debatable whether a modified form of the C_4 pathway exists in some species.
- Entire-plant carbon budgets of *T. testudinum* and *H. wrightii* show that below-ground components account for over 50% of a plant's respiration.



Widgeongrass, *Ruppia maritima*

Ron Phillips photo

SEAGRASS MORPHOLOGY and ANATOMY

Detailed descriptions of seagrass morphology and anatomy can be found in den Hartog (1970), Ancibar (1979), Tomlinson (1980, 1982), and Kuo and McComb (1989). Also see the Appendix, Taxonomy of Florida Seagrasses, in this document. The basic construction of *most* seagrasses (Arber 1920) is an indeterminate horizontal stem (plagiotropic rhizome or long shoot) that periodically produces determinate erect stems (orthotropic rhizomes or short shoots) having leaves and flowers. Adventitious roots develop from both types of rhizome. Rhizomes are usually cylindrical and below the sediment surface in species with robust morphologies. In contrast, rhizomes of species with more delicate morphologies (*e.g., H. decipiens* and *H. johnsonii*) often occur above the sediment surface. Rhizome growth is either sympodial (*e.g., H. wrightii* and *R. maritima*) or monopodial (*e.g., T. testudinum* and *S. filiforme*). Leaves of the Gulf-coast Florida species differ greatly in morphology, being long, wide and thick in *T. testudinum;* long, narrow, and thin in *H. wrightii* and *R. maritima;* long, rigid, and cylindrical in *S. filiforme;* and short, thin, and membranaceous in species of *Halophila.*

The rhizomes of Florida seagrasses are herbaceous, with little fiber tissue. In seagrasses similar to *T. testudinum,* the vascular stele and fiber bundles in the cortexes of the blades, short shoots, and rhizomes are poorly lignified (Dawes 1986). Epidermal cells of seagrass blades lack stomata and associated guard cells, contain most of the blades' chloroplasts, and have a thick outer cell wall covered by a thin, porous cuticle. As determined by uptake studies (Larkum *et al.* 1989), the cuticle apparently does not prevent absorption (*e.g.,* of CO_2, cadmium, or manganese) by the blade. As with those of *T. testudinum,* the epidermal cells of *R. maritima* may be involved in osmoregulation. Epidermal cells of *R. maritima* blades that are grown in higher salinities (*e.g.,* 32 ppt) develop masses of gelatinous polysaccharides and form cell-wall ingrowths that may be involved in ion binding and exchange between the seawater and cytoplasm (Kruzcynski 1994).

SEXUAL REPRODUCTION

Although sexual reproduction is known in all the

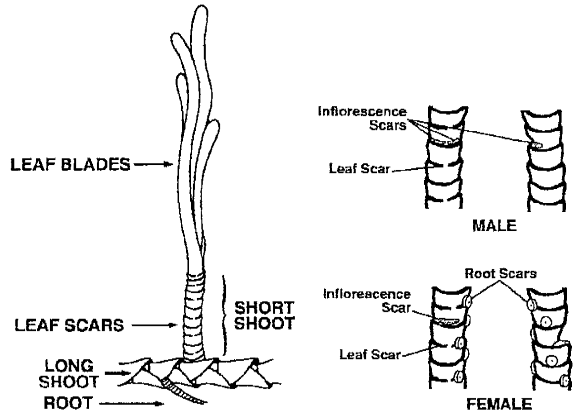


Figure 3.1 *Inflorescence, leaf, and root scars on short shoots of* Thalassia testudinum *(modified from Witz 1994).*

seagrass species of Florida, with the possible exception of *H. johnsonii* (see Appendix), data on flowering and seed production and survival are limited (Ferguson *et al.* 1993). Leaf and inflorescence scars (Figure 3.1) have been used to determine short-shoot age, sex, and frequency of flowering in *T. testudinum* (Cox and Tomlinson 1988; van Tussenbroek 1994; Witz and Dawes 1995), with short shoots that produce female flowers often having narrower leaves than short shoots that produce male flowers (Durako and Moffler 1985). Inflorescence scars on short shoots of *T. testudinum* (Fig 3.1) suggest that abundant flowering occurs in northern areas along Florida's Gulf coast (*e.g.,* St. Joseph Bay and Apalachee Bay) and throughout the Florida Keys (C. Dawes *pers. obs.*), yet flowering and seed production have not been documented for most *T. testudinum* beds along the northern Gulf coast. In contrast, in May or June of each year, thousands of *T. testudinum* seeds may occur in the beach wrack at Mathieson Hammock near Miami and in the wrack lines in the Florida Keys (C. Dawes *pers. obs.;* Lewis and Phillips 1980), and countless more are eaten by birds (Fishman and Orth 1996).

Seagrass flowering and fruiting occur annually between February and August along the Gulf coast of Florida (Phillips 1960c; Durako and Moffler 1987; Witz and Dawes 1995) and on the Caribbean coast of Mexico (van Tussenbroek 1994). Photoperiod does not appear to influence the onset of flowering in *T. testudinum* (Moffler and Durako 1987), *S. filiforme,* or *H. wrightii* (McMillan 1982), as these three species flowered under continuous light. Instead, water temperature influences flower development (Moffler and Durako 1987), and all species in Florida flower within a temperature range of 20°–26°C (McMillan 1982). Lower water temperatures (10° to 18°C) in the winter in the

Tampa Bay area may cause *T. testudinum* to flower later in the spring than it does in the Florida Keys, causing immature fruits to dehisce early in response to rapidly rising water temperatures in May and June (Witz and Dawes 1995).

Seed germination has not been studied in most Florida Gulf-coast seagrass species. *Ruppia maritima* seed germination is influenced by salinity and temperature but not by photoperiod. Seeds collected from the sediment at the mouth of the Weeki Wachee River germinated at all temperatures (17°, 23°, and 39°C) and in 0 and 15 ppt but not 30 ppt salinities. In contrast, seeds from North Carolina germinated in all temperature and salinity combinations (Koch and Dawes 1991a). Studies on fish predation of *R. maritima* seeds demonstrated that they can pass through the gut and thus be dispersed (Agami and Waisel 1988). The importance of seed reserves as an early source of carbohydrate energy for seedlings of *T. testudinum* was proposed by Durako and Sackett (1993). Seedlings had a lower carbon isotopic fractionation ($\delta^{13}C_{plant} - \delta^{13}C_{source}$ = 15.4 ppt) than did one-year-old plants (21.0 ppt), possibly indicating a shift from using carbon reserves in the seed to taking up CO_2 from the water column. However, the one-year-old plants were cultured under artificial conditions and were preconditioned, which may have altered their fractionation level.

ASEXUAL REPRODUCTION and CLONAL BIOLOGY

Vegetative growth by the long-shoot rhizome is thought to be the principal means of expansion for Gulf-coast seagrasses, in light of the curtailment of sexual reproduction explained above. Seagrass short shoots can be regarded as ramets, and the clonal group of ramets connected by long-shoot rhizomes derived from a single propagule is considered to be the genet (see Harper 1990). Rhizome extension is the basis for vegetative expansion in all seagrasses (Tomlinson 1974; Dawes 1998a; Andorfer and Dawes 2002; Dawes and Andorfer 2002).

Two possible advantages in being clonal are the ability to carry out vegetative expansion or foraging (Cain 1994) and the ability to share resources between ramets of the same genet growing in areas of stress or low nutrients (Tomasko and Dawes 1989; Wijesinghe and Handel 1994; Andorfer 2000). Short shoots of *T. testudinum* near Mullet Key in Tampa Bay were isolated from others by severing the long-shoot rhizome on each side of the short-shoots that were then shaded. These short shoots had significantly lower blade growth than did shaded short shoots that were connected to other short shoots (Tomasko and Dawes 1989). Rhizomes adjacent to shaded short shoots were depleted of soluble carbohydrates and proteins, while the rhizome portion beyond the severed short shoots was not, suggesting that sugars and amino acids stored in the adjacent rhizomes could be mobilized.

Laboratory culture studies using the stable nitrogen isotope $^{15}NO_3$ demonstrated that nitrogen in the form of glutamine was translocated from the fourth-oldest ramet of *T. testudinum* to the growing long-shoot rhizome meristem (Andorfer 2000). Further, leaf regrowth, after the four youngest short shoots were clipped, was supported by carbon fixed in the fifth short shoot and transported to it via the rhizome. This high degree of short-shoot integration, over a distance of five ramets, demonstrates the importance of the physiological integration that allows *T. testudinum* to expand through regions of low light or nutrients and to tolerate periods of intense grazing (Andorfer 2000). These studies support earlier findings for *T. testudinum* subjected to weekly clipping of blades (Dawes and Lawrence 1979) and for *S. filiforme* in the Indian River Lagoon subjected to shading of connected and severed short shoots (Rey and Stephens 1996). In the latter study, soluble-carbohydrate levels declined from 26.5% to 18.4% and then stabilized in rhizomes connected to shaded short shoots; this suggests movement of soluble carbohydrate from adjacent non-shaded short shoots, thus showing physiological integration of the genet.

Production of new long-shoot rhizome branches by *T. testudinum* occurs principally at the long-shoot meristem and rarely occurs through branching of the older long-shoot rhizome. Dawes and Andorfer (2002) found that older short shoots were more likely to produce a new long-shoot rhizome than were younger ones and that initiation of rhizomes was suppressed unless the existing long-shoot meristem was removed. The presence of "inactive" or dormant short shoots and rhizomes on *T. testudinum* suggests that a meristem bank may exist in *T. testudinum* beds, as was found on the Caribbean coast of Mexico (van Tussenbroek 1996a). Just what role these inactive short shoots play in vegetative expansion in a seagrass bed is yet unknown. Perhaps, under certain conditions, the dormant short shoots will again resume growth and produce new blades or rhizome meristems. Further, seagrasses differ in rhizome-branch frequency. For example, *H. wrightii* rhizomes branch frequently and grow rapidly, whereas those of *T. testudinum* do not. Species that exhibit more aggressive growth are often chosen for restoration in Florida. Thus *H. wrightii* is more often selected for restoration projects than *T. testudinum*, although the latter species forms the dominant beds in Florida and contains the greatest diversity of species (Zieman and Zieman 1989). The types of growth (foraging) strategies of seagrasses are the same as those of terrestrial clonal plants. Rhizomes of *H. wrightii* show a "guerrilla"-type growth by branching frequently and spreading rapidly. In contrast, *T. testudinum* rhizomes show a "phalanx"-type growth, growing linearly and with few lateral axes (Dawes 1998a).

EVOLUTION and GENETICS

The discovery of fossil seagrasses in the Avon Park formation in Florida (Lumbert *et al.* 1984) indicates that species of *Thalassodendron* and *Cymodocea* occurred with *T. testudinum* in the late Middle Eocene (*ca.* 40 million ybp). These fossils were preserved as carbonized imprints within the bedding planes of a micritic dolomitic limestone in a rock outcrop of the Ocala Arch in central Florida, which contains the oldest exposed rocks in the state. Generic determinations were certain, except for one of the fossils, and species identifications were questionable for two of the fossils. The fossils were identified as *Thalassodendron auricula-leporis* den Hartog, *Cymodocea floridana* den Hartog, *T. testudinum*, *Cymodocea* sp., *Halodule* sp., and an unknown Zosteroid.

Species of *Thalassodendron* and *Cymodocea* presently occur only in the Old World tropics (Indo-Pacific region), indicating that a more diverse seagrass flora existed in the Caribbean Sea in the past. One hypothesis suggests that they disappeared from the Caribbean region when the Central American isthmus elevated and separated the Atlantic and Pacific oceans, changing dominant circulation patterns, which caused Caribbean water temperatures to fall. Evidentially, an extensive and diverse seagrass flora existed in central Florida in the past, judging by the abundance and extent of the fossilized seagrasses and by the diversity of less well-preserved animals from seagrass beds (two families of foraminifera, some bivalves, a bryozoan, a crab carapace, and possibly an ostracod). The fossil findings support the vicariance model of Heck and McCoy (1979), who proposed that the present-day distribution of seagrass species is a product of continental drift, speciation, and extinction. Hypotheses regarding the origin of seagrasses include evolution from salt-tolerant terrestrial shrubs (den Hartog 1970) or from freshwater hydrophilous ancestors (Cox and Humphries 1993).

Comparison of isozymes of various enzymes and molecular-DNA techniques have been used to examine genetic diversity within and between present-day seagrass populations and species in Florida and the Caribbean region. Early isozyme studies examined genetic differences between Caribbean Sea and Gulf of Mexico populations of *T. testudinum*, *S. filiforme*, and *H. wrightii* but found little intraspecific variation (McMillan 1980). The studies supported McMillan's (1978) earlier culture experiments, which revealed that leaf width was influenced by the immediate environment and not by genetic differences between plants.

Being the dominant seagrass in Florida and the Caribbean (Zieman and Zieman 1989), *T. testudinum* has been the principal species to have its genetic diversity measured using isozymes (Schlueter and Guttman 1998) and molecular-DNA approaches (Kirsten *et al.* 1998; Davis *et al.* 1999; Waycott and Barnes 2001). Allozyme loci of 14 enzymes in 18 populations in the lower Florida Keys indicated that asexual reproduction is probably the basis for the low genetic diversity there and for a trend towards genetic uniformity (Schlueter and Guttman 1998). Allozyme and Amplified Fragment-Length Polymorphism (AFLP) analyses were used to compare genetic diversities of *T. testudinum* from two sites in Panama and from another in Bermuda (Waycott and Barnes 2001). The authors found high levels of genetic uniformity, and they suggested that it is due to vegetative-fragment dispersal, even over a distance of 2,700 km.

In contrast to isozyme and allozyme studies, two other molecular DNA studies found a higher

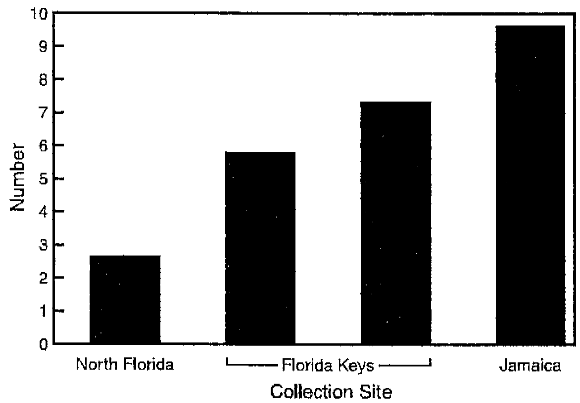


Figure 3.2 *Randomly amplified polymorphic DNA (RAPD) phenotypes within four populations of* Thalassia testudinum. *(Modified from Kirsten* et al. *1998)*

level of genetic diversity within populations of *T. testudinum*, rather than between geographically distinct ones. Randomly Amplified Polymorphic DNA (RAPD) analysis showed high genetic diversity within two proximal Florida Keys populations (*e.g.*, Fiesta Key and Craig Key) and within another northern population off the Steinhatchee River (as Apalachicola Bay in Kirsten *et al.* 1998). Further, almost all samples from an outlier Jamaican population and the two Florida Keys sites were distinct genetic individuals within and between the three populations. This is in contrast to the northern population that had the fewest RAPD phenotypes (Figure 3.2). The lower within-community genetic diversity of northern populations of *T. testudinum* may reflect the limited introduction of new genets (*e.g.*, drift plants) or a low level of flowering and seed production, perhaps because of less-than-optimum water temperatures or water transparencies. A second study on *T. testudinum*, using DNA-fingerprinting techniques, concentrated on clonal variation in populations in Florida Bay and found discrete beds that were not genetically uniform (Davis *et al.* 1999), again emphasizing the role of sexual reproduction in maintaining population genetic variation. Thus, beds of *T. testudinum* in more tropical regions contain a greater number of distinct genets than do beds at higher latitudes. The difference in genetic diversity between tropical and subtropical beds may reflect a lower rate of seed production in more northern sites, as shown for seagrasses in Tampa Bay (Witz 1994; Witz and Dawes 1995). This may explain the lower genetic diversity for the northern population of *T. testudinum* found off the Steinhatchee River (Kirsten *et al.* 1998). The concept that sexual reproduction is less likely to be successful when an organism encounters less-than-optimal temperatures was described by Gessner (1970). However, little is known about flowering and the production of viable seeds on most of the Gulf coast of Florida, with the exception of some data for Tampa Bay and the Florida Keys.

Another study (Angel 2002) using RAPD analysis compared three populations of *H. wrightii* from Texas (Christmas Bay, Corpus Christi) and from Florida (Florida Bay). All individuals appeared to have unique genotypes, with plants from Corpus Cristi more closely clustered to those of Florida Bay, which Angel suggested was due to similar habitats that acted as a selective force. The molecular phylogeny of 11 species of *Halophila* found that *H. decipiens* and *H. engelmannii* were distinct species and that there was a 100% overlap between populations of the former species between populations from Australia, the Caribbean, and Florida (Waycott *et al.* 2002). Further, the internal transcribed spacer (ITS) region of the ribosomal DNA indicated that *H. johnsonii* from the Indian River in Florida could not be distinguished from *H. ovalis* and needs further study.

PHYSIOLOGICAL ECOLOGY

At least five abiotic properties influence the morphological and anatomical adaptations of seagrasses (Dawes 1998a), including the (1) osmotic effects of salt water; (2) availability of dissolved CO_2 and nutrients; (3) intensity and quality of illumination; (4) density (greater than air) and mechanical drag of an aqueous medium; and (5) effects of an aquatic medium on the dispersal of pollen and seeds.

The general physical requirements of five Florida seagrass species were discussed in Phillips (1960a). Seagrasses show physiological adaptations to a variety of abiotic and biotic conditions, including salinity, temperature, water motion, anoxia, nutrient limitation, epiphytes, irradiance, infection, and herbivory (Kuo and den Hartog 1989). The most-studied factor has been the relationship between light and the depth distribution of seagrasses. Nevertheless, other physical, geological, and chemical characters must be examined to explain the patchy distribution of seagrasses on the Gulf coast of Florida (Koch 2001). Koch identified

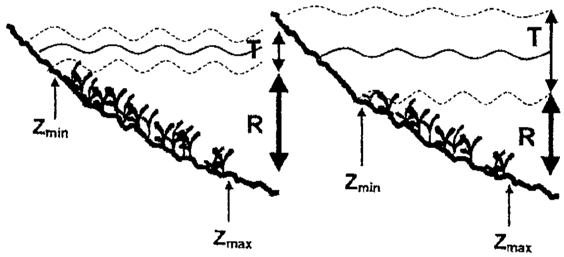


Figure 3.3 *Influence of tidal range on seagrass depth distribution. Minimum depth is deeper with greater tidal range (Koch 2001). Reprinted with permission from Estuarine Research Federation.*

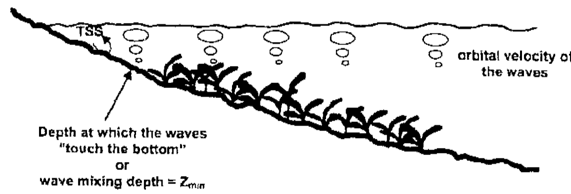


Figure 3.4 *Influence of wave energy on seagrass depth distribution. Greater wave energy and deeper wave-mixing depths result in deeper minimum depths (Koch 2001). Reprinted with permission from Estuarine Research Federation.*

tidal amplitude (Figure 3.3) and wave energy (Figure 3.4) as two factors that influence seagrass depth distribution. Tolerances to common abiotic factors may differ between populations of a species from different environments, as shown for *R. maritima* grown from seed (Koch and Dawes 1991b). Different strains grown from seeds collected in the Weeki Wachee River estuary and from North Carolina had growth rates that were similar under different combinations of temperature and photoperiod but differed with regard to salinity. This was also reported in earlier studies for other species (McMillan 1979, 1984). In those studies, different strains of *T. testudinum, S. filiforme,* and *H. wrightii* showed different tolerances to temperature, and these tolerances were often related to distinct environmental origins. These findings suggest that transplanting from one area to a different site at greater distances (*e.g.,* seeds from Biscayne Bay to Tampa Bay) may not be as successful as when using local plants.

A large global-level literature base shows the critical effects of water quality on the presence, growth, and vitality of seagrasses. Adequate light transmission is vital to the presence of seagrasses and affects the density and biomass of seagrasses at all depths (Dixon and Leverone 1991; Duarte 1991; Johansson 1991; Kenworthy and Haunert 1991; Lapointe and Clark 1992; Tomasko 1992, 2002; Lapointe *et al.* 1994; Fletcher and Fletcher 1995; Kenworthy and Fonseca 1996; Kurz *et al.* 1999, 2000; Dixon 2000; Neely 2000). Depth determinations (±10 cm) can be obtained with a mapping-grade differential Global Positioning System, carrier-phase equipment and surveyed benchmarks (Johansson 2002b). In Tampa Bay, the deep edges for *H. wrightii* ranged from –0.30 to –0.76 m below mean low water (MLW), from –1.19 to –1.96 m for *S. filiforme,* and from –0.57 to –1.73 m for *T. testudinum.* The maximum depth of *T. testudinum* at Port Manatee in Tampa Bay was –1.6 m, in agreement with the above determinations carried out before the 1997–1998 *El Niño* event (Dixon and Leverone 1995). The shallowest deep edges for all three species occurred at the northernmost sites, and the deepest deep edges were near the mouth of Tampa Bay, where more oceanic (clear water) conditions exist.

