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Proceedings of

The Twenty Seventh Annual Conference on Ecosystems Restoration and Creation

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PATRICK J. CANNIZZARO
Editor

Hillsborough Community College
1206 North Park Road
Plant City, Florida 33566

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INTRODUCTION

The Annual Conference on Ecosystems Restoration and Creation provides a forum for the exchange of results of scientific research in the restoration, creation, and management of freshwater and coastal systems. The conference is designed to be of particular benefit to governmental agencies, planning organizations, colleges and universities, corporations, and environmental groups. These proceedings are a compilation of papers and addresses presented at the Twenty Seventh Annual Conference.

As in years past, this year's conference would not have been possible without the assistance and cooperation of Mr. Roy R. "Robin" Lewis, III. Mr. Lewis has been an important contributor since the very first conference twenty six years ago. We are grateful for his help and participation. Appreciation is also extended to Fred Webb and Felix Haynes for providing administrative support for the conference.

The following people also deserve acknowledgment for contributing to the conference and assisting in the preparation of the proceedings for publication: Elaine Baskin, Peter Rossi, Erica Moulton, Charles Mason and his staff. A very special thanks to Johnnie Hurst for her untiring assistance in handling the many details of conference planning.

Thanks are extended to **Mark Brown** of the **Southwest Florida Water Management District** for arranging and conducting a very successful field trip to a wetland restoration site.

These proceedings could not have been completed without the time and efforts of the authors and reviewers.

To all these people, thank you.

INNOVATIVE MITIGATION FOR HARDENED SEAWALL STRUCTURES

Janice Sands Ash, President, Ash Engineering, Inc.
Brian J. Moschetto, Project Manager, Ash Engineering, Inc.
Robert Musser, Jr., Project Manager, Ash Engineering, Inc.
Ash Engineering, Inc.
1107 East Jackson Street, Suite 200
Tampa, FL 33602

Jeff Stewart, Environmental Supervisor, IMC Phosphates Company
P.O. Box 2000
Mulberry, FL 33860-1100

ABSTRACT

In a collaborative effort with IMC Phosphates Company, Ash Engineering designed a system to incorporate intertidal habitat in the creation of port seawall structures through the creation of habitat pods.

The pods are an innovative approach for providing restorative habitat in areas that traditionally are entirely industrialized with vertical hardened shorelines. Port areas traditionally have extremely low ecological contribution. Many port occupants have no other sites to provide mitigation when constructing seawalls, removing rip-rap, or conducting site improvements. The pods provide a positive solution to the ever-increasing ecological dilemma of port development.

The pods will consist of a main channel that is always inundated with water. Above the main channel will be an intertidal and salt flat area that will be inundated at high tide. Water will enter into the pods from openings in the seawall. The openings will be at staggered heights so that at higher tides water will enter all openings, and at lower tides, water will enter only the opening for the main channel. Grade elevations will be specifically designed for plant diversity and low density of plant species, providing foraging areas and habitat for wading birds. The pods are also designed in such a way that they can be built and planted along with the phases of the seawall construction.

INTRODUCTION

The nearly 1036 square kilometers (400 square miles) of Tampa Bay is home to three major seaports and a cruise industry that contributes more than S10- billion annually to the area. The Port of Tampa is the Florida's largest port and consistently ranks in the top ten nationally in trade activity. IMC Phosphates Company (IMC) operates a marine terminal facility at Port Sutton, Tampa, Hillsborough County, Florida. The facility consists of two ship berths, one for phosphate products, and one for anhydrous ammonia. The two Terminal Berths, 6 and 7, are located just east of the Tampa Electric (TECO) Energy Gannon Station power plant outfall in the Port of Tampa.

IMC became concerned with the persistent loss of their shoreline due to erosion and began exploring options to extend and improve their seawall along their property abutting the Port Sutton Channel. The overall purpose for the project will be to stabilize the shoreline, estimated to be 609 linear meters (2000 feet), in order to stop the erosion occurring in the area.

In late 1998, the then IMC Agrico Co. (now IMC Phosphates Company) retained Ash Engineering to design permitting options to replace their eroding seawall along their facility at the Port Sutton Terminal. Based upon information provided by IMC and review of the historical aerial photographs, existing site conditions, past permits, alignment of the seawall, permitting requirements and options, and construction techniques, Ash provided several proposed seawall extension options for review and discussion.

Pre-Application meetings with the various permitting agencies were conducted. Based on these meetings, it was learned that there would be a requirement to provide some type of mitigation to offset the potential loss of aquatic habitat due to the installation of the seawall and removal of the existing rip-rap. During these meetings, several options for the seawall extension and mitigation were discussed. IMC, Environmental Protection Commission of Hillsborough County (EPCHC), and the US Army Corps of Engineers (USACOE) collaborated closely on the project and the design of the proposed systems. The innovative mitigation pod system became the preferred project method since it would provide restorative habitat in an area - industrial port environment - where vertical hardened shorelines and seawalls are commonplace. Port areas traditionally have extremely low ecological contribution and poor water quality due to dredge and fill, development projects, and deep port waters and because of the high cost of port property, on-site mitigation is severely limited and costly.

The following sections will present several of the seawall extension and mitigation options that were considered and discuss the advantages and disadvantages of each. Discussion follows highlighting why the mitigation pod system became the preferred method for providing the necessary repairs to the seawall and mitigation for potential loss of intertidal habitat. A summary follows, showing how the innovative mitigation pod engineering concept helps accomplish several of the goals set forward the Tampa Bay Estuary Program's "Comprehensive Conservation and Management Plan for Tampa

Bay," and how the system may benefit other port areas in their habitat restoration projects.

Study Site

IMC Phosphates Company operates a marine terminal facility at Port Sutton consisting of two ship berths, one for phosphate products, and one for anhydrous ammonia. Terminal Berths 6 & 7 are located just east of the Tampa Electric (TECO) Energy Gannon Station power plant outfall. The Site is located in Section 4 & 5, Township 30 South and Range 19 East and Section 9, Township 31 South, Range 19 East, Tampa, Hillsborough County Florida, Lat: 27° 54' 15" Long: 82° 25' 07". The specific location of the project area on the IMC property is along their nearly 609 meters (2000 LF) seawall frontage on Port Sutton Channel. The following photograph (Figure 1) is an aerial photograph of the IMC facility at Port Sutton with a line indicating the approximate previous extent of the shoreline.

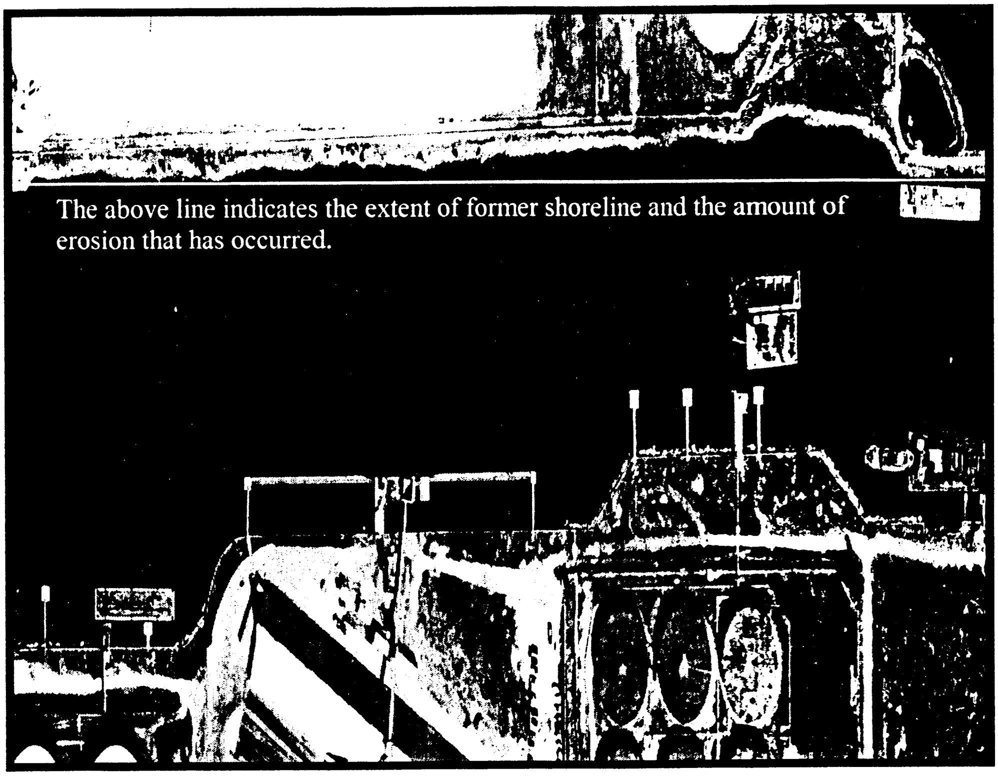

Figure 1-Aerial photograph of the IMC Phosphates Company Terminal Facility.

MATERIALS AND METHODS

The following describes the tasks that were accomplished in order to provide an agreeable seawall extension and mitigation project for the IMC Phosphates Company Terminal Berth Facility in Port Sutton.

The scope of work for this project included review of historical photographs, documents, and permits, field reconnaissance, engineering design and planning, permitting agency coordination, environmental resource permitting, dredge and fill permitting application, and assembly of permit applications. Ash Engineering reviewed all regulations regarding limitations and restrictions of each proposed project. Ash researched the "historical" shoreline limits from EPCHC aerial library and conducted several site visits to investigate the proposed areas of impact with respect to vegetation, hydroperiod, viability of wetland, and habitat present. Photographs were taken to document current conditions. Figure 2 shows the existing seawall system looking west-to-east down Port Sutton Channel highlighting the extent of loss of property and the erosion that has occurred. Ash Engineering delineated the current wetland vegetation and received concurrence from the permitting agencies. Each regulatory agency was contacted to ascertain any special permit concerns for the project. A joint pre-application meeting was held to promote agency agreement and increase permit processing. The project included preparation of two permit applications (FDEP Environmental Resource Permit and/or Joint FDEP/USACOE Dredge & Fill Permit Application).

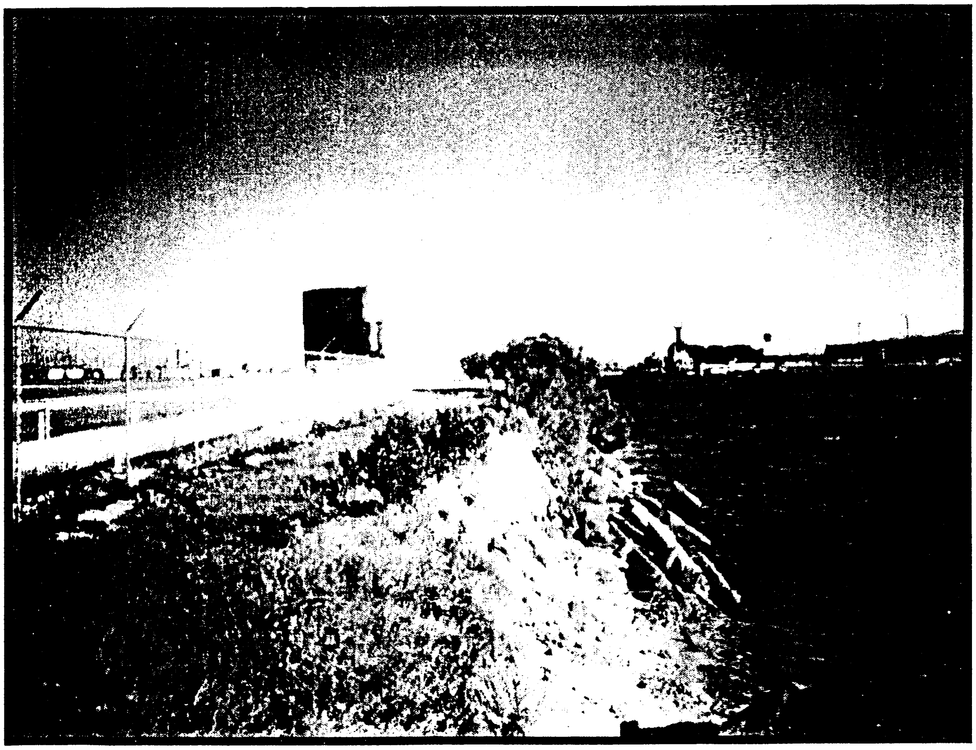

Figure 2-Looking at existing seawall from the west to the east.

Several mitigation options were discussed with the various permitting agencies: among the options discussed included placing rip-rap in front of the new seawall, installing pre-cast concrete panels on the seawall, and utilizing reef balls or seawall reefs. Each option is discussed below, presenting the advantages and disadvantages of each. The selected concept plan, the mitigation pod system, is detailed in the results section.

- Rip-Rap in Front of Seawall

This option entails placing broken concrete rubble, large boulders, and other concrete items in front of the seawall. Two approaches under this option were discussed; the first would be to place the rip-rap at the foot of the seawall; the second would be to place the rip-rap on a slope of approximately 2:1 to a height of the mean high water level (MHWL). An advantage to each of these approaches is ease of construction. The rip-rap material can be placed in front of the seawall using a backhoe from the shoreline. Also, the placement of rip-rap at the foot of the seawall requires a minimal amount of material.

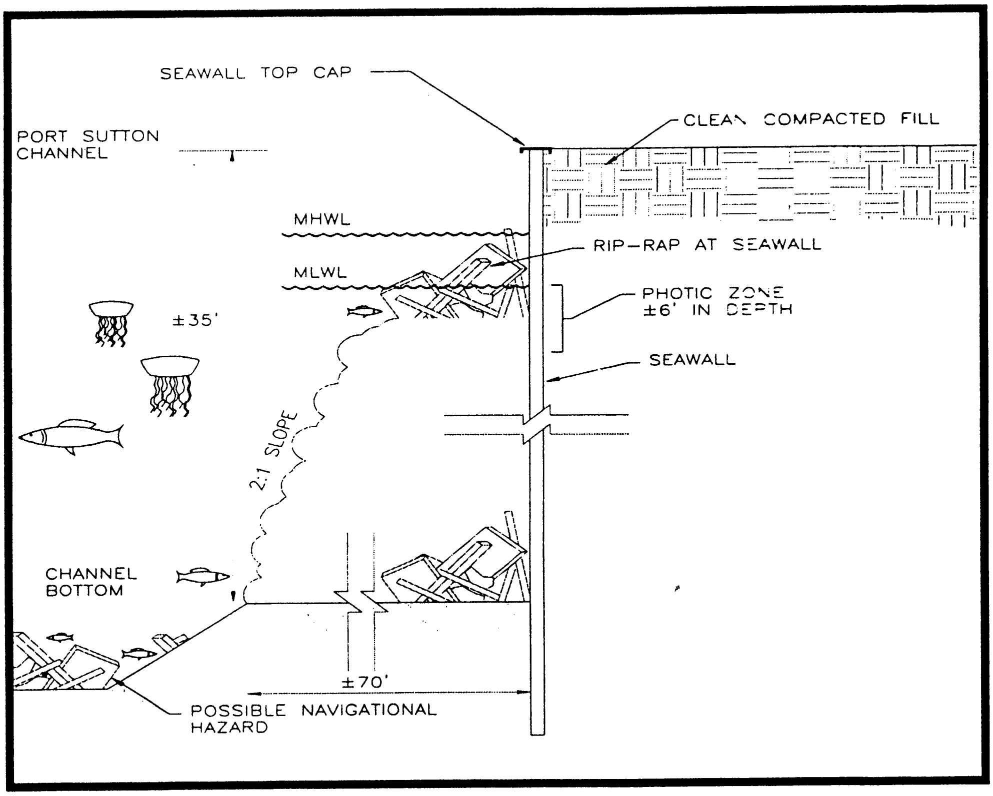

Figure 3-Advantages and disadvantages of a rip-rap seawall structure.

There are many disadvantages with these approaches. In the first approach, the rip-rap placed at the toe of the seawall will not be of the same quality as the rip-rap being removed since it will be clean prior to installation. In order for the proposed rip-rap to be equal to that of the existing, it will require that it be located within the photic zone, which extends approximately 1.8 meters (6 feet) below the mean low water level (MLWL).

Since placing rip-rap within the photic zone is not possible without building up a base, it is anticipated that the rip rap would be installed at the base of the seawall. Typically, the initial colonizers on a clean-hard substrate in the marine environment are algae and slimes. These species require photosynthesis and presence of light for survival. With turbidity issues and the depth of the rip-rap, it is anticipated that recruitment from oyster and barnacle spat will occur first. There will be habitat for larger fish, but surface dwelling fish will most likely not frequent the area. The like-for-like habitat will not be created with the rip-rap at the bottom of the seawall alternative since foraging and wading birds will not be able to access the submerged rip-rap.

Another disadvantage to this approach is that given the slope and the required height of the rip-rap, the rip-rap could extend into the channel about 19.8eters (65 feet) or more. This could create a navigational and potentially environmental hazard, should a ship get too close to the proposed seawall and rip-rap during its movement in the channel. Also, there will be a considerable amount of material that will need to be placed. Using the given slope and an estimated height of 9.8 meters (32 feet) at the seawall, more than 58,874 cubic meters (77,000 cubic yards) of rip-rap over the entire length of seawall will be required.

Another disadvantage associated with both approaches occurs when maintenance dredging of the channel is required and the accumulated material is removed from the bottom of the channel. As this material is removed, the material on the sides of the channel will slough off to the center of the channel. As this material sloughs off, there is a possibility that the rip-rap placed in front of the seawall will slough off as well. Not only could this create a navigational hazard to shipping, but this may require installation of additional rip-rap over time to compensate for the "lost" rip-rap.

- Installing Pre-Cast Concrete Panels On The Seawall

This method of mitigation would consist of installing multiple pre-cast concrete panels directly on the seawall. The pre-cast panels would be formed with undulating interstitial ridges and textured to emulate corals or rocks. A steel channel would be welded to the outside of the seawall panels prior to installation, once the seawall is in place. The pre-cast panels would be then placed in this channel. The panels would be positioned on the seawall at the inter-tidal zone elevation. One concern associated with this type of mitigation is if a ship or barge breaks loose from its moorings and hits the seawall, damage to the panels could result causing debris to fall into the waterway. A second disadvantage is the panel's weight. The steel channel will have to be sized and braced sufficiently to support the panels. A third disadvantage to this option is the limited life span of the steel channel. The steel channel is welded to the seawall panel and then immersed in seawater. Given this corrosive environment, this could lead to a premature failure in the support and the panel falling off the seawall panel.

Once again like-for-like habitat replacement is not being accomplished. Access for wading birds is not provided. The interstitial ridges would provide only minimal shelter for epifauna. We can expect recruitment of oysters, barnacles and colonial tunicates, but since the surface is primarily vertical, surface area for settlement of non-attached species is not available.

- Reef Balls Or Seawall Reefs

This option consists of purchasing or renting a fiberglass mold and making precast concrete artificial reefs. A fiberglass mold is used in the casting of the reef ball. Inside the mold, an internal, inflatable bladder is installed. Once inflated, small plastic balls are positioned around the bladder. The mold is then filled with concrete. After the concrete hardens, the mold is then stripped and the reef ball can be installed in front of the seawall using a crane. The reef ball is then anchored to the seawall or the bottom of the channel. Many of the disadvantages associated with the rip-rap option apply here. The reef ball materials are not equivalent to the rip-rap being removed as far as the quantity, interstial spaces or surface area for colonization of attaching organisms. Divers are also needed to install the reef balls. This would not only be costly, but the reef balls would have to be installed when there were no ships moving in the channel. Finally, the reef ball's weight causes a structural challenge in mounting them on the sea wall.

RESULTS

The preferred mitigation method and the most popular seawall extension and mitigation option was the mitigation pod system. This option would consist of creating small mitigation areas behind the seawall where ecosystems using rip-rap would be installed. Figure 4 is a drawing showing a cross section of the proposed installation.

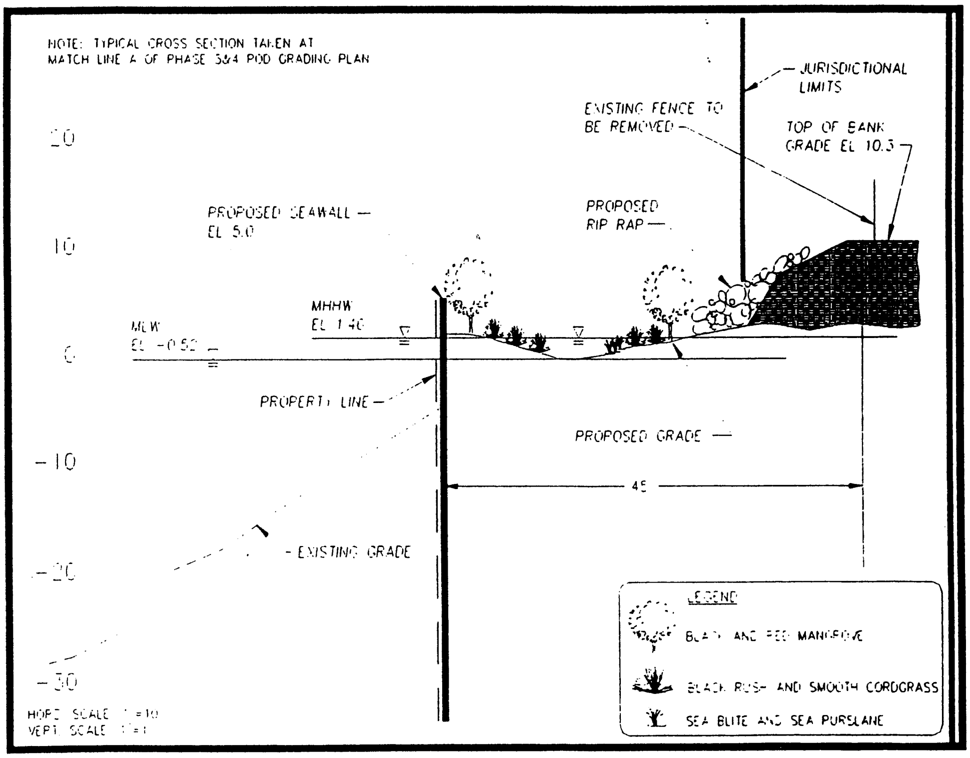

Figure 4-Cross sectional view of the mitigation pod system.