Neely (2000) demonstrated an inverse relationship between light reduction and short-shoot numbers for *H. wrightii* in Tampa Bay. Leaves on plants exposed to a 43% light reduction were longer than those on shoots in control plots or in other light-reduction treatments. Her experiments showed that loss of biomass was a result of winter die-back and also occurred with a >60% reduction in light. The data showed that epiphytes and surface scattering of light must be accounted for when calculating carbon budgets. Durako and Hall (1992) found that for *T. testudinum* the carbon supply became nonlimiting when light was reduced to levels that limited photosynthetic rates. Tomasko (1992) demonstrated that *H. wrightii,* when growing under a canopy of *T. testudinum* leaves, had longer rhizome internodes, less frequent branching, and lower above-ground to below-ground biomass ratios than when growing alone. Studies by Sand-Jensen (1977, 1990), Cambridge *et al.* (1986), and Tomasko and Lapointe (1991) showed that heavy epiphyte loads on seagrass leaves are indicative of nutrient over-loading in the water column and, therefore, eutrophication, *i.e.,* poor water quality (see Chapter 5). In addition to the adverse effects of nutrient-enriched water on photosynthetic functioning of seagrass leaves, increased levels of nutrients can result in high epiphyte loads that shade and weigh down the leaves, further lowering them in the water column.

Table 3.1 Light requirements of Florida seagrasses.

Species and Sites	Minimum Light Requirement (percentage of total surface irradiance)	Reference
Thalassia testudinum		
Big Bend area, FL	15.3%	Iverson and Bittaker (1986), as reported by Duarte (1991) and by Dennison *et al.* (1993)
Northwest Cuba	23.5%	Duarte (1991)
Puerto Rico	24.4%	Duarte (1991)
Charlotte Harbor, FL	20%	Tomasko and Hall (1999)
Tampa Bay, FL	22.5%	Dixon and Leverone (1995)
Tampa Bay, FL	20.1% (annual mean)	Dixon (2000)
Corpus Christi Bay, TX	14% (4% survival after 12 months)	Czerny and Dunton (1995)
Syringodium filiforme		
Florida Bay, FL	18.3%	Iverson and Bittaker (1986) as reported by Duarte (1991)
Indian River Lagoon, FL	17.2%	Duarte (1991) *pers. comm.* from J. Kenworthy (1990)
Indian River Lagoon, FL (southern region)	24%–37%	Kenworthy and Fonseca (1996)
Halodule wrightii		
Indian River Lagoon, FL	17.2%	Dennison *et al.* (1993) *pers. comm.* from J. Kenworthy (1990)
Florida Bay, FL	10%–20%	Fourqurean and Zieman (1991)
Laguna Madre, TX	7%–23%	Tomasko and Dunton (1991); Dunton (1994); Czerny and Dunton (1995)

The relationship between light, both quantity and quality, and the depth at which seagrasses grow was the subject of two workshops in Florida in the 1990s, one sponsored by NOAA (Kenworthy and Haunert 1991) and the other by the Indian River Lagoon National Estuary Program (Morris and Tomasko 1993). Even though they can grow under high irradiences, seagrasses are regarded as shade plants (Hillman *et al.* 1989), with compensation values (I_c) of 25 to 50 µmole-photons m^{-2} s^{-1} and saturation irradiances (I_k) of <200 µmole-photons m^{-2} s^{-1}. Studies comparing photosynthetic responses of seagrasses to different irradiance levels (*i.e.*, I_c, I_k, and P_{max} levels) often show a relationship to temperature and salinity, as seen for two species of *Halophila* (Dawes *et al.* 1989). For example, the estuarine, intertidal populations of *H. johnsonii* in the Indian River Lagoon tolerate a wide range of temperatures (10°, 20°, and 30°C) and salinities (15, 25, and 35 ppt) and did not become photoinhibited by high photosynthetically active radiation (PAR; *ca.* 500 µmole-photons m^{-2} s^{-1}). In contrast, *H. decipiens* from deeper, nonestuarine Gulf-coast populations were intolerant of a 10°C temperature, 15 and 25 ppt salinity, and PAR above 300 µmole-photons m^{-2} s^{-1} (Dawes *et al.* 1989).

Depth distributions of Florida's seagrasses are governed by PAR levels in Tampa Bay (Miller and McPherson 1995; Dixon and Leverone 1995, 1997; Dixon 2002) and the Indian River Lagoon (Gallegos and Kenworthy 1996). Recent work has demonstrated more specific light requirements for the dominant seagrass species (Table 3.1). PAR levels measured at the deep edges of *T. testudinum* beds in Tampa Bay were significantly higher than the required average light level of 11% (of surface value) proposed for seagrasses by Duarte (1991). Also, *T. testudinum* in Florida Bay (Fourqurean and Zieman 1991) and Caribbean seagrasses (Onuf 1994) required at least 22% of surface PAR levels, when whole-plant requirements and average daily irradiances were considered. Continuous *in situ* measurements of underwater PAR levels for one year at the shallow and deep edges of four *T. testudinum* beds in Tampa Bay also indicated the

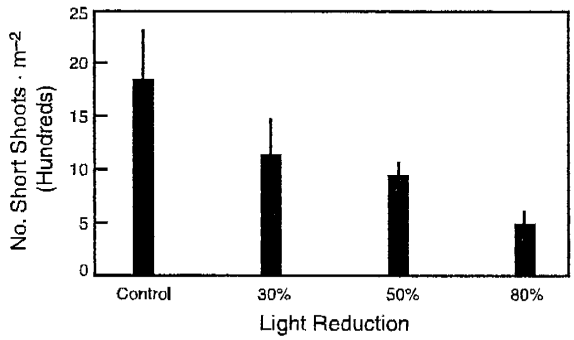


Figure 3.5 *Average density (short shoots m*$^{-2}$*) of* Halodule wrightii *at control and three increasing levels of shading (30, 50, 80%) in Tampa Bay seagrass beds (± 1 S.D.). (Modified from Neely 2000)*

maximum depth limit in the bay occurred at about 20.5% of subsurface PAR (Dixon and Leverone 1995, 1997). Another study on irradiance in the more oceanic waters at the mouth of Tampa Bay showed that, using 20% light penetration as the threshold, sufficient light was available for *T. testudinum* beds to extend to two meters of depth (Miller and McPherson 1995). That depth is similar to measured seagrass-bed depth limits, which ranged from 1.98 to 2.37 m in estuaries (Dixon and Leverone 1995). Evaluating short-shoot density, Neely (2000) found that shallow, monospecific beds of *H. wrightii* showed a direct relationship between density and irradiance level at Mullet Key in Tampa Bay (Figure 3.5). The same level of density reduction with shading occurred in the cool and warm seasons, although summer short-shoot densities were almost twice those of the winter densities, indicating the critical effect that underwater irradiance has on seagrasses. Similar declines in leaf growth, short-shoot density, biomass and primary production have been caused by shading *T. testudinum* (Lee and Dunton 1997; Kraemer and Hanisak 2000) and *H. wrightii* (Czerny and Dunton 1995).

Light attenuation that limits seagrass depth distribution can result from a variety of sources (Kenworthy and Haunert 1991; Morris and Tomasko 1993). One factor governing light effects on seagrass depth distribution is the level of epiphytic biomass. The average annual attenuation by epiphytes on water-column PAR levels available to *T. testudinum* blades was from 32%–47% in Tampa Bay, 40%–56% in Sarasota Bay, and 21%–44% in Charlotte Harbor (Dixon and Leverone 1997). Variation in epiphyte loads on *T. testudinum* blades resulted in a 7%–67% seasonal range in PAR attenuation in Tampa Bay, 13%–99% in Sarasota Bay, and 6%-89% in Charlotte Harbor (Dixon and Leverone 1997). Thus, in determining seagrass light requirements, seasonal levels of epiphyte loads should be considered in addition to the actual PAR levels (Dixon 2002).

Other factors shown to have critical effects on light available to seagrass, in a light model developed for the Indian River Lagoon, were total suspended solids (*e.g.*, tripton or non-algal particulate matter) and chlorophyll *a* concentration, which were the dominant causes of light attenuation affecting seagrass depth distribution (Christian and Sheng 2002). Attenuation of light by turbidity is a critical abiotic factor governing availability of light to seagrasses, as shown by the effects of dredging in the Laguna Madre of Texas that resulted in the decline of *H. wrightii* (Onuf 1994). Depth distribution, biomass, and photosynthetic responses were compared for shallow and deep populations of *T. testudinum* on the Gulf coast of Florida (Dawes and Tomasko 1988; Dawes 1998b). In general, biomass decreased while chlorophyll *a* increased with greater depth (Table 3.2), and the ratio of above- to below-ground biomass remained similar.

Also, light quality (*i.e.*, wave-length distribution) and PAR affect seagrass growth. Exposure of *H. wrightii*, *H. engelmannii*, and *S. filiforme* to UV-A and PAR irradiation resulted in photosynthesis inhibition in the latter species (Trocine *et al.* 1982). A low ratio of red:far-red wave lengths reduced branching and node formation in *R. maritima*, a response that may allow plants shaded by larger plants to escape by emphasizing horizontal rhizome elongation (Rose and Durako 1994). A similar response by *H. wrightii*, when shaded by *T. testudinum*, was noted in the Florida Keys (Tomasko 1992).

Photosynthetic responses have been used to evaluate seagrass tolerances to salinity and temperature variations (Dawes *et al.* 1987, 1989). Estuarine populations of *H. engelmannii* and *H. johnsonii* from the Gulf coast and Indian River Lagoon of Florida, respectively, had broader tolerances to a range of temperatures and salinities when compared to Gulf-coast oceanic populations of *H. engelmannii* and *H. decipiens*. Differences in photosynthetic factors (*e.g.*, P_{max}, α, I_k) were evident with freshly collected plants and after culturing

Table 3.2 Photosynthetic characters (P_{max}, alpha, I_c, total chlorophyll), primary production, and leaf growth (± S.D.) of *Thalassia testudinum* in deep- and shallow-water populations at two Florida Gulf-coast sites.

Site	Leaf Relative Growth Rate ($mg\ dw \cdot g\ dw^{-1} \cdot d^{-1}$)	Primary Production ($g\ dw \cdot m^{-2} \cdot d^{-1}$)	Total Chl ($mg \cdot g\ dw^{-1}$)
Egmont Key			
Shallow (–0.4 m)	28.7 (5.4)	11.71	4.86 (0.99)
Deep (–2.5 m)	27.4 (6.3)	8.17	3.92 (1.28)
Anclote Key			
Shallow (–1.0 m)	31.1 (9.3)	1.39	3.00 (0.84)
Deep (–2.5 m)	20.5 (0.3)*	1.00	2.39 (0.70)

Site	P_{max} ($mg\ O_2 \cdot g\ dw^{-1} \cdot h^{-1}$)	I_c ($\mu E \cdot m^{-2} \cdot s^{-1}$)	Alpha (P_{max}/I_c)
Egmont Key			
Shallow	4.54 (0.70)	39	0.063
Deep	6.31 (1.21)	45	0.069
Anclote Key			
Shallow	6.08 (0.92)	32	0.103
Deep	2.60 (0.33)*	24	0.097

Modified from Dawes and Tomasko (1988). * = probability <0.01

plants under common garden conditions for a number of weeks using various combinations of temperature and salinity. Salinity tolerance of *T. testudinum* from San Carlos Bay in the Caloosahatchee River Estuary in southwest Florida was assessed using long-shoot rhizomes bearing two to four short shoots (Doering and Chamberlain 2000). After a four-week acclimatization period in ambient seawater (35 ppt) in the laboratory, salinity was changed daily in 1.5 ppt increments.

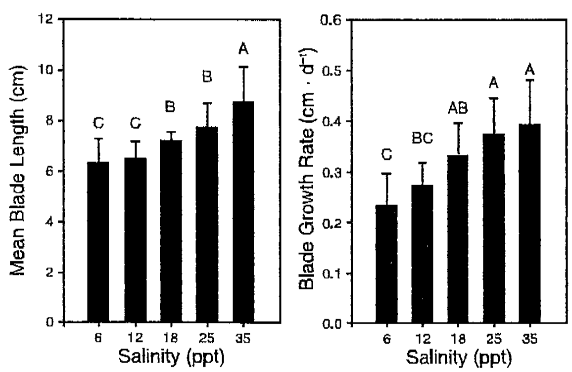


Figure 3.6 *Blade length and mean blade elongation rates for* Thalassia testudinum *cultured for 43 days in salinities ranging from 6 to 35 ppt. Letters indicate statistical differences between treatments and means, different letters are statistically different* ($P < 0.05$). *(Modified from Doering and Chamberlain 2000)*

Regardless of other variables, blade length decreased (Figure 3.6) and blade production ended after 43 days in the lowest (6 ppt) salinity. Blade length was positively correlated with salinity after 43 days of exposure. Also, the number of blades per short shoot and blade biomass were similar in 12, 18, 25, and 35 ppt salinities after 43 days of exposure (data not shown).

Salinity affects the local distribution of seagrass species on the Gulf coast of Florida (Phillips 1960b, c), with euryhaline species such as *H. wrightii* able to grow in a broad range of salinities (*e.g.*, 5 to 55 ppt; Dunton 1996). However, the effect on seagrass distribution due to salinity alone is difficult to separate from the effects of other factors, as shown in the general reduction of seagrass beds throughout Tampa Bay after the 1997–1998 *El Niño* event. The 1998 rainfall increase resulted in higher levels of dissolved inorganic nitrogen, chlorophyll *a* (phytoplankton), and color content (tannins) from extensive runoff into the bay (Johansson 2002a), which in turn reduced PAR penetration in the water column. In addition, the increase in rainfall directly lowered salinities, with Middle Tampa Bay salinities declining from a winter high of 30 ppt to 10 ppt by March and then to less than 5 ppt over a two-week period in April, 1998 (Dawes, unpublished data). Therefore, com-

Table 3.3 Structural features of *Ruppia maritima* epidermal cells from a single monoculture grown in 10 ppt and 32 ppt salinity.

Component of Cell Volume	Mean (± SD) at 10 ppt	Mean (± SD) at 32 ppt	Significance Level
Vacuolar volume	28.4% (± 19.8)	9.5% (± 9.3)	$P = 0.03$*
Cell membrane invagination	0.5 μm (± 0.7)	5.0 μm (± 4.2)	$P = 0.001$**
Polysaccharide volume	6.7% (± 3.5)	25.0% (± 13.4)	$P = 0.03$*
Chloroplast volume	8.6% (± 4.8)	13.3% (± 5.1)	$P = 0.02$*
Mitochondria number	12.2 (± 8.9)	17.3 (± 5.5)	$P = 0.03$*

Modified from Kruzcynski (1994). * = significant; ** = highly significant.

bined with higher nutrient loadings and turbidity-caused light attenuation, lower salinities resulted in a die-back of *T. testudinum* in Cockroach Bay by June 1998 and a reduction in seagrass acreage throughout west-central Florida coastal areas (see Chapter 2).

Seagrass osmoregulatory responses to changing salinities involve structural and physiological changes. The epidermal cells of *T. testudinum* and *R. maritima* show cell-wall and organelle modifications when grown or collected in salinities above 30 ppt (Jagels and Barnabas 1989). In *R. maritima*, clones of a single genetic strain cultured in 32 ppt had convoluted cell membranes, smaller vacuoles, and numerous mitochondria associated with the cell membrane (Table 3.3). Also, plasmodesmata were not evident between the epidermal and cortical cells, and a significant increase occurred in acidic mucopolysaccharides associated with the inner cell wall (Kruzcynski 1994). Clones from the same genetic strain of *R. maritima* did not show any of the above features when cultured at a lower salinity (*ca.* 10 ppt). The increase in cell membrane surface area and associated mitochondria are characteristic of cells active in osmoregulation, and acidic carbohydrates may be involved in ion transport and binding (Dawes 1998a). In addition, osmotic roles of the amino acids proline, alanine, and glutamate have been identified in seagrasses (Pulich 1986; Adams and Bate 1994). Pulich (1986) reported that proline functions as an organic osmoticum in *R. maritima, T. testudinum,* and *H. wrightii,* and alanine serves that role in *H. engelmannii.*

Data on temperature effects on seagrasses are limited to studies examining flowering and seed germination (see earlier discussion) and from a study of leaf-blade production near an electricity-generating plant (Barber and Behrens 1985). In the latter study, the productivity of *S. filiforme* increased in cooler months and decreased in warmer months in areas where water temperatures were enhanced by thermal pollution, whereas *T. testudinum* showed little or no response.

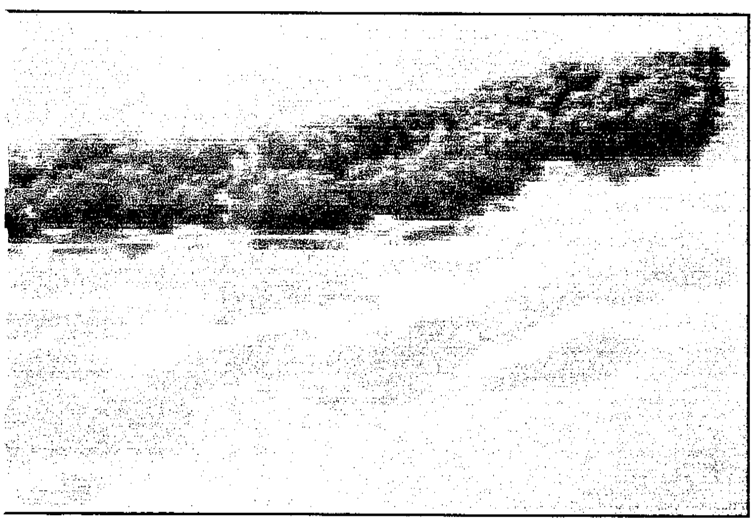
Water movement influences the spatial distribution of seagrass beds, in addition to the effects on depth distribution from tidal and wave activity (see also Chapter 5). Water velocities, degree of exposure to waves, and relative water depths strongly affect the distribution of *H. wrightii* and *Z. marina* beds near Beaufort, North Carolina (Fonseca and Bell 1998). Water movement, expressed as blade-friction velocities ($u_* = cm\ s^{-1}$), reduced boundary-layer effects around the leaf, and photosynthetic rate increased in *T. testudinum*, up to a current velocity of 0.25 cm s^{-1} (Koch 2001). In addition, increased water movement causes a decrease in concentration of sediment sulfide, a phytotoxin. Further, seedlings of *T. testudinum* collected in the Florida Keys showed optimum growth under intermediate flow rates ($u_* = 0.3$ cm s^{-1}), whereas stagnant water ($u_* = 0.0$) contributed to lower biomass possibly because of increased sulfide levels, and high flow rates ($u_* = 1.0$ cm s^{-1}) reduced nutrient availability in the sediment pore water (Koch 1999a). Back-and-forth wave motion increases nutrient exchange between blades and the water column, in contrast to unidirectional movement or currents (skimming) that flow over *T. testudinum* meadows in the Florida Keys (Koch and Gust 1999). When the flow rate (u_*) equaled 25 cm s^{-1}, the water current began to erode the sand; this caused a 50% reduction in seagrass coverage.

Repeated intertidal exposure, and thus the development of tolerance to desiccation, has been suggested as a causal factor in the ability of

H. wrightii to grow intertidally, where it may form extensive beds, in contrast to the subtidal distribution of *T. testudinum* (Phillips 1960a). However, factors other than desiccation tolerance may play a more critical role in terms of the higher vertical zonation for *H. wrightii*, for example, a greater tolerance to high irradiances and benefits from higher nutrient input from the shore (Björk *et al.* 1999).

Tolerance of exposure to high light levels in shallow or intertidal waters suggests that seagrasses may have evolved photosynthetic mechanisms (*e.g.*, C_4 photosynthesis) that reduce damage by UV radiation or intense PAR. However, photosynthetic mechanisms of all seagrass studied thus far appear to involve carbon-fixation reactions characteristic only of the Calvin cycle (C_3 plants) (Beer *et al.* 1977, 1980; Andrews and Abel 1977; Benedict *et al.* 1980; Durako 1993), with the possible exception of the Mediterranean species, *Cymodocea nodosa* (Beer *et al.* 1980). Carbon fixation in C_3 plants occurs via the Calvin Cycle, in which the enzyme ribulose-1,5-bisphosphate carboxylase-oxygenase (rubisco) initially produces a three-carbon (C_3) compound, phosphoglycerate (Abel and Drew 1989; Beer 1996). However, an earlier study (Benedict and Scott 1976) reported that high levels of labeled carbon (^{14}C-bicarbonate) were incorporated into malate (30%) and aspartate (33%) in *T. testudinum.* These two four-carbon acids are commonly associated with the initial fixation step of the Hatch-Slack pathway of C_4 plants. The process described by Benedict and Scott (1976) for *T. testudinum* is similar to Crassulacean Acid Metabolism (CAM), which prevents loss of fixed carbon (as CO_2) resulting from photorespiration suffered by plants under high light irradiance. Because seagrass lacunae store respired CO_2, determining the level of photorespiration in seagrass blades is difficult, although it appears to be lower than in susceptible terrestrial plants (Abel and Drew 1989). More studies are needed to determine whether any of the six Gulf-coast species have modified C_4 carbon-fixation pathways. Durako (1993) demonstrated that *T. testudinum* can utilize both bicarbonate (HCO_3^-) and carbon dioxide, with relatively efficient HCO_3^- utilization, despite an apparently low affinity for this form of carbon.

Figure 3.7 Stable-carbon isotope values of seagrasses are influenced by adjacent mangroves.



Plants with C_4 photosynthesis have higher (less negative) $\delta^{13}C$ values than those of plants using only the C_3 pathway. It has been shown that seagrasses have $\delta^{13}C$ values similar to those of C_4 plants. The similarity in $\delta^{13}C$ values may be due to diffusional restrictions on carbon movement into the chloroplast in a relatively closed carbon-fixation system rather than reflecting their mode (*e.g.*, C_3 or C_4) of carbon fixation (O'Leary 1988). Overall, average seagrass $\delta^{13}C$ values range between −10 and −11 ppt, showing stable-isotope-ratio signatures that are usually less depleted in ^{13}C than they are in other aquatic primary producers (Hemminga and Mateo 1996). Thus, $\delta^{13}C$ values can be used to trace carbon flow in short-term carbon-allocation and production studies. In contrast to the overall averages for seagrasses given by Hemminga and Mateo, the $\delta^{13}C$ values for *T. testudinum* leaves in south Florida, when growing adjacent to mangroves (Figure 3.7), ranged from −7.3 to −16.3 with stable-isotope ratios of carbon that were similar to those of mangrove detritus (Lin *et al.* 1991). The difference in $\delta^{13}C$ values suggests influence of mangrove detritus on nearby seagrass beds. Macroalgae may have nitrogen stable-isotope ratios similar to those of seagrasses, as shown for $\delta^{15}N$. Using $\delta^{15}N$ values, Dillon *et al.* (2002) determined the sources of nitrogen in Florida. In Sarasota Bay, macroalgae had $\delta^{15}N$ values that averaged +4 per mil greater than those of seagrasses, the higher values being positively correlated with $\delta^{15}N$ values of wastewater discharge and being similar to macroalgae $\delta^{15}N$ values near populated areas in the Florida Keys.

Seagrasses facilitate the transport of inorganic carbon from seawater to the chloroplasts of their epidermal cells to make up for slow CO_2 diffusion rates and low CO_2 levels in water, as well as for the low affinity of rubisco for CO_2 when the lacunae have high concentrations of O_2 (Beer 1996). More importantly, seagrasses can use HCO_3^- from seawater via carbonic anhydrase-catalyzed extracellular conversions. Unlike seaweeds, which have photosynthetic rates that are saturated by present-day CO_2 levels, seagrasses continue to be CO_2-limited (Beer and Koch 1996). The authors suggest that when seagrasses colonized the sea in the Cretaceous, CO_2 levels were higher. With atmospheric CO_2 levels again increasing, the authors suggest that nearshore beds may expand (but see Beer *et al.* 2003). However, CO_2 concentration in seawater need not be a limiting factor to seagrass growth under low irradiance conditions, as shown by Durako and Hall (1992). Using $\delta^{13}C$ values, they reported that CO_2 concentration in natural seawater was not limiting for *T. testudinum* under low light when photosynthetic rates were low, a relationship that may be relatively common in turbid water.

Entire-plant carbon budgets have been measured for *T. testudinum* in Florida Bay (Fourqurean and Zieman 1991) and for *H. wrightii* in Tampa Bay (Neely 2000). Below-ground biomass (roots, rhizomes, and short shoots) of *T. testudinum* accounted for 85% of the standing stock and 57.5% of total-plant respiration (Fourqurean and Zieman 1991). In contrast, below-ground biomass of *H. wrightii* ranged from 94% (winter) to 69% (summer) in Tampa Bay, with an above-ground productivity of 0.25 g C m^{-2} d^{-1} in September (Neely 2000).

Tomasko and Dunton (1995) compared four methods (blade clip-and-reharvest, above-ground biomass values, leaf-production turnover rates, and below-ground:above-ground-biomass ratios) for estimating diel rates of primary production in *H. wrightii* populations of Texas. The whole-plant biomass and leaf-turnover approaches appeared to be useful tools for estimating productivity in *H. wrightii*. The blade clip-and-reharvest method devised by Virnstein (1982) for determining primary production in narrow-bladed seagrasses such as *H. wrightii*, underestimated primary productivity. Further, they concluded that the H_{sat} model that calculates total PAR for a photoperiod was reliable and accurate in the prediction of daily carbon gain. However, they stated that although the *in situ* measurement of underwater light levels and P vs. I parameters, as used in Zimmerman *et al.* (1994), is a more rigorous approach for calculating primary production, it requires a large investment of time and resources.

Because of their conspicuous roles in productivity and biomass generation, both the organic composition and the caloric values of seagrasses have been studied (Dawes 1998a). Annual mean caloric values per gram of dry weight (g dry wt) for leaves, short shoots, and rhizomes of *T. testudinum* were 10–13, 8–11, and 12–14 kJ, respectively. Similar values were obtained for *S. filiforme* (10–13, 10–14, and 15–16 kJ, respectively) and *H. wrightii* (13–15, 12–13, and 14–16 kJ, respectively). Another study in seagrass beds between Tarpon Springs and Cedar Key estimated that available kilocalories ranged from a 16-month low of 344 to a high of 1,837 $kcal^{-1}$ m^{-2}, with the highest SAV biomass and caloric values occurring in the late spring and summer (Dawes *et al.* 1987).

Dawes (1998a) found that lipid levels for *T. testudinum, S. filiforme,* and *H. wrightii* were low, ranging from <0.1% to 6.3% of the dry weight for various organs. Soluble protein ranged from 5% to 22% of the dry weight, with leaves having the highest content in all three species. Soluble carbohydrates ranged from 6% to 54% of the dry weight, with rhizomes having the highest levels. Soluble protein and soluble carbohydrate levels show pronounced seasonal and species variations, as summarized by Zieman and Zieman (1989) and Dawes (1998a).

Rhizomes, followed by short shoots, are the principal storage organs for soluble carbohydrates and proteins in *T. testudinum, S. filiforme,* and *H. wrightii* (Dawes and Lawrence 1980) and in *H. engelmannii* (Dawes *et al.* 1987). Further, rhizomes are the source of soluble carbohydrates and proteins for regrowth of cropped blades and for initiation of spring blade growth in *T. testudinum* (Dawes and Lawrence 1979, 1980; Tomasko and Dawes 1989). In a review of carbon, nitrogen, and phosphorus content in the leaves of 27 seagrass species, Duarte (1990) found that they accounted for 34%, 2%, and 0.2% of the dry weight, respectively, with a mean C:N:P ratio of 474:24:1. Although the cell walls of seagrasses contain lignin, celluloses, and hemicelluloses, they are in lower concentrations than in terrestrial monocots (Table 3.4). Soluble, nonstructural carbohydrates (hemi-

Table 3.4 Cell-wall constituents of seagrass leaves, including lignin, cellulose, and soluble carbohydrates.

Species	Site (Ref.)	Lignin	Cellulose	Sol. Carb.
Thalassia testudinum	Florida (1)	0.2–2%	18–32%	1–9%
Syringodium filiforme	Florida (1)	1–3%	19–26%	10–16%
Halodule wrightii	Florida (1)	2–4%	25–33%	4–14%
H. uninervis	Gulf of Acaba (2)	<1%	41%	–
Halophila stipulacea	Gulf of Acaba (2)	2%	36%	–
H. ovalis	Gulf of Acaba (2)	<1%	33%	–
Heterozostera tasmanica	Philip Bay (3)	5%	20%	–

Modified from Dawes (1986). 1. Dawes (1986); 2. Baydoun and Brett (1985); 3. Webster and Stone (1994).

celluloses) can account for 1%–16% of cell-wall dry weight in seagrass blades, whereas structural cellulose and lignin account for 18%–40% and 0.2%–5% respectively. By comparison, tropical grasses such as tall fescue (*Festuca arundinacea* Schreb.) and Bermudagrass (*Cynodon dactylon* (L.) Pers.) have 37% and 40% hemicellulose, 32% and 27% cellulose, and 10% and 6% lignin per g dry wt^{-1}, respectively (Dawes 1986). The adaptations of seagrasses to a hydrophytic environment are seen in their flexible blades (*i.e.*, few fiber bundles) and low amounts of lignin. Perhaps the brief life spans of leaves of many seagrass species, *ca.* 15 days in *T. testudinum* (Witz and Dawes 1995; van Tussenbroek 1996b), may not allow time for significant production of lignin to occur, compared to the long leaf life spans (months) of terrestrial plants, thus making seagrass blades more edible to grazers.

RHIZOSPHERE and SEDIMENT DYNAMICS

Seagrasses serve as sediment traps by acting as baffles, causing sediment-laden water to slow and drop its sediment as shown for seagrasses of Florida Bay (Prager and Halley 1999). Even species with diminutive morphologies, such as *H. decipiens*, can reduce sediment movement (Fonseca 1989). However, studies in *T. testudinum* beds in Tampa Bay show that sediment resuspension does occur because of tidal currents, so these communities are both sinks and sources of suspended matter (Koch 1999b).

Seagrasses modify the anaerobic sediment in which they grow. Roots and rhizomes release oxygen translocated from the shoot, cause bioturbation of the soil, and add organic matter via decomposition (Moriarty and Boon 1989). Chemical changes wrought by the below-ground components are critical for plant survival because high levels of sulfides in anoxic reducing sediments are toxic to plants (Erskine and Koch 2000; Koch and Erskine 2001; Carlson *et al.* 2002). The above-cited experiments created sediment sulfide concentrations up to 13.0 mM; natural sulfide levels of healthy seagrass beds in Florida Bay average <2 mM, whereas in areas of seagrass die-off, the phytotoxin averages 4–10 mM (Carlson *et al.* 2002). Some evidence exists that die-off of overdeveloped beds of *T. testudinum* in Florida Bay may be due partly to lowering of plant resistance to the parasite *Labyrinthula* sp. during periods of increased environmental stresses such as high salinity, high or low temperatures, hypoxia, and high sediment sulfides (Durako 1994; Blakesley *et al.* 2002; see Chapter 5). Evidence for sulfide toxicity was found when sulfide addition (6 mM) in tank cultures was combined with high salinity and temperature over a period longer than 28 days (Koch and Erskine 2001), thus mimicking die-off conditions in Florida Bay. Carlson *et al.* 2002 suggested that the higher sensitivity of *T. testudinum* to sulfide levels than that of *H. wrightii* may be due to the former species having a higher below- to above-ground biomass ratio. They also reported high sediment-sulfide levels in other estuaries, including Sarasota Bay, which may help explain the patchy distribution of seagrass beds (Figure 3.8). This suggests that carbonate sediments, as found in Florida Bay, are not the only type of substrate that contain high sulfide concentrations and that seagrass losses (but not die-off) in other areas on Florida's Gulf coast may also reflect sediment conditions. The release of oxygen into its rhizosphere by *T. testudinum* and the resultant decline in sulfides (converted to sulfates) was shown in seagrass beds in Laguna Madre, Texas (Lee and Dunton 2000a).

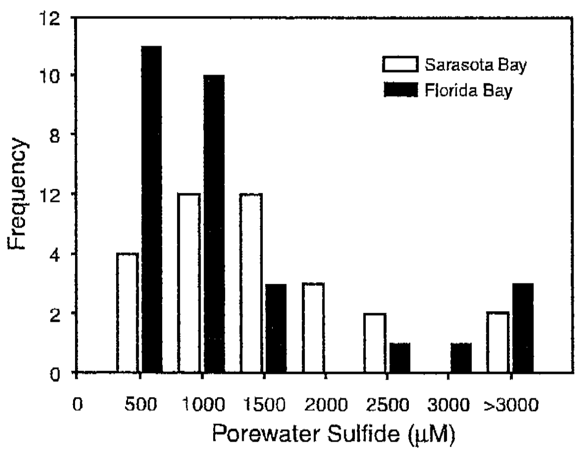


Figure 3.8 *Frequency distribution of pore-water sulfide concentrations in carbonate sediments of Florida Bay (Rabbit Key Basin) and in siliceous, terrigenous sediments of Sarasota Bay (Carlson* et al. *2002).*

Much of the sulfide in anoxic sediments derives from the activities of sulfate-reducing microorganisms. Many microbial associations in the bulk soil and with the plant's roots can provide a means for obtaining scarce nutrients. For example, fungal associations (mycorrhizal) might provide phosphorus or micronutrients. Nielsen *et al.* (1999) hypothesized that the nature of seagrass sediments restricts the development of vesicular-arbuscular mycorrhizae (VAM) because they could not find the association in the rhizosphere of *T. testudinum*, in contrast to their finding that VAM are associated with submergent and emergent freshwater angiosperms. Because they did not find any (VAM) associations with the roots of *T. testudinum*, Nielson *et al.* (1999) suggested that formation of the association was restricted by the combined effects of highly anaerobic nature and high salinity of seagrass sediments.

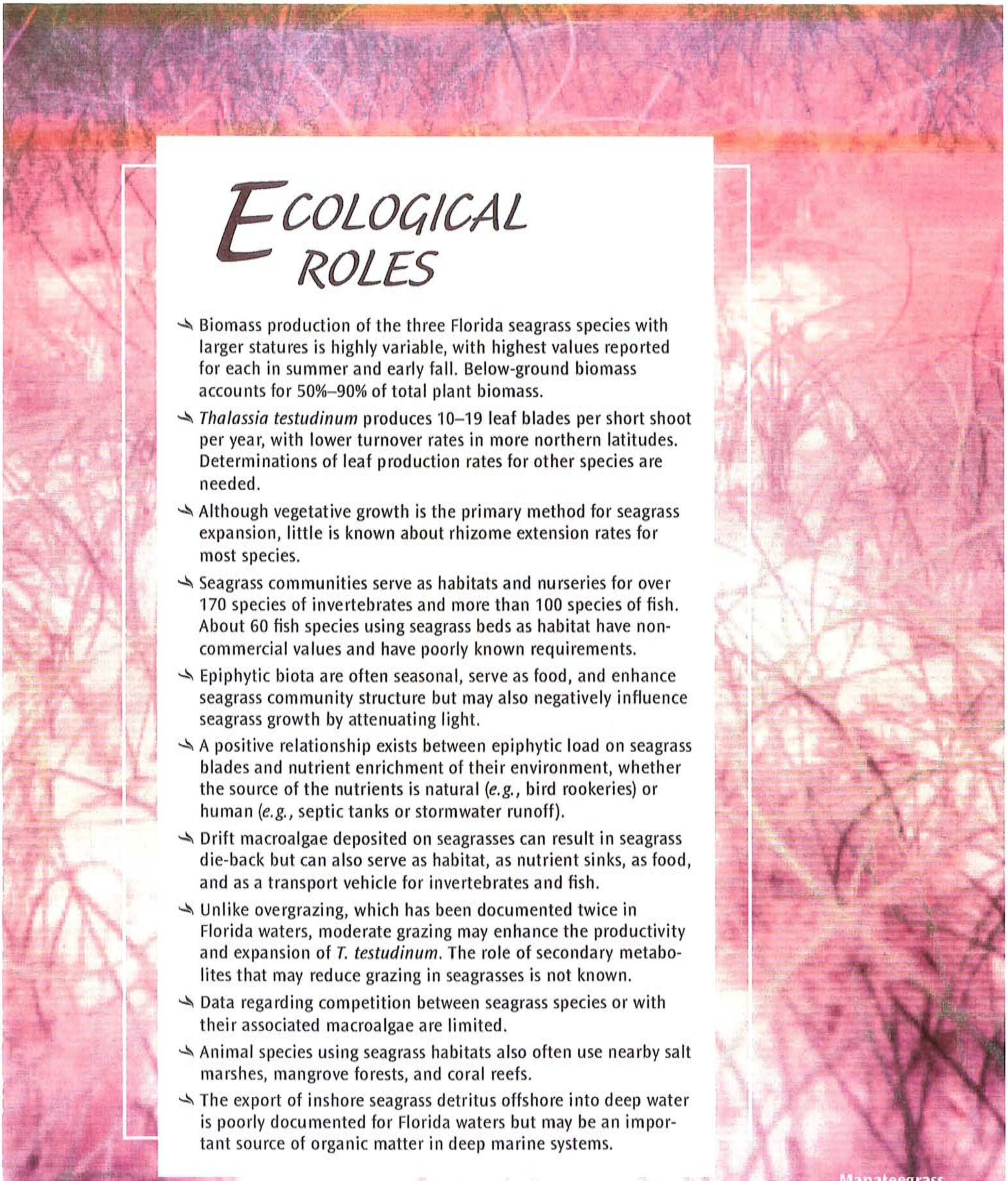
Since the classic studies of Patriquin and Knowles (1972), who used acetylene reduction by the seagrass rhizosphere to infer nitrogen fixation, a number of studies have described nitrogen fixation and nutrient uptake by marine angiosperms in greater detail. Based on acetylene-reduction experiments, Kenworthy *et al.* (1987) determined that bacteria associated with the roots and rhizomes of *T. testudinum* fixed nitrogen. Nitrogen fixation occurs in *Lyngbya wollei* (Phlips *et al.* 1992), a freshwater cyanobacterium. Perhaps *L. majescula*, a common mat and epiphytic species in seagrass beds of Florida's Gulf coast, has a similar capability.

Seagrasses take up nutrients principally from sediment pore water (*e.g.*, ammonium and phosphorus; Fourqurean *et al.* 1992) but also from the water column (*e.g.*, nitrate and ammonium; Touchette and Burkholder 2000). However, pore-water nutrient concentrations in seagrass beds can vary widely, as shown in Florida Bay, where median values of 0.34 μM for soluble reactive phosphorus and 78.6 μM for ammonium occur (Fourqurean *et al.* 1992). Because of rapid growth rates, seagrasses require large amounts of fixed nitrogen (10 to 450 mg N m^{-2} d^{-1}), with ammonium being the preferred form (Moriarty and Boon 1989). By contrast, nitrate and nitrite concentrations are usually low (<5 μM) in anaerobic sediments, presumably because they are rapidly used by denitrifying and anaerobic bacteria.

Seagrasses show a variety of responses when nutrients become limiting. Phosphorus is usually the most limiting nutrient in seagrass sediments of Florida Bay, where calcium carbonate rapidly binds any free PO_4^{-3} (Powell *et al.* 1989; Short *et al.* 1990; Touchette and Burkholder 2000), and its levels have been correlated with seagrass-bed development (Fourqurean *et al.* 1992). In Florida Bay, phosphorus apparently controls the successional sequence between early-stage *H. wrightii* beds and late-stage *T. testudinum* (Fourqurean *et al.* 1995). The former species tolerates higher nutrients better than *T. testudinum* does and will replace it in areas of natural or anthropogenic eutrophication. Nevertheless, factors other than nutrient levels may contribute to the replacement of *T. testudinum* by *H. wrightii*. Studies in Florida Bay (Carlson *et al.* 2002) reported that higher sulfide levels in the root zone, resulting from enhanced seagrass nutrition, can act as a phytotoxin in sediments and limit *T. testudinum*. By contrast, ammonium deficiency limits growth of *T. testudinum* in Laguna Madre, Texas (Lee and Dunton 2000b) and of *S. filiforme* in the Indian River Lagoon (Short *et al.* 1993).

*E*COLOGICAL ROLES

- Biomass production of the three Florida seagrass species with larger statures is highly variable, with highest values reported for each in summer and early fall. Below-ground biomass accounts for 50%–90% of total plant biomass.
- *Thalassia testudinum* produces 10–19 leaf blades per short shoot per year, with lower turnover rates in more northern latitudes. Determinations of leaf production rates for other species are needed.
- Although vegetative growth is the primary method for seagrass expansion, little is known about rhizome extension rates for most species.
- Seagrass communities serve as habitats and nurseries for over 170 species of invertebrates and more than 100 species of fish. About 60 fish species using seagrass beds as habitat have non-commercial values and have poorly known requirements.
- Epiphytic biota are often seasonal, serve as food, and enhance seagrass community structure but may also negatively influence seagrass growth by attenuating light.
- A positive relationship exists between epiphytic load on seagrass blades and nutrient enrichment of their environment, whether the source of the nutrients is natural (*e.g.*, bird rookeries) or human (*e.g.*, septic tanks or stormwater runoff).
- Drift macroalgae deposited on seagrasses can result in seagrass die-back but can also serve as habitat, as nutrient sinks, as food, and as a transport vehicle for invertebrates and fish.
- Unlike overgrazing, which has been documented twice in Florida waters, moderate grazing may enhance the productivity and expansion of *T. testudinum*. The role of secondary metabolites that may reduce grazing in seagrasses is not known.
- Data regarding competition between seagrass species or with their associated macroalgae are limited.
- Animal species using seagrass habitats also often use nearby salt marshes, mangrove forests, and coral reefs.
- The export of inshore seagrass detritus offshore into deep water is poorly documented for Florida waters but may be an important source of organic matter in deep marine systems.



Manateegrass, *Syringodium filiforme*, with drift algae

FWC–FWRI photo

SEAGRASS COMMUNITY ECOLOGY

Like Florida's coastal mangrove and salt-marsh communities, seagrass communities are important primary producers, stabilize mobile sediments, serve as habitats and nurseries, and are direct and indirect food for diverse fauna (Dawes 1998a). Further, the characteristics of seagrasses (*e.g.* short-shoot densities, presence of inflorescence scars, levels of storage products) can aid in determining whether seagrass beds are stressed, thereby contributing to the monitoring of conditions in coastal and estuarine communities (Dennison *et al.* 1993; Dawes 1998a).

In a study of seagrass distributions and conditions on the northeastern Gulf of Mexico, Livingston *et al.* (1998) listed four significant predictors of seagrass community health. These predictors are photic depth, light quality, water quality (color, dissolved organic carbon, and chlorophyll *a*), and sediment characteristics. The principal predictor is light quantity (duration and intensity) in relation to seagrass depth distribution, which is related to water transparency, as shown in the review on seagrass depth limits by Duarte (1991). In this regard, water transparency was found to be the principal factor influencing the depth distributions of *T. testudinum* in Tampa Bay (Dixon and Leverone 1995, 1997) and growth form of *H. wrightii* below a canopy of *T. testudinum* in the Florida Keys (Tomasko 1992). However, light quality influences seagrass morphology as shown by altering the red to far-red ratios in cultures of *Ruppia maritima* (Rose and Durako 1994).