It is proposed that the seawall will be constructed in several phases. Each phase would require development of its own mitigation area (otherwise termed as "pod"). The shape of these pods would be half ovals, bound by the seawall. Holes or slots, measuring 0.6meters (2-feet) wide by 1 meter (3-feet) tall, will be cut into the seawall at various tidal heights to allow seawater exchange with the overall elevation of these pods within the inter-tidal zone. Plantings would also be provided at various locations to stimulate the natural vegetation that is sustained in this environment. The seawall would provide a barrier to the turbulence created by the ship traffic in the channel. The seawall slots will allow for somewhat quiescent tidal inundation and minimize erosion.

There are many specific advantages associated with this type of mitigation. First, it is very constructible. The grading, placing of the rip-rap and plantings can be performed from the land. It is cost effective. There is no need for special materials or installation procedures with this approach. The pods are protected from navigational hazards. If a ship breaks loose of its moorings and hits the seawall, the pods will be protected from being disturbed by the seawall itself. The pods can be positioned within the phased construction limits to allow for most of the bulkhead to be accessible.

These mitigation pods provide like-for-like habitat replacement with increased estuarine habitat quality. The pods may vary depending on the type of habitat to be replaced or quantity of compensatory area needed. The most ecologically diverse pod will include a small salt-flat intertidal area with a small channel. The elevation would slope up to an elevation suitable for seagrass and mangrove recruitment. The remainder of the slope up to existing grade, would be rip-rapped for erosion control.

As previously stated, it is proposed that the seawall be constructed in several phases. The design of the mitigation pods was set with restricted growth in mind. The goal of the system was to provide a salt strand ecosystem with open water and sand areas. Specifically designing grade elevations for low density of plant species, provides foraging areas and habitat for wading birds. With such a small system, it is possible for one species to densely overrun the site, thus eliminating wading and foraging areas. It was therefore designed at varying specific depths to minimize over population of a single plant species allowing for more habitat diversity.

DISCUSSION AND CONCLUSION

IMC Phosphates Company's innovative mitigation concept for hardened seawall structures will help the Tampa Bay Estuary Program meet several of their stated goals in "Charting the Course – The Comprehensive Conservation and Management Plan for Tampa Bay, 1996. A few of the goals include:

- BH-6-Encouraging waterfront residents to enhance shoreline and limit runoff,
- BH-7-Impoving compliance with and enforcement of wetland permits,
- SW-2-Develop landscaping guidelines for commercial use,
- SW-4-Reducing impervious paved surfaces, and

- An overall goal of increasing bay habitat for fish and wildlife and increasing habitat diversity throughout the estuary.

The innovative mitigation pod concept is proposed to be constructed in several phases along the IMC Phosphates Company seawall at the Port Sutton facility. Construction observation and monitoring of the project planting success, as well as determinations of the recruitment of species and plant and animal species diversity will be conducted for several years, including during and after construction. It is believed that the mitigation pod engineering concept will become standard practice in port facilities throughout the country. This concept, mitigation pods, will provide a positive solution to the ever-increasing ecological dilemma of port development. As the project progresses, Ash will monitor the success and provide details at a future Conference on Ecosystem Restoration and Creation.

ACKNOWLEDGEMENTS

Ash Engineering would like to thank IMC Phosphates Company for allowing Ash to present the mitigation pod concept at the Hillsborough Community College 27th Annual Conference on Ecosystems Restoration and Creation. Thanks go especially to Mr. Jeff Stewart, Environmental Supervisor with IMC Phosphates Company for his guidance in the project and for this presentation.

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ECOLOGICAL USES FOR *PASPALUM VAGINATUM* (SWARTZ) SEASHORE PASPALUM

James Anderson
Paspalum Turf, Inc
3523 24th Street South
Ruskin, Florida

J. Nicholas Ehringer
Hillsborough Community College
10414 E. Columbus Drive
Tampa, Florida 33619

ABSTRACT

Ecological uses for *Paspalum vaginatum* (Seashore Paspalum) are discussed. This is a salt tolerant grass that can be used along shorelines in saline environments to stabilize the shore and to filter runoff. It may also be used along the banks of salt-water aquaculture ponds to lessen the amount of turbidity that may flow into the pond. In many situations planting grass along a shoreline is preferable to riprap.

INTRODUCTION

Ecological restoration of saline shorelines in Florida includes the use of aquatic emergent plants, like *Spartina* spp, planting of mangroves via seeds, and the planting of seagrasses further into the water. Seashore Paspalum (*Paspalum vaginatum*) grows in saltwater coastal marshes and coastal mud and sand flats in the Hawaiian Islands, American Samoa, Caroline Islands, Guam, and the Commonwealth of the Northern Marianas Islands. It is one of the most salt-tolerant grasses known and has been reported to grow with water containing total soluble salts of more than 10,000 parts per million. It will also grow in fresh water. In ecological restoration efforts plants have significance because of their ability to filter water, stabilize sediments, provide habitat, and add organic matter to the system. Along the shoreline, between the mangroves and *Spartina*, is a zone where few plants can survive. *Paspalum vaginatum* is a hardy grass that can survive and thrive in this zone, providing the same benefits as other restoration plants. It is reported to tolerate brackish sites much better than Bermuda grass. Along the Texas coast the species is often the only grass found growing around brackish ponds and estuaries (Duble, 1999).

Identification

Seashore Paspalum *(Paspalum vaginatum* (Swartz) is also referred to as Siltgrass, Sheathed Paspalum, Salt Jointgrass, Seaside Millet, Sand Knotgrass, and Saltwater Couch. It is native to East Central South America, from Argentina through Uruguay and into Brazil. Today, Paspalum grows in tropical areas throughout the world. Paspalum is being maintained on golf courses in Asia, South Africa, South America, Hawaii, the Caribbean Islands, and in the United States. Seashore Paspalum is a warm season perennial grass that spreads by rhizomes and stolons. The stolons and leaves of Seashore Paspalum are slightly coarser than those of common Bermuda grass. However, when mowed regularly at heights of one inch or less, the grass produces a dense turf, hence the use of paspalum on golf courses. Some sub-species of paspalum have a blue-green color and texture similar to that of Kentucky bluegrass.

Paspalum vaginatum can be recognized by its forked pairs of spikelet branches at the tips of relatively tall stems, growing in dense colonies on salty shores. Geese, manatees and other wildlife eat it. Its almost identical twin, *Paspalum distichum*, knotgrass, grows on freshwater shores.

Seashore paspalum is a grass with stems to 30 in. tall, erect or leaning at base; leaf blades folded or flat, smooth, tapering to tip, to 6 in. long, to 3/8 in. wide, long hairs at base; sheaths conspicuous; inflorescence 2 spreading branches at tip of stem, branches to 2 1/2 in. long; spikelets in 2 rows; flowers dense, on underside only; seeds flat, rounded, white, smooth (Univ. of Florida, 1999).

Fig. 1: Photo from the University of Florida
Stem of *Paspalum vaginatum*

Ecological uses

Paspalum vaginatum has the highest salt tolerance of any of the warm season grasses. Because of this ability to thrive in an ecologically stressful zone, paspalum has a number of useful ecological roles in seashore restoration. Planting paspalum may be beneficial for the following reasons:

1. Paspalum can stabilize the shoreline preventing erosion of the soil. Once a shoreline is stabilized, mangroves and other salt tolerant plants, can survive more easily with sediment that does not shift or erode beneath their roots. Seashore paspalum can grow along the edge of the water; water that often has 40 or more ppt salts. It was also the only grass species found growing in saline outcroppings of soil along streams and ditch banks. Therefore, paspalum can be planted along shoreline of an estuary where salinities may vary from zero to 40 ppt.

2. A shoreline planted with paspalum will filter runoff from land as it flows over the plants. Grasses have the ability to filter runoff more effectively than plants, like *Spartina*, because they cover the entire surface of the slope of the shoreline, not just a portion of it. The filtration of the runoff includes nutrients, debris, and dirt.

3. In some parts of the world, where salt has intruded into soil that was once used for farming, paspalum may be planted to stabilize the soil and to prepare it for future growth by removing some of the salt. This method is being used in parts of western Australia (Duble, 1999).

4. The use of paspalum may be ideal for situations in which:

    - The only irrigation water source is desalinized seawater. Paspalum can withstand high salinity levels.
    - The ground water available for irrigation is of poor quality such that it will not ordinarily be capable of supporting a high quality landscape.
    - Areas where the soils are salt-affected and incapable of supporting other grasses.
    - Coastal areas where salt spray may be a problem.
    - Coastal areas or islands where tidal surges from storm events may inundate the site with seawater
    - Aquifers with salt-water intrusion may be pumped to irrigate paspalum.

Nutrient requirements

If Paspalum is planted along the shoreline of an estuary, it will not need any nutrients to survive, just the nutrients that flow from land in a normal rainy season, or the nutrients that flow over the grass at high tide. If fertilizer is needed the following information from Duble (1999) may be helpful. Fertilizer requirements of seashore paspalum are less than those for Bermuda grass. At low annual rates of nitrogen application, seashore paspalum maintains density better than Bermuda grass. Research at the University of California showed that seashore paspalum responds to nitrogen fertilizer by increased growth and a darker green color up to about 8 pounds of nitrogen per 1,000 sq. ft. per year. However, above 4 pounds of nitrogen per year, scalping becomes a problem on seashore paspalum. Scalping is particularly a problem following summer applications of nitrogen. Most of the nitrogen fertilizer should be applied in the spring and fall with emphasis on fall fertilization. A suggested nitrogen fertilization schedule for seashore paspalum on lawns, athletic fields and golf course fairways where clippings are not removed would be 1 pound in March, 1/2 pound in May and July and 1 pound in October.

CONCLUSION

Paspalum vaginatum is a salt tolerant grass that grows in salinities that vary from zero ppt up to 100 ppt. It grows mostly by horizontal vegetative means and does not grow tall enough to be a nuisance. With these properties, paspalum may be a useful grass for planting along estuarine shorelines where riprap and *Spartina* are more commonly used. Planted along the shoreline, paspalum will stabilize the shoreline and filter runoff. As such, it may be an ideal plant for restoration efforts where salt limits the planting of many species.

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Duble, Richard L. 1999 "Seashore Paspalum" web page at http://aggie-horticulture.tamu.edu/plantanswers/turf/publications/seashore.html Texas Agricultural Extension Service The Texas A&M University System

University of Florida. 1999, Center for Aquatic and Invasive Plants: "Aquatic and Invasive Plants" **Paspalum vaginatum** Seashorepaspalum.http://plants.ifas.ufl.edu/pas.html

ECOLOGICAL RESTORATION IN A COASTAL SUBURBAN COMMUNITY: OPPORTUNITIES AND CONSTRAINTS

Paul J. Thorpe
Northwest Florida Water Management District
81 Water Management Drive
Havana, FL 32333

ABSTRACT

The city of Valparaiso, Northwest Florida Water Management District, and Florida Department of Environmental Protection have initiated a multi-faceted restoration project along Choctawhatchee Bay, in northwest Florida. Project objectives include the reduction of nonpoint source (NPS) pollution, restoration of an integrated upland and wetland shoreline plant community, and enhancement of shoreline stability. Implementation options are limited by land use constraints inherent to a suburban environment, as well as funding limitations and the topography of the area. Nevertheless, opportunities were identified to construct wetland treatment systems along stormwater discharge channels that bisect three city parks and to establish a community of wetland and upland vegetation along a public waterfront. The wetland treatment systems are expected to improve baseflow and runoff water quality and enhance habitat quality along the channels. The planted waterfront vegetation, in turn, is intended to improve shoreline and intertidal habitat, demonstrate "bay friendly" landscape management to the community, enhance shoreline stability, and serve as a buffer zone for additional NPS pollution abatement. Further NPS pollution reduction will be sought through the development and dissemination of educational materials concerning personal best management practices. Shoreline habitat restoration, public education, and the construction of stormwater treatment systems are planned for the summer of 2000, and upland community restoration is planned for winter 2000-2001. Monitoring and analysis are scheduled to be complete by March 2002.

INTRODUCTION

Florida Panhandle, proposed in 1996 to implement stormwater treatment best management practices (BMPs) and shoreline habitat restoration within several city parks. The city of Valparaiso, a suburban community located on Choctawhatchee Bay in the This concept evolved into a multi-faceted project funded by the U.S. EPA's 319(h) nonpoint program and Florida's Surface Water Improvement and Management (SWIM) program, with additional funding and in-kind services provided by the city and the Florida Department of Environmental Protection (DEP).

The project has three complimentary objectives: reduction of nonpoint source (NPS) pollution, restoration of a natural shoreline plant community to provide habitat and serve as a waterfront buffer zone, and enhancement of shoreline stability. To achieve these objectives, wetland treatment systems will be constructed along stormwater discharge channels, upland and wetland vegetation will be established along a city waterfront, and public awareness activities will be initiated. Although implementation possibilities are limited by available funding, topography, and land use constraints, several sites suitable for habitat restoration and construction of wetland treatment systems have been identified on city property.

PROJECT SITE

Choctawhatchee Bay is a northwest Florida estuary characterized by a major river discharge at its eastern end and an inlet to the Gulf of Mexico on its southwest shore. The bay has a surface area of about 334 square kilometers, and its watershed covers approximately 13,854 square kilometers in Alabama and Florida (Figure 1). The bay has experienced many of the impacts that are common to Florida estuaries, including habitat loss, NPS pollution from urban runoff and rural sources, and point source pollution (Livingston 1986; 1987). Impacts are particularly concentrated in the southern and western portions of the watershed, proximate to the bay and Gulf of Mexico, where intensive land use prevails. The bay has a number of minor embayments ("bayous"), where the basins and shorelines tend to be heavily developed.

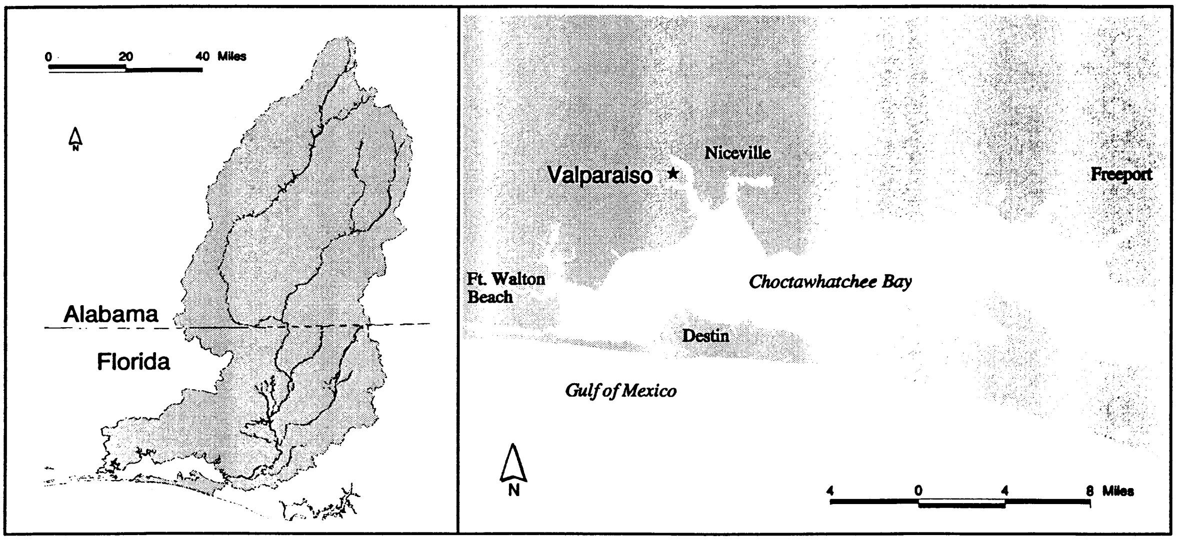

FIGURE 1. Choctawhatchee River and Bay Watershed and Project Vicinity

The city of Valparaiso (approximate population 6,645) is situated adjacent to Toms and Boggy bayous on Choctawhatchee Bay's northwestern shoreline. Valparaiso is bordered by the city of Niceville to the north and Eglin Air Force Base to the south. Land use is primarily single family residential, with commercial and institutional uses concentrated along major thoroughfares (Figure 2). Among the distinguishing features of the city is a system of public parks that encompass much of its waterfront, as well as some inland areas. These parks are primarily open and grassy, with limited tree cover. Surface water runoff channels course through several of the parks.

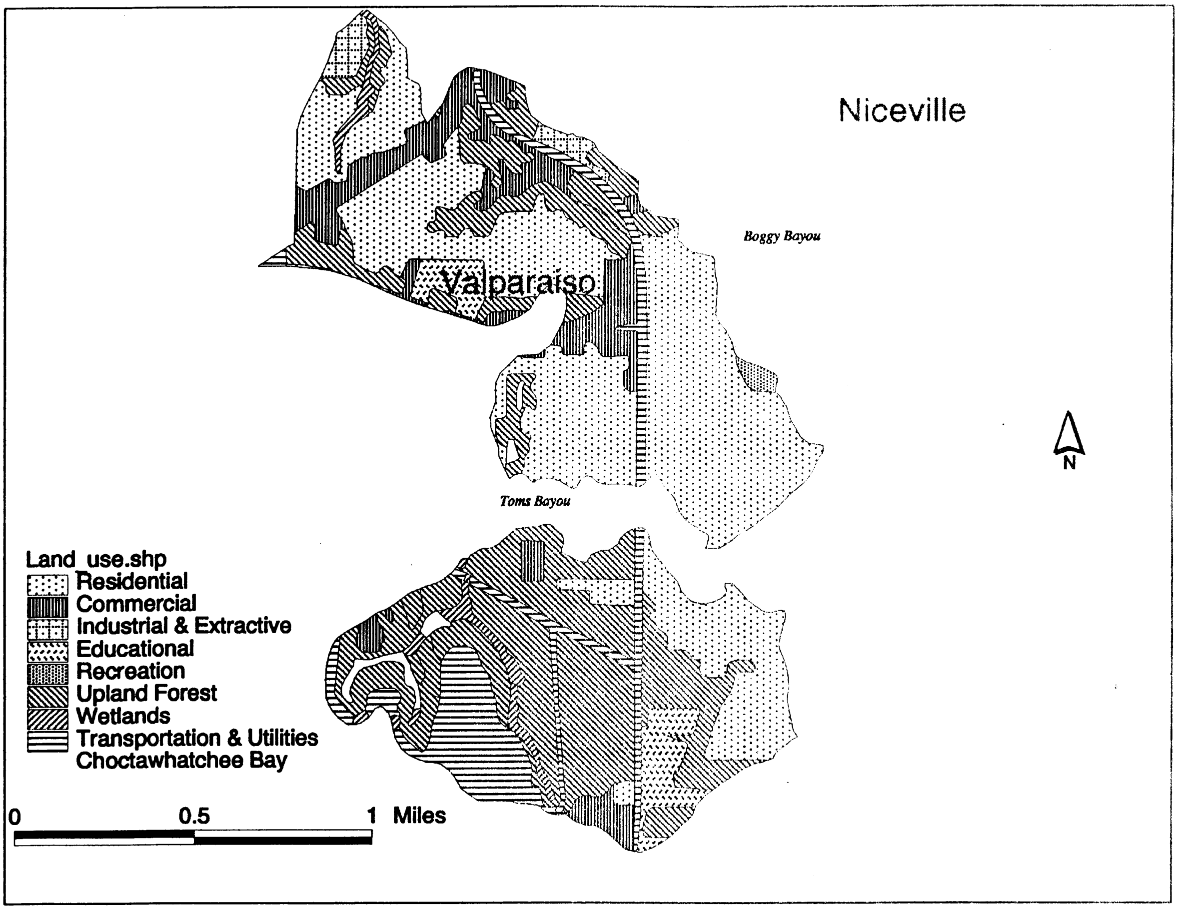

FIGURE 2. City of Valparaiso Land Use

METHODS

Project staff have worked closely with city officials and residents to develop plans that both achieve restoration objectives and are consistent with more broad community goals. Detailed proposals were provided at two city commission meetings and at a public workshop early in the process. The city recreation and environment committee and city administrator have also been involved throughout the process. The result is a plan to accomplish stormwater treatment and shoreline habitat enhancement within several city parks while maintaining or enhancing public use and park appearance.

Stormwater treatment will be accomplished primarily through the creation of wetland treatment systems along discharge channels that bisect three city parks. Natural plant communities, including wetland and upland vegetation, will also be planted along bayou shorelines to enhance shoreline habitat and stability and provide a buffer zone for additional NPS pollution abatement. Further NPS pollution reduction will be sought through development and dissemination of educational materials concerning personal BMPs to the community and the creation of demonstration sites of "bay friendly" landscape management practices.

Ferlow (1993) noted that wetland treatment systems enhance stormwater treatment while providing habitat diversity and visual interest. Wetland systems improve water quality by slowing runoff velocity and forcing it through vegetation. This leads to increased settling of sediments and attached pollutants prior to discharge. Soluble pollutants are also removed through biological processes within macrophytes, algae, and the soil. Characteristics that enhance treatment capability include extended detention and forcing water though a maximum area of biofilter. It was also noted that biofilter systems tend to require two-to-five years to stabilize and grow into functional wetlands, and that dominant plant communities may change due to locally specific successional patterns.

Increasing natural vegetation within a watershed may, in general, help to reduce some of the adverse effects of urbanization and stormwater runoff. Properly sited over adequate area, vegetation cover provides habitat, regulates runoff, promotes stable surface and surficial ground water flow, and moderates effects of floods and droughts (Wang et al. 1997; Ferguson and Suckling 1990). Riparian buffer zones in particular may reduce runoff velocity, increase storage, filter sediments and other pollutants, stabilize shorelines, and provide habitat (Desbonnet et al. 1995; Johnson et al. 1997; Wang et al. 1997). The pollutant removal capability of a shoreline buffer zone depends on such factors as width, slope, soils, and water table conditions. By analyzing the results of a number of studies, Desbonnet et al. (1995) estimated that, on average, 50% removal of total suspended solids (TSS), sediment, nitrogen, and phosphorus can be achieved by a 5 meter wide vegetated buffer. Beneficial reductions in TSS and nitrogen were estimated to occur with buffer widths of as little as 2 and 3.5 meters, respectively. It was noted, however, that nitrate-nitrogen removal is more dependent on soil and water table conditions that regulate denitrification than buffer width.