Seagrass communities have been measured for standing stock biomass (g dry wt m^{-2}) and short-shoot densities (numbers m^{-2}). Biomass data are commonly limited to above-ground material, mostly the photosynthetic blade tissue. Such data are available for the larger-stature seagrass species, including *T. testudinum, H. wrightii, R. maritima,* and *S. filiforme* (Table 4.1), but data are usually lacking for the smaller-stature species (*i.e.*, species of *Halophila*). In general, the below-ground biomass (roots and rhizomes) constitutes 50% to 90% of standing stock for the larger-stature species (Zieman and Zieman 1989). For example, total biomass estimates (above and below ground) for *T. testudinum* in Florida Bay ranged from 195 to 2,254 g dry wt m^{-2}, and 85% of this was below ground (Fourqurean and Zieman 1991). Beds of *S. filiforme* in the Indian River Lagoon have an annual mean above-ground leaf biomass of 87 g dry wt m^{-2} (± 151) or 43% of the total, whereas below-ground roots and rhizomes accounted for 117 g dry wt m^{-2} (± 94) or 57% of the total plant biomass (Short *et al.* 1993). Dunton (1990) found that in the Laguna Madre of Texas below-ground biomass for *H. wrightii* was 50% to 85% of the total and for *R. maritima* was 20% to 70% of the total biomass. On Florida's Gulf coast, the greatest leaf biomass for *T. testudinum* occurs in spring and early summer, whereas below-ground biomass (roots and rhizomes) is greatest in the fall (Dawes *et al.* 1985). Unlike below-ground biomass, leaf biomass in *T. testudinum* can show a four-fold seasonal fluctuation, with above- to below-ground ratios of 0.17 to 0.4 in December and 0.4 to 1.0 in April in Tampa Bay (Dixon and Leverone 1995).

Leaf turnover rates were reviewed by Short and Duarte (2001), and techniques to measure leaf growth were compared by Tomasko and Dunton (1995) and van Tussenbroek (1996b). Leaf production (g dry wt $shoot^{-1}\ y^{-1}$) in *T. testudinum* was measured by puncturing leaf clusters at their bases and measuring new leaf production after a few days (Tomasko and Dawes 1989). In a review of leaf turnover rates for *T. testudinum*, Marbá *et al.* (1994) reported that 14 to 19 leaves are produced annually by each short shoot. Leaf longevity on short shoots of *T. testudinum* in the Tampa Bay area using leaf-scar chronology was 14.6 days at Sunset Park in Tarpon Springs and 19.2 days in south Tampa Bay (Witz and Dawes 1995) and 24 days in a lagoon in the Yucatán, Mexico (van Tussenbroek 1996b). Leaf production generally ranged between 10 and 19 leaves short $shoot^{-1}\ y^{-1}$ in Florida Bay (Zieman *et al.* 1989), the Indian River Lagoon (Gacia 1999), Tampa Bay (Witz and Dawes 1995), Charlotte Harbor (Tomasko and Hall 1999), Lower Laguna Madre, Texas (Kaldy *et al.* 1999), and the Caribbean coast of Mexico (Marbá *et al.* 1994; van Tussenbroek 1996b). Populations growing in cooler waters had lower annual rates of leaf production (10–15 leaves $shoot^{-1}$) for the Indian River Lagoon and the Lower Laguna Madre in Texas compared to those in Tampa Bay. Determination of leaf turnover in narrow-bladed seagrasses, such as *H. wrightii* (Tomasko and Dun-

Table 4.1 Standing stock (biomass) and productivity of southeastern United States seagrasses and closely related species (congeners) from other areas. Procedures differ greatly and influence the ranges in biomass and productivity.

Species	Locality	Biomass (g dry wt · m^{-2})	Productivity (g C · m^{-2} · d^{-1})
Halophila			
H. ovalis	India	48	
	Western Australia	40–60	
H. engelmannii	Texas (Gulf coast)	1.6	
Thalassia			
T. testudinum	Florida (general)	20–8,100	
	Florida (Atlantic coast)	20–1,800	0.9–16.0
	Florida (Gulf coast)	75–8,100	
	SW Florida Bay (Gulf coast)	60–125	
	Indian River, FL (Atlantic coast)	890	
	Corpus Christi, TX (Gulf coast)	454–885	
	Mexico, lagoon (Gulf coast)	420–1,418	
	Mexico, reef (Gulf coast)	573–811	
	Cuba (Caribbean Sea)	20–800	9.3–12.5
T. hemprichii	Queensland, Australia	70	
Syringodium			
S. filiforme	Florida (general)	15–200	
	Indian River, FL (Atlantic coast)	27–81	
S. isoetifolium	New Guinea (East Indies)	327	
Halodule			
H. wrightii	Mullet Key, FL (Gulf coast)	120	0.25
	Florida (general)	0.8	
	North Carolina (Atlantic coast)	105–200	0.5–2.0
	Laguna Madre, TX (Gulf coast)	70–300	
	Mississippi Sound (Gulf coast)	256	
H. uninervis	New Guinea (East Indies)	150	
Ruppia maritima	Texas (Gulf coast)	0–200	

Modified from McRoy and McMillan (1977), Zieman and Wetzel (1980), and Hillman *et al.* (1989).

ton 1995) and *S. filiforme* (Fry and Virnstein 1988), requires using an approach different from the leaf-punch technique. Leaf productivity by *S. filiforme*, determined using leaf clipping and photography, was 1.8 g dry wt $m^{-2}d^{-1}$ (Virnstein 1982; see Short and Duarte 2001 for a detailed review of techniques).

Little is known about rhizome growth rates of Florida's seagrasses, yet this is the sole method for vegetative expansion. Reviews indicate that vegetative growth differs among species, rhizome elongation rates being higher for smaller-stature seagrass species (Marbá and Duarte 1998). In their review, mean rhizome elongation rates were highest for *H. wrightii*, the smallest stature of the larger Caribbean seagrasses (223, range; 81–365 cm yr^{-1}), followed by *S. filiforme* (123, range: 52–182 cm yr^{-1}) and then the largest stature species *T. testudinum* (69, range: 22–152 cm yr^{-1}). Short *et al.* (1993) found that *S. filiforme* rhizome elongation exceeded 100 cm y^{-1} in the Indian River. At Mullet Key in Tampa Bay, rhizome internode length and increase in seagrass patch size for *H. wrightii* were positively correlated; the larger the internodes of *H. wrightii*, the greater the increase in seagrass coverage at the edges of patches (Jensen and Bell 2001). The authors also found that a 100-fold increase in phosphorus, but not nitrogen, resulted in a significant increase in rhizome internode length. Jensen and Bell (2001) suggested that the observed patch-size patterns in seagrass beds (*e.g.* larger landscape features) may be determined by small-scale factors (*e.g.* nutrient availability).

Table 4.2 Densities of macroinvertebrates at various sites in Florida, arranged geographically from the Atlantic coast to the northern Gulf of Mexico. Single-density values are means; ranges generally represent several sampling sites. Several values are derived indirectly.

Study Site	Seagrass Species*	Faunal Group	Mesh Size (mm)	Density (indiv. m^{-2})	Number of Species	Reference
Card Sound	*Tha*	total	0.8	1,085	–	Brook (1977)
Bahia Honda	*Tha*	Amphipoda	1.0	102	5	Nelson (1980)
Florida Bay	*Tha*	total	0.8	2,794	52	Brook (1978)
Rookery Bay	*Hal*	Amphipoda	1.0	910	3	Nelson (1980)
Tampa Bay	*Hal*	Polychaeta	0.62	13,313	44	Santos and Simon (1974)
	Tha	Polychaeta	0.62	33,485		Santos and Simon (1974)
Anclote Anchorage	*Syr*	total	1.0	2,347	68	Mahadevan and Patton (1979)
	Syr	total	0.5	9,538	58	Mahadevan and Patton (1979)
	Tha	total	1.0	3,724	63	Mahadevan and Patton (1979)
	Tha	total	0.5	18,916	50	Mahadevan and Patton (1979)
Apalachee Bay	*Tha/Syr*	total	1.0	1,782 to 2,424	72	Lewis and Stoner (1981)
	Tha/Syr	total	0.5	3,154 to 4,754	86	Lewis and Stoner (1981)
	Tha	total	0.5	16,108	80	Lewis and Stoner (1983)
	Tha/Hal	Crustacea	0.5	6,716	46	Lewis (1984)
	Tha/Syr/Hph	total	0.5	2,827	170	Stoner (1980b)
Apalachicola Bay	*Hal*	total	0.5	38,780	58	Sheridan and Livingston (1983)
St. Andrew Bay	*Tha*	total	0.7	7,567	89	Saloman *et al.* (1982)
	Hal	total	0.7	3,370	67	Saloman *et al.* (1982)
	Tha/Hal	total	0.7	4,192	86	Saloman *et al.* (1982)
Santa Rosa Sound	*Tha*	total	0.5	13,260	144	Morton *et al.* (1986)
	Hal, core	total	0.5	9,020	41	Stoner *et al.* (1983)
	Hal, suction	total	0.5	6,077	37	Stoner *et al.* (1983)

Modified from Virnstein 1987. **Hal = Halodule wrightii, Tha = Thalassia testudinum, Syr = Syringodium filiforme, Hph = Halophila engelmannii.*

STRUCTURE, SHELTER, AND PREDATION

Seagrass beds function both as nurseries (Lewis and Stoner 1981; Lewis 1984; Virnstein 1987; Zieman and Zieman 1989; Fonseca *et al.* 1996b; Bell *et al.* 2001; Heck *et al.* 2003) and as habitats for invertebrates (Greening and Livingston 1982; Virnstein 1987; Valentine and Heck 1993), fish (Stoner 1983; Gilmore 1987), sea turtles (Williams 1988a), and manatees (Lefebvre *et al.* 1989). The role of seagrass meadows as nurseries was reviewed by Heck *et al.* (2003) who reported a strong link between seagrass abundance and abundances of juvenile fin fish and shell fish. The principal factor in this positive correlation was the structure that seagrasses added to the habitat.

Invertebrates add structure and serve as food, thus supporting increased diversity of other forms. For example, high densities of the mussel *Modiolus americanus* in St. Joseph Bay reached 2000 individuals m^{-2}, which enhanced invertebrate diversity and secondary production (Valentine and Heck 1993). The high variation of animal diversities among seagrass sites may be due in part to wave and current activity (Bell *et al.* 1994). The authors found that the mean numbers of fish and copepods and mean numbers of fish species were higher in low-energy seagrass beds (*e.g.*, minimum exposure to wind direction, speed, and effective fetch in Tampa Bay and Onslow Bay, North Carolina). Densities of macroinvertebrates in seagrass beds on Florida's Gulf coast vary widely among sites (Table 4.2), ranging from 910 individuals m^{-2} (Rookery Bay) to 33,485 individuals m^{-2} (Tampa

Bay). Invertebrate communities of seagrass beds in Florida are highly regional, and overlap occurs between subtropical, tropical, and warm-temperate faunas (Virnstein 1987). Holmquist *et al.* (1989) found that seagrass beds in Florida Bay play a secondary role as habitat for decapods and stomatopods compared with their reactions to winter cold fronts as a function of their positions on mud banks. Decapod crustaceans, such as caridean shrimps, usually dominate the larger fauna numerically, similar species of shrimp being widespread in Florida's Gulf-coast seagrass beds (Holmquist *et al.* 1989). The macrofauna varies widely in species composition and animal density over distance and time, including those of amphipods, gastropod molluscs, and polychaete worms (Virnstein 1987).

Because infaunal, epibenthic, and epiphytic animals of seagrass beds are prey for larger animals, fish are abundant there (Gilmore 1987). Principally, the larger-sized fish (*e.g.*, spotted seatrout, *Cynoscion nebulosus*, and pinfish, *Lagodon rhomboides*) have been studied. Smaller nonfishery species (*e.g.*, gobiids, syngnathids), which account for most of the resident species in seagrass beds, are less well known but include over 100 species (Gilmore 1987). As with invertebrates, fish faunas vary with geographic regions on Florida's Gulf coast and include warm-temperate species, eurythermal tropical species, and stenothermal tropical species (Gilmore 1987). Four subenvironments in Florida Bay had an overall average density of 11 fish m^{-2} and a total of 56 species (Sogard *et al.* 1987). The two-year study found seagrass standing crop and litter to be the most important determinates of fish numbers.

Monitoring animal densities and diversity in planted seagrass beds is a useful method for determining habitat restoration success. A study of a three-year-old planted seagrass bed in Tampa Bay (Fonseca *et al.* 1996a, 1996b) found that shrimp, fish, and invertebrate densities were equivalent to those of natural communities, although short-shoot density was only one-third those of natural beds. Another study in Tampa Bay found that higher numbers of polychaetes occurred in two-year-old planted sites than in natural *H. wrightii* beds (Bell *et al.* 1993). The rapid increase of animals in planted beds suggests that the threshold value of habitat structure may be much lower than previously thought and that the lack of correlation between patch size and animal abundance suggests other factors are involved in maintaining animal populations. Clearly, more studies are needed to determine animal population relationships in restored, created, and patchy seagrass beds.

Studies on seasonal animal-population fluctuations and patch formation in seagrass meadows suggest that they are not static, even under "stable" environmental conditions. For example, Tampa Bay seagrass beds experiencing more rapid water movement have a lower number of fish and harpacticoid copepods (Bell *et al.* 2001), which may also be influenced by organic matter content in the sediment. In St. Croix, Virgin Islands, tropical seagrass beds fluctuate in response to seasonal conditions (Williams 1988b). In addition to seasonal changes, severe plant die-off has occurred in Florida Bay, probably hastened by spatial variations in environmental stresses (Durako 1994; Zieman *et al.* 1999; see also Chapter 5). Water-column nutrient increases resulting in eutrophication have been cited as important environmental stressors that can shift species dominance in seagrass beds and influence sulfide production (Carlson *et al.* 2002). Williams (1987) found that *T. testudinum* could shade and replace *S. filiforme* beds in St. Croix. She also reported that the successional sequence from bare sediment began with rhizophytic (psammophytic) algae, then proceeded to *S. filiforme*, and ended with *T. testudinum*, as sediment nutrient concentrations increased over time (Williams 1990). In this regard, considering nutrient increases emanating from bird perches installed in Florida Bay, Fourquean *et al.* (1995) proposed that *H. wrightii* might replace *T. testudinum* in Florida Bay as sediment nutrient levels rise. However, this study did not consider the effect of increased sulfide levels in the sediment (Carlson *et al.* 2002) or the effect of phosphate and nitrate on seagrass growth (Powell *et al.* 1989).

The competition for space or the "space race" is evident by the numbers of macroalgae, cyanobacteria and microalgae (Hall 1988; Harris 1997) that grow on seagrass blades and that show strong seasonal changes. At Egmont Key in Tampa Bay, the five species of cyanobacteria and 20 species of epiphytic macroalgae varied in dominance (by algal division) during a 15-month study of *T. testudinum.* Brown algae dominated during the winter and spring months and cyanobacteria in the

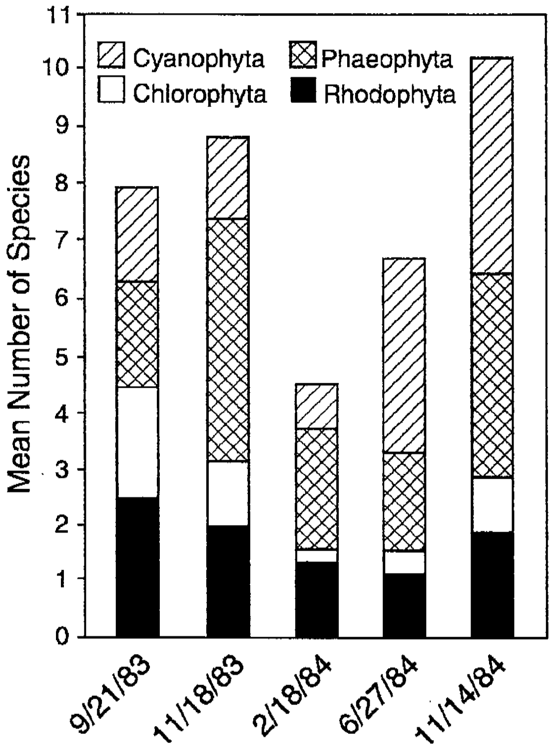


***Figure 4.1** Seasonal variations in the mean numbers of cyanobacteria and macroalgae, grouped by divisions, epiphytic on* Thalassia testudinum *blades at Egmont Key in Tampa Bay over a 15-month period (Hall 1988).*

summer months (Figure 4.1). Hall (1988) divided the algae into those that (1) are characteristically epiphytic on seagrasses; (2) settle and reproduce on seagrass blades, but are commonly epilithic; and (3) germinate on blades and then break free before reproduction. A study of *T. testudinum* beds near Leffis Key and Siesta Key in Sarasota Bay (Table 4.3) found many species of centric and pennate diatoms, six species of cyanobacteria, and 21 species of macroalgae (Harris 1997). Algae epiphytic on *H. wrightii* and *T. testudinum* in Tampa Bay, Sarasota Bay, and Charlotte Harbor (Dixon and Leverone 1995; Dixon and Kirkpatrick 1995, 1999) and Santa Rosa Sound in Pensacola Bay (Macauley *et al.* 1988) change seasonally, species diversity being negatively correlated with water temperature. Gacia *et al.* (1999) found that sheet-like and filamentous species of green-algae genera (*Enteromorpha, Cladophora*) were less resistant to grazing fish than were species of more coarsely branched red-algae genera (*Hypnea, Chondria, Acanthophora*) in the Indian River Lagoon. Algae epiphytic on seagrass blades can account for 46% of the total biomass and 60% of the benthic primary production, as found using stable-isotope analysis, in *H. wrightii* beds in Mississippi Sound (Moncreiff and Sullivan 2001).

Studies have shown that epiphytes, in combination with PAR attenuation and seasonal low-growth periods, depress blade growth and primary production and reduce the depth of *T. testudinum* in Tampa Bay (Dixon and Leverone 1995, 1997), Florida Bay (Frankovich and Fourqurean 1997), the Florida Keys and Keys in Belize, Central America (Tomasko and Lapointe 1991), and Perdido Key in northwest Florida (Wear *et al.* 1999). Tomasko and Lapointe (1991) found water-column dissolved inorganic nitrogen (DIN) concentration was high near Big Pine Key (3.96 μM), an island in the Florida Keys with over 2,000 septic tanks. This DIN level is similar to that of a mangrove island in Belize (Man-O-War Key) having 75 pairs of nesting frigate birds (3.80 μM). In contrast, DIN levels were low around Cutoe Key (0.50 μM), a remote mangrove island in the Florida Keys. The seagrass beds near Big Pine Key and Man-O-War Key had higher epiphytism, lower short-shoot densities, lower leaf-area indices, and lower biomass in contrast to those near Cutoe Key (Tomasko and Lapointe 1991). Wear *et al.* (1999) reported similar results from an experiment using slow-release fertilizer (Osmocote®) in northwestern Florida at Perdido Key. Nutrification caused significant increases of diatoms, as well as red and brown macroalgae, on blades of *T. testudinum, H. wrightii,* and *S. filiforme* over a 12-month period. Frankovich and Fourqurean (1997) reported that epiphytic loads on *T. testudinum,* along a nutrient-enrichment gradient in Florida Bay, gave similar results to the previous studies, and this study indicated that the effect is localized. The authors concluded that epiphyte levels alone are not as responsive to moderate nutrient enrichment as are other seagrass characters, such as leaf tissue N:C ratios. As noted in Chapter 3, epiphytes of seagrasses reduce water-column PAR by as much as 99% seasonally. The question of whether organic carbon, nitrogen, or phosphorus can be transferred from seagrass blades to the epiphytic community or vice versa is not clear (see Lobban and Harrison 1994).

Some of the most abundant invertebrates in

Table 4.3 Epiphytic algae on blades of *Thalassia testudinum* at Leffis Key and Siesta Key in Sarasota Bay (modified from Harris 1997) and at Egmont Key in the mouth of Tampa Bay (modified from Hall 1988).

Species	Leffis Key	Siesta Key	Egmont Key
Cyanobacteria			
Anabaena oscillarioides	x	x	x
Anacystis sp.	x	x	x
Calothrix crustacea	x	x	x
Entophysalis conferta	x		
Microcoleus lyngbyaceus	x	x	x
Porphyrosiphon notarisii	x		
Chlorophyta			
Boodleopsis pusilla	x		
Chaetomorpha minima		x	x
Cladophora spp.	x	x	x
Enteromorpha chaetomorphoides			x
Ulva lactuca	x		
Phaeophyta			
Cladosiphon occidentalis	x		x
Ectocarpus elachistaeformis			x
Ectocarpus rallsiae (as *Giffordia rallsiae*)	x	x	x
Ectocarpus sp. (as *E. rhodochortonoides*)	x	x	x
Hincksia mitchellae (as *Giffordia mitchellae*)	x	x	x
Hummia onusta	x	x	x
Myrionema magnusii (as *M. orbiculare*)	x	x	x
Myriotrichia occidentalis	x	x	x
Rhodophyta			
Acrochaetium spp.	x	x	x
Centroceras clavatum	x	x	x
Ceramium cimbricum (as *C. fastigiatum*)	x	x	x
C. flaccidum (as *C. byssoideum*)	x	x	x
Chondria dasyphylla	x	x	x
Chondrophycus papillosus (as *Laurencia papillosa*)	x		
Erythrotrichia carnea			x
Hydrolithon farinosum (as *Fosliella farinosa*)	x	x	x
Hypnea musciformis	x	x	
Polysiphonia subtilissima	x	x	
Stylonema alsidii (as *Goniotrichum alsidii*)			x

seagrass beds are the meiofauna, including crustaceans (Lewis 1987) and copepods (Hall 1988). Harpacticoid copepods are often the most common animal group associated with seagrasses (Hall and Bell 1988, 1993; Walters and Bell 1986; Walters 1991). One study reported that more than 20,000 harpacticoid copepods migrated h^{-1} m^{-2} from the sediment during the night into the water column, representing over 50% of the total benthic harpacticoid community (Walters and Bell 1986). Further, this postsunset entry into the water column from the sediment involved over 30 species in 15 families (Walters 1991). At Mullet Key in Tampa Bay, artificial blades (green ribbon) with artificial epiphytes (cotton fibers) attached had significantly higher densities, compared to green ribbons alone, of copepods, polychaetes, and nematodes associated with them after three days. This shows that epiphytic biota enhance structural complexity of seagrass blades, thereby increasing habitat values (Hall and Bell 1988). In a similar study, Hall and Bell (1993) showed that the most abundant meiofaunal groups on seagrass blades at Egmont Key were adult harpacticoid copepods, copepod nauplii, and nematodes. They also determined that meiofauna density was most signifi-

Figure 4.2 Drift algae are entangled by seagrass leaves, as in this Thalassia testudinum *bed.*

cantly correlated with percentage cover of filamentous algae. A 15-month study of *T. testudinum* blades at Egmont Key at the mouth of Tampa Bay (Hall 1988) showed seasonal shifts in the abundance of nematodes (highest in winter) but not that of harpacticoid copepods and nauplii (abundant throughout the year). Epiphytes trap detritus, which attracts significantly higher numbers of copepods that feed on it (Meyer and Bell 1989). Small grazers (*e.g.*, copepods) can play a role in epiphyte control (Virnstein 1987), as shown for *H. wrightii* plants in the Indian River Lagoon (Howard and Short 1986).