Implementation Constraints

Because funding limitations preclude additional land acquisition, construction of wetland treatment systems is limited to lands already in public ownership. These sites are not necessarily within the basins generating the highest pollutant loading. Likewise, shoreline restoration is limited to existing public waterfront property. Most available waterfront areas are too steep and narrow, however, to serve as ideal buffer zones.

Potential project activities are also limited due to the suburban nature of the surroundings and community wishes to maintain the general use and appearance of city lands. Undeveloped shorelines in the region tend to be heavily forested. Community desires to maintain passive recreation opportunities and views of the bay, however, preclude extensive tree planting.

Despite these constraints, several sites were identified within city parks that are appropriate for the construction of wetland treatment systems and establishment of shoreline vegetation. In effect, the restoration opportunities found on public lands provide for "projects of opportunity" that can improve local environmental conditions at relatively low cost.

Shoreline Restoration

The first component of the project is restoration of wetland and upland shoreline vegetation along city waterfront. The intent is to approximate a natural northwest Florida ecological structure as closely as possible, while remaining consistent with community wishes for the use and character of the land. In this respect, landscape design and plant selection need to maintain views of the bay, access to the water, and passive recreation opportunities. Thus, the restoration plan emphasizes native grasses and shrubs on the upland and emergent vegetation in the intertidal zone.

The success of shoreline restoration on Choctawhatchee Bay depends on such factors as depth, slope, substrate composition, and shoreline energy. The northwest Florida coast is subject to both long-term erosional forces and periodic tropical cyclones and other major storms. To better understand the viability of planted marshes in the project area, three pilot marshes were planted in early summer 1998, one in the interior of Toms Bayou and two on more exposed shorelines of Boggy Bayou (Figure 3). Species planted include *Spartina alterniflora*, *Spartina patens*, *Distichlis spicata*, *Paspalum vaginatum*, *Sesuvium portulacastrum*, *Scirpus robustus*, and *Iva frutescens*.

The pilot marsh within Toms Bayou was successfully established despite the impact of Hurricane Georges three months after planting. The two Boggy Bayou sites fared less well, most likely because they experienced greater shoreline energy and were subject to more intensive recreational visitation. *Spartina alterniflora*, *S. robustus*, and *P. vaginatum* proved most successful of the species planted. The *S. patens* is thought to have been impacted primarily by city maintenance activities. Better education of city public works employees may enhance future success.

The primary shoreline restoration area selected is indicated in Figure 3. It stretches southeast from the successful Toms Bayou pilot project site along the north shore of the bayou. The selection of this site was based on expected habitat, water quality, and shoreline enhancement benefits, as well as visibility and the likelihood of success. This site will also serve as a polishing marsh for the Glen Argyle and Toms Bayou bridge stormwater discharges and treatment system, described below.

Emergent and other wetland vegetation will be planted along this shoreline during summer 2000. Upland vegetation is to be planted during the succeeding fall and winter, which will allow root development and spring growth prior to the heat of the next summer. Wetland species planned include those that were previously successfully established at the Toms Bayou pilot project site, as well as *S. patens* and *Juncus roemerianus*. Comparative test plots of *Ruppia maritima* are also planned adjacent to the restoration shoreline and on a similar non-restored shoreline. Upland and transitional species and their layout are still under discussion with the city environmental committee. Discussions are also ongoing with the city and permitting agencies about the possibility of augmenting the substrate and placing sections of an old, non-functional seawall approximately three meters off the shore to provide additional planting area and protection for emergent plants.

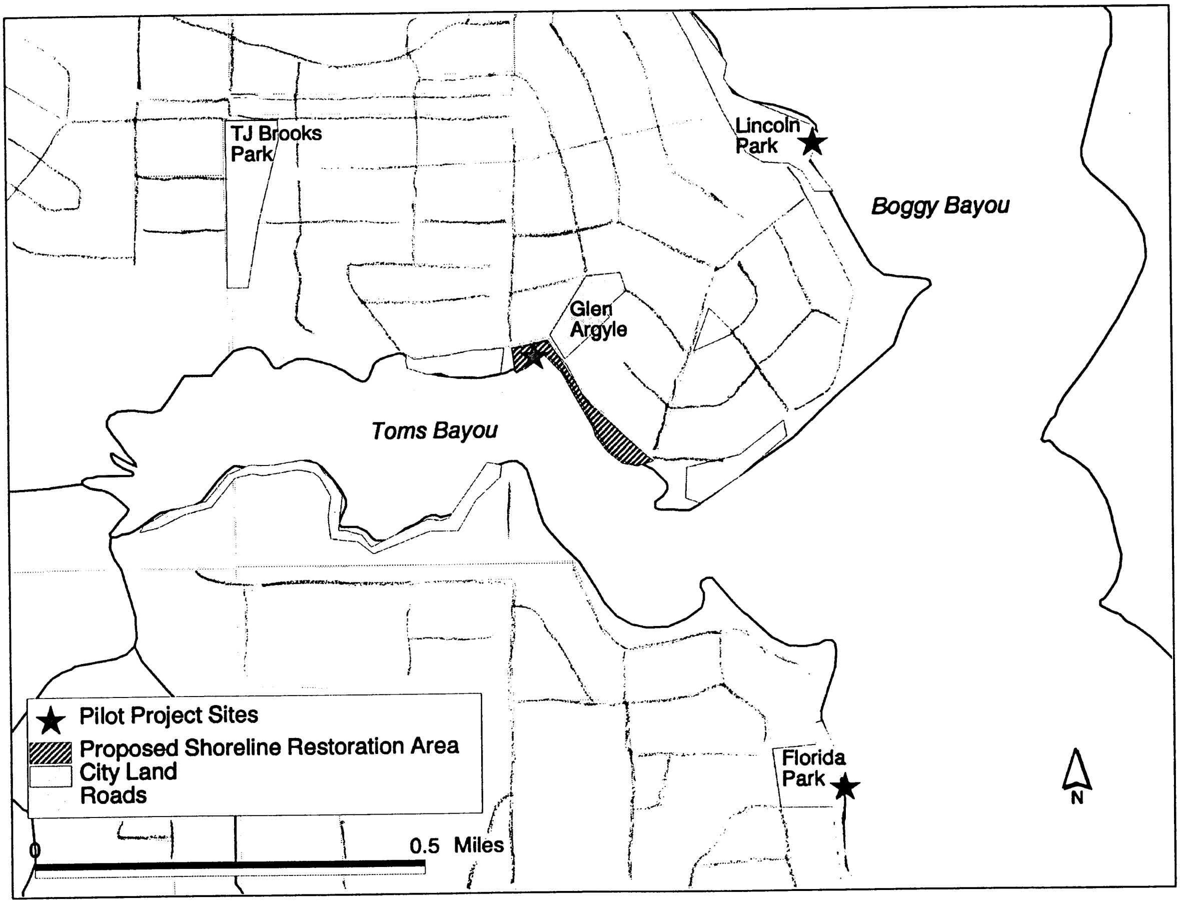

FIGURE 3. City of Valparaiso, Shoreline Restoration Sites

Stormwater Treatment Systems

The first of three sites selected for stormwater treatment is within Valparaiso's Lincoln Park (Figure 4). This park is popular among residents for swimming, boating, picnicking, and other activities. Stormwater runoff drains from a 14-hectare basin and discharges via a ditch through the park into Boggy Bayou. The discharge point happens to be in the middle of the city's designated public swimming beach, adding to the need for pollution treatment. Within the park, the drainage ditch runs through an elongated island of vegetation that has high visibility but receives little actual public use. It is at this location that the treatment system is proposed. Facility design includes a small detention pool, meandering channels, low marsh terraces, and wetland buffers (Duvall and Potts 1999).

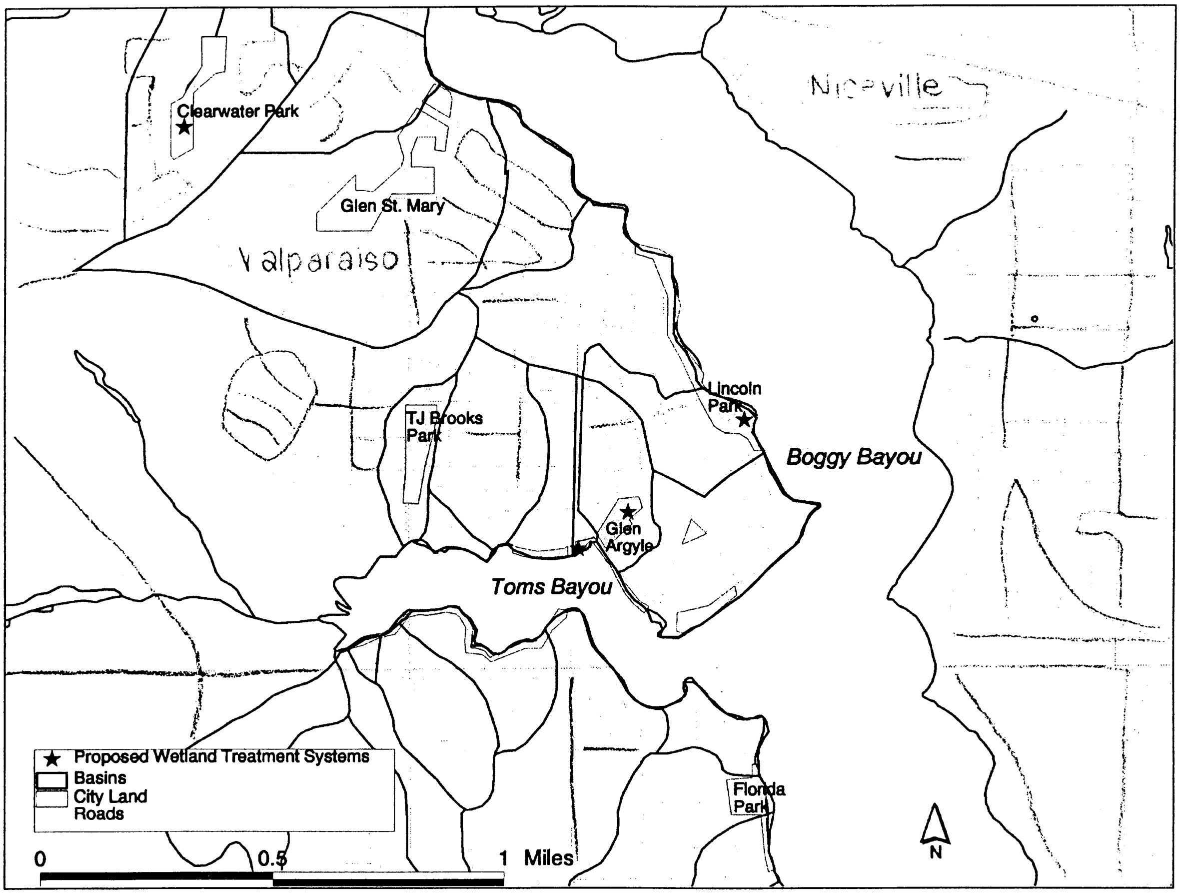

FIGURE 4. Proposed Wetland Treatment System Sites

The second stormwater treatment site is on city property that drains into Toms Bayou from the north. Known as Glen Argyle, this site encompasses a steep depression at the terminus of a 20-hectare residential basin. Ground water seeps into the depression and drains through a channel into the bayou. Additionally, stormwater runoff from John Sims Parkway and adjoining roads discharges from the north foot of Toms Bayou bridge and enters the bayou adjacent to Glen Argyle. This shoreline is also the site of the most successful pilot project marsh.

Within upper Glen Argyle, the design includes shallow, terraced pools and associated wetlands, including approximately 40% high marsh, 40% low marsh, and 20% deep pool (Duvall and Potts 1999). Runoff from the bridge discharge will be treated by a baffle box and infiltration swale. The baffle box includes three chambers to increase detention time, allow settling, and to trap floating liter and petroleum products. Following discharge from the baffle box, the runoff is to enter a 77-meter stone-filled trench. A vegetated buffer will be incorporated adjacent to the trench. Further marsh restoration, building upon the pilot restoration site, may provide polishing treatment of runoff entering the bay.

The third water quality treatment system is proposed for Clearwater Park, which is currently undeveloped and is the site of an historic impoundment that was blown out many years ago. The 3-hectare park receives runoff and baseflow from a 38-hectare basin, which includes residential, commercial, and open land use. The treatment system design includes a multi-stage discharge structure, an extended detention basin, and an enhanced shoreline vegetation zone.

Public Education

It has become apparent that many residents wish to participate in the protection and restoration of Choctawhatchee Bay through developing bay-friendly landscapes on their property. Additionally, a number of waterfront property owners have requested information and assistance to help them plant and maintain saltmarsh vegetation and native riparian upland vegetation along their shorelines.

In response, the public education component of the project provides for the printing of appropriate guidance in a concise and user-friendly document. The document will incorporate information on the methods and native plants identified through implementation of the shoreline restoration activities, as well as information available in existing literature. It will suggest options for implementing bay-friendly landscaping practices and other personal BMPs and will include answers to such questions as what plants should be established, where can they be obtained, what seasons are appropriate for planting, what permits may be required, etc. Development, printing, and distribution of this information are planned for summer-fall 2000.

Coincident with these project activities is a local initiative to develop a community walking trail. Named the "Fanny-Fern Davis Trail," after a prominent botanist and educator that retired in Valparaiso, the trail passes by a number of planned restoration sites and incorporates public information and education kiosks. The portion of the trail passing through Glen Argyle and Lincoln Park was completed in April 2000. The trail is expected to enhance the public awareness of stormwater treatment systems and habitat restoration practices.

Monitoring

Pre-implementation water quality samples were collected at the Glen Argyle, Lincoln Park, and Clearwater Park treatment basins and a separate control basin between February and July 1999. Parameters measured include nutrients, total suspended solids, total dissolved solids, heavy metals, conductivity, pH, and dissolved oxygen. Due to sustained dry weather, all of these samples reflect baseflow conditions. Post-implementation sampling is anticipated for winter 2000-2001 through summer 2001.

Plant densities and distributions, as well as the shoreline profile, will be mapped and monitored throughout the shoreline restoration area from June 2000 through July 2001. In October 1999, the DEP Bureau of Laboratories collected biological samples from sediment cores and net sweeps taken in Toms Bayou off the planned shoreline restoration area. Pre-implementation samples were also collected at a reference site in nearby Rocky Bayou to help identify natural variation for analysis purposes. Post-implementation biological sampling is anticipated for late summer-early fall 2001.

Four Hydrolab meters were also operational within the interior of Toms Bayou and near the mouth of Boggy Bayou between March and July 1999. Parameters measured include salinity, dissolved oxygen, and temperature. The purpose of this monitoring is to develop an understanding of the duration, magnitude, and spatial pattern of salinity and dissolved oxygen changes associated with storm runoff events.

DISCUSSION

De Freese (1991) stated that the goal of ecological restoration "should be to attain and maintain a functional ecosystem with natural abiotic and biotic linkages and community structure." A number of authors (e.g., National Research Council 1992) have stressed that restoration efforts should be of a landscape or watershed scale and suggested that the importance of small-scale restoration projects may be difficult to establish in the context of a greater ecosystem. Given this, it appears reasonable for emphasis to be placed on large-scale ecosystem restoration and perhaps programmatic initiatives such as state and federal wetland mitigation programs.

There can, however, be considerable incentive for small-scale restoration, particularly when it would enhance local environmental quality and address community needs and desires. Citizens, civic organizations, and elected officials may be motivated by recognition of the importance of environmental quality for quality of life and community character. They may also be encouraged by outreach efforts of resource management agencies to protect habitat, reduce NPS pollution, and mitigate the adverse effects of growth. Additionally, local governments and private developers may be required to incorporate restoration components into stormwater management and treatment systems.

While small restoration efforts may not by themselves normally be capable of addressing chronic, system-wide conditions, they can provide localized improvements with significance within an ecosystem or watershed framework. Some of what can be achieved includes water quality improvement, habitat creation, restoration of native plant diversity, improved public awareness of resources and issues, public health protection (through reduced bacterial contamination in recreational waters, for example), and shoreline protection. Local initiatives can also demonstrate what is feasible and set an example for other communities. While it would be preferable for such activities to be implemented system-wide and in a coordinated manner, it is not necessarily best for local initiatives to wait for the day that watershed and ecosystem programs gain additional momentum and funding.

An objective of the Choctawhatchee River and Bay SWIM program is to work with communities to implement a variety of BMPs to control NPS pollution and to enhance shoreline and aquatic habitat quality. Largely due to the enthusiasm and initiative demonstrated by citizens and officials in the city of Valparaiso, grant funding was targeted toward this community. Despite constraints imposed by topography, land use, and limited funding, suitable sites have been identified on city parklands for construction of wetland treatment systems and shoreline vegetation restoration.

As the project approaches implementation, a number of challenges remain. For example, although the sites targeted for stormwater treatment systems are essentially altered channels with degraded natural functions, they still maintain hydric soils and other wetland characteristics. Thus, wetland resource permits must be obtained for excavation and planting.

An additional challenge relates to public education and how to effectively prescribe personal practices for protecting surface waters. In particular, it is difficult to attribute specific outcomes to any particular actions residents may take. While it is commonly accepted, for example, that limiting residential fertilizer and pesticide use can be beneficial for surface waters, the specific changes required to have measurable effects are typically unknown. We are unable to tell residents how much they need to do, or how many need to do it, to result in appreciable benefits for the aquatic environment. Given this uncertainly, it may be difficult to convince citizens that are not already committed to environmental protection to go to the time and effort necessary to change their personal practices. This is one area in which additional research would be beneficial.

Considerable planning and outreach activities have been accomplished, and most implementation is anticipated to be complete by winter 2001. It is expected that water quality improvements, habitat restoration, and shoreline protection will be realized. Completion of the stormwater treatment systems and development of supporting information should also assist the community in achieving its long-term stormwater management goals and compliance with National Pollutant Discharge Elimination System (NPDES) Phase II requirements.

An additional benefit of the shoreline restoration component of the project is its tangibility. While direct benefits of stormwater treatment and public education on the quality of a receiving waterbody can be difficult for observers to discern, the creation of new habitat is readily apparent. The use of restored sites by waterfowl, fish, and invertebrates is likewise apparent. Thus, residents will have direct evidence of the success of the project and its benefits for the community. Such tangibility also helps to enhance public awareness and appreciation of associated resources.

ACKNOWLEDGEMENTS

I wish to express my appreciation to a number of people who have been instrumental in the development and implementation of this project. Michael Flynt of the city of Valparaiso has provided notable leadership in the initiation of the project and important assistance throughout its implementation. Rick Harter and Taylor Kirschenfeld of the Florida Department of Environmental Protection have been instrumental in developing shoreline restoration methods and in designing and implementing the shoreline restoration component of this project. Judith Duvall, Lee Marchman, Ron Potts, Gary Miller, Nick Wooten, Mark Ihlefeld, and others at the NWFWMD have provided extensive services in engineering design and water quality monitoring. Chris Verlinde and Nadine Craft of the Northwest Florida Aquatic Preserves Office have performed a great deal of work in developing educational materials and habitat restoration approaches. Tyler Macmillan and Duncan Cairns of the NWFWMD and Michael Scheinkman of DEP have provided general guidance that has been most valuable throughout the project. Additionally, Steve Wolfe, Vicki Whiting, and Ken Espy of DEP provided biological monitoring services. And finally, numerous residents of Valparaiso, including John and Annie Cameron and Lydia Hernandez of the Environmental and Recreation Committee, city commissioners, and others, deserve great credit for the initiative and energy they have demonstrated in pursuing environmental protection and restoration in their community. The U.S. Environmental Protection Agency has provided \$176,000 (approximately 53% of the total cost) toward implementation of this project. Approximately \$141,000 has been contributed by the Surface Water Improvement and Management (SWIM) program, implemented by the Northwest Florida Water Management District and administered by the Florida Department of Environmental Protection. Approximately \$17,000 has also been contributed by DEP's Northwest District Office, the Northwest Florida Aquatic Preserves Office, and the city of Valparaiso.

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DEVELOPMENT OF MARSH HYDROGEOMORPHOLOGY AND MARSH VEGETATION WITHIN A SALT HAY FARM WETLAND RESTORATION SITE

Lee L. Weishar, Aubrey Consulting, Inc. & Woods Hole Group
John Teal, Teal Limited & Woods Hole Oceanographic Institution
Ray Hinkle, URS Greiner Woodward Clyde

ABSTRACT

Salt hay farming along the New Jersey shoreline of the Delaware River Estuary eliminated normal daily tidal flows over thousands of acres of coastal marshes. These sites were high marshes vegetated mostly with *Spartina patens*, *Distichlis spicata*, and *Juncus gerardi*. They were diked to facilitate farming. The restoration plan called for the breaching of the perimeter dikes and the dredging of inlets and new channels to re-establish the hydraulic connection with the estuary. The restoration construction at a salt hay farm at Dennis Township was completed in the fall of 1996. The restoration site is located in the Delaware River Estuary and is approximately 600 acres.

The restoration design called for construction of the primary (largest) and secondary channels. Development of the tertiary and smaller channels was to be completed through natural processes. An end-point model was developed to assess hydrogeomorphic development of the restoration site. We chose to use a stream order analysis, originally developed for fluvial systems to evaluate the development of the site hydrogeomorphology because, in large complex systems, it is not practical to measure tidal elevations at the required spatial density to equivocally demonstrate whether the desired site hydroperiod has been obtained. To complete our assessment of channel and hydroperiod development, we adapted the traditional stream order analysis techniques to examine changes in tidal channel morphology within the restoration site. Our modification of the system presents a new approach, which simplifies monitoring and evaluating hydrogeomorphologic development at large complex sites.

Establishment of site hydrogeomorphology is important but must be accompanied by the establishment of desirable marsh vegetation for restoration to be successful. Data are presented to show that the development of favorable vegetation within the site occurred rapidly. The project design called for limited marsh grass planting. However, natural re-vegetation occurred so quickly that it was unnecessary to plant marsh grasses within the restoration site. This marsh restoration project has been determined to be successful using the two key indicators of hydrogeomorphology and natural revegetation of the marsh plain.

Site Description

The Dennis Township Salt Hay Farm Wetland restoration site covers approximately 578 acres of wetland and is located in Dennis Township, Cape May County, NJ (Figure 1).

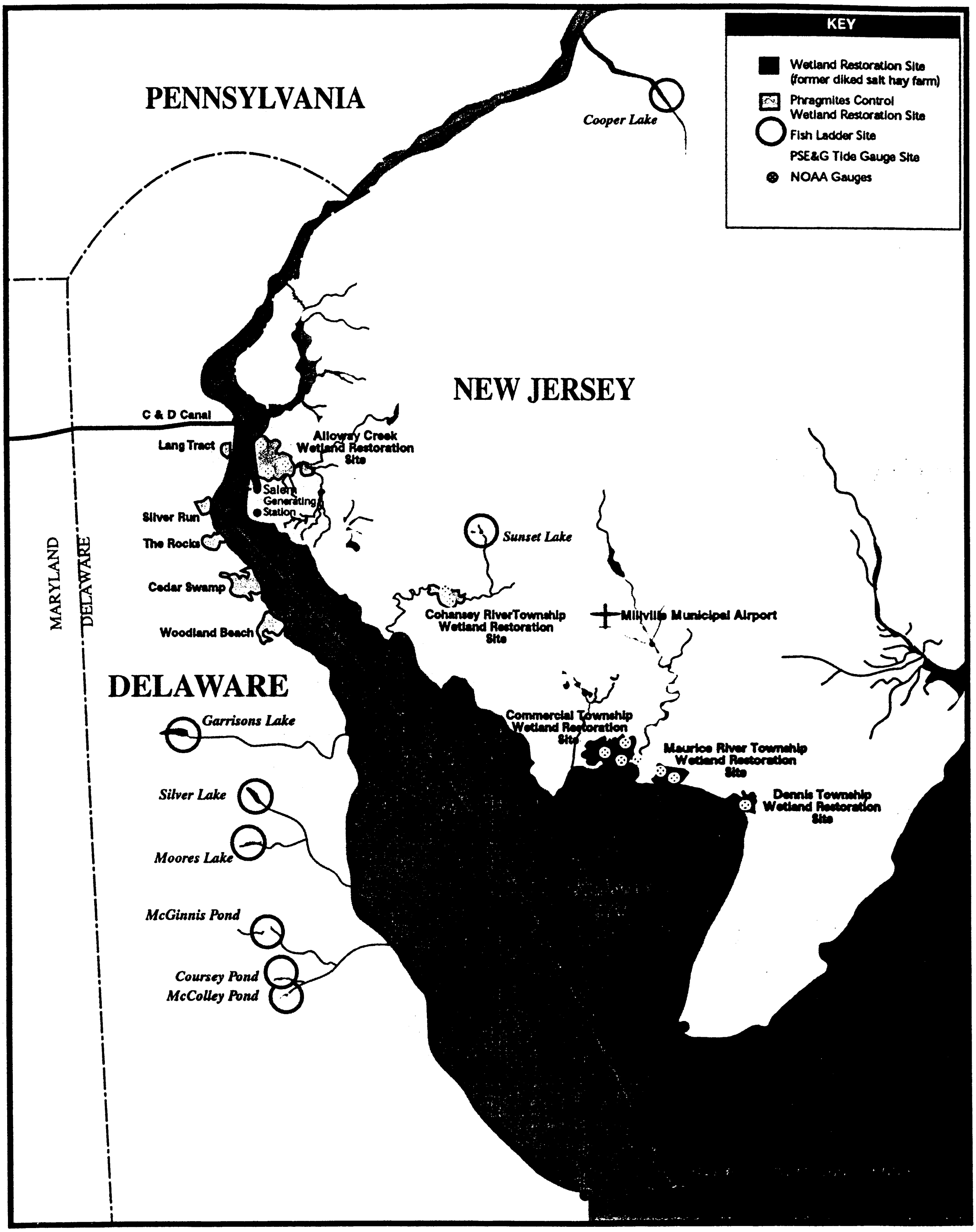

Figure 1. Location diagram.

The restoration area (369 acres) is bordered by West Creek on the west, the West Creek Gun Club on the north, East Creek on the east, and the Delaware Estuary on the south. Perimeter dikes were built around this area during the 1950's, eliminating normal tidal inundation over the entire site. During the 1980s, salt hay farming was abandoned on an approximately 195-acre area located in the northeast portion of the site. Much of the remaining acreage continued to be farmed for salt hay until acquired as a wetland restoration site in 1995. The diked salt hay farms were isolated from tidal flow and were in the process of becoming dominated by *Phragmites*. A detailed discussion is presented in Weishar et al., 1996 and 1997. The restoration objectives at this site were to restore tidal inundation, restore the natural high and low marsh mosaic, and reduce *Phragmites* coverage. With the completion of restoration construction in August 1996, the entire restoration area receives normal daily tidal inundation and drainage.

Background

A marsh restoration intuitively seems a worthwhile project. However, many times competing interests require more than a casual justification for restoring a marsh ecosystem. We embarked upon the marsh restoration project because the marsh ecosystem is a dynamic and changing environment with an intricate interaction of biological and physical processes that had been significantly degraded by the elimination of tides and the invasion of *Phragmites*. Tidal waters bring sediments, nutrients, and seeds into the marsh, and export detritus and other marsh by-products into the adjoining waters. Fish and other aquatic organisms travel up the tidal channels into the higher marsh with the tide to forage, returning with the ebbing tide to deeper channels and the Estuary. Tidal salt marshes provide essential links between coastal lands and estuarine waters (Childers and Day 1991; Mitsch and Gosselink 1993). Salt marshes provide foraging, breeding, nursery and refuge areas for aquatic and terrestrial animals, including many commercially important fish and shellfish species. Many fishes, for example, live in the open estuary, feeding at times on the marsh edge and traveling higher into the marsh via the tidal channels to forage (Hoss and Thayer 1993; Mitsch and Gosselink 1993; Fell et al. 1998). Vegetative characteristics of the marsh plain are associated with tidal inundation and drainage patterns, geomorphology, and salinity.

The three main components of the marsh ecosystem include tidal channels, marsh plains, and ponds/pannes. Tidal channels provide drainage pathways within the marsh, transporting nutrients, organisms, sediment, and other materials between the marsh and adjacent Estuary over the course of tidal cycles. Additionally, these channels provide the pathway for tidal waters to flow onto and off of the marsh plain, which, in turn, controls the marsh plain hydroperiod.

The vegetation on marsh plains contribute primary productivity and detritus to the open waters of the estuary and serves as habitat for birds and other terrestrial organisms. Vegetation also enhances sediment deposition, dampens wave energy, slows water velocity, and stabilizes the marsh plain (Kraeuter 1976; Edwards and Frey 1977). Plant roots also enhance sediment porosity, permeability, aeration, water percolation, and chemical diffusion (Frey and Basan 1985). Open water, in the form of ponds or pannes, is retained at low tide and is essential habitat for aquatic fishes and macroinvertebrates.

Importance of Marsh Plain Hydroperiods

The inundation and drainage of the marsh plain during the normal tidal cycle is one of the most critical processes within the marsh system. The wetting duration of the marsh plain surface by tides is termed the hydroperiod. Tidal activity generally determines the upper and lower extent of vegetation in the marsh. The lower vegetation limit is set by processes such as the depth and duration of tidal flooding, the mechanical effects of waves, sediment availability, and erosional forces (Chapman 1960), and the ability of the higher plants to survive periods of immersion. The upper limit of marsh vegetation (high marsh) usually extends to the limit of flooding on extreme tides (Beeftink 1977). High marsh usually extends to the limit of flooding on extreme tides.

Tidal inundation has physical and chemical effects on marshes. Flooding of the marsh plain raises pore water levels, decreases oxygen diffusion, and increases soil saturation (Mitsch and Gosselink 1993). When the marsh plain is covered by tidal waters, chemical transformations occur, which, in turn, affect the biogenic processes. Some of these transformations include a shift from oxic to anoxic conditions; increased pH; organic nitrogen transformation to ammonia; and a shift from oxidized to reduced forms of iron, manganese, and sulfur (sulfide). All of these processes have a dramatic effect on the wetland biological community.

Tides carry sediments from the estuary to marshes. They also serve to physically transport nutrients and organic matter to and from marshes (Hellings and Gallagher 1992). Tidal flooding exposes plants to mechanical wave energy. Soil aeration, chemistry, and salinity are altered by tidal flooding and subsequently, control plant growth. Additionally, the amount of open water area, sediment type, and density of tidal channels all have an affect on the hydroperiod of the marsh plain.

The relationship between the establishment of hydroperiod and growth of marsh plain vegetation is well understood; however, little data exists that quantifies this relationship. Seneca et al. (1985) examined the long-term relationship between growth of *Spartina spp.* and invasive plant species and hydroperiod. They found that a hydroperiod of 4 hours or less was favorable for the growth of *Phragmites* and other invasive non-*Spartina* species. Their study showed that *Spartina spp.* would grow on a marsh plain that was inundated for up to 12 hours per day, while development of *Phragmites* and other invasive species was impeded by this hydroperiod. The optimum hydroperiod, which resulted in the largest standing crop for marsh plain re-vegetation, was in the 3-hour range during the first 3 years after planting. After the 5^{th} growing season, however, the conditions, which supported the maximum standing crop, shifted from a 3-hour to an 11-hour hydroperiod.

"Top Down" Channel Order Analysis

We incorporated Ecological Engineering (Mitsch, 1996) into the design for this restoration. Only the primary and secondary marsh channels were constructed. The design depended upon natural processes to develop the tertiary and smaller streams (Weishar et al. 1996, 1997, and 1998). Therefore, we needed to quantify the development of the tertiary and smaller channels across the marsh plain.

We initially selected the classic stream order analysis of Horton (1945) because it had proven successful in restoring riparian streams. Horton (1945) emphasized topographic characteristics of the drainage area and gave a hierarchical order to every channel in the drainage basin. With this analysis, he was able to establish relationships between river order and lengths of courses (channels) between river order and size of the respective drainage basin, as well as the number of streams of a certain order. The Horton method is a "top-down" approach that relied on determining the order of the central drainage channel (Fig. 2), which is then carried through the entire drainage area. The Horton method becomes subjective when the drainage area is highly bifurcated or has several branches that are nearly equal in length and number of branches. Horton later attempted to quantified this technique (Chow, 1964) however, the initial stream channel layout was still highly subjective

Strahler (1957; 1964) modified this system by starting the next highest order at the confluence of two tributaries of lower order (Fig. 3). This eliminated the need to trace one of the central streams back to its source through the entire drainage basin. Strahler's method is based on the premise that, for a sufficiently large sample size, order number is directly proportional to relative watershed dimensions, channel size, and volume of stream discharge. Also, because the order number is a dimensionless value, two drainage basins of different sizes can be compared at corresponding points through the use of order numbers.

The stream/channel order analysis was completed for both the restoration site and the reference marsh. Two hydrogeomorphic comparisons were made using the channel order analysis. A comparison of the number of channels within each channel order was made for the restoration site and the reference marsh. The number of channels per class is defined as the summation of all channels within a class across the entire drainage area. For the reference marshes and restoration sites, the total area was used as the drainage area. A measurement of the total number of channels is useful when comparing sites of similar size. However, one cannot assess the site hydrogeomorphology of two different sized sites using only the total number of channels within each channel class.

To address this limitation, two additional hydrogeomorphic comparisons were made: channel frequency and channel sinuosity. The channel frequency (F_C) is defined as the average number of channels of all orders (N_T) per unit area (A_B) of the drainage basin:

$$F_C = N_T/A_B$$

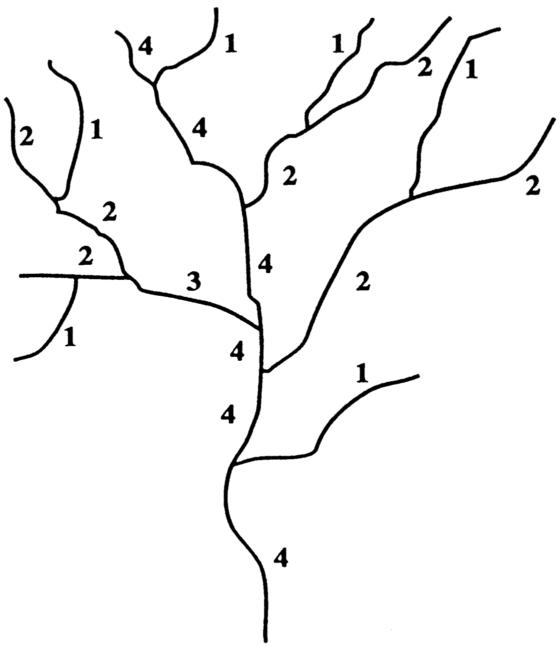

Figure 2. Horton Stream Order Technique (1954).

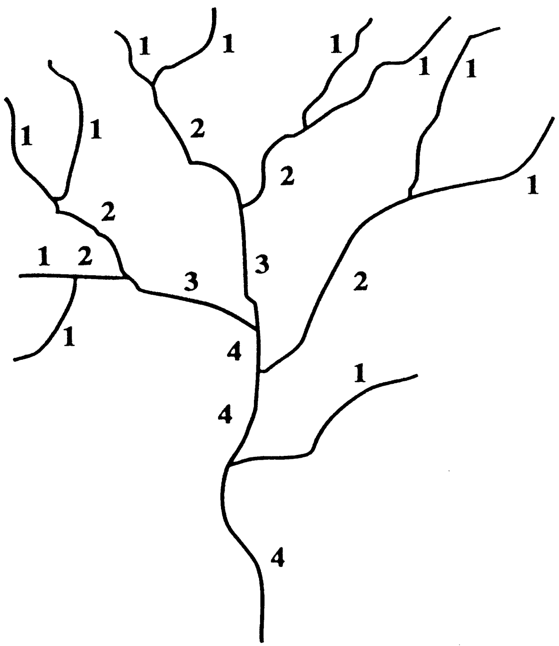

Figure 3. Channel order of analysis after Strahler (1957).

Channel frequency is a measurement of channel density. This measurement can be viewed as a normalized number of channels and is a measure of hydraulic efficiency, which can be used to compare different sized sites. When comparing a small site with a larger site, the smaller site often has a smaller number of channels, but a larger channel frequency. As a result, the smaller site will have a greater hydraulic efficiency than the larger site.

RESULTS

Channel frequency and order at Dennis Township are shown in Figure 4. The Dennis Township restoration site was opened to tidal flow in August 1996 following excavation of the large primary and secondary channels as reflected in the September 1996 data (Figure 4).

Use of Ecological Engineering in the design left the tertiary and smaller channels to form naturally over time. This is reflected in the increase in channel orders from three to four (Figure 4). The largest channel density increase is inversely correlated with the size of the channel. This is expected because as the system begins to evolve, new channels form on the channel margins of the large, dredged primary and secondary channels. Channel density was calculated beginning in 1997 because immediately after the site was opened channel densities would have not been representative of the evolving marsh.

The channel order analysis is a nondimensional analysis. The large dredged channels in the traditional ordering have the highest (largest number) order. To compare the changes that occurred at Dennis Township during the first year after restoration, the 1996 data were shifted so that the largest orders could be directly compared (Figure 5). Several inconsistencies are apparent. There were thirty-one 2nd and 3rd order (shown as 4th and 5th on Figure 5) channels in 1996 (Table 1). In 1997 our analysis shows there are only 7 4th and 5th order channels. If we include the 3rd order channels in this sum it increase only to 25. This means that we have lost 7 of the largest channels identified and mapped in 1996. These results prompted a re-examination of the assumptions and methodologies used by Horton and Strahler.

Table 1
Number of Marsh Channels

Channel Order	Number of Channels (1996)	Number of Channels (1997)
1	65	216
2	26	53
3	5	18
4	0	6
5	0	1

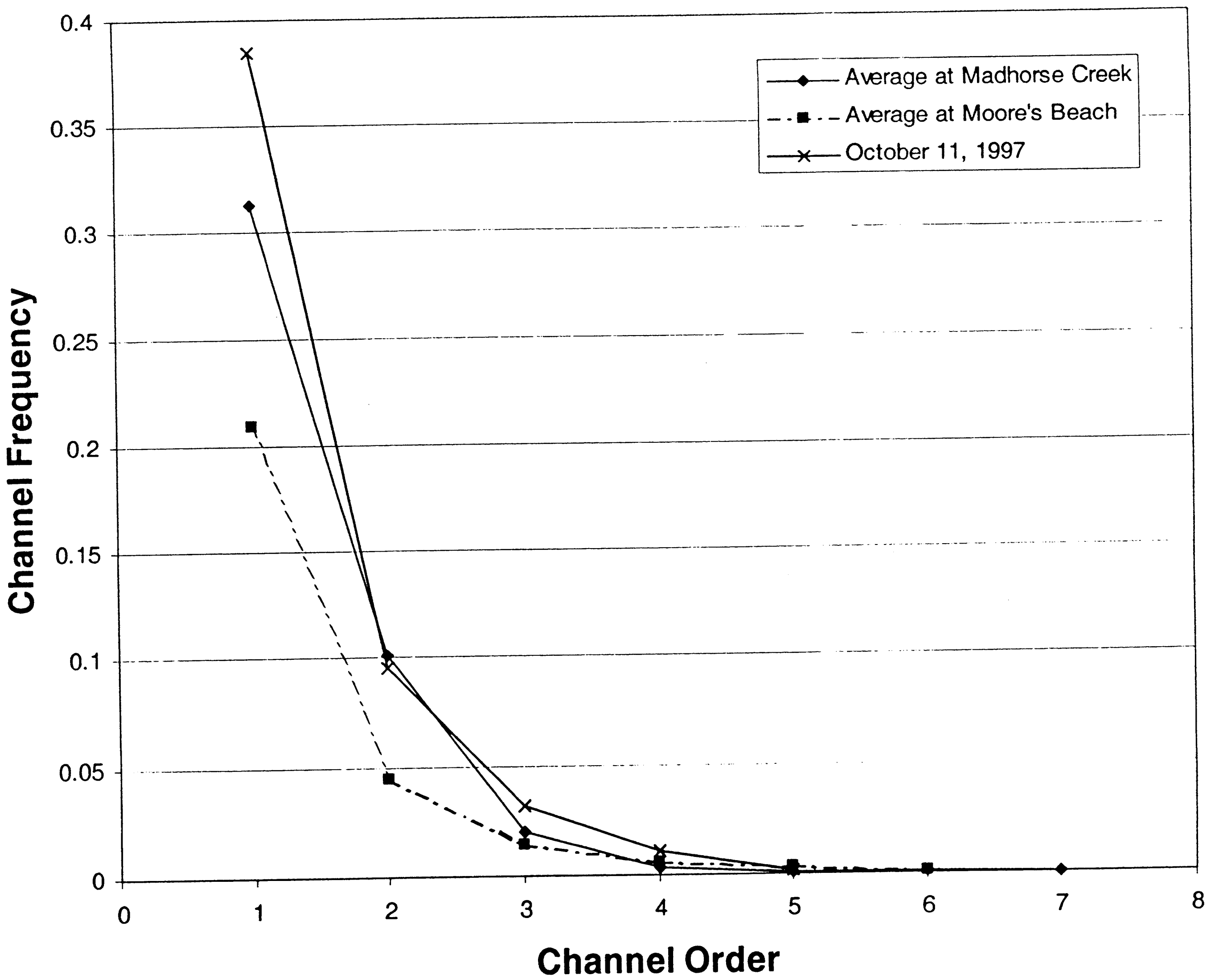

Figure 4. Channel frequency for the "top down analysis" at the Dennis Township site.

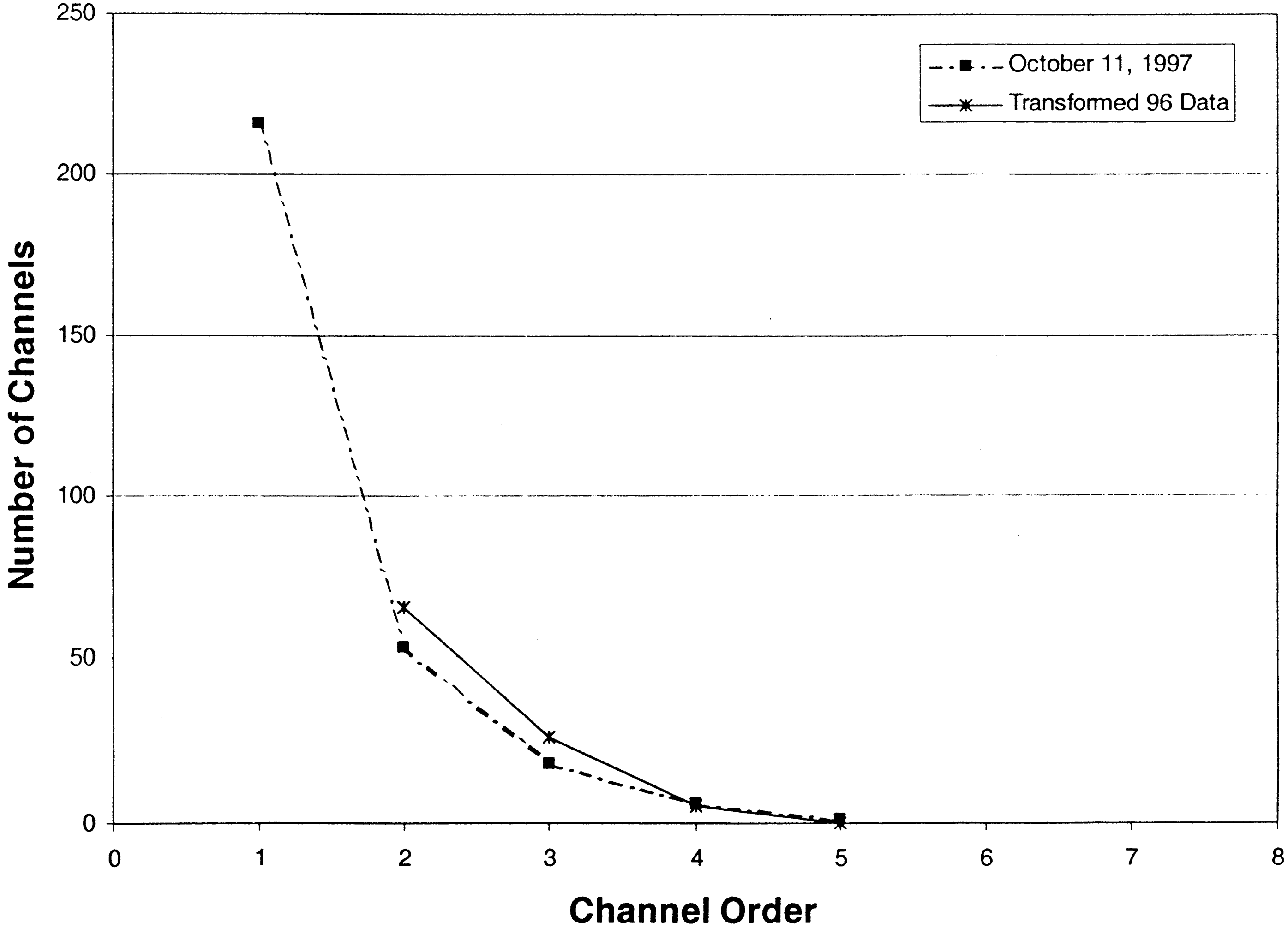

Figure 5. Transformed number of channels ("top down analysis) at the Dennis Township site.