Along with drift macroalgae, rhizophytic (psammophytic) algae may equal or surpass seagrass biomass in Florida Gulf-coast seagrass beds (Dawes *et al.* 1985). With the exception of some tropical coenocytic green algae, macroalgae usually cannot attach to sand or mud. Coenocytic green algae are a diverse group of siphonaceous (lacking internal cell walls) algae placed in the order Caulerpales. They form extensive rhizoid holdfasts and include species of calcified (*Halimeda, Penicillus, Udotea*) and noncalcified (*Caulerpa, Riphilia, Avrainvillea*) genera. Even though rhizophytic coenocytic algae may compete for space and light with seagrasses, they may also serve as pioneer plants, which then may be replaced by seagrasses, as shown in a coral-reef lagoon in St. Croix (Williams 1990).

Over 230 species of unattached macroalgae (drift algae) are known throughout the world (Norton and Mathieson 1983). Drift algae are usually noncalcified, remain infertile, and reproduce vegetatively (Collado-Vides *et al.* 1994). Two studies, one in Tampa Bay, Boca Ciega Bay, and Anclote Anchorage (Phillips 1960b) and the second in Crystal Bay (Phillips 1960c), listed 195 and 46 taxa, respectively, of algae that could not be distinguished as either drift or attached. Drift algae are concentrated in seagrass beds where water-current velocities are reduced and blades will entangle the algae (Figure 4.2). To some extent, seagrass blade size may influence entanglement (Bell *et al.* 1995). Seagrass beds on the Gulf coast of Florida are known to contain from 8 to 65 species of drift algae with the total biomass ranging from 0.002 g to 930 g dry wt m^{-2} (Table 4.4). Brown (2001) found that algal biomass differed for three sites on the Gulf coast of Florida, both by season and by site. Annual means of 6.01, 3.83 g, and 2.25 g dry wt m^{-2} were obtained for Tampa Bay in Cockroach Bay, Tarpon Bay, and Sunset Beach respectively. Although biomass varies with season and site on the Gulf coast, the types and numbers of species are similar (Table 4.4).

Drift algae are an important ecological component of seagrass beds because they serve as habitat, provide transportation, and provide a food source for invertebrates (Ballantine *et al.* 1994; Holmquist 1994; Greenway 1995; Knowles and Bell 1998; Maciá 1999; Brooks and Bell 2001; Rydene and Matheson 2003). In Florida Bay, Holmquist (1994) found 61 invertebrate taxa in drift algae mats in

Table 4.4 Number of drift-algae species and dominant species, biomass, and presence/absence (by division) in seagrass beds on the Gulf coast of Florida. Locations include (1) Anclote Estuary near Tarpon Springs (Hamm and Humm 1976), (2) Hillsborough Bay including studies 2a (Kelly 1995) and 2b (Avery 1997), (3) Sunset Beach at Tarpon Springs (Brown 2001), (4) Cockroach Bay in Tampa Bay (Brown 2001), and (4) Tarpon Bay at Sanibel Island (Brown 2001).

	Locations					
	1	2a	2b	3	4	5
Number of species	65	19	18	9	9	8
Number of dominant species	4	5	9	9	9	8
Mean biomass (g dry wt · m^{-2}) low	–	–	80	0.07	0.0002	0.14
high	–	–	930	6.34	9.45	9.32
Cyanophyta						
Lyngbya majescula					x	x
Chlorophyta						
Caulerpa prolifera			x			
Chaetomorpha crassa			x			
C. gracilis			x			
Chaetomorpha sp.		x				
Enteromorpha spp.						x
Enteromorpha clathrata			x			
Ulva lactuca		x	x		x	
Phaeophyta						
Sargassum pteropleuron				x		
Sargassum spp.	x					
Rhodophyta						
Acanthophora spicifera			x		x	x
Chondrophycus papillosus (as *Laurencia papillosa*)	x					
Digenia simplex	x					
Gracilaria armata					x	x
G. caudata				x	x	x
G. cornea (as *G. debilis*)					x	
Gracilaria spp.		x	x			
Hypnea musciformis				x	x	x
Laurencia intricata (as *Laurencia obtusa*)	x			x		
L. poiteaui				x		
Polysiphonia ramentacea				x		
P. subtilissima			x			
Solieria filiformis (as *Agardhiella tenera*)		x	x	x	x	x
Spyridia filamentosa		x	x	x	x	x

seagrass beds. Average drift rate was 0.5 km d^{-1}, indicating that drift algae are an effective mode of transport for animals. Ballantine *et al.* (1994) reported that balls of algae in Venezuela contained 12 species of invertebrates. The numbers of amphipods, isopods, and tanaeids in Venezuela were significantly higher on two species of red algae than were associated with blades of *S. filiforme,* as similarly found in other previous studies (Knowles and Bell 1998). Virnstein and Howard (1987) noted that drift algae serve as habitat and food sources for gammaridean amphipods. Brooks and Bell (2001) found that drift clumps of the red alga *Hypnea cervicornis,* as they moved through seagrasses and into sandy areas, had significantly higher amphipod densities; they concluded that drift algae clumps provide a mobile corridor for animals. In Tampa Bay, drift algae form an important alternative habitat for 12 of the 20 most abundant juvenile and small adult fish (Rydene and Matheson 2003). However, drift algae deposited in seagrass beds can also affect these habitats by causing a seagrass die-back as a consequence of light and oxygen reduction (Norkko *et al.* 2000). A combination of algae deposition and sea-urchin grazing increased the die-back of *T. testudinum* in Florida Bay (Maciá 1999). The amount of drift-algae biomass can also have a negative correlation with seagrass bed expansion if dissolved nutrients are high, as shown for Hillsborough Bay (Avery 1997). In a 10-year study, Avery (2000) found that with improved water quality the 18 species of dominant drift algae declined in average biomass from 164 g dry wt m^{-2} in 1987 to 0.0029 g dry wt m^{-2} in 1998 in Tampa Bay. The green coenocytic alga *Caulerpa prolifera* had colonized Hillsborough Bay in 1986 with an initial coverage of almost 220 ha (543 acres) but had declined to zero in 1997. In contrast, *H. wrightii* coverage increased from 0.2 ha (0.5 acres) in 1986 to nearly 57 ha (141 acres) in 1998 (Avery 2000).

A few studies exist concerning competition between seagrasses or between seagrasses and attached macroalgae, with two reports on *T. testudinum*, *S. filiforme*, and *H. wrightii* and rhizophytic algae in the Caribbean (Williams 1987, 1990). Williams (1987) removed the leaf canopy of *T. testudinum* in St. Croix, resulting in increased irradiance reaching the *S. filiforme* understory, and its biomass doubled within nine months. A study in Tampa Bay indicated that competition occurred between *T. testudinum* and *H. wrightii* (Rose and Dawes 1999), where *T. testudinum* had a lower biomass when growing with *H. wrightii*, suggesting interspecific competition. Further, leaf biomass and growth were significantly lower in dense, monotypic beds of *T. testudinum* compared to less dense beds, suggesting light was reduced via shading in dense beds (Rose and Dawes 1999). There are also reports regarding competition between *H. wrightii* and the coenocytic green macroalga *C. prolifera* (Bottone and Mattson 1987; Bottone and Savercool 1993). Although the data are not conclusive, *C. prolifera* may act as a weak competitor for space with *H. wrightii*, coexisting with it as an opportunistic species under stable environmental conditions in Tampa Bay (Bottone and Savercool 1993). This result is similar to those found in studies in the Indian River Lagoon (White and Snodgrass 1990). Further, *C. prolifera*, although susceptible to sudden environmental changes (*e.g.*, low salinity), can rapidly colonize areas devoid of vegetation that may occur following seagrass die-back (Bottone and Mattson 1987).

Overgrazing of seagrass beds is a rarity but has occurred on the Florida Gulf coast. Overgrazing by *Lytechinus variegatus* (purple sea urchin) resulted in large-scale denudation of seagrass beds. Over 20% of an area 26 km by up to 9.5 km were consumed near the Pepperfish Keys south of the Steinhatchee River in the northern peninsula (Camp *et al.* 1973). Density at the front of a single aggregate averaged 636 sea urchins m^{-2}, with individuals piled upon one another 2–8 individuals deep that covered the substrate. Dense aggregations of the same urchin species overgrazed about 0.81 km^2 of *T. testudinum* in outer Florida Bay; mean densities ranged from 364 to <1 individual m^{-2} (Rose *et al.* 1999). The origins of the urchin feeding fronts are not understood. In Florida Bay, high urchin densities may reflect unusually high recruitment or a release from predation pressure because of overharvesting of spiny lobsters and stone crabs (Rose *et al.* 1999).

Moderate grazing pressures on *T. testudinum* blades were correlated with specific leaf growth rates (0.024 mg dry wt. d^{-1}) in the Yucatán, Mexico; this showed that sporadic grazing had little detrimental effect on *T. testudinum* (Cebrián *et al.* 1998). Studies on *T. testudinum* beds in northwest Florida and a review of the literature indicated that herbivory plays a major role in stimulating seagrass growth by removing macroalgae (Heck and Valentine 1995; Valentine and Heck 1999). Also, long-term effects of grazers have been shown in a relationship between *L. variegatus* and *T. testudinum* in the Gulf of Mexico (Heck and Valentine 1995), where urchins and seagrass coexist in balance. In these cases, a balance developed among intensive grazing, loss of habitat, and predation by fish on the urchins. In the 1995 experiment, protection from predator fish by enclosures resulted in intense grazing by the urchins, which became most destructive in winter when *T. testudinum* could not recover as rapidly. The more intensively grazed beds showed significant reductions in above- and below-ground biomass, which was apparent even 3.5 years after grazing had ceased. Varying the number of *L. variegatus* in experimental plots in St. Joseph Bay, Valentine *et al.* (1997) found an increase in shoot density and productivity of *T. testudinum* under moderate grazing pressure. In a later study, Valentine *et al.* (2000) demonstrated that the effect of grazing in Florida Bay was related

Table 4.5 $\delta^{15}N$ and $\delta^{13}C$ values of seagrasses and marine macroalgae from various locations.

Plants	$\delta^{15}N$	$\delta^{13}C$
Seagrasses		
Thalassodendron ciliatum (Australia)	+3.5	−9.3
Syringodium isoetifolium (Australia)	+5.0	−4.0
Thalassia testudinum (Nicaragua)	+3.5	−13.2
Halodule wrightii (Texas)	+3.9	−10.3
Ruppia maritima (Texas)	+3.6	−7.9
Halophila engelmannii (Texas)	+3.8	−7.9
Thalassia testudinum (Texas)	+3.9	−8.9
Thalassia testudinum (Jamaica)	+4.3	−11.1
	$\bar{x}$ = 3.9 ± 0.5	−9.1 ± 2.7
Marine Macroalgae		
Ulva fasciata (Texas)	+8.1	−14.6
Ulva lactuca (Texas)	+8.1	−14.6
Gelidium crinale (Texas)	+7.9	−14.3
Ascophyllum nodosum (Maine)	+8.0	−16.9
Fucus vesiculosis (Maine)	+8.1	−16.5
Acetabularia kilnori (Australia)	+6.5	−9.5
	$\bar{x}$ = 7.8 ± 0.6	−14.4 ± 2.6

Macko (1981) cited in Fry *et al.* (1987).

to season and water depth, with grazing having a stronger effect in the winter or in seagrass beds at greater depths. Thus, repeating experiments in environments with differing physical conditions and in different seasons is critical in order to determine the effects of blade loss and seagrass bed maintenance.

Few studies have been carried out on predation within seagrass beds since the reviews by Orth *et al.* (1984) and Zieman and Zieman (1989). Based on feeding and caging studies, predation, especially by pinfish and pink shrimp, is probably a major biological interaction influencing invertebrate community structure (Virnstein 1987). In a study in St. Joseph Bay, increased biomass of a mussel (*Modiolus americanus*) in *T. testudinum* beds resulted in greater abundance, biomass, and annual production of other invertebrates (Valentine and Heck 1993).

TROPHIC DYNAMICS

The ultimate fate of plant biomass is mineralization to simple inorganic compounds, with a portion of seagrass leaf decomposition occurring while it is still attached to the plant. Nevertheless, most biomass decomposition occurs on and in the sediment of seagrass meadows (Hemminga and Duarte 2000).

A long-term study (419 days) in Laguna Madre, Texas of *H. wrightii* senescent blades suspended in the water column revealed that decomposition resulted in a loss of 36% of the organic matter within the first 24 days (Opsahl and Benner 1993). By the end of the study, decomposition had resulted in a 76% loss of the organic matter. Neutral sugars were the most abundant in the starting material and also the most rapidly lost. In contrast, the most persistent sugars in the senescent blades were xylose and glucose, reflecting the more stable polymers of cellulose and xylan from which the sugars are derived. Near St. Croix, at depths between 14 and 32 m, the decomposition rates of a more delicate seagrass, *H. decipiens,* differed between litter bags that were buried in the sediment and those tethered at the surface of the sediment (Kenworthy *et al.* 1989). After 6.5 days, buried leaves lost 56% of the original ash-free dry weight compared to only 28% lost by those left on the surface. These findings were similar to two 7-day studies made in two consecutive years that included photosynthetic measurements in the same area and using the same species (Josselyn *et al.* 1986), this earlier

Table 4.6 $\delta^{34}S$ values for sulfur sources and plants, Redfish Bay, Texas, November 1980–February 1981 (from Fry, 1981).

Sources	$\delta^{34}S$
Seawater Sulfate	+19.7 to +20.0
Sediment Sulfide	−23.4
Porewater Sulfate	+15.0 to +17.0
Rain Sulfate	+6.3[a]

	Leaves		Roots	
	Total	After Washing	Total	After Washing
Algae, Submerged Plants				
Digenia simplex	+18.7	+17.2		
Gracilaria verrucosa	+18.6			
Gracilaria debilis	+18.9	+17.5		
Thalassia epiphytes[b]	+17.4	+15.2		
Seagrasses, Submerged Plants				
Thalassia testudinum				
Sample 1 (November 29)[c]	+15.2		−12.3	−15.9
Sample 2 (November 29)	+12.9[d]			
Sample 3 (January 3)		6.9[d]		−17.3
Halodule wrightii	+10.4		−9.3	
Syringodium filiforme[c]	+11.5		−3.3	
Halophila engelmannii	+11.2		+11.5	
Intertidal, Emergent Plants				
Spartina alterniflora[e]	+3.5		−9.4	
Avicennia germinans[e] (as *A. nitida*)	−0.2		−3.2	

[a]From Jensen and Nakai (1961).
[b]Epiphytic community collected after freeze drying. Contained some small animals and mud.
[c,e]Plants marked with the same letter were growing intertwined in the same sediments.
[d]Epiphyte-free seagrass.

study reporting greater than 50% decomposition of all buried seagrass material.

Seagrass epiphytes appear to be a more significant source of direct food for many invertebrates than are seagrass detritus or living tissue. Virnstein (1987) has proposed the following sequence for a south Florida seagrass food web: (1) the important primary producers are epiphytic algae, which have rapid turnover rates; (2) epiphytic algae are preferentially grazed by most species of small invertebrates associated with seagrass blades; (3) small invertebrates are preyed upon by decapod crustaceans or small fishes that include resident adults and juvenile seasonal visitors; and (4) decapods and small fishes are preyed on by larger, mostly nonresident fishes. Of the 154 grazers listed by McRoy and Helfferich (1980) that directly feed on seagrass blades, the most important invertebrates are echinoderms, molluscs, and crustaceans. For example, seagrass blades constitute up to 50% of the total diet for crustaceans (Klumpp *et al.* 1989). Crabs, isopods, and sea urchins are the principal direct grazers on seagrasses, whereas other invertebrates consume seagrass detritus and various algal epiphytes. Fry and Parker (1979) and Fry (1984), using stable carbon isotopes ($\delta^{13}C$), showed that microalgae on the sediment and seagrass blades are a major source of carbon for grazers. In some seagrass meadows, micro- and macroalgae predominate in food webs (Virnstein 1987). In a review of stable-isotope studies, Fry *et al.* (1987) concluded that algae are nutritionally more important for consumers than are seagrasses but that $\delta^{13}C$ data alone can be misleading because benthic algae have values similar to those of seagrasses. Thus, they recommended using other elements with stable isotopes, including nitrogen and sulfur (Tables 4.5 and 4.6).

RELATIONSHIPS with OTHER COMMUNITIES

Because seagrass beds are mostly found in areas of low wave energy, they often occur next to tidal-flat, salt-marsh, and mangrove communities along Florida's Gulf coast and are influenced by these intertidal communities. Salt marshes are estimated to cover about 170,000 ha (419,900 acres) of Florida's coasts; about half of the marsh area extends from Tampa Bay north to the Alabama border on the Gulf coast (Montague and Wiegert 1990). The estimated salt-marsh area is substantially less than the estimate of McNulty *et al.* (1972) of 214,000 ha (528,580 acres) for the Gulf coast of Florida. The largest salt marshes on the Gulf coast of Florida are in the Big Bend area, from Aripeka to Apalachicola Bay, a coast with low wave energy and extensive seagrass beds. About 60% of northwest Florida salt marshes are monotypic stands of *Juncus roemerianus* Scheele (Needle Rush), which often extend down to 0.2 to 0.5 m above MLW and thus are adjacent to near-shore seagrass beds. Above-ground primary production ranges from 250 to 950 g dry wt m^{-2} yr^{-1} for *J. roemerianus* and 130 to 700 g dry wt m^{-2} yr^{-1} for *Spartina alterniflora* Loisel. (Smooth Cordgrass). (Montague and Wiegert 1990), the difference probably due to the higher density of *J. roemerianus* culms. The large biomass of salt-marsh plants and low direct consumption by herbivores (10%) means that most of the biomass decomposes and becomes part of the salt-marsh detritus (Montague *et al.* 1987). Apparently little of the detritus is exported to near-shore seagrass beds because of the relatively high elevation of Florida's salt marshes and often the presence of a berm that retains the detritus within the salt marsh (Montague *et al.* 1987).

In contrast to the low level of detrital export, a diverse fauna is shared between salt marshes and adjacent seagrass beds, for example, mullet, spot, blue crabs, oysters, and penaeid shrimps (Montague and Wiegert 1990). In addition, tarpon (*Megalops atlanticus*), snook (*Centropomus undecimalis*), red drum (*Sciaenops ocellatus*), seatrout (*Cynoscion* spp.), and kingfish (*Menticirrhus* spp.) move from near-shore seagrass beds into salt-marsh tidal streams (Lewis *et al.* 1985b).

The three Caribbean mangrove species, *Rhizophora mangle* L. (Red Mangrove), *Avicennia germinans* (L.) L. (Black Mangrove), and *Laguncularia racemosa* (L.) C. F. Gaertn. (White Mangrove) are estimated to cover 189,725 ha (468,620 acres) along Florida's coasts (Lewis *et al.* 1985b). About 90% of mangrove forests (or mangals) occur in the most southern four counties of Florida (Lee: 14,275 ha, Collier: 29,126 ha, Monroe: 94,810 ha; Dade: 32,931 ha), a region of low wave energy and consequently abundant seagrass beds. Because of the lack of severe freezing temperatures since 1989, mangroves extend intermittently northward of Tampa Bay to the western panhandle on the Gulf coast and north to the Tomoka River on the Atlantic coast (Odum and McIvor 1990; D. Crewz *pers. obs.*). Export of mangrove-leaf detritus is highest in riverine (1.2–2.7 g carbon m^{-2} d^{-1}) and fringing forests (0.5–0.7 g carbon m^{-2} d^{-1}), and these contribute to detrital-based food webs in near-shore seagrass beds (Odum and McIvor 1990). Stable carbon isotope levels ($\delta^{13}C$) of seagrass blades and mollusk shells taken from seagrass beds near south Florida mangrove forests had significantly lower mean values (–12.8 and –2.3 ppt, respectively) than did blades and shells far from the coastal forests (–8.3 and +0.6). The lower $\delta^{13}C$ values near mangrove forests indicate release of carbon dioxide by mangrove-detritus mineralization, conversion to bicarbonate, and subsequent uptake of bicarbonate by the adjacent seagrass beds (Lin *et al.* 1991).

The habitat values of mangals, adjacent seagrass beds, and nonvegetated open water were compared for densities of fish, shrimp, and crabs in Rookery Bay near Naples (Sheridan 1992). Fish densities were highest in nonvegetated areas (74% of the total caught), while shrimp and crab densities were highest in seagrass beds (74% and 47% of the total capture respectively). However, flooded *R. mangle* forests had resident and transient fish and crab numbers equal to those of other areas on some occasions. The data suggest that seagrass beds are a principal habitat for shrimp and crabs, whereas mangrove prop roots and pneumatophores may serve an ancillary role for a variety of fish and invertebrates, contrary to the conclusion drawn in earlier studies (*e.g.*, Thayer *et al.* 1978, 1987).

South Florida's shallow-water coral reefs are unique in North America. Florida's reefs are similar in species composition and physiographic features to those in the Caribbean Sea and Bahama Islands (Dawes 1998a). Occasionally, hard corals occur as far north as Jupiter Island on the Atlantic coast (27°N lat.). Coral reefs form extensive three-dimensional structures south and west of Cape Florida and along the Florida Keys archipelago (Jaap and Hallock 1990). Seagrass beds cover 80% of the sea bottom between Cape Sable and throughout Florida Bay, along the Florida Keys, extending westward to the Dry Tortugas, and north on the Atlantic coast into Biscayne Bay, thus co-occurring with the Florida reef tract (Jaap and Hallock 1990). Aerial photography of Biscayne National Park showed that moderately dense to highly dense seagrass beds covered 25,445 ha (62,849 acres) of the 55,000 ha (135,850 acres) in the park (Lewis *et al.* 2002) and were closely associated with coral patch reefs.

The relationship of seagrass beds to patch and tract reefs is considered to be in danger due to nutrient-rich runoff from canals in Biscayne Bay (Lewis *et al.* 2002) and from septic tanks in the Florida Keys (Jaap and Hallock 1990). A key feature of coral-reef dependence on adjacent seagrass beds is their sensitivity to nutrient enrichment, which enhances macroalgae overgrowth on the coral structures (Dawes 1998a). Thus, nutrient removal from the water column by adjacent seagrass beds may play a major role in protecting coral reefs. In addition, the ecological role of seagrasses as habitat and nursery in the life cycle of the spiny lobster (*Panulirus argus*), whose juveniles settle in algae associated with seagrass beds, has been noted (Marx and Herrnkind 1985).

Seagrass detritus and vegetative parts are exported into deep-water habitats, especially on the Atlantic coast. Deep water (>200 m) is farther offshore on the Gulf coast of Florida than along the Atlantic, but seagrass beds are more developed in the Gulf. The larger-stature seagrass species extend to about 9 m (Dawes 1974; Iverson and Bittaker 1986). In contrast, the smaller-stature *Halophila engelmannii* grows in 1–5 m in Tampa Bay (Dawes 1967), in 1.4 m off Tarpon Springs (Phillips 1960b), and to 73 m off the Gulf coast (Dawes and van Breedveld 1969; Dawes and Lawrence 1990) and the Dry Tortugas (Taylor 1928). The more diminutive *H. decipiens* appears to be limited to deep water on the Gulf coast and occurs in 20 to 90 m (Dawes and van Breedveld 1969; Zieman 1982; Dawes and Lawrence 1990; Fonseca *et al.* 2001; see also Chapter 4). In the summer and early fall on the Gulf coast, *H. decipiens* often forms extensive beds in 20–30 m of water (Dawes and Lawrence 1990). However, no information currently exists regarding the export or role of detritus from inshore seagrass beds to the 200-m deep continental shelf west of Florida (Florida Institute of Oceanography 1994).

NATURAL and ANTHROPOGENIC EFFECTS

- Seagrass regression and die-off observed in Florida Bay in the late 1980s resulted from a combination of natural and human causes, including overproduction of seagrasses that resulted in dense shoots; anoxia that increased sediment sulfide levels; nutrient inputs that caused algal blooms, reducing light levels; lack of freshwater inputs that resulted in hypersalinity; and infection by *Labyrinthula*, a pathogen of *Thalassia testudinum*.
- The relationship between *Labyrinthula* infection and die-off of *T. testudinum* is not clear, as the pathogen has been found in a number of Florida Gulf-coast estuaries in seagrass beds that have not experienced die-off.
- Storms appear to have little direct impact on most seagrass communities, except for erosion and deposition of sediment in some areas, as found following Hurricane Andrew.
- The 1997–1998 *El Niño* event caused a general die-back of seagrass communities because of low salinities and increased nutrient loads and turbidity from runoff.
- The importance of long-shore sand bars is not adequately understood, but they may protect seagrass beds from waves and erosion in some locations.
- Mechanical damage to seagrass beds continues, with propeller scarring being common in shallow-water communities.
- The effects of small-scale seagrass-bed damage on local animal populations is not adequately understood; for example, moderately scarred beds show little change in shrimp and pinfish densities.
- Nutrient pollution continues to be a serious problem, with 8 of the 15 Florida Gulf-coast estuaries regarded as being eutrophic.
- Nutrient enrichment from natural or human sources results in increased phytoplankton density and resultant chlorophyll levels, reduction in light penetration, increased seagrass loss, increased epiphytism, increased sediment hypoxia, and shifts in seagrass species dominance.
- The effects of sediment contaminants on seagrass communities are not clear. The highest contaminant levels of metals and pesticides are associated with fine muds, limited PAR, and low salinities.

Stargrass, *Halo*

Many studies, including those by resource management programs of the National Estuary Programs for Tampa Bay, Sarasota Bay, and Charlotte Harbor and by the National Estuarine Research Reserves at Apalachicola and Rookery bays, have emphasized the importance of Florida's Gulf-coast seagrass communities. Understanding of natural- and human-induced seagrass disturbances has increased substantially, as shown in a review by Durako (1988), Short and Wyllie-Echeverria (1996) and Duarte (2002). Since 1989, many publications have examined the condition of seagrass communities on Florida's Gulf coast. These include studies of the north-central Gulf coast (Mattson 1995, 2000), Tampa Bay (Lewis *et al.* 1991, 1998; Johansson and Ries 1997; Kurz *et al.* 1999; Pribble *et al.* 1999; Greening 2002a; Johansson 2002a), and Sarasota Bay, Lemon Bay, and Charlotte Harbor (Kurz *et al.* 1999; Staugler and Ott 2000; Tomasko *et al.* 2001). Declines in seagrass coverage in various estuaries on the Gulf coast (including Florida Bay) have often been attributed to interactions between natural and anthropogenic factors.

In Florida Bay, *T. testudinum* die-off was noted in late 1987 by Robblee *et al.* (1991) and has been studied by many others since then (Carlson *et al.* 1994; Durako 1994; Durako and Kuss 1994; Thayer *et al.* 1994; Carlson and Yarbro 2001; Fourqurean and Robblee 1999; Hall *et al.* 1999; Zieman *et al.* 1999). Often, natural processes can result in increased damage to seagrass beds if they had been previously stressed by anthropogenic impacts, as appears to have happened regarding the seagrass die-off in Florida Bay. Despite the acknowledged interactions of natural and anthropogenic influences in these and many other systems, however, these categories are addressed separately below.

NATURAL PROCESSES

Natural processes have biological and nonbiological sources and include such influences as storms, sea urchin population increases, phytoplankton blooms, and macroalgae overgrowth. Such sources can cause direct or indirect damage that include shading, overgrazing, or disease.

Although moderate grazing is common and may even affect seagrass communities positively, overgrazing by urchins, and to a lesser extent by manatees or sea turtles, can result in complete denudation in some areas. For example, overgrazing by *Lytechinus variegatus* (purple sea urchin) resulted in severe seagrass denudation near the Pepperfish Keys (Camp *et al.* 1973) and in outer Florida Bay (Maciá and Lirman 1999; Rose *et al.* 1999).

As summarized in Chapter 4, epiphytes on seagrass blades have both positive and negative effects, with most damage being linked to shading and reductions in photosynthesis. In Tampa Bay, shading by epiphytes of *T. testudinum* blades is an important controlling factor in its depth distribution (Dixon and Leverone 1997).

High levels of drift algal biomass suppress seagrass-bed expansion and, similar to seagrass epiphytism, are usually linked to nutrient enrichment. In Hillsborough Bay, Avery (2000) reported in a 10-year study (1986–1994) that the 18 species of dominant drift algae (see Table 4.6 and Chapter 4) declined from an average biomass of 930 to 80 g dry wt m^{-2} and continued to decline through 1997. In contrast, due to reductions of water-column nutrients in Hillsborough Bay, *H. wrightii* beds expanded from 0.2 ha to 40 ha (Avery 2000). On the positive side, drift and epiphytic algae probably serve as nutrient sinks and as food for a variety of invertebrates and fish (Kharlamenko *et al.* 2001; Moncreiff and Sullivan 2001).

The decline in the past 20 years of seagrass communities in Florida Bay is a conspicuous example of the effects of natural and possibly human influences on seagrass populations on the Gulf coast. In 1987, vast areas of *T. testudinum* began dying rapidly. Short-shoot densities dropped by 22% and standing crop by 28% at 107 sampling stations (Figure 5.1) between 1984 and 1994 (Hall *et al.* 1999). Losses were highest in western Florida Bay in areas with high standing crops. Similar or greater declines in standing crops were evident for *H. wrightii* (92%) and *S. filiforme* (93%) between 1984 and 1994. Hall *et al.* (1999) suggested that the most likely cause was chronic light reduction due to increased water turbidity.

A pathogen, *Labyrinthula*, was also suggested as being involved in the die-off of *T. testudinum* in Florida Bay (Porter and Muehlstein 1989; Robblee *et al.* 1991). It is similar to one that was implicated in the wasting disease of *Z. marina* over the past 50 years in the Atlantic (Burdick *et al.* 1993). Porter

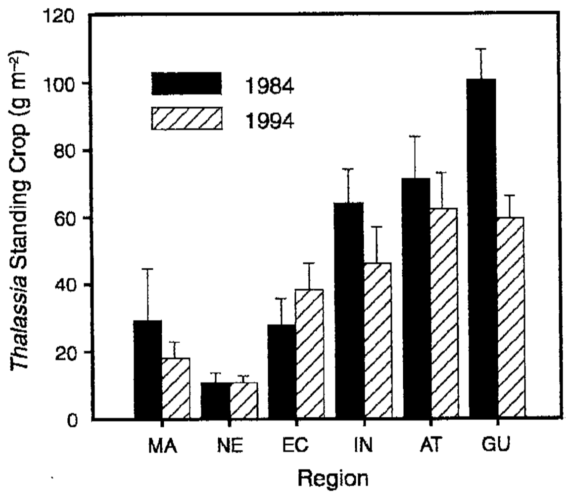


***Fig 5.1** Standing crop (±SD) of* Thalassia testudinum *in six ecological regions of Florida Bay 1984 and 1994 (Hall* et al. *1999). MA = Mainland, NE = Northeast, EC = East Central, IN = Interior, AT = Atlantic, GU = Gulf.*

and Muehlstein (1989) reported the presence of an undescribed species of *Labyrinthula* in blackened, necrotic lesions on the leaves of *T. testudinum* collected in seagrass die-off areas of Florida Bay. Durako and Kuss (1994) found that photosynthesis in necrotic lesions on *T. testudium* blades was impaired. They suggested that this may have reduced oxygen available for transport via the blade lacunae to belowground organs, resulting in increased sediment hypoxia and leading to sulfide toxicity. The pathogen has also been found to be infecting from 0% to 100% of *T. testudinum* blades in at least 10 sites on the Gulf coast (Figure 5.2) from the Chandeleur Islands (LA) to Florida Bay (Blakesley *et al.* 2002). The authors found that 60% to 90% of the sites sampled in Tampa Bay had infected short shoots of *T. testudinum.*

Thayer *et al.* (1994) ascribed the die-off in Florida Bay to "as yet unknown environmental stresses." Studies now suggest that the die-off arises from a combination of human-derived and natural factors that may collectively stress *T. testudinum* and thereby enhance infectivity by the pathogen (Blakesley *et al.* 2002). The factors involved include hypersalinity (Fourqurean and Robblee 1999); persistent microalgal and cyanobacterial blooms and resuspended sediments that reduced illumination (Hall *et al.* 1999); anoxia that increased levels of sediment sulfide (Carlson *et al.* 1994, 2002; Carlson and Yarbro 2001); and enhanced growth that resulted in high biomass (Zieman *et al.* 1999).

Hypersaline areas of Florida Bay probably resulted in part from a lack of flushing in the absence of periodic hurricanes. This condition may also be exacerbated by a reduction in freshwater flow from the Everglades because of surface-water diversion. Nevertheless, data covering 1989–1995 suggest that seagrasses were once again growing rapidly in Florida Bay and that the loss of *T. testudinum* appeared to be slowing (Zieman *et al.* 1999).

Little information is available regarding the effects of storms on Florida's Gulf-coast seagrass communities, except for that following Hurricane Andrew, which swept across southern Florida on August 24, 1992, and exited into Florida Bay at Lostmans River (Ogden 1992; Dawes *et al.* 1995). Although coastal mangrove forests were destroyed, seagrass beds in Lostmans Bay showed no signs of alteration or depletion of the meiofauna when sampled two and nine months after the storm (Dawes *et al.* 1995). To be sure, during hurricanes large volumes of water fall simultaneously upon broad landscapes, leaching large amounts of nutrients and other compounds from soils. Together with the lowering of salinities, this short-term pulse of pollutants may alter community dynamics in seagrass beds.

Also, excessive rainfall over an extended period can damage seagrass communities. An *El Niño* event between December 1997 and March 1998 resulted in over 52 cm (approximately 20 inches) of rain, which triggered widespread, persistent phytoplankton blooms, decreasing the light available to seagrasses, along the Gulf coast of Florida (Carlson *et al.* 2003). In 1997, 1998, and 1999, sampling near the Homosassa and Anclote rivers and in Tampa Bay and Charlotte Harbor found that short-shoot densities, blade widths and numbers, leaf-area indices, rhizome-apex densities, and stored carbohydrates of *T. testudinum* declined (Carlson *et al.* 2003) in response to the 1997–1998 *El Niño.*

Long-shore sand bars often occur seaward of seagrass communities and have been suggested to play a role in protecting seagrasses from strong waves and currents (Lewis 2002). Thus, reductions in seagrass coverage in some areas of Tampa Bay may reflect historical loss of these bars, similar to those in North Carolina (Fonseca and Bell 1998). In this regard to this idea, Fonseca *et al.* (2002) employed a wave-exposure model (Relative Expo-

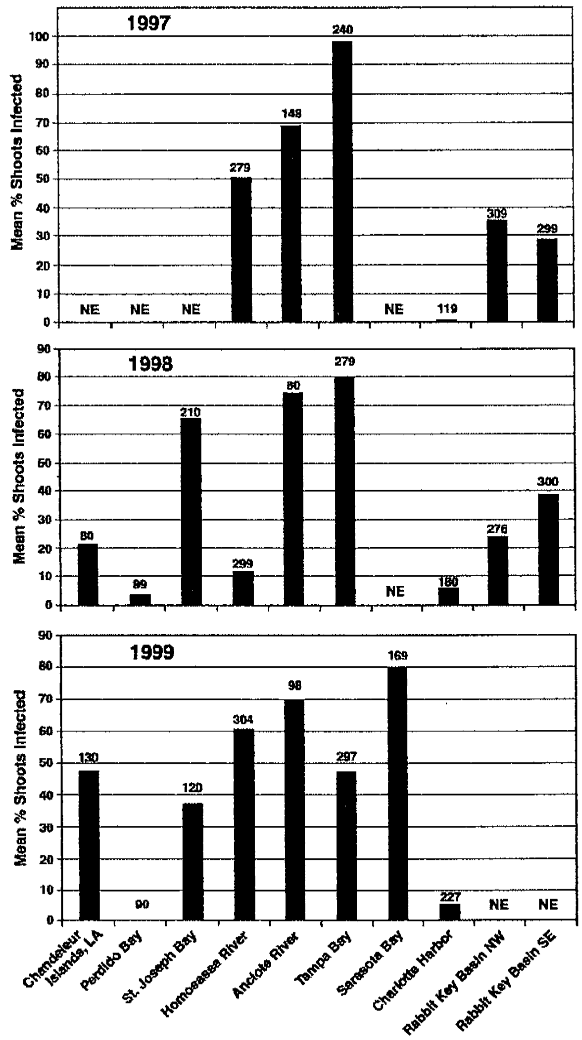


Figure 5.2 *Mean percentage of* Thalassia testudinum *short-shoots infected with a pathogenic species of* Labyrinthula *at ten sites along the Gulf coast. Numbers over bars are sample sizes. NE = not examined. (modified from Blakesley* et al. *2002).*

sure Index—REI) to evaluate the influence of long-shore sandbars on seagrass coverage in Tampa Bay. Their results hindcasted that erosion or loss of long-shore sand bars on the southeastern shore of the bay, where wave exposure is relatively high, had caused the loss of seagrass originally located between the shore and the historical sand bars. They recommended that no restoration efforts be conducted in areas of strong wave exposure without including engineering to reduce REIs.

ANTHROPOGENIC EFFECTS

Livingston (1987) summarized anthropogenic (human-derived) effects on seagrass meadows (Table also presented in Zieman and Zieman 1989), including direct physical damage and pollution, with an emphasis on nutrient enrichment. Since that review, various studies have described anthropogenic effects and also include estimates of seagrass losses (see Chapter 4). Nutrification and sediment loading from maintenance dredging of shipping channels and vessel-generated resuspension are cited as important causes of seagrass declines (Schoellhamer 1991; Tomasko and Lapointe 1991; Culter and Leverone 1993; Quammen and Onuf 1993; Lapointe *et al.* 1994). Dredging, although now generally restricted, continues in all estuaries on the Gulf coast to maintain channels and create new harbors. Certainly, such activities cause temporary resuspension of contaminated sediments and contribute to reduction of water transparency (Godcharles 1971; Schoellhamer 1991; Ailstock *et al.* 2002).

Mechanical damage is also done to seagrass beds by erosive effects following boat (and ship) groundings, by propeller wash, and by ship and boat wakes in shallow waters. Kenworthy *et al.* (1988a) found that boat wakes substantially increased bottom shear stress along edges of shallow seagrass beds. Even though nets used for bait-shrimp trawling in Tampa Bay do not appear to cause much direct damage to seagrass beds (Meyer *et al.* 1999) a large diversity of animals are killed as by-catch, plus trawling may suspend sediments which decreases water clarity.

Propeller scarring is another type of physical damage to seagrass beds (Figures 5.3, 5.4) that continues to increase in all areas of coastal Florida (Sargent *et al.* 1995). Many shallow flats and mud banks are now severely eroded due to constant scarring, ship groundings, chronic wave action from boats, and water-current scouring (Kruer 1994). Culter and Leverone (1993) stated that prop scarring was visible in almost all seagrass beds in Sarasota Bay. Sargent *et al.* (1995) determined that 6.2% (over 70,000 ha or 183,000 acres) of Florida's 1.1 million ha (2.7 million acres) of seagrass beds have been scarred by boat propellers (prop-dredging, prop cuts) and by similar causes, principally in coastal waters less than 2 m deep. They concluded that scarring in seagrass beds has become acute because of increasing human population densities, increasing popularities of boating, fish-

FWC–FWRI photo

Figure 5.3 Propeller scarring from recreational boating in a Thalassia testudinum *bed near Panama City, Florida.*

ing, diving, and other water sports, and increasing tourism. Scarring level was divided among three categories: 1) light scarring, in which less than 5% of the seagrasses in a particular map polygon were scarred; 2) moderate scarring, in which 5% to 20% of the seagrasses within the polygon were scarred; and 3) severe scarring, in which more than 20% of the seagrasses in the polygon were scarred (Sargent *et al.* 1995). The highest level of scarring was found in Monroe and Citrus counties, which also contained the highest amount of seagrass coverage (688,259 ha; 1.6 million acres). Of this total, they calculated that 23,332 ha (57,630 acres) were scarred with 17.3% of the seagrasses being in Monroe County and 15.8% in Citrus County.

The influences of prop scars on seagrass community production have been studied in Tampa Bay and Charlotte Harbor (Durako *et al.* 1992; Clark 1995; Dawes *et al.* 1997; Bell *et al.* 2002), Sarasota Bay (Folit and Morris 1992), and the Florida Keys (Matthews *et al.* 1991). Fragmentation of seagrass beds in Tampa Bay due to propeller cuts did not appear to have any consistent effects on some animal populations over a one-year period, as long as seagrass patch sizes were greater than 1 m^2 (Bell *et al.* 2002). The numbers of pinfish (*L. rhomboides*), pipefish (*Syngnathus scovelli*), and eight species of epibenthic shrimp were similar in moderately scarred (6% to 31% loss of the beds) and nonscarred seagrass beds in Tampa Bay. The results of these studies suggest that propeller scars that fragment seagrass beds may enhance certain faunal development caused by edge effects along the cuts as long as they are not too severe. Nevertheless, a recent study of scarring in a *T. testudinum* bed in Puerto Rico revealed a negative effect of scarring on crabs and molluscs up to 5 m from the scar. Also, shrimp species within the scar differed from those in the non-scarred seagrasses. Fish populations did not show an effect from the scarring. Further studies are clearly needed to define the effects of moderate scarring compared to those of severe scarring on seagrass productivity.