These analytical stream geomorphology tools were developed for mature stream systems. An implicit assumption of order analysis is that a comparison of any two-channel orders should compare streams of comparable size. These techniques do not work well for rapidly developing salt marsh stream channels. The increasing the number of small channels dramatically changes the order number of the largest channels (Figure 5). These changes in order, especially when summed across the restoration site, make it impossible to identify a channel dimension with a channel order.

"Bottom-Up" Channel Order Analysis

To correct the problems associated with application of the "top-down" channel order approach, the hydrogeomorphic analysis technique was modified to be more useful for a dynamic system. All sites were re-analyzed using a "bottom-up" hydrogeomorphologic channel class analysis. A comparison of these two techniques is shown in Figures 6 and 7. Using this hydrogeomorphic "bottom-up" technique ensures that the largest channels are always the lowest order (1st order) and that increasing order numbers are assigned to the rapidly changing smaller channels.

We reanalyzed the data from Moores Beach and the Dennis Township restoration site ordering channels using the "bottom up" channel ordering technique. Figure 8 shows the increase in the number of channels at the Dennis Township marsh restoration site for the years 1996, 1997, and 1998, and the number of channels at the two reference marshes Moores Beach and Mad Horse Creek. The rapid increase in the number of order 3 through 9 (smaller) channels over the three-year period is apparent. The "bottom-up" channel order analysis anchors our large channels and shows that the distribution and number of channels by channel class is beginning to approximate the reference marshes.

Figure 9 shows the channel frequency for the Dennis Township restoration site analyzed using the "bottom-up" technique for 1996, 1997, and 1998. This figure shows a rapid increase in the channel frequency. The distribution of channel classes at the wetlands restoration site is similar for both of the reference marshes. In fact, between 1997 and 1998 the channel frequency at Dennis Township surpassed the Moores Beach reference marsh and was rapidly approaching the channel frequency at the Mad Horse Creek reference marsh. The "bottom-up" channel order analysis shows the rapid increase in channel formation and provides a tool for adaptive managers to track the development of the frequency distribution of channel development over time. It also provides a tool to monitor the evolution of channel formation in restored marshes in comparison to the reference marshes.

Changes in Marsh Plain Vegetation

Our design for the marsh restoration was predicated on the hypothesis that if the proper hydraulic conditions were established, the marsh would revegetate naturally from the seeds deposited on the marsh plain from adjacent marshes. Additionally, the reduction and elimination of *Phragmites* would occur as a result of the re-introduction of relatively

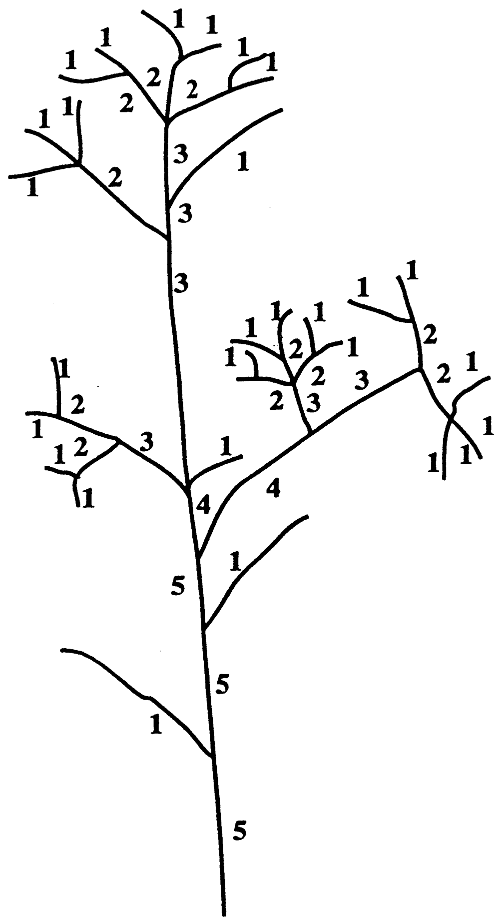

Figure 6. "Top Down" stream oder convention.

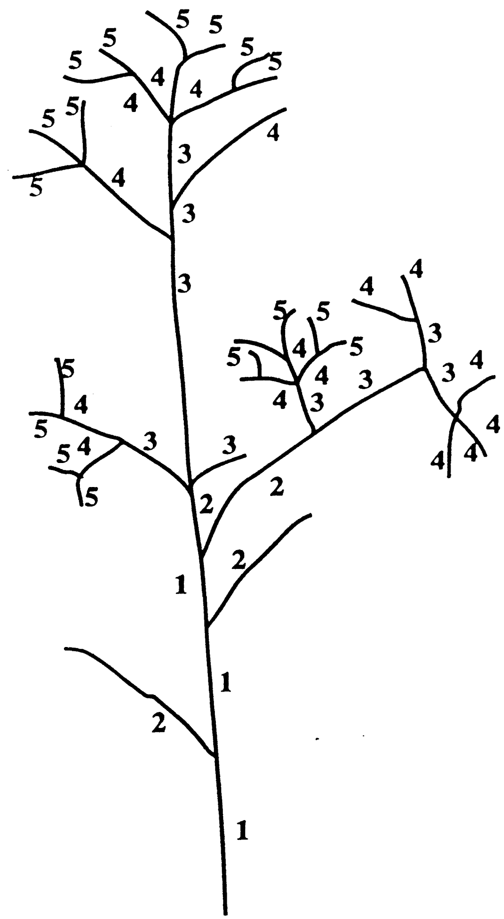

Figure 7. "Bottom Up" stream oder convention.

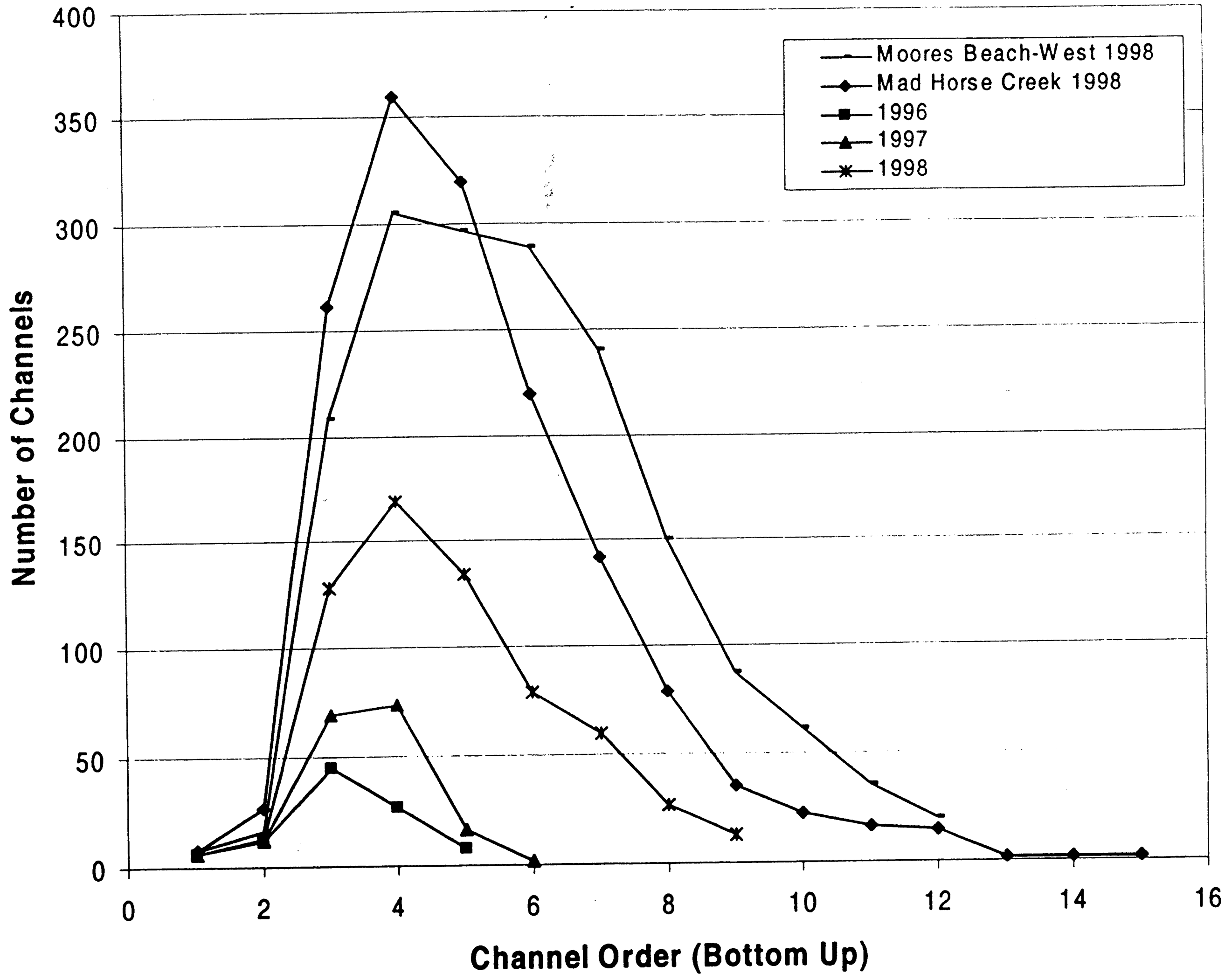

Figure 8. Number of channels for the "bottom up" analysis at the Dennis Township site.

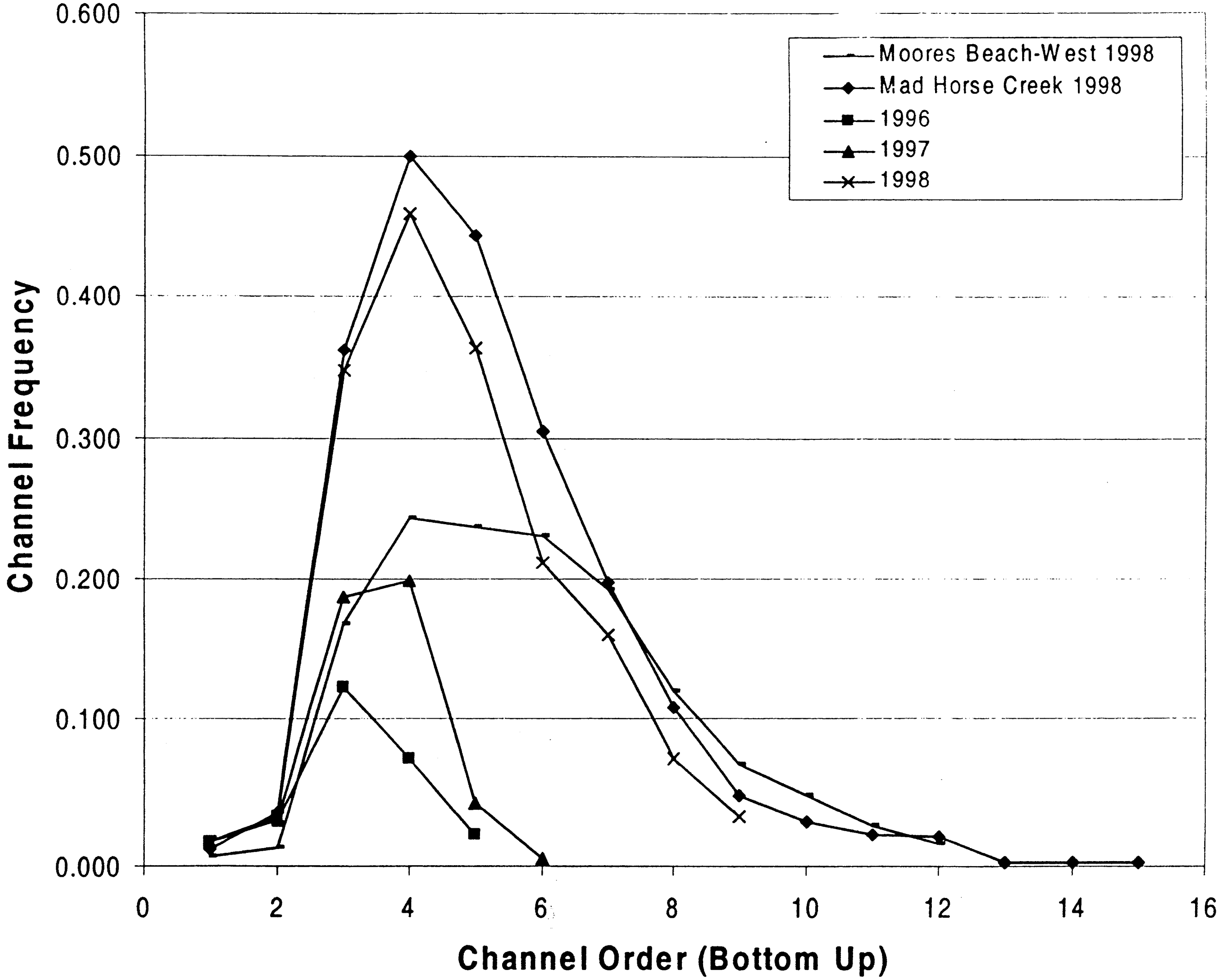

Figure 9. Channel frequency for the "bottom up" analysis at the Dennis Township site.

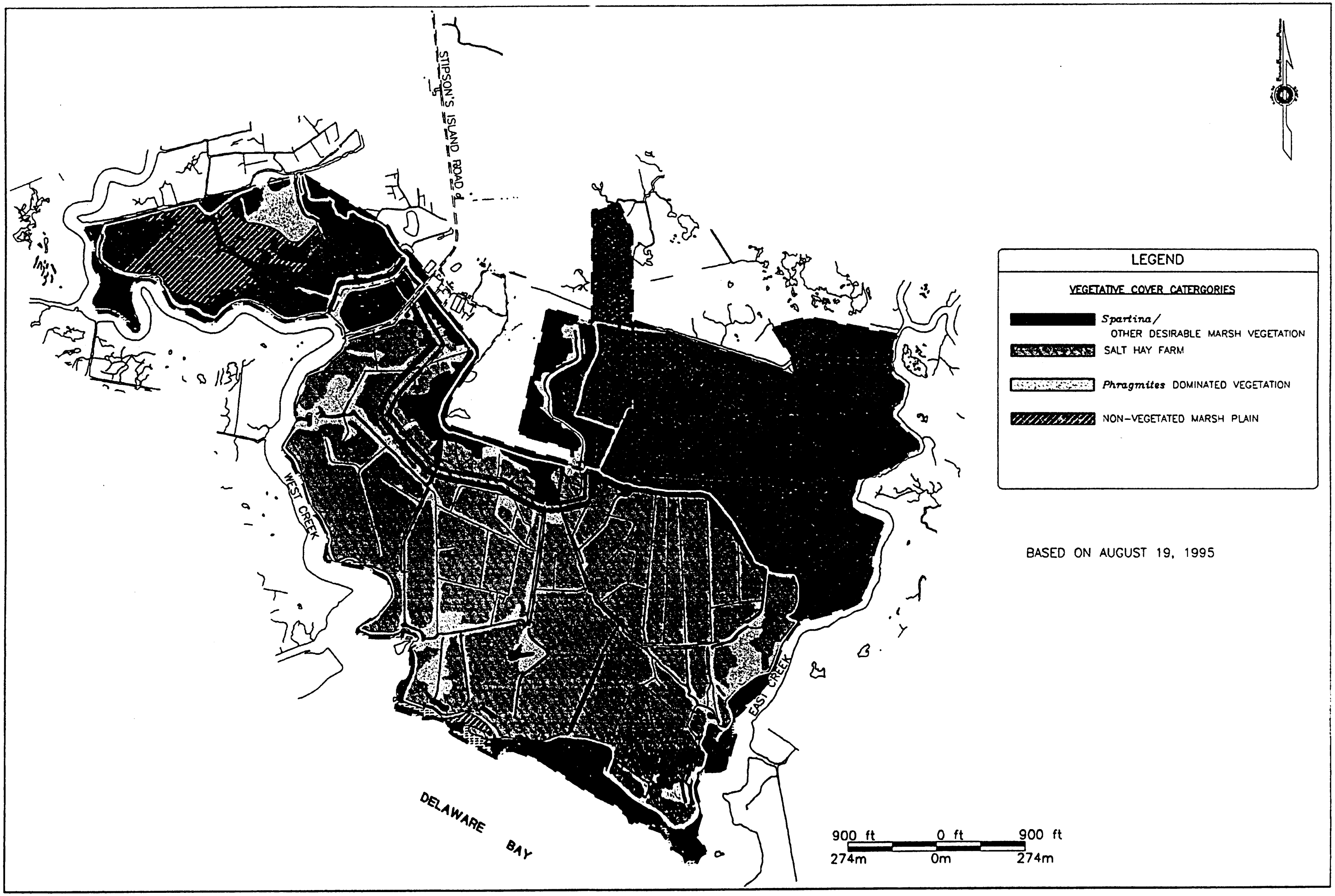

Figure 10. Pre-restoration conditions at the Dennis Township site.

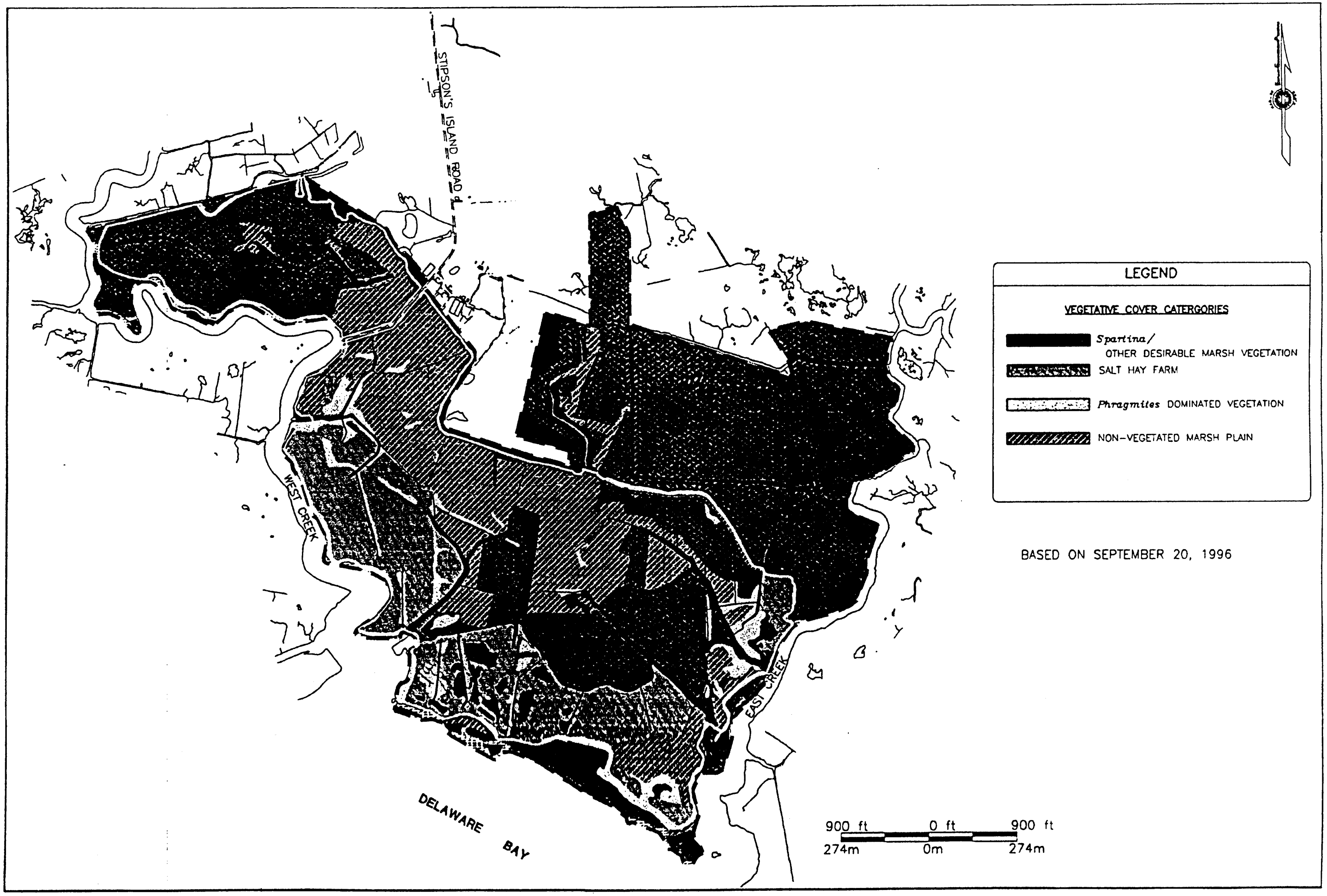

Figure 11. Vegetation mapping after the 1996 growing season at the Dennis Township site.

high salinity tidal waters to the site. The restoration design did not call for the complete elimination of *Phragmites* from the site. It will still occur along the upland boarder and provide a valuable edge for wildlife. However, our goal was to eliminate monotypic stands *Phragmites* from the marsh plain.

The vegetation conditions that existed at the site prior to the restoration are shown in Figure 10. There were several large areas of open water, extensive salt hay fields, and areas of *Phragmites*. The open water areas were due to a pre-existing dike breach at the site. The salt hay fields are within the perimeter dikes of the salt hay farm. Figure 11 shows the site after construction of the primary and secondary channels and the opening of the dikes. The most notable differences between Figures 10 and 11 are the increases in the open water areas, *Spartina alterniflora*, and a corresponding decrease in *Spartina patens*.

During the three years between 1996 and 1998, the channels increased in number and size. The result was the establishment of a favorable hydroperiod. Tidal velocities on the marsh plain were low enough to encourage sedimentation and the deposition of seeds. Figure 12 shows the marsh plain vegetation at the end of the 1998-growing season. There has been an increase in open water areas and a dramatic increase *Spartina alterniflora*. The increase in open water areas are the result of herbivory from snow geese and the die-off of *Spartina patens*. Visual observations during the 1999 growing season have shown that these areas are now vegetated with *Spartina alterniflora*.

CONCLUSIONS

A hydroperiod favorable for the growth of *Spartina spp.* and other desirable, naturally occurring marsh vegetation has been established at the Dennis Township restoration site. The establishment of favorable hydroperiods provided low velocities within the tidal channels and favorable conditions for sediment and seed deposition on the marsh plain. Following the completion of restoration activities in 1996, monitoring indicated increased areas of mud flats and shallow ponded water. By the end of 1997, areas previously vegetated with salt hay (*Spartina patens*) were covered with new sediment and *S. alterniflora* seeds, which established stands of *Spartina alterniflora*. By 1998, monitoring data indicated that *Spartina alterniflora* had increased from 42.1 percent coverage in 1996 to 77.8 percent in 1998. The extent of *Phragmites* coverage has been reduced and much of the *Phragmites* that remains at the site is stunted from daily inundation of saline tidal waters. Mud flats and unvegetated marsh plain declined from nearly 32.6 percent in 1996 to 11.8 percent in 1998. This restoration at this site has been successful. The tidal flows have been re-established and the marsh plain has re-vegetated with *Spartina alterniflora* and other desirable marsh plants. The open water areas are decreasing in size and now are at a level equivalent to that in the natural marsh mosaic.

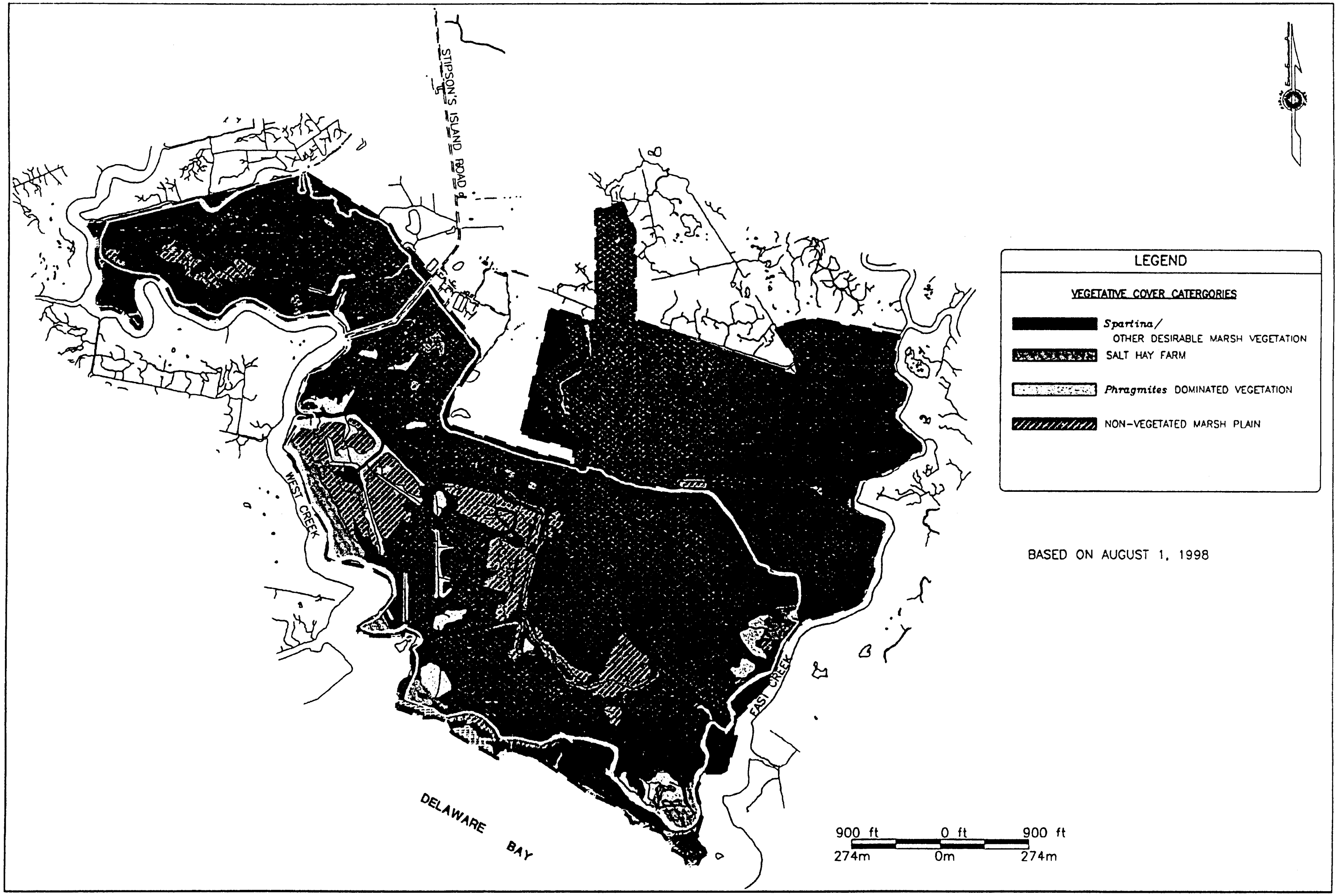

Figure 12. Vegetation mapping after the 1998 growing season at the Dennis Township site.

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HOW (AND WHY) TO BUILD A TIDAL FRESHWATER MUDFLAT MESOCOSM

Peter I. May
District of Columbia Watershed Protection Division
51 N Street, NE
Washington, DC 20002

University of Maryland
Marine, Estuarine, Environmental Science (MEES) Program
College Park, Maryland 20742

ABSTRACT

The ecological role of tidal freshwater mudflats is rarely studied and poorly understood. These systems may be more complex and of greater importance than a casual observation may suggest. The elimination of these areas from tidal freshwater coastal areas as a result of decades of dredging and filling, and more recently from marsh restoration projects, have placed greater importance and immediacy on the study of these relatively rare ecosystems. Currently, some tidal mudflats are considered prime areas for emergent tidal marsh restoration using dredge material. Two years of observational and experimental field data on algae, benthos, fish, and birds from a mudflat adjacent to a marsh restoration site in Washington, D.C. revealed interesting results that begged further investigation. The use of mesocosms to further study these systems is employed as a valuable tool for confirming field experiments and observations. These mesocosms are expected be the key to unlocking the hidden secrets of the tidal freshwater mudflat systems. In an effort to better understand the freshwater intertidal biotic community and some of its interrelationships with the physical environment, three, *500* gallon, 1x3m mudflat mesocosms are being constructed so that linkages in the intertidal mudflat food chain may be better studied, understood and described. Currently, one 500 gallon prototype mesocosm model has been built to determine the feasibility of construction and the ability of the model to match a natural system. Initial physical, biological and water quality measurements collected in the prototype show that a realistic model comparison between the mesocosm and that of the actual mudflat and river systems can be achieved. The prototype model has run for 11 months without significant 'mechanical' problems and has yielded interesting physical and biological data. Criteria for a successful model have been developed, tested, and are presented.

INTRODUCTION

The study of food webs and trophic level interactions have been the source of significant research since Elton's landmark work Animal Ecology in 1927 and Lindeman's deviation in the trophic dynamic aspect of ecology (1942). The importance of investigations into the very basic levels of biotic inter-relationships to gain a greater understanding of the structure of a studied ecosystem cannot be overstated. Taking the study of trophic dynamics to the next level, beyond simple observational and field experimentation, requires the physical or mathematical modeling of a studied system. Ewel (1987) stated that the ability to recreate an ecosystem "is the ultimate test of ecological theory." It is the intent of this current research to create a physical, living model, or mesocosm, of a tidal freshwater mudflat in order to better understand the system and some of the food web dynamics affecting the biotic and abiotic aspects of the system.

Aquatic food webs and community inter-connectedness with the biotic and physical environment have been studied extensively in rivers (Power, 1984, 1989, 1990a, 1992), marine systems (Paine, 1966, 1969, 1974; Reise, 1985) and estuarine systems (Odum, 1971; Teal, 1976; Diaz, 1992; Everett and Ruiz, 1993). These investigations have often revealed interesting hidden relationships that were only discovered after extensive observation and field experimentation.

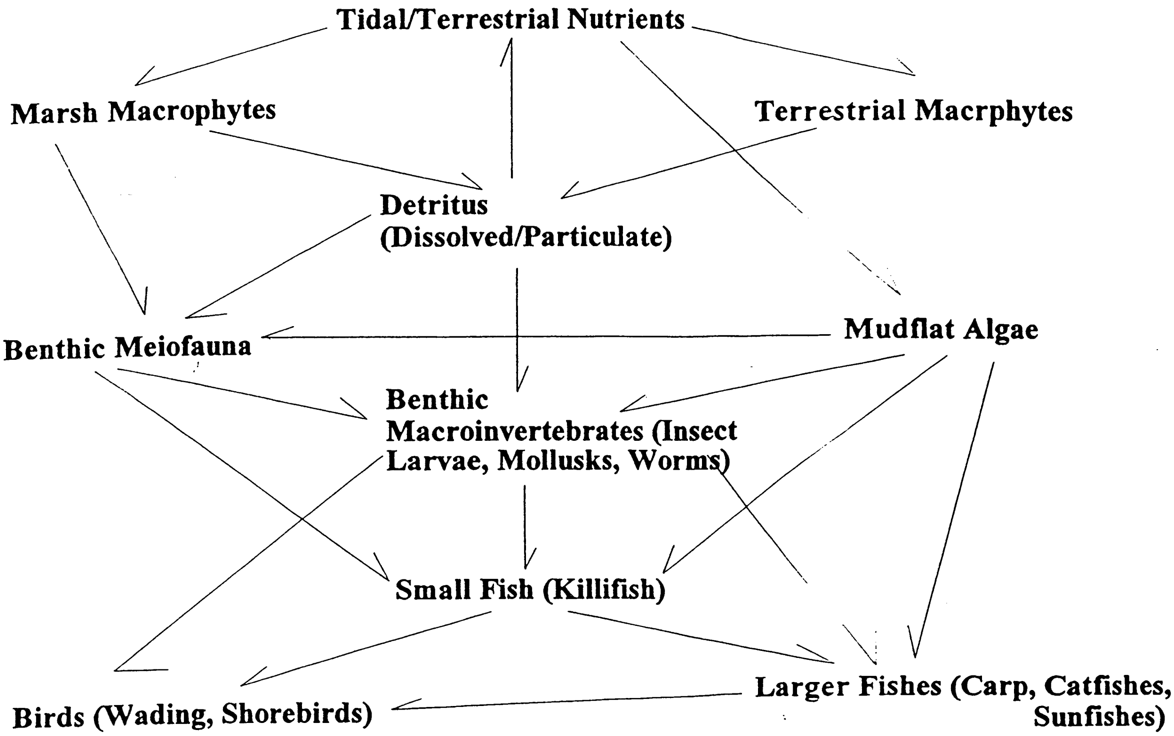
The comparatively less extensive tidal freshwater ecosystems have much wider gaps in the experimentally derived knowledge of basic functional relationships (Odum, 1988). The work of W.E. Odum (1984) and Diaz (1977) state the importance of and need for further work into the study of these freshwater tidal systems. The ecological role of some freshwater tidal subsystems may be more complex than a casual observation may suggest. W.E. Odum (1984) found that the "knowledge of energy flow in tidal freshwater wetlands is almost totally speculative." With basic energy flow data on tidal fresh wetlands considered speculative, the knowledge base for mudflats may be considered a complete mystery.

The freshwater tidal subecosystem which is most seriously under-represented in the ecological literature is the mudflat. Extensive marine tidal flat experimental investigations have been undertaken encompassing years of accumulated data and observations (Reise, *1985).* Conversely, there are no comprehensive studies of the tidal fresh mudflat ecosystem. This would not be so troubling but for the recent trend in tidal wetland restoration efforts in the District of Columbia to convert all significant mudflats to emergent marsh utilizing dredge spoil deposited on the flats to raise their elevation to a suitable point for emergent macrophyte growth (USACOE, 1993). While most would agree that restoring tidal marshes is worthwhile considering their historic losses and ecological value, the almost complete lack of information concerning the inherent value of mudflats should give pause to plans to convert all mudflats to emergent marsh.

An important example of one possible consequence of converting all mudflats to marshlands in the District of Columbia is the elimination of valuable feeding areas for shorebirds during their long migrations. With the gradual loss of feeding habitat in coastal areas, some of these birds may have found a new migratory stopover on the mudflats of the District which developed over much of the last century. Eliminating this significant habitat type from the District could have hidden costs which have not yet been accounted for.

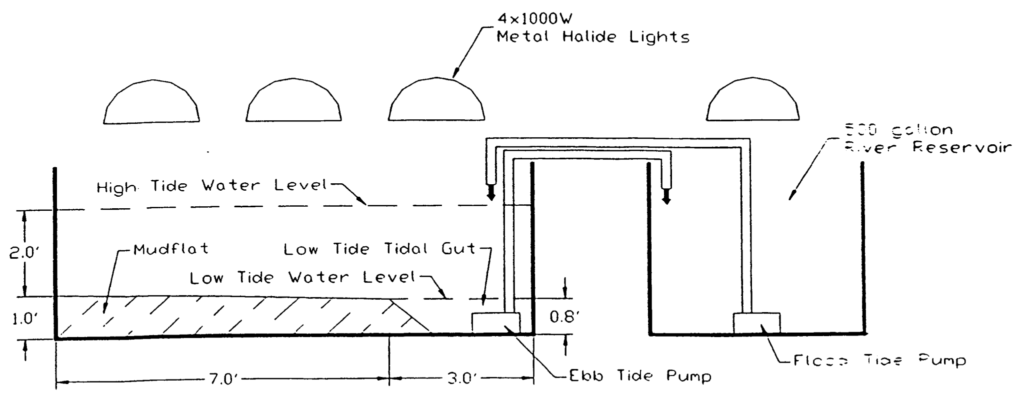
In an effort to better understand the freshwater tidal mudflat biotic community and some of its inter-relationships, two years of field experiments and observations were conducted on a Washington, D.C. tidal mudflat. An energy flow diagram based on these studies is represented in Figure 1.

Figure 1. Freshwater tidal mudflat energy flow diagram



These observations have lead to the development of a prototype mudflat mesocosm model in order to better understand and study the freshwater tidal mudflat system (Figure 2).

Figure 2. Schematic diagram of the mudflat mesocosm model

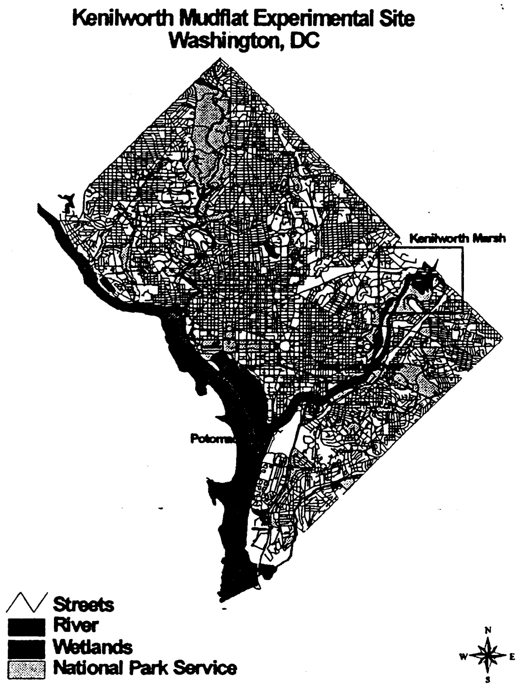


The use of mesocosms to allow for the closer examination of natural aquatic systems has existed in some form since the first aquarium thousands of years ago. Today these systems are employed as more than a curiosity, but a valuable tool for ecological research that can be engineered at many scales to reflect their wild counterparts (Adey and Loveland, 1991). It is believed that by doing so with the freshwater tidal mudflats, the mesocosm will be the key to unlocking some unknown aspects of these systems. It is also expected that linkages in the intertidal mudflat food chain may be better understood and described using the mesocosm mudflat in a controlled set of experiments.

Background / Site Description

The field study site (Figure 3) is located adjacent to the Anacostia River just below the Maryland/District line in Northeast Washington, D.C. *(38°54'37"* N *76°56'54"* W). The average tidal amplitude is approximately 1.0 m. At low tide, large areas of unvegetated mudflats still exist around and in between the seasonally dense, restored vegetated areas. Dominated on the surface by green and bluegreen algae, these exposed intertidal areas are also inhabited by patchy yet dense populations of oligochaete worms, chironomid midge fly larvae and corbicula clams (May, 1996).

Figure 3. Kenilworth Mudflat Experimental Site, Washington, DC



The hydrogeomorphic situations of tidal fresh systems along the U.S. mid-Atlantic East coast influenced the early development of port towns into cities at the head of tide on rivers nearest the fall line. Richmond, Washington, D.C., Baltimore, and Philadelphia all have historically had freshwater tidal wetlands in their vicinity (Simpson et al. 1983) and all have permanently altered these environments in some fashion. A significant aspect of these unique areas that have tides and yet no salt are the once expansive and historically diminished tidal freshwater wetlands. The growth of the cities often required the destruction of the majority of these marshes with subsequent sedimentation creating expansive mudflats in low energy areas at low tide.

Tidal freshwater mudflats are relatively rare morphological features found at the head of some river estuarine systems. Washington, D.C. lies at the head of tide for the Potomac river estuary and has a coastal plain tidal river flowing through its eastern half. This river, the Anacostia, has had mudflats dominate much of the river scape at low tide for more than 50 years. While these mudflats are considered relatively new, an artifact of increased sedimentation, there is no way to know if they existed to any great degree prior to the European conquest.

Recently, the emergence of ecological restoration as a discipline and a practice has encouraged the replacement or restoration of tidal freshwater marshes in and around the cities where they were destroyed decades earlier (USACOE, 1993; Sacco et al, 1994; Havens et al, 1995). Within the last decade, a restoration effort by the U.S. Army Corps of Engineers in Washington, D.C. has planned the conversion of tens of hectares of mudflats to emergent tidal marshes with graded dredge material from the river. One project completed in 1993 restored approximately 13 hectares of tidal fresh emergent wetland in an area called the Kenilworth Marsh on the upper Anacostia River.

Once an expanse of unvegetated tidal mud flats (a result of Army Corps of Engineers dredging in the 30's and 40's), the marsh was restored in 1993 by a Corps improvement project (USACOE, 1992). Using adjacent Anacostia River dredge material, the elevations of the tidal flats that had laid exposed at low tide for decades were raised to encourage the growth of newly planted emergent macrophytes (USACOE, 1993).

METHODS

An initial two year evaluation (1997 and 1998) of the food chain linkages on the tidal mudflats of Kenilworth Marsh was conducted through the use of observational and experimental studies on mudflats. Field observation and sampling data were taken on algal coverage, invertebrate densities, and fish and bird utilization over the two year period. Algal coverage was determined through the monthly use of a 1.0 m square 100 point grid frame overlay which was randomly laid on three points in each cell once a month. Algal type and density for each grid overlay was given an average percent cover for each cell and treatment.

Sampling of the Kenilworth Marsh benthic infauna has been conducted by May (Unpublished data) for the last several years. Benthic invertebrate abundance and biomass of the dominant infauna, mollusks, chironomids and oligochaetes (Pennak, 1978) were evaluated within the experimental and reference areas using a manual coring device (Vorberg, 1993).

Fish surveys were conducted in the Kenilworth Marsh using an electrofishing boat once each spring, summer and fall season. Approximately 1000 seconds of shocking were conducted in areas adjacent to the experimental mudflat at a spring high tide during each shocking event. A bag seine survey of the fishes leaving the mudflat on an ebb tide was also conducted. Fish diversity and biomass were recorded. Observations were made with respect to fish disturbance (Flecker, 1996), most notably carp, which is suspected of being a significant modifier of the tidal flat substrate while in search of food or during breeding.

Observations of bird usage of the mudflat experimental area were made three times per month on morning high tides. Records were kept of the numbers and species of birds (Hayman et al., 1986) utilizing the experimental tidal flat areas. Attempts were made to identify tracks and other disturbances made in the mudflat.

Field Data Results

The data appears to reflect some correlations between fish and bird access to the mudflat and biotic mechanisms affecting the benthos and algae. The number of oligochaetes found in bird and fish excluded areas were consistently greater than those found in either of the accessible areas in each of the study years. The algae data reflected a noticeable effect only in 1998, where seven of the months sampled revealed a significant increase in algal coverage in the totally fish and bird excluded mudflat areas.

The fish data reflects the diversity of species found in the river that also use the mudflat at different tidal stages (Table 1). On one occasion numerous carp were shocked off of the mudflat, presumably in the midst of breeding. This data confirms the presence of a major disturbance factor from the carp on and around the experimental mudflat.

Bird observational data on and around the experimental mudflats revealed a variety of bird life interacting with the mudflat (Table 2). Shorebirds on the mudflat were dominated by the ubiquitous Killdeer. While several other species of shorebirds were evidenced on a much less frequent basis, some of them are considered threatened. Overwhelming evidence of heavy Canada goose usage of the mudflat was found in the form of "carpets" of footprints and shoveled out craters in the mud, work done by the geese looking for young shoots and tubers of the sparse vegetation unsuccessfully attempting to grow on the mudflat.