More recent studies have confirmed previous observations by Jones (1968), Godcharles (1971), and Zieman (1976) for the long time period required for scars to heal (Eleuterius 1987; Durako *et al.* 1992; Dawes *et al.* 1997). When seagrass rhizomes and roots are completely removed by scarring, sediment is destabilized and resuspension occurs, thereby lowering water transparency and retarding seagrass regrowth into the scar. Regrowth of *T. testudinum* into prop scars in Tampa Bay was estimated to require an average of 3.5 to 4.1 years for existing propeller scars and up to 7.6 years in newly made ones (Dawes *et al.* 1997). Shorter recovery periods in existing scars probably reflect their older ages and shallower depths. Based on studies at Weedon Island (Durako *et al.* 1992) and Cockroach Bay (Dawes *et al.* 1997) in Tampa Bay, the authors recommended that shallow-water seagrass beds be protected from propeller scaring. Criteria for the protection of seagrass beds have been proposed and adopted for Tampa Bay (Clark 1995; Stowers *et al.* 2002).

Another source of physical impacts that degrade seagrass communities is docks, which shade seagrass beds, as shown in Perdido Bay (Shafer 1999), Charlotte Harbor (Loflin 1995), and the Indian River Lagoon (Beal and Schmit 2000). Smith and Mezich (1999) surveyed 200 out of the 3,592 permit-exempt single- and multi-family docks that were deemed to have the potential to

FWC–FWRI photo

Figure 5.4 Propeller scarring from commercial fishing in a seagrass bed in Pine Island Sound, Florida.

damage seagrass beds in Palm Beach County. They found that 16% of the docks were larger than regulations allowed, owing to additions, and that approximately 1,491 single-family docks in the county had affected seagrass negatively. They estimated that, in total, docks eliminated 20.4 ha (50.4 acres) of seagrass beds, which is equal to 2.1% of the seagrass extents in Palm Beach County. Their recommendations were that all docks in Florida be considered within the jurisdiction of FDEP permitting programs. Currently, environmental resource permits are not required within designated Aquatic Preserves if the docks are less than 46.5 m^2 (500 ft^2) or if they are less than 92.9 m^2 (1,000 $ft.^2$) when outside Aquatic Preserves. Smith (1998) concluded that strong enforcement of the regulations protecting sovereign submerged lands (253.04–05, 380.05, F.S. and Chapter 18-14, F.A.C.) would act as a powerful deterrent against boat and dock damage to seagrass systems.

Direct physical damage of seagrasses can result from changes in freshwater inputs. The importance to watershed management and reduction of freshwater removal from tributaries flowing into Gulf-coast estuaries has been reviewed for Tampa Bay (Zarbock 1991) and for Charlotte Harbor (Kurz *et al.* 1999). Estevez (2000) found that changes in the amount, timing, and location of freshwater inflow are primary stressors to estuarine and oceanic seagrass communities, with salinity changes often being a first-order stressor (Montague and Ley 1993). The present estimated daily freshwater inflows into Tampa Bay (Zarbock 1991) range from 152.0 to 214.6 $m^3 s^{-1}$ (1,792 to 2,530 $ft^3 s^{-1}$) compared to historical estimates of 193.4 $m^3 s^{-1}$ (2,280 $ft^3 s^{-1}$). Although timing and duration of riverine inflow, along with nutrient loading and changes in water color, clearly affect seagrass communities in Charlotte Harbor, the relationships between these factors is more complex in Tampa Bay and Sarasota Bay (Kurz *et al.* 1999). Similarly, diversion of fresh water before it enters the Everglades, coupled with a decrease in hurricane-induced flushing (Thayer *et al.* 1994) and rising salinities and sediment anoxia (Zieman *et al.* 1999), has been proposed as influencing factors in the precipitous decline of Florida Bay seagrasses.

Short and Neckles (1999) hypothesized that global warming will probably influence seagrass distribution by causing increases in sea level, in storm frequency and intensity, in disease from higher water temperatures, and in turbidity from eutrophication. The authors also predicted an increase in ultraviolet radiation that will damage seagrasses, as has been shown for macroalgae (Larkum and Wood 1993) and terrestrial plants (Caldwell *et al.* 1989). In addition, the shallow coastal and estuarine waters and low elevations on the Gulf coast of Florida will certainly be affected by any eustatic sea-level rise. A potential positive effect on seagrass distribution may occur from an increase in dissolved inorganic carbon (Ci) composition in seawater, as seagrasses are presently CO_2 limited and have an affinity for Ci (Beer and Koch 1996).

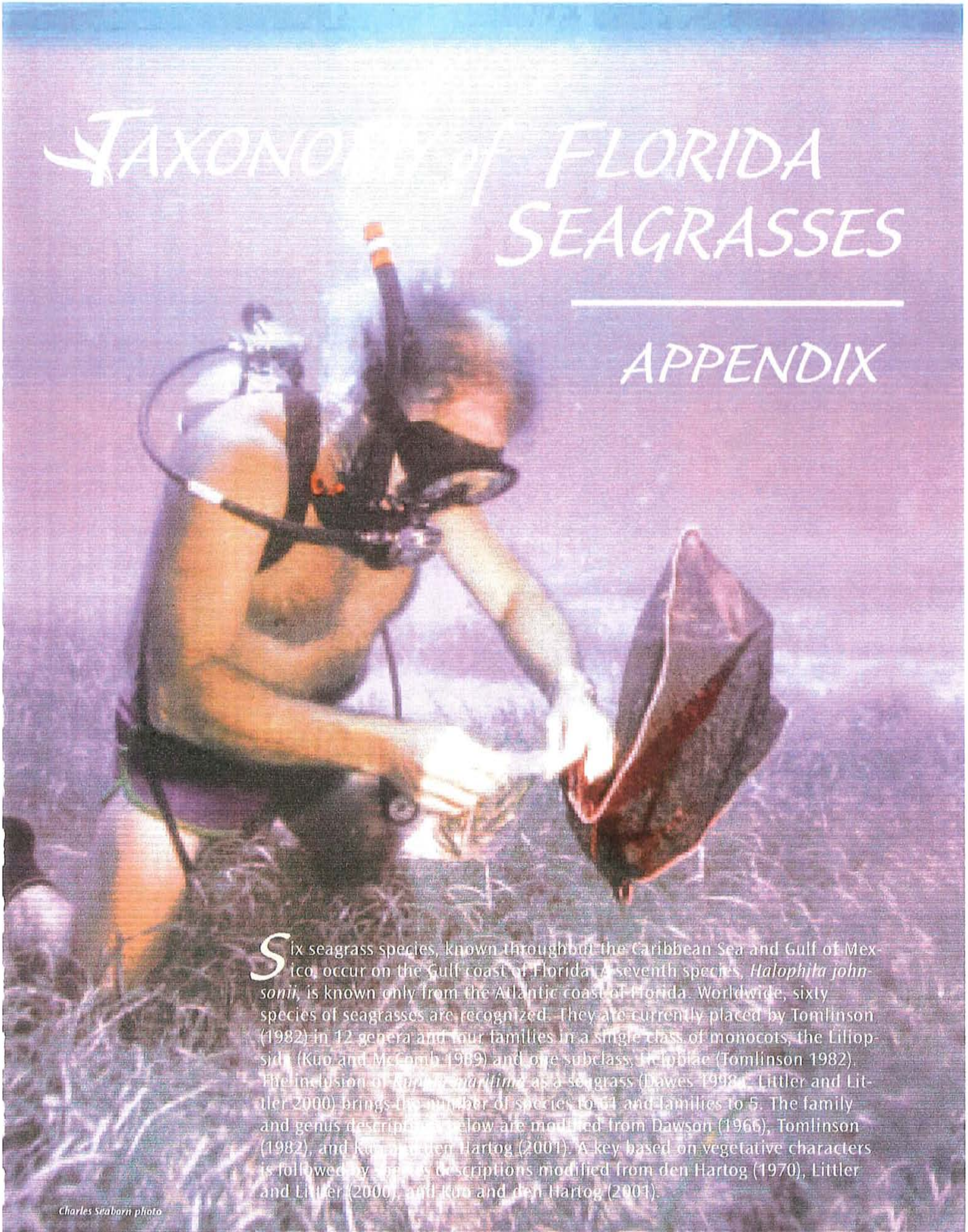
Nutrient enrichment, probably the most common human effect in Gulf-coast estuaries, can result in a variety of changes in seagrass communities. A number of these changes have been presented in Chapter 4. These include an increase in water-column chlorophyll levels (Johansson 1991; Janicki *et al.* 1999; Tomasko *et al.* 1996, 2001; Morrison *et al.* 1997), in algal epiphytism and shading of seagrass blades (Tomasko and Lapointe 1991; Tomasko *et al.* 1996; Dixon 2002), in shifts in dominant seagrass species (Duarte 1995; Fourqurean *et al.* 1995), and in sediment hypoxia (Carlson *et al.* 2002).

A review of U.S. estuaries (Bricker *et al.* 1999) cited 15 estuaries on the Gulf coast of Florida that had various levels of eutrophic conditions. Eight of these estuaries (Florida Bay, the southern Ten Thousand Islands, Caloosahatchee River, Charlotte Harbor, Sarasota Bay, Tampa Bay, Choctawhatchee Bay, and Perdido Bay) had high levels of eutrophic symptoms. More detailed data are available regarding nutrient loadings and damage to seagrasses in Tampa Bay (Treat and Clark 1991; Zarbock *et al.* 1994, 1996; Treat 1997; Lewis *et al.* 1998; Pribble *et al.* 1999; Greening 2002b), Sarasota Bay (Haddad 1989; Tomasko *et al.* 1992, 1996), and Lemon Bay (Tomasko *et al.* 2001). Tampa Bay has been the subject of several reviews (Treat and Clark 1991; Treat 1997; Greening 2002a) that include data regarding point- and nonpoint-source pollution, domestic and industrial effluents, accumulation of toxic substances in the sediment, and potential brine damage from desalination facilities.

Many studies worldwide support the contention that seagrass distribution, survival, and growth are principally determined by water clarity (Batiuk *et al.* 1992; Dennison *et al.* 1993; Duarte 1991; Kenworthy and Haunert 1991; Kenworthy 1993; Koch and Beer 1996; Morris and Tomasko 1993; and Tomasko *et al.* 2001; also individual papers contained in the publications of Bortone 2000 and Greening 2002a). However, other factors such as waves and water currents can affect seagrass distribution as well (Koch 2001; see Chapter 2). Water clarity is influenced by nutrient inputs, which stimulate the growth of phytoplankton (particularly by nitrogen), and by total dissolved and suspended solids. An overabundance of nutrients leads to eutrophication that supports increased levels of phytoplankton, drift algae biomass, and coverage by epiphytes on seagrass blades, all of which result in shading of seagrass leaves (Sand-Jensen 1977, 1990; Cambridge *et al.* 1986). In all cases a decrease in water clarity over seagrass beds was correlated with a decline in seagrass standing stock (Orth and Moore 1983; Short *et al.* 1996; Short and Wyllie-Echeverria 1996; Fitzpatrick and Kirkman 1995; Lewis *et al.* 1985a).

The influence of possible sediment contaminants on seagrass beds is not understood. The concentration of metals, nutrients, petroleum, chlorinated hydrocarbons, and radionuclides correlate with the smaller particle-size sediments (muds; <63μm in diam.) in Tampa Bay (Brooks and Doyle 1991) and with sediment-quality factors (Zarbock *et al.* 1997). Thus, concentrations of all contaminants are highest in west-central Hillsborough Bay and Old Tampa Bay (Brooks and Doyle 1991) for total organic matter (to 16%), total hydrocarbons (>40 $\mu g\ g^{-1}$), total organic nitrogen (0.1%), and total phosphorus (0.4%). Using the triad method of weighting sediment chemistry, toxicity, and benthic samples, Zarbock *et al.* (1997) determined that upper and middle Hillsborough Bay, parts of Old Tampa Bay, Boca Ciega Bay, and western Middle Tampa Bay had the most contaminated sediments. In a review of sediment quality in Tampa Bay, Grabe (1999) found that approximately 1% of its sediments were subnominal and had a high probability of being toxic. However, at the levels known for Tampa Bay, evidence that the heavy metals and pesticides directly affect seagrasses does not exist.

In conclusion, it is apparent that a mix of natural and human-induced events has negatively influenced the seagrass meadows on the Gulf coast of Florida. Because of limited historical data, determining the extent of seagrass decline is often difficult, although detailed historical analyses are possible in some areas, such as for Tampa Bay (Greening 2002a). Anthropogenic influences, particularly those that result in a decline in water quality, are considered the principal causes of seagrass losses throughout the world (Short and Wyllie-Echeverria 1996) and in the estuaries of Florida's Gulf coast (Lewis *et al.* 1985a). The loss of seagrass communities continues worldwide (Duarte 2002) as well as on Florida's Gulf coast (see Chapter 2). However, restoration management can result in the expansion and enhancement of seagrass meadows, as seen in Tampa Bay and Sarasota Bay (Greening 2002b). Future studies are needed to distinguish secondary and primary stressors that result in seagrass declines, such as the modification of watershed-level stormwater runoff and direct nutrient input.



Taxonomy of Florida Seagrasses

Appendix

Six seagrass species, known throughout the Caribbean Sea and Gulf of Mexico, occur on the Gulf coast of Florida. A seventh species, *Halophila johnsonii*, is known only from the Atlantic coast of Florida. Worldwide, sixty species of seagrasses are recognized. They are currently placed by Tomlinson (1982) in 12 genera and four families in a single class of monocots, the Liliopsida (Kuo and McComb 1989) and one subclass, Helobiae (Tomlinson 1982). The inclusion of *Ruppia maritima* as a seagrass (Dawes 1998, Littler and Littler 2000) brings the number of species to 61 and families to 5. The family and genus descriptions below are modified from Dawson (1966), Tomlinson (1982), and Kuo and den Hartog (2001). A key based on vegetative characters is followed by species descriptions modified from den Hartog (1970), Littler and Littler (2000), and Kuo and den Hartog (2001).

Charles Seaborn photo

ARTIFICIAL KEY to SPECIES, BASED on VEGETATIVE FEATURES

(see also Florida Department of Environmental Protection: http://www.fiu.edu/~seagrass/key/seagrasskey.html)

1. Leaf blades cylindrical; terete in cross section .... *Syringodium filiforme.*
1. Leaf blades flat .... 2.

2. Leaves paddle-shaped, associated with scale-like leaves .... 3.
2. Leaves strap-like or linear .... 5.

3. Leaves in a pseudo-whorl; each shoot with 2 scales at the base and 2 scales halfway up the shoot .... *Halophila engelmannii.*
3. Leaves paired, with 2 scales at their base .... 4.

4. Leaves linear-elliptical, margins entire .... *Halophila johnsonii.*
4. Leaves oblong to elliptical, margins minutely serrate .... *Halophila decipiens.*

5. Leaves greater than 3 mm wide; rhizomes scaley .... *Thalassia testudinum.*
5. Leaves usually less than 3 mm wide .... 6.

6. Leaf tips blunt with dentate points; rhizomes usually straight .... *Halodule wrightii.*
6. Leaf tips with fine points; rhizomes often in a zig-zag pattern .... *Ruppia maritima.*

HYDROCHARITACEAE Jussieu

Family of 15 genera, diverse and cosmopolitan, of which 3 are seagrasses (*Enhalus, Halophila, Thalassia*). Plants aquatic herbs, leaves either large, linear to strap-shaped and with sheathing base (*Thalassia*) or small, usually nonlinear, with distinct petiole and without sheathing base (*Halophila*). Rhizomes with scale-like leaves, and branching via apical bifurcation. Flowers unisexual and anthers either sessile or on long slender filaments. Female flowers usually with long hypanthium and inferior ovary. Fruits fleshy and often indehiscent.

***THALASSIA* Banks and Solander ex König.** 1805. Ann. Bot. (König *et* Sims) 2: 96 (Gr. *thalassa:* marine, of the sea).

Rhizomes creeping, horizontal, thick, fleshy, and indeterminate; bearing scale leaves and erect short-shoots (rhizomes) at irregular intervals that arise from rhizome meristem. Erect short shoots determinate, encased in leaf sheaths, producing foliate leaves and flowers. Roots unbranched, fleshy, arising at nodes of short shoots. Leaves strap-shaped, with sheathing bases, and growing from basal meristem. Short shoots with conspicuous leaf and inflorescence scars. Plants are dioecious. Male flowers on short stalks, in clusters of 1–3. Female flowers solitary. Fruits globose and opening by irregular splitting, containing several large angular "seeds" (seedlings).

***Thalassia testudinum* Banks and Solander *ex* König.** 1805. Ann. Bot. (König *et* Sims) 2: 96 (L. *testudinis:* a tortoise). Common name: Turtlegrass (Figure A.1.4).

Rhizomes creeping, 3–6 mm in diameter, 4–7 mm long between nodes, with scale leaves. Roots single, unbranched, arising at short-shoot nodes, producing delicate root hairs at tips. Erect short shoots with clusters of 3–7 leaves; leaves to 2 cm wide, with persistent colorless basal sheath, 9–17 parallel veins, and lacunae that are continuous throughout the plant. Plants dioecious. Flowers on short peduncles, with single whorl of white tepals. Male flowers with 3 to 12 stamens, pollen grains in mucilage, forming moniliform chains. Female flowers bearing one ovary with 6–8 carpels; style divided into 2 filiform stigmata. Fruits buoyant, 15–20 mm long, rough, fleshy, tips pointed, with one to few "seeds" (seedlings).

***HALOPHILA* Du Petit-Thouars.** 1806. Nova Madag. 2 (L. *halo:* salt + *philus:* loving).

Rhizomes horizontal, usually on surface and bearing two scales at each node, producing a lateral shoot and one unbranched root, short erect shoots either with paired leaves on long petioles, distichously arranged along the axes, or in a pseudo-whorl at top of shoot. Leaves oval, elliptical, lanceolate or linear, with mid and marginal veins. Plants monoecious or dioecious. Flowers covered by 2 bracts; sepals small, petals absent. Male flowers stalked, with 3 stamens having sessile anthers. Female flowers sessile, with 3–6 styles. Fruits ovoid capsules, bearing many seeds.

Halophila decipiens **Ostenfeld.** 1902. Bot. Tidsskr. 24: 260 (L. *decipio:* beguiling, deceptive). Common name: Paddlegrass (Figure A.1.1).

Rhizomes thin, with transparent, hairy scales, internodes 1.0–4.5 cm long. Petioles 3–15 mm long, bearing one pair of leaves; leaves oblong to elliptical, 10–25 mm long, 3–6 mm wide, with short rigid unicellular hairs on one or both sides of blades, margins finely serrate. Plants monoecious, male and female flowers on same stalk, covered by spathe, stalks to 1.5 mm long. Male flowers with 2 anthers to 1 mm long. Female flowers with 3 styles 1.5–2.5 mm long; single ovary to 1 mm long. Fruits 2.5 mm long, 1.5 mm wide, elliptical, bearing up to 30 seeds; seeds oval, to 0.2 mm long.

Halophila engelmannii **Ascherson in Neumayer.** 1875. Anl. Wiss. Beobeibet Reiser. p. 368 (Named for George Engelmann [1809–1885], an American physician and German botanist who settled in St. Louis). Common name: Stargrass (Figure A.1.3).

Rhizomes indeterminate, narrow, with internodes 2–4 cm long. Determinate, erect shoots 20–40 mm tall at each node. Leaves with petioles, 2 scales at base and another pair half-way up shoot, petioles to 2 mm long, bearing 2–4 pairs of leaves in pseudo-whorls. Blades oblong to linear-oblong, 10–30 mm long, 3–6 mm wide, tips pointed and margins serrate. Plants dioecious. Male flowers with 3 imbricate tepals and 3 stamens. Female flowers with one sessile, inferior ovary, ovaries 3–4 mm long, ovoid, with 1–3 styles; styles to 30 mm long. Fruit globose, fleshy capsule, 3–4 mm in diam. with several minute subspherical seeds.

Halophila johnsonii **Eiseman.** 1980. In Eiseman and McMillan, Aquatic Bot. 9: 16 (Named for J. Seward Johnson, cofounder of Harbor Branch Oceanographic Institute, where N. Eiseman studied). Common Name: Johnson's Seagrass. (Figure A.1.2).

Rhizomes thin, 1 mm in diam., nodes bearing scale leaves on upper and lower surfaces, internodes 1–2 cm long. Petioles 10–20 mm long, bearing pair of linear to spatulate leaves; leaves slightly asymmetrical, 5–25 mm long, 1–4 mm wide, margins entire and surfaces glabrous. Plants dioecious (?), only female plants found. Female flowers sessile, with three styles 4–6 mm long; seeds unknown. occurring only in Atlantic Florida (Sebastian Inlet to Biscayne Bay) and classified as a threatened species. May not be distinct from *H. ovalis* (R. Brown) J.D. Hooker *f.*, 1858.

CYMODOCEACEAE N. Taylor

Family of 5 morphologically distinct genera and about 20 species, all seagrasses. Plants perennial herbs. Rhizomes creeping, leafy, herbaceous or distinctly woody, scale-bearing. Leaves distichous with distinct sheath and blade; blades linear, flat or terete, leaves with numerous tannin cells. Plants dioecious. Flowers solitary or in cymose inflorescences and usually terminal. Male flowers subsessile or stalked with 2 anthers producing filiform pollen. Female flowers with 2 free carpels, each with 1 style. Fruits 1-seeded nuts, indehiscent.

HALODULE **Endlicher.** 1841. Gen. 1368 (L. *halo:* salt + *dule:* loving).

Rhizomes monopodially branched; each node producing one to several unbranched roots and erect short shoot with 1–4 leaves. Leaves narrow, linear, with 3 longitudinal veins and short basal sheaths. Plants are dioecious. Flowers solitary, terminal, enclosed by leaf. Male flowers stalked, with 2 anthers. Female flowers with 2 free carpels, with long undivided styles. Fruits oval to slightly flattened, with a stony pericarp.