Table 1. Fish survey results at Kenilworth mudflat
* note the differences in catch per sampling method

Electrofishing Surveys 1997 and 1998

Brown Bullhead	79
Pumpkinseed	63
Gizzard Shad	49
Blueback Herring	23
White Perch	14
Goldfish	7
Alewife Herring	6
Golden Shiner	5
Eastern Silvery Minnow	5
Mummichog Killifish	4*
Atlantic Silversides	4
Yellow Perch	4
Common Carp	4
Bluegill Sunfish	2
Shorthead Readhorse	2
Channel Catfish	2
Striped Bass	1
American Shad	1
Spottail Shiner	1

Bag Seine Survey 1998

Mummichog Killifish	677*
Banded Killifish	137
Blueback Herring	47
Pumpkinseed Sunfish	27
Golden Shiner	17
Golden Shiner	17
Bluegill Sunfish	13
White Perch	4
Brown Bullhead	3
Tessellated Darter	2
Largemouth Bass	2

Table 2. Bird survey results at Kenilworth mudflat

Total # counted over 36 observations / year

	1997	1998
Killdeer	197	231
Canada Goose	140	233
Mallard	46	112
Ring Billed Gull	54	91
Great Blue Heron	71	42
Great Egret	61	15
Greater Yellowlegs	27	32
American Crow	16	31
Herring Gull	27	1
Belted Kingfisher	13	10
Double Crested Cormorant	12	4
Black Duck	3	16
Bufflehead	-	14
Wood Duck	-	8
Osprey	3	4
Solitary Sandpiper	-	7
Spotted Sandpiper	-	6
Hooded Merganser	5	-
Pintail	4	-
Red Tail Hawk	3	-
Bald Eagle	2	1
Green Heron	2	1
Forsters Tern	-	3
Lesser Yellowlegs	1	1
Bonaparts Gull	-	2
Common Merganser	1	-
Least Sandpiper	1	-
Semipalmated Plover	-	1

Mudflat Mesocosm Model

The collection of this data allowed for the development of a greater understanding of the major physical and biologic factors interacting on the mudflats. This understanding provided the inspiration for the living model which was then translated into the construction of a tidal mudflat mesocosm prototype in a lab for applications involving control and manipulation of the system. A list of the components used in the building of the mesocosm are summarized in the form of a "recipe" used as a metaphor for the construction of the system (Table 3).

Table 3. A starter 'recipe' for tidal mudflat mesocosms (makes one mudflat, multiply for replication)

1	Preform fiberglass trough 10x4x3 ft LHW
1	500 gallon 'river' reservoir
4	1000w metal halide light systems
2	1000gph submersible pumps with 10ft head capacity
3	24 Hour Digital timer switches
30	Feet of 3/4 in hose

INGREDIENTS	8 64 L Coolers of mud from the top 10cm of a natural mudflat 500 Gallons of natural river water taken at least 96 hrs after last rain event
CONSTRUCT	Add one pump and timer each to the mudflat trough and river Reservoir set timers fro a semi-diurnal tidal cycle (2 ebb, 2 flood tides /24 hr. cycle Hang 4 metal halide lights over trough and one light over river Reservoir Connect all 5 lights to one timer set for seasonal light Duration required
LAYER IN	8 64 L Coolers of mud from the top 10cm of a natural mudflat
POUR IN	(Just add water, makes its own sauce!) 500 Gallons of natural river water to the reservoir
MIX WELL	Activate ebb/flood tide and solar timers for time of month and season
COOKING TIME	Allow to self organize for one week before adding fish, snails, Turtles in any combination
SERVE	Serve for interested mudflat ecologist who want to learn more About these systems through thoughtful experimentation

Currently, one 500 gallon prototype mudflat mesocosm model was successfully built to determine the feasibility of construction and the ability of the model to match a natural system (Figure 2). The system was run on a semi-diurnal tidal cycle continuously for almost a year, producing significant algal coverage and invertebrate densities in the absence of vertebrate effects. In addition to the layering of mud in the mesocosm from a natural field site, a 500 gallon "river" reservoir was filled with field site river water and pumped on timers to tidally fluxuate.

A list of physical, chemical and biological criteria for a successful mudflat mesocosm model have been developed and have been tested prior to the construction of the second and third mesocosms (Table 4).

Table 4. Mudflat / river mesocosm: physical, chemical & biological comparison matrix of factors to evaluate "realness" when compared to the natural field system

	Anacostia River	Mesocosm River	Kenilworth Mudflat	Mesocosm Mudflat
Diurnal Oxygen Averages (Day/Night) mg/L	4.42/4.44	5.16/5.71	7.7	4.29/4.60
Diurnal Water Temp (Day/Night) C°	27.6/26.2	27.5/26.9	21.0	27.5/26.8
pH	6.8	7.3	6.9	7.1
Conductivity mmhos/cm	0.361	0.470	0.303	0.474
Light Intensity um/m2/s	0.53*10-2	0.57*10-2	0.53*10-2	0.59*10-2
Nutrient Conc.				
(Nitrate+Nitrite)mg/L	0.44	0.10	0.44	0.20
(PO4) mg/L	0.03	0.01	0.03	0.01
(NH4) mg/L	0.42	0.23	0.54	0.25
Algal Coverage/ m2	NA	NA	64%	94%
Benthic Macroinvertebrates Avg # Oligochaetes/ 6.5cm dia X 8cm core	NA	NA	6	53
Sediment Particle Size	NA	NA	%sand 44	55
			%silt 40	32
			%clay 16	12

This matrix of 'realness' factors reflect a surprising similarity between the real world natural mudflat and river systems, and the mesocosms that were modeling those systems. The only major dissimilarities occurred with the benthic invertebrate oligochaete densities and algal coverage which were different due to the complete lack of predation effects on the mesocosm mudflat increasing the densities of oligochaetes and algal coverage. These predation and disturbance effects seen in the differences between the field system and the mesocosm system beg the application of experiments to the lab mesocosm to further test theories related to the mudflats food web dynamics and interconnectedness.

Mesocosm Calibration, Replication and Experimentation

Once the system has been tuned to the natural mudflat system sufficiently, the construction of three identical mesocosm mudflat systems is expected. A plan to construct the three experimental mudflat mesocosm models is proposed with which they will be used to test predation and disturbance hypotheses on algal coverage and invertebrate densities. Another significant finding during the two year research period on the field mudflats revealed the possibility of fish and bird predation effects on macrophyte seed germination and growth on the mudflats. This finding may reveal insights into one of the hidden unknowns imbedded in the food web of the mudflats, potentially explaining one of the factors that help to keep mudflats unvegetated for decades and even longer. By utilizing a mesocosm experimental scheme in the lab, the effects of fish predation and disturbance can be defined and thus shed light on the relative effects that they contribute verses those of bird induced influences. A list of mudflat biomechanic hypotheses and several tests of them utilizing the mesocosms are outlined in Table 5.

Table 5. Mudflat biomechanic hypotheses and initial mesocosm test proposed

I. *Fish/Bird predation/disturbance impacts the benthic macroinvertebra community.*

Mesocosm Tests:
- Tethered chironomid – fish predation experiment
- Oligochate density - fish predation
- Marked snail - fish predation experiment

II. *Biotic / abiotic disturbance impacts microtopography - algal coverage.*

Mesocosm Tests:
- Three types of fish (killifish, catfish, carp) disturbance
- Simulated waterfowl disturbance (footprints, shovel,crater)
- Turtle disturbance
- Abiotic (wind, tide) disturbances combine to magnify biotic effects

III. *Algal coverage impacts benthic macroinvertebrate community.*

Mesocosm Tests: Simulate algal maximum (carpet) invertebrate max densities

Field Tests: Compare with field benthic invert/algal data

IV. *Biotic predation/disturbance impacts macrophyte seed germination and growth.*

Mesocosm Tests: Marked macrophyte seed / seedling placement under 3 fish species / no fish influence and compare germination / growth

Macrophyte seedlings under 3 fish influence / no fish

CONCLUSION

The experimentation proposed for the tidal mudflat mesocosm system may prove to be the first of its kind on the tidal freshwater ecosystem. The complete lack of information regarding these systems, especially in light of their conversion to other ecotypes, answers the question as to why to study the tidal freshwater mudflat. By building the mesocosm model of the system, it is believed that a possible strong interaction (Power et al. 1985) can be proven to exist between algal coverage, invertebrate distribution, and macrophyte seed germination and growth due to fish and bird predation and disturbance on the intertidal flats of the Kenilworth Marsh. By using mesocosm experimentation, it is expected that the intertidal mudflats of the marsh would prove to be productive infaunal and emergent macrophyte habitat but for the heavy predation and disturbance by the marshes intermediate and top end consumers. These pressures possibly allow for a positive algae feedback which ultimately characterizes the tidal marsh flats (Power, 1990b).

The level of interconnectedness of the food chain in the freshwater tidal mudflats is now speculative (Odum, 1984; Findlay et al, 1989). It is unclear if fish or bird predation of invertebrates is an exclusive dominant force in the top-end consumer activity on the Kenilworth tidal mudflats or if they are co dominants. Utilizing the mesocosm model to evaluate the predation efforts of several fish species on the invertebrate community will provide a clearer picture of the levels that fish and birds play on the natural infaunal community. Algal biomass may be affected positively or negatively by the exclusion of fish grazing and disturbance factors (Power, 1985, 1988; McCormick and Stevenson, 1989) while it is also unknown to what extent the fish have affected the seed germination and growth of some emergent macrophyte species.

Determining the extent of fish predation and disturbance on mudflats will effectively narrow one biotic factor from the list of unknowns in the mudflat food web dynamic. By confirming or eliminating several unknown links in the freshwater tidal mudflat food web structure, these field and mesocosm data results would add significantly to a base of ecological research on the mudflat subecosystems and the larger freshwater tidal marsh ecosystem as a whole (Odum et al, 1984; McIvor and Odum 1988; Findlay et al, 1989; Yozzo and Odum, 1993).

There is a great importance and immediacy in understanding the tidal freshwater mudflat ecosystem. The mistakes of our human past have shown us that it is very easy to eliminate a system that is considered unsightly or unwanted, just as 'swamps' had been destroyed without knowing their benefits to the environment and society. It is entirely possible that tidal fresh mudflats may be just as important and even more endangered than other, more popular 'green' emergent marshes. Our experience has also shown that it is much harder to recreate or restore a system than it is to preserve them in the first place. As researchers and restoration ecologists we must take these cues from our past and learn to look first, before we leap.

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MERCURY LEVELS AND CONCERNS IN FLORIDA WATER BODIES

C.W. Sheffield, PE
Michael P. Bahor, PE
Deborah Ingersoll, EI
Sheffield Engineering & Associates, Inc.
4322 Anderson Road
Orlando, Florida 32812
(407) 658-0512 Voice
(407) 482-5691 Fax
mbahor@aol.com

ABSTRACT

Numerous papers have been written reporting data on mercury content in various game fish. This paper addresses the mercury content in freshwater fish, specifically, largemouth bass from stormwater retention/detention ponds and/or borrow pits. The object of the study was to determine: (1) if the older fish retain higher amounts of mercury and (2) if there was a variation in mercury content due to seasonal changes. Sufficient data was not obtained to determine if there were seasonal variations. This study did confirm that, in general, the older fish have higher mercury concentrations. The study concluded that additional monthly sampling of small and large bass is needed to obtain a more definitive conclusion on seasonal changes.

INTRODUCTION

Sheffield Engineering & Associates and Test America Laboratory of Orlando, Florida have been studying the mercury concentrations from fish in stormwater retention ponds and/or borrow pits since 1993. These investigations were intended to determine if these fish were exhibiting the same mercury content as reported in the literature. This interest began when our companies began having company/client fish fry's approximately 2-3 times per year with bass from these ponds.

The literature indicates that mercury, in both the United States and Canada, has been of great concern particularly for those persons that rely heavily on fish for their diet. The Florida Department of Environmental Protection published a paper by Thomas D. Atkeson, Ph.D., Mercury Coordinator, (June 1994) that indicated mercury was a wide spread air and water-borne problem. One of the most interesting pieces of literature is a "Florida Health Advisory in Florida Fresh Water Fish" by the Florida Department of Health and Rehabilitative Services (June 1993). They indicated certain areas should limit fish consumption from one meal per week to no consumption at all. Most of this advisory was in the Everglades farming district and parts of the upper St. Johns River. This health advisory indicated that a concentration range of 0 to 0.5mg/kg of mercury required no warning. Fish with 0.5 to 1.5 mg/kg of mercury should only be eaten once per week by adults, children once per month and not at all by pregnant women. Over 1.5 mg/kg of mercury in the flesh portion should not be eaten at all. Additionally, the Florida Wildlife magazine (1998) discusses how the Game and Fresh Water Fish Commission (GFC), Florida Department of Health, and the Florida Department of Environmental Protection are educating people to limit the amount of fish eaten in many freshwater bodies that have high enough mercury levels to pose a potential health risk.

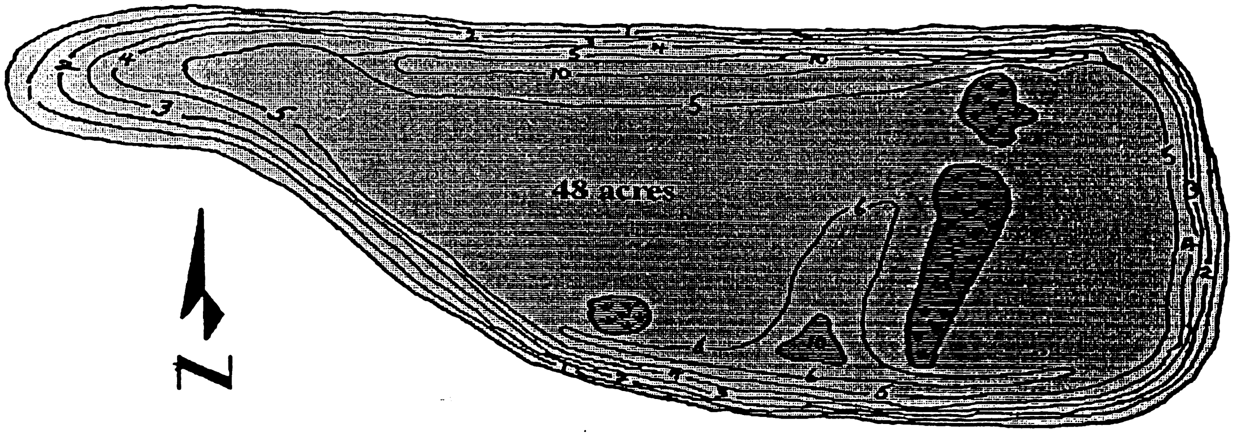
Throughout the years, Sheffield Engineering has sampled different ponds for a total of thirty different sampling events. At each sampling event a composite sample of 10 small bass and 10 large bass fish was desired. A small bass weighs less than three pounds while a large bass weighs more than three pounds. Study limitations were that all fish had to be taken by hook and line and not by chemical, electrical shocking or by net. Due to these limitations, some of the sampling events did not produce a composite sample as desired. The object of this study was to determine the mercury content in area bass fish and ascertain if the older fish with greater bass weight have increased mercury content in their flesh as reported in the literature.

STUDY SITES

Five ponds were selected and sampled at different times throughout the years. Limited chemical data was obtained from these ponds due to budget constraints. The following summarizes the pond location, acreage, and chemical data:

1. Brevard County Pond #1: This drainage pond is located approximately 1/4 mile west of Highway 407 (within private property). This four-acre pond has an average depth of approximately five feet as shown in Figure 1. The water into this pond comes from a subdivision about one mile to the east. The water level fluctuates two to three feet depending on rainfall. The pond has an outlet that flows west to the St. Johns River. Brevard County Pond #1 has the greatest amount of chemical data. Dissolved oxygen (D.O.) averaged approximately 8.5 mg/L, temperature ranged from 61°F to 73°F, chlorides approximately 1,580 mg/L (which was comparatively high for a fresh water lake), while salinity and conductivity were low. The total nitrogen averaged 1.3 mg/L, total phosphorus less than 0.05 mg/L. This data indicates that both nutrients are comparatively low. The seechi readings (deepest portion of the lake) averaged approximately 10 feet.

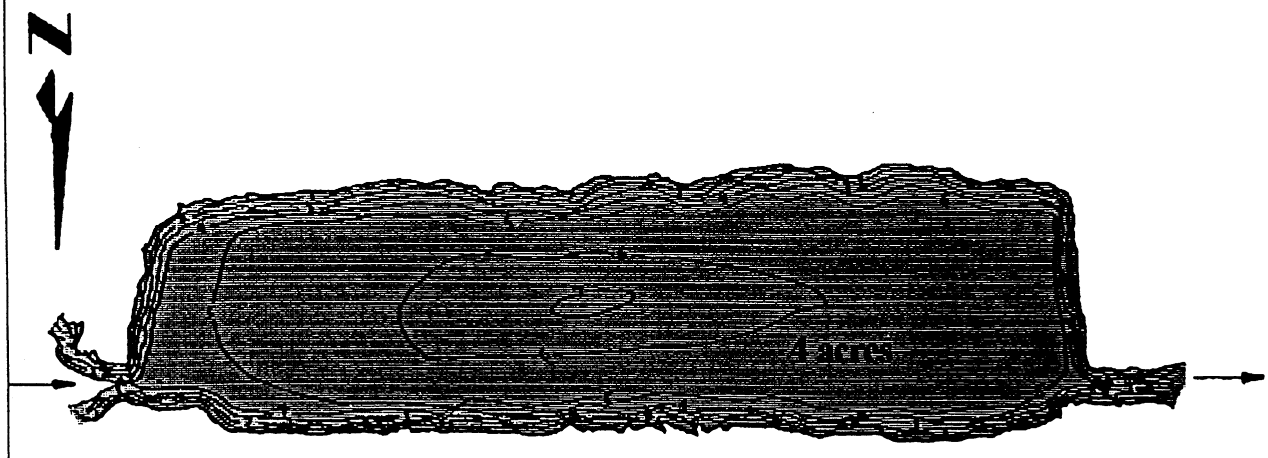
2. Brevard County Pond #2: This pond is located approximately half way between the cities of Cocoa and Titusville and one mile west of U.S. Highway 1. This pond is a forty-eight acre borrow pit dug in the 1960's and is shown in Figure 2. The pond had an average depth of five feet with the typical rim ditch of ten feet deep around the edge. This particular pond does not have an inlet or outlet and therefore is considered a "background" facility. The water quality data for Brevard County pond #2 indicated total nitrogen at 1.74 mg/L and total phosphorus at 0.15 mg/L. The chlorides were approximately 100 mg/L and the seechi was only two feet. The D.O. during the summer had a



BOTTOM PROFILE - BREVARD COUNTY POND 1

1" = 400'

Figure 1



BOTTOM PROFILE - BREVARD COUNTY POND 2

NTS

Figure 2

value of 9.2 mg/L, which is considered supersaturated.

3. Pond #3 in the Grenelefe Resort Golf Course: This site is located in Polk County, just outside of Haines City, Florida. This is a golf course drainage pond, five acres in size, with an average depth of ten feet as shown in Figure 3. It does have an inflow and an outflow pipe going to the east. For the Grenelefe pond, sampling indicated total nitrogen at 1.27 mg/L and a comparatively high total phosphorus level at 0.32 mg/L. Seechi in this lake averaged approximately two feet indicating the possibility of an algae bloom.

4. Redditt South Pond: This borrow pit is located in East Orange County, near Orlando, Florida as shown in Figure 4. This twelve-acre pond is approximately eight feet deep and has a rim ditch up to twenty feet. It does not have an inflow pipe, but has an 8" outfall pipe. This pond is being filled by the owner and was not available for mercury sampling after 1999. The Redditt pond had comparatively low nitrogen and phosphorus values at 1.5 and 0.07 mg/L. Chlorides in this lake were less than 20 mg/L. The D.O. was measured at +8.2 mg/L. This pond does have an outfall pipe that only discharges during excessive summer rains. The aquatic weed Nitella and Hydroditlon in this pond were affected by the cold weather and basically they drop to the bottom during the winter.

5. Realizing that the Redditt pond would not be available after 1999, an unnamed drainage pond east of Orlando was selected for monthly sampling. This drainage pond consisted of three ponds, each 5-6 acres, and connecting canals of 6 acres. There are many inlet pipes and one 48" outfall pipe to the Little Econ Lockhatchee drainage basin. No bottom profile map is available. The pond/canal east of Orlando had an average D.O. content of 8.1 mg/L, a seechi of 2 feet and no nutrient data was collected.

MATERIALS AND METHODS

All fish in the study had to be taken by hook and line. No chemical, electrical shocking or nets were used. At each sampling event a composite sample of 10 small bass (<3 lbs) and 10 large bass fish (>3 lbs) was desired. However, at many of the sampling events, 10 fish in each category were not caught, especially for the large bass fish. In which case, the number of fish caught made up the composite sample. For each sampling event, two ounces of fish flesh per fish was harvested from each specimen and used to create the composite sample. All testing was done by Test America and approved EPA Testing Methods were used.