Halodule wrightii **Ascherson.** 1868. Bot. Zeitung (Berlin) 26: 511 (Named for Charles Wright [1811–1885], who collected extensively in the southwest U.S. and Cuba and sent specimens to Ascherson). Common names: Shoalgrass, Cuban Shoalgrass, or Shoalweed (Figure A.2.3).

Rhizomes slender, bearing 2–4 roots and a short shoot at each node; internodes 0.75–3.5 cm long, with elliptic scale leaves 5–10 mm long. Leaf sheaths 1.5–6.0 cm long; blades 5–12 (–20) cm long, 0.50–1.5 (–2.0) mm wide, with 3 parallel veins; blade tips with 2–3 short horn-like points. Plants are dioecious. Flowers lack tepals; male flowers on peduncles 1.5–2.0 cm long, anthers slender, 3.5–5.0 mm long. Female flowers with one oval to elliptic ovary, 1.5–2 mm wide, with 10–28 mm long style. Fruits about 1.5–2.0 mm in diam. with stony pericarp and stylar beak.

***SYRINGODIUM* Kützing.** 1860. In Hohenacker, Alg. Marin. Sicc. 9: 426 (Gr. *Syringx:* a tube + *odium:* similar to; thus like *Syringa,* a genus of flowering plants).

Rhizomes indeterminate, with monopodial branching and scale leaves; each node bearing 1–3 branching roots and erect, unbranched, determinate short shoot. Short shoots producing 2–3 cylindrical leaves with basal sheaths. Plants dioecious. Flowers in erect cymose infloresences; male flowers stalked, with 2 anthers. Female flowers with 2 free carpels, each with short style. Fruits with stony, smooth pericarp.

***Syringodium filiforme* Kützing.** 1860. In Hohenacker, Alg. Marin. Sicc. 9: 426 (L. *filiforme:* long and thin). Common name: Manateegrass (Figure A.2.2).

Rhizomes 2–4 mm in diameter, nodes bearing 2–4 roots with abundant root hairs, scale leaves, and erect short shoot. Short shoots with 2–3 leaves; leaves to 30 cm long, 1–2 mm in diam., cylindrical, with extensive basal sheathing, cylindrical. Plants dioecious. Male flowers on short peduncles, with 2 anthers. Female flowers sessile, with leaf sheath and 2 free carpels. Fruits oval to oblique, to 6 mm long, 3–5 mm in diam.

RUPPIACEAE Hutchins

Family of one genus and 2–3 species, all seagrasses, closely related to the Potomogetonaceae. Plants glabrous, submerged perennial herbs found in alkaline lakes and brackish to oceanic waters. Rhizomes creeping and little differentiated from erect axes, with monopodial branching. Leaves opposite or alternate, narrowly linear, with single medial vein and short basal sheath. Plants monoecious. Flowers perfect, on spikes subtended by 2 subopposite involucral leaves with slightly inflated sheaths; two flowers per spike, each with 2 stamens and few to 4 carpels with short, stout to finely attenuate styles and peltate stigmas. Fruits indehiscent achenes, the outer layers soft, decaying and inner pericarp stony.

***RUPPIA* Linnaeus.** 1753. Species Plantarum, p. 127 (Named for Heinrich Reinhard Ruppius [1688–1719], a German botanist who wrote the Flora of Jena).

Genus with characters of the family.

***Ruppia maritima* Linnaeus.** 1753. Species Plantarum, p. 127 (L. *maritima:* of the ocean, marine). Common names: Ditchgrass; Widgeongrass (Figure A.2.1).

Rhizomes thin, 1–3 mm in diameter, profusely branched, with growth forms; often geniculate. Leaves produced at nodes, sheath 6–10 mm long. Reproductive axes on erect stalks 60–90 cm long. Leaves to 1 dm long, 0.3 mm wide, 1 veined, with pointed tips and appearing to arise directly from rhizome. Plants monoecious. Flowers on short (>6 cm) peduncles elongating after anthesis, becoming loosely coiled spiral. Flowers with 2 sessile anthers 2-celled, elliptical, 0.6–0.7 mm long; carpels oval, to 2 mm long, style short and stout to attenuate. Fruitlets (nutlets) 2–3 mm long, on short stipe, often curved.

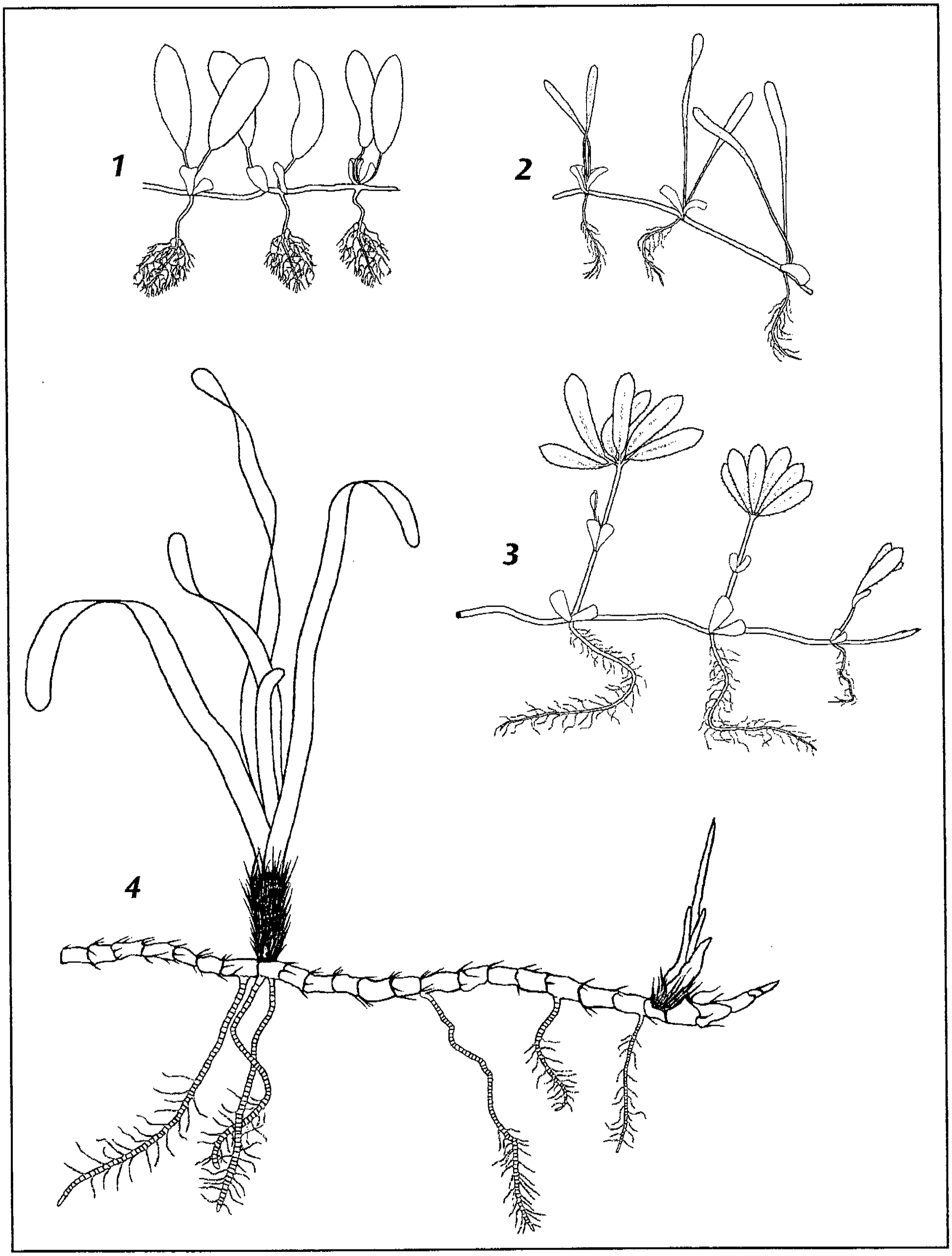


Figure A.1 *HYDROCHARITACEAE:* ***1*** Halophila decipiens, *Paddlegrass (× 2⁄3);* ***2*** H. johnsonii, *Johnson's Seagrass (× 3⁄4);* ***3*** H. engelmannii, *Stargrass (× 3⁄4);* ***4*** Thalassia testudinum, *Turtlegrass (× 1⁄3). Scale approximate. Smaller phenotypes are common.*

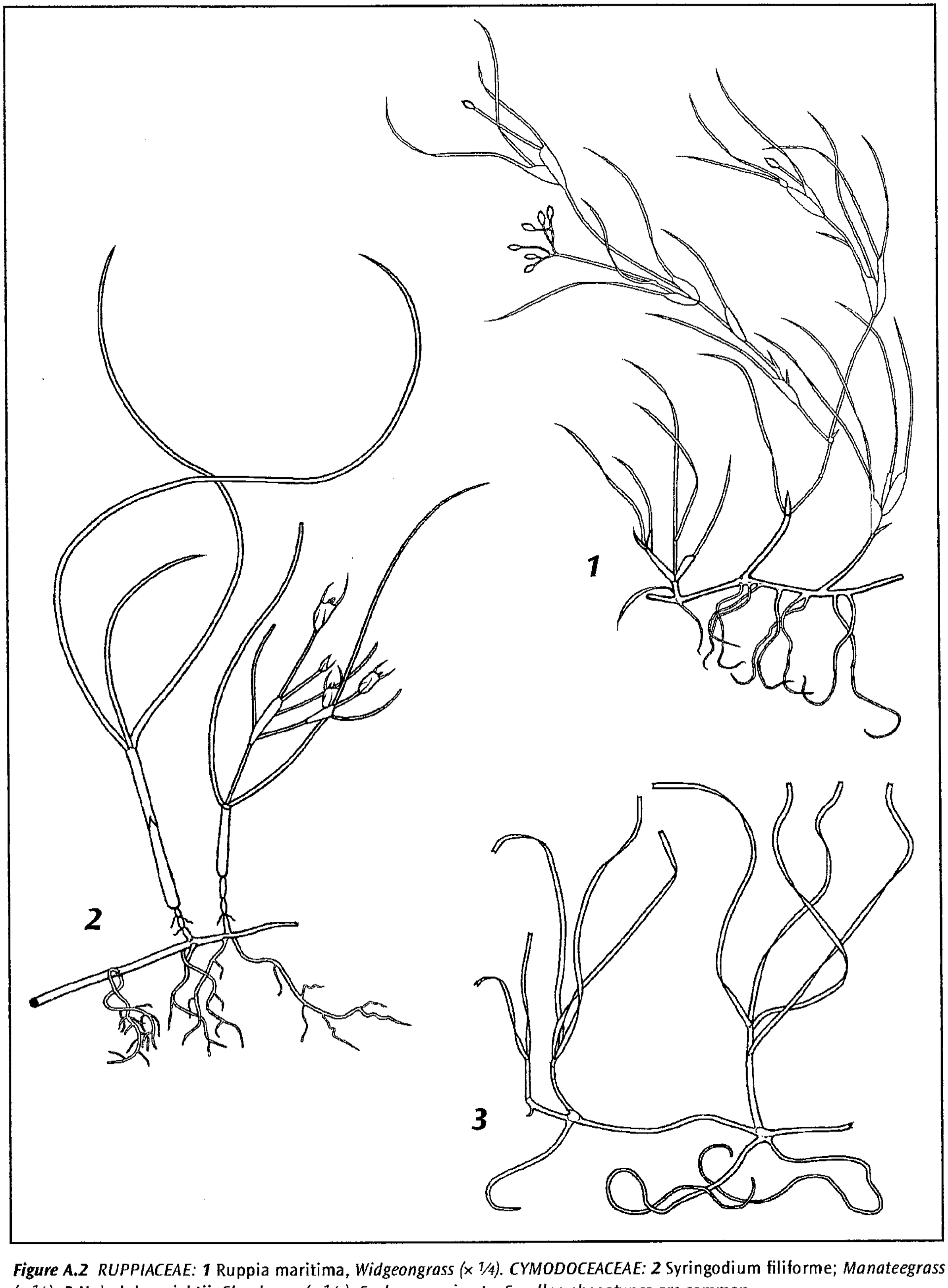


Figure A.2 *RUPPIACEAE:* **1** Ruppia maritima, *Widgeongrass (× ¼). CYMODOCEACEAE:* **2** Syringodium filiforme; *Manateegrass (× ¼);* **3** Halodule wrightii, *Shoalgrass (× ⅓). Scale approximate. Smaller phenotypes are common.*

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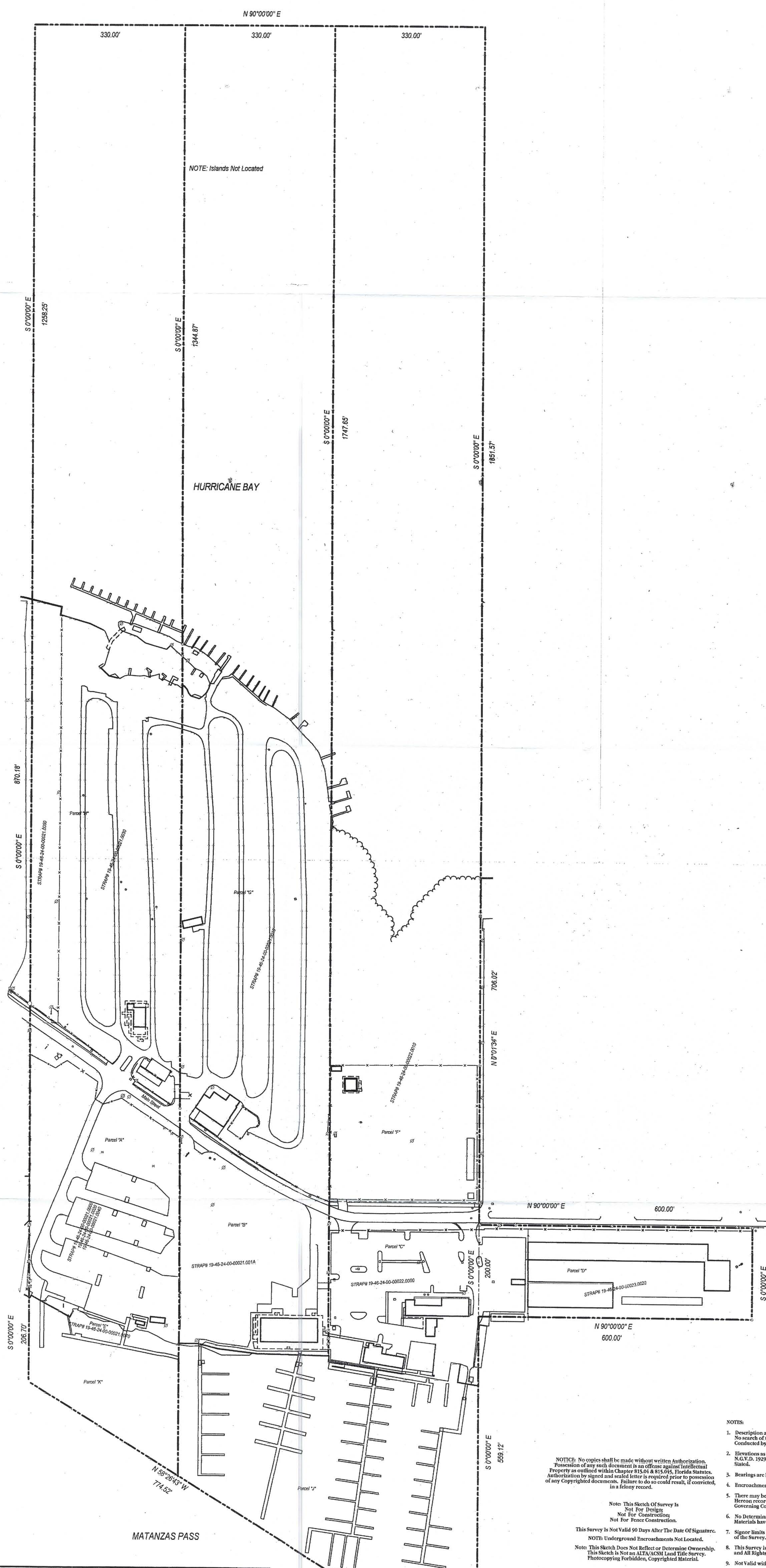
ENVIRONMENTAL LAND SERVICES, INC.
3677 CENTRAL AVENUE SUITE G
FORT MYERS, FLORIDA 33901
PHONE: (239) 274-8022 *ELS*
FAX: (239) 274-8019 *LB 5986*

Graphic Scale: 1.0" = 110.00'

110 0 110 220 330 440

CERTIFIED TO:

Hanson Marine Properties, Inc.;
Oyster Bay Land Company, Inc.



ALFRED J. WATSON
PROFESSIONAL SURVEYOR AND MAPPER
#2330 - STATE OF FLORIDA

ABBREVIATIONS:

ADD'N	=ADDITION	NG	=NATURAL GRADE
ALUM	=ALUMINUM		
AVE	=AVENUE	OHUL	=OVERHEAD UTILITY LINE
		ORB	=OFFICIAL RECORDS BOOK
BLK	=BLOCK		
BM	=BENCHMARK	{P}	=PLAT
BRB	=BARBED WIRE FENCE	PB	=PLAT BOOK
		PC	=POINT OF CURVATURE
{C}	=CALCULATED	PCP	=PERMANENT CONTROL POINT
CBS	=CONCRETE BLOCK & STUCCO	PI	=POINT OF INTERSECTION
CHD	=CHORD	PK	=PARKER KALON
CL	=CENTERLINE	PL	=PROPERTY LINE
CLF	=CHAINLINK FENCE	POB	=POINT OF BEGINNING
CM	=CONCRETE MONUMENT	POC	=POINT OF COMMENCEMENT
CONC	=CONCRETE	PRM	=PERMANENT REFERENCE MONUMENT
CR	=CABLE RISER	PT	=POINT OF TANGENCY
		PU&DE	=PUBLIC UTILITY & DRAINAGE EASEMENT
{D}	=DEED	PUE	=PUBLIC UTILITY EASEMENT
DB	=DEED BOOK		
DE	=DRAINAGE EASEMENT	RNG	=RANGE
		R/W	=RIGHT-OF-WAY
ELEV	=ELEVATION		
EOP	=EDGE OF PAVEMENT	SEC	=SECTION
EOW	=EDGE OF WATER	SIR	=SET IRON ROD
ESMT	=EASEMENT	SR	=STATE ROAD
		SS	=SANITARY SEWER
FC	=FENCE CORNER	SUBD	=SUBDIVISION
FFE	=FINISHED FLOOR ELEVATION		
FIP	=FOUND IRON PIPE	T	=TANGENT
FIR	=FOUND IRON ROD	TBM	=TEMORARY BENCH MARK
FND	=FOUND	TOB	=TOP OF BANK
		TWP	=TOWNSHIP
GIP	=GALVANIZED IRON PIPE		
GOVT	=GOVERNMENT	UE	=UTILITY EASEMENT
		UG	=UNDERGROUND
L	=ARC LENGTH	USGS	=UNITED STATES GEODETIC SURVEY
LME	=LAKE MAINTENANCE EASEMENT	UTIL	=UTILITY POLE
LP	=LIGHT POLE	UTS	=UTILITY SERVICE
{M}	=MEASURED	WM	=WATER METER
MH	=MAN HOLE	WMR	=WATER METER, RECYCLED
MHWL	=MEAN HIGH WATER LINE	WV	=WATER VALVE

NOTE: All visable improvements and/or use has been either physically located and/or shown hereon, unless otherwise noted. Any underground utilities and/or underground improvements lying within the subject property have not been located or shown. This sketch of survey was prepared without benefit of abstract title. ENVIRONMENTAL LAND SERVICES, INC. {ELS} and/or signing surveyor are in no way liable or responsible for right-of-ways, easements, or takings other than those provided by the client and/or shown on the recorded plat. Lands Shown Hereon may be subject to setbacks, easements and/or restrictions not shown on the record plat. "Not valid without the signature and original raised seal of a florida licensed Surveyor and Mapper" Additions or deletions to the survey map{s} or report{s} by parties other than the signing party or parties is prohibited without written consent of the signing party or parties.

Last Date of Field Survey: 08/07/2007	
Scale: 1" = 110.00'	
Revision:	Date:
Date Of Signature: 08/15/2007	
This Survey Is Not Valid 90 Days After The Date Of Signature.	

FLOOD ZONE DATA			
	Community Number 125124	Panel 0429	Suffix D
	Effective Date 09/20/1996	Firm Zone A12	Elevation 12 Feet

Note: This Sketch Of Survey Is
Not For Design;
Not For Construction;
Not For Fence Construction.

This Survey Is Not Valid 90 Days After The Date Of Signature.

NOTE: Underground Encroachments Not Located.

Note: This Sketch Does Not Reflect or Determine Ownership.
This Sketch is Not an ALTA/ACSM Land Title Survey.
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NOTES:

1. Description as furnished by Client. No search of the Public Records was Conducted by this Firm.
2. Elevations as shown are based on N.G.V.D. 1929 Datum unless otherwise Stated.
3. Bearings are based on Plat or Deed.
4. Encroachments are based on Plat.
5. There may be other easements not shown Hereon recorded in the Public Record of Governing County.
6. No Determination of Hazardous Waste Materials have been made by this Firm.
7. Signor limits liability only up to the cost of the Survey.
8. This Survey is protected by Copyright and All Rights Are Reserved.
9. Not Valid without signature and Raised Seal.

BEARINGS SHOWN HEREON ARE BASED ON:

West Line Of The East 1/2 Of Governement Lot 3 Being N 00°00'00" E, { Assumed }

DRAWN BY:	CHECKED BY:	JOB NUMBER:	PAGE:
KLL	RAW	2007-1114	1 Of 2