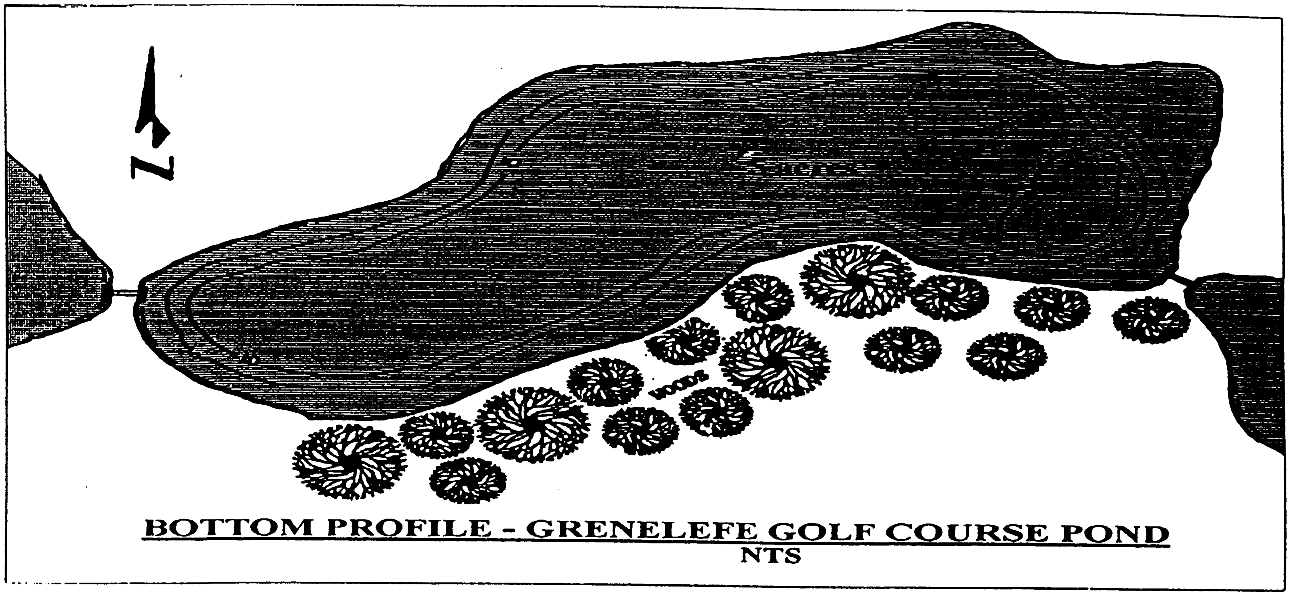


Figure 3

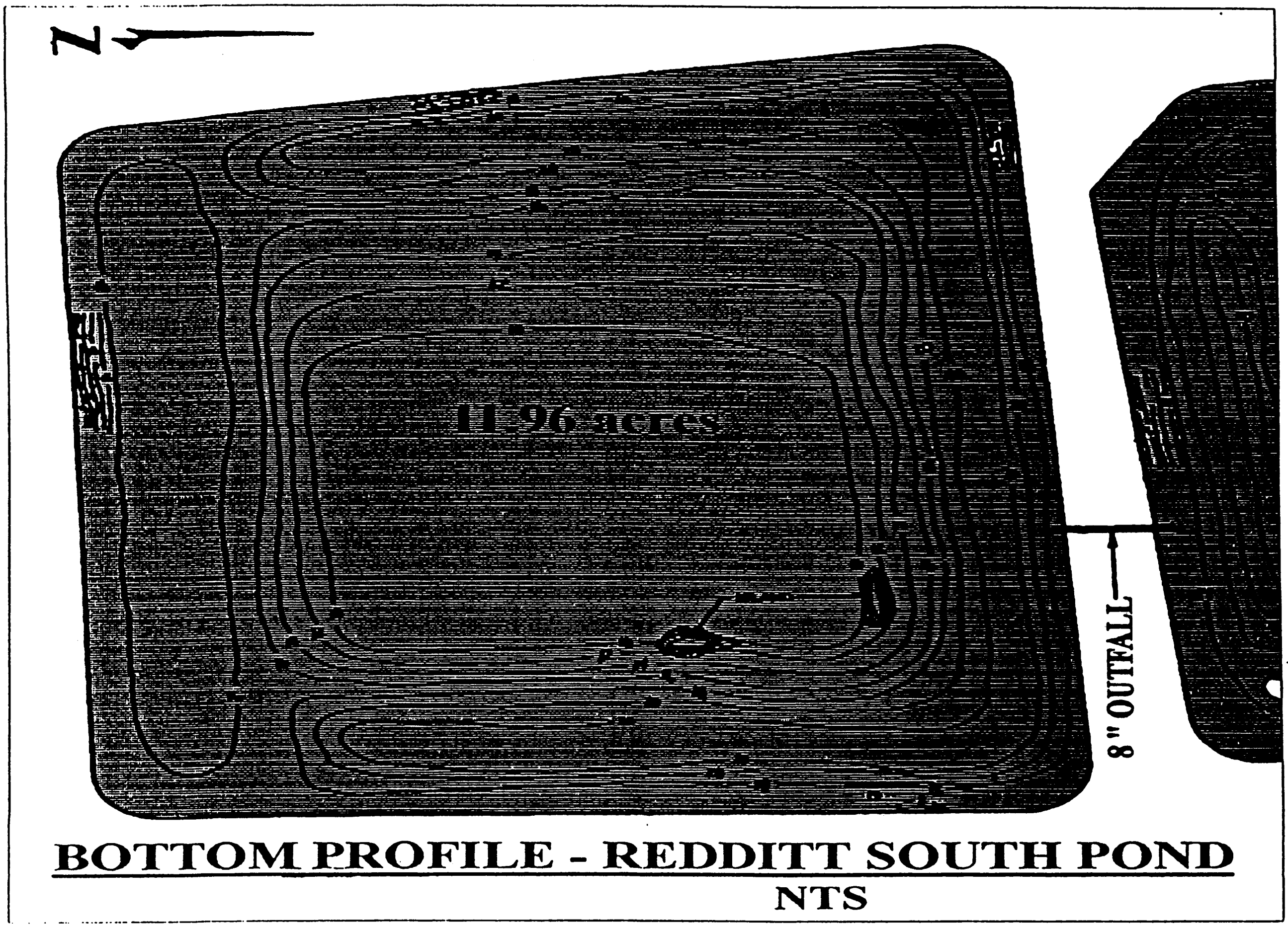


Figure 4

INDIVIDUAL POND SAMPLING RESULTS

The results of the mercury sampling for the large bass fish and the small bass fish are shown respectively in Table 1, and Table 2. Table 1 and Table 2 show the sampling location, sampling date, the Hg concentration, the quantity and the size of the fish(s) caught for each sampling event. For Pond 1, there were a total of eight sampling events with both large and small fish caught. For Pond 2, there was one sampling event with both large and small fish captured. However, for Grenelefe, Redditt, and East Orlando Drainage Canal, large bass fish were not caught at each sampling event even though small bass fish were captured. A total of one out of three sampling events at Grenelefe produced large bass fish, five out of six sampling events at Redditt, and four out of twelve sampling events at the East Orlando Drainage Canal.

Brevard County Pond #1 had the greatest amount of data for both large bass (greater than 3 lb) and small bass (less than 3 lb) fish. For each of the eight sampling events, both large and small bass fish were captured. The larger bass, three to ten pounds, had consistently higher concentrations of mercury than those of the smaller bass. The mercury concentrations for the large bass ranged from 0.312 to 1.62 mg/kg. The smaller bass, approximately 3/4 pound, had mercury concentrations ranging from 0.141 to 0.667 mg/kg. On January 1, 1997 sampling date, one ten pound bass was analyzed which indicated the mercury content of 0.628 mg/kg and a ¼ pound bass only had 0.14 1 mg/kg of mercury. This confirmed that in general, the larger the fish, the greater the mercury content.

Table 1: Large Bass Fish, Sampling Location, Hg Concentration (ppm) and Quantity-Weight

Date	Hg concentration (ppm)	Quantity-Weight	Location
4/6/98	0.158	1-10lb	E. Drainage Canal
1/1/97	0.312	7>3lb	Pond 1
1/24/97	0.312	7>3lb	Pond 1
11/4/93	0.32	1-3lb	Pond 2
11/4/93	0.47	1-5lb	Pond 1
12/5/95	0.471	4-3lb	Pond 1
4/9/98	0.49	1-10lb	E. Drainage Canal
11/1/93	0.623	1-5lb	Grenelefe Pond
1/1/97	0.628	1-10lb	Pond 1
1/24/97	0.628	(1>10lb)	Pond 1
12/15/99	0.844	3-large	E. Drainage Canal
5/4/95	0.967	2-5lb	Pond 1
1/4/97	1.37	(1-5lb)	Redditt
2/3/96	1.42	(1-8lb)	Redditt
3/9/94	1.54	3-5lb	Redditt
1/9/00	1.59	1-8lb	E. Drainage Canal
3/15/95	1.62	3-4lb	Pond 1
11/9/96	1.68	(1-6lb)	Redditt
9/5/95	1.75	(1-8lb)	Redditt

Table 2: Small Bass Fish, Sampling Location, Hg Concentration (ppm) and Quantity-Weight

Small Bass	Hg concentration (ppm)	Quantity-Weight	Location
10/10/96	less than 0.1	8-3/4lb	Pond 3
2/16/98	less than 0.1	5 small	E. Drainage Canal
4/9/98	less than 0.1	4 small	E. Drainage Canal
4/14/98	less than 0.1	4 small	E. Drainage Canal
12/20/98	less than 0.1	6-small	E. Drainage Canal.
1/26/98	0.106	10 small	E. Drainage Canal
12/16/94	0.126	8-3/4lb	Pond 3
1/1/97	0.141	1-1/4lb	Pond 1
1/24/97	0.141	1<1lb	Pond 1
12/5/95	0.164	10-3/4lb	Pond 1
6/1/98	0.182	8 small	E. Drainage Canal
11/1/93	0.183	10-3/4lb	Pond 3
1/1/97	0.198	10<3lb	Pond 1
1/24/97	0.198	10<3lb	Pond 1
1/9/00	0.229	6-small	E. Drainage Canal
10/26/98	0.245	7<3lb	E. Drainage Canal
11/4/93	0.25	4-3/4lb	Pond 2
4/6/98	0.29	10 small	E. Drainage Canal
7/8/98	0.29	14 small	E. Drainage Canal
5/11/98	0.331	4 small	E. Drainage Canal
3/9/94	0.387	10-3/4lb	Redditt
2/15/98	0.455	7 small	E. Drainage Canal
11/4/93	0.49	10-3/4lb	Pond 1
1/4/97	0.533	4-3/4lb	Redditt
3/15/95	0.545	10-3/4lb	Pond 1
2/3/96	0.624	10-3/4lb	Redditt
5/4/95	0.667	10-3/4lb	Pond 1
11/9/96	0.742	5-3/4lb	Redditt
3/9/94	0.793	10-3/4lb	Redditt
9/5/95	0.822	10-3/4lb	Redditt

Brevard County Pond #2 had one sampling event. The larger bass had a mercury concentration of 0.32 mg/kg while the composite sample for the smaller bass had a concentration of 0.25 mg/kg. Both the composite small bass fish and large bass fish samples fall into the "no warning on consumption" category. Although one sampling event of this pond could not be used to show a statistical representation of the mercury concentration in the fish, the larger bass fish had the higher concentration of mercury.

For the Grenelefe pond, the five pound bass had a mercury concentration of 0.623 mg/kg which falls into the eat with warning category. However, the three composite samples of the smaller bass collected at the three sampling events had mercury concentrations ranging from 0.1 to 0.183 mg/kg, which falls into the category of "no warning on eating the fish".

The Redditt pond has been sampled sporadically from March 1994 up until January 1997 for a total of six sampling events. This pond consistently produced large bass, which provided excellent sampling data. The larger bass, five pounds and over, ranged from 1.37 mg/kg to 1.75 mg/kg. The smaller bass, ¾ pound ranged from 0.3 87 mg/kg to 0.822 mg/kg. Only one of the six sampling events for the small bass fish met the criteria of "no restrictions on consumption" while the other five sampling events produced small bass fish requiring "warning about consumption". None of the small bass fish fell into the "don't eat" category but three out of the five large bass sampling events did. The other two sampling events for the large bass fish required restrictions on eating while none of the large bass sampling events produced fish in the "no warning on consumption" category. It was interesting to note the mercury content in this borrow pit pond was the highest of any observed in the study even though it did not have an inflow and only limited water going out during high rainfall periods of 1996.

The East Drainage Canal/Pond had a total of twelve sampling events with four events producing large bass. This pond had the most complete data for monthly sampling however, a trend of seasonal changes cannot be predicted with this limited data. The small bass ranged from 0.455 mg/kg to 0.10 mg/kg. The large bass fish ranged from 0.158 to 1.59 mg/kg. In this pond, the mercury concentration in the large bass exceeded the small bass concentration for two of the sampling events.

CUMMULATIVE RESULTS OF POND SAMPLING

Figures 8 & 9 show the distribution of mercury concentrations in the small and large bass fish by the categories listed in the Florida Health Advisory in 1993. Figure 8 shows that for all five sampling locations, none of the 30 composite samples for the small bass (<3 lbs) exceed the 1.5 ppm Hg concentration which corresponds to the "do not eat" the fish category. Of the composite sampling events, 23 of them fall into the 0 to 0.5 ppm category, or "no restrictions on consumption" while the other 7 sampling events fall into the 0.5 to 1.5 ppm category that has "restrictions on consumption" of the fish. Even though the number of composite samples totaled 30, the total number of small bass fish caught in the ponds totaled 226.

Figure 9 depicts the mercury concentration in the large bass fish. The large bass fish have five sampling events in the >1.5 ppm, 7 sampling events in the 0.5 to 1.5 ppm, and 7 sampling events in the 0 to 0.5 ppm. Obviously when comparing this distribution of large bass fish to the smaller bass fish distribution, it is apparent that in general, the larger the weight of the bass, the greater the mercury concentration.

SUMMARY/CONCLUSIONS

The object of this report was to determine if the older and heavier bass had higher concentrations of mercury as reported in the literature. It can be concluded from our study, that in general, the larger the weight of the bass in a pond, the greater the chance of increased mercury concentration. The second object was to determine if there were

Figure 8: Large Bass (>3 lbs)

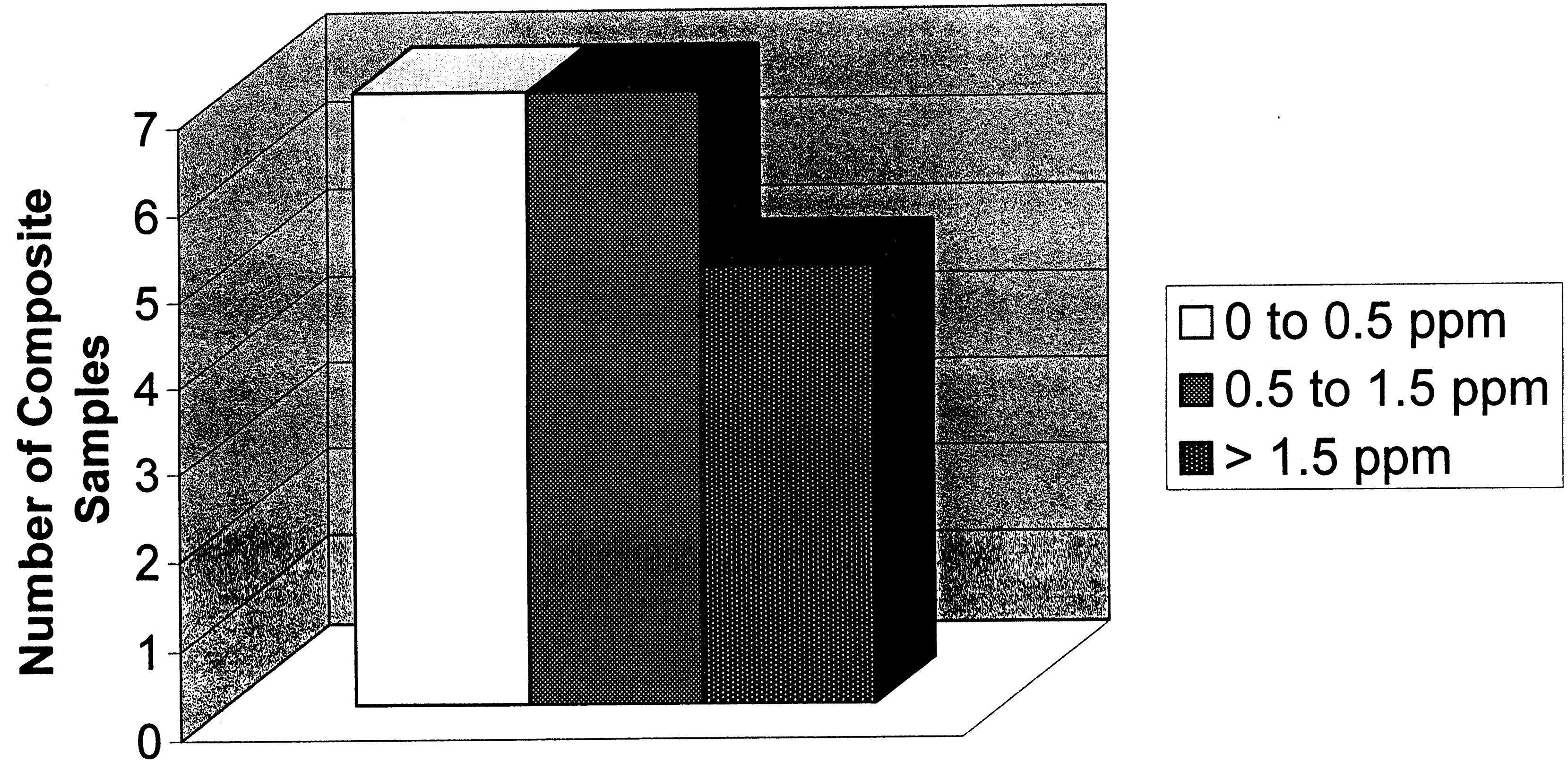
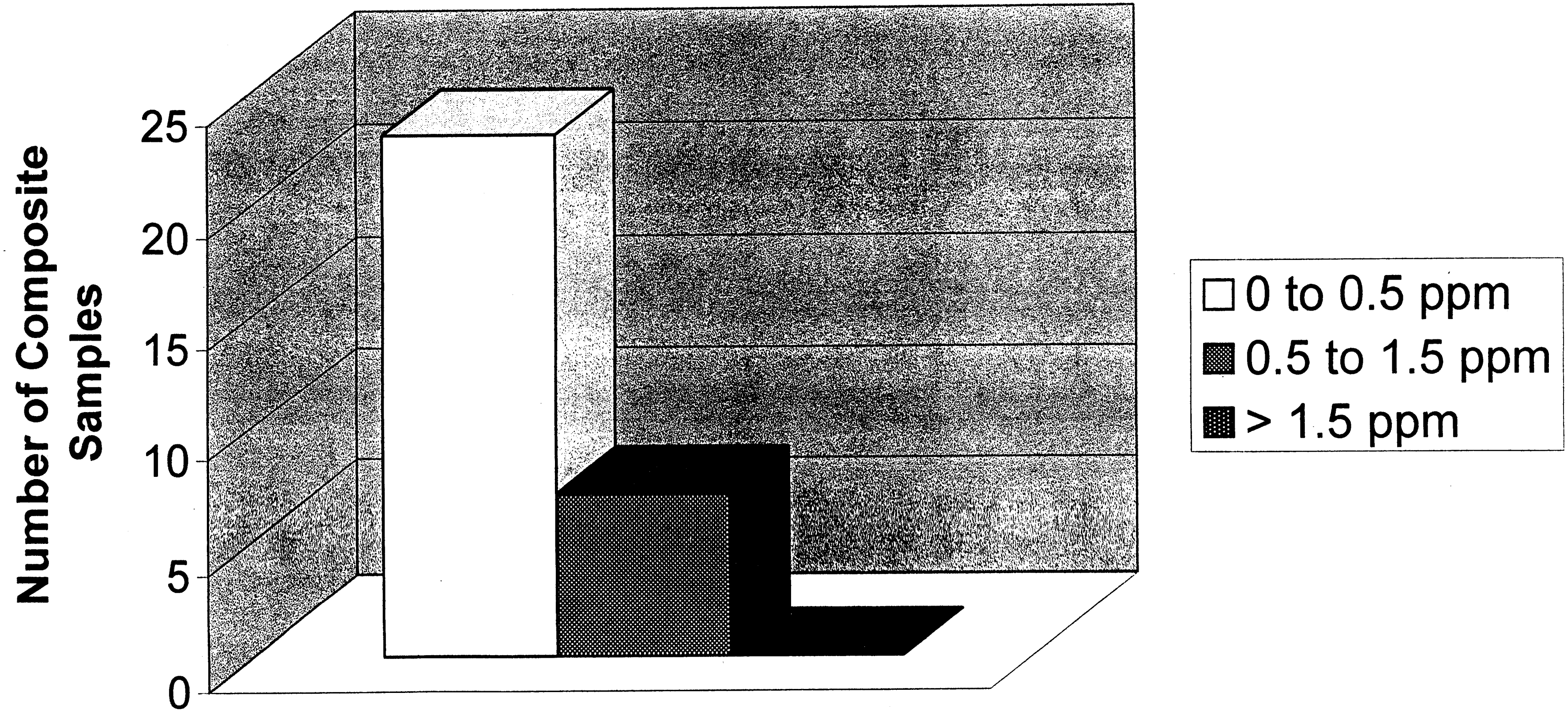


Figure 9: Small Bass (<3 lbs)



seasonal mercury changes in the bass. Due to the limited number of samples obtained from a particular pond within a year time frame, this could not be determined.

Additional studies are suggested where data is collected on a monthly basis at these four ponds and possibly additional ponds. With sufficient funding, a more thorough study is possible for each individual pond and with more manpower, the likelihood of catching large bass fish increases. In addition, more public awareness about the potential of consuming mercury in bass fish is needed as well as knowledge about the extent of mercury contamination in urban fish populations.

The problem of mercury in central Florida game fish will certainly rise if there is additional urban/agriculture runoff and increased global volcanic activity.

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A Survey of Freshwater Fishes in the Hydric Flatwoods of Flint Pen Strand, Lee County, Florida

David W. Ceilley, Restoration Ecologist
The Sanibel-Captiva Conservation Foundation, Inc.
P.O. Box 839 Sanibel, Florida 33957

Stephan A. Bortone, Ph.D., Director of Environmental Science
The Conservancy of Southwest Florida
1450 Merihue Dr., Naples, Florida 34102-3449

ABSTRACT

This study investigated the freshwater fish communities in three isolated, shallow-water hydric flatwood wetlands in the Flint Pen Strand in Lee Co., Florida using clear plastic fish traps (Breder, 1960) The study objectives were to determine fish community structure and evaluate the potential for using wetland fish communities and individual species as indicators of hydrologic alteration and water-level drawdown. Sampling was conducted during February, April, and September-October 1998 to assess seasonal fluctuations in water levels and fish populations and community structure. A total of six fish families, including nine genera, and at least 12 species (11 native fish species and one exotic cichlid) were collected using Breder Traps. The highest fish diversity (H'=1.542 and 1.414) was found in the slash pine dominated canopy that included scattered cypress. Predictive models using stepwise (interactive) multiple linear regression indicated that water depth, habitat type, and sediment type were closely associated with number of species, individual abundance, and species diversity. Several potential indicator species and assemblages were identified that may be useful in monitoring of wetlands for hydrologic disturbance (e.g., water-level drawdown). Study results indicate that hydric pine flatwoods are associated with the overall production and diversity of small forage fish species in Southwest Florida's forested wetlands. Due to their expansive shallow surface waters, it is likely that the hydric pine flatwoods will be the first areas to show biological evidence of water table drawdown. Due to the important linkage that wetland fish serve in the food web of South Florida ecosystems, we recommend that fish community monitoring be included as part of functional assessments and to provide the data necessary for planning future restoration initiatives in hydric flatwoods. Additional research is needed to fully understand: 1) the life history requirements of freshwater, wetland fish species, 2) responses wetland associated fishes make to water level manipulations, and 3) the tolerance that these have to acute and chronic anthropogenic disturbances.

INTRODUCTION

The water supply demands of rapidly increasing coastal populations and extensive agricultural operations in south Florida have challenged water resource managers responsible for maintaining healthy aquatic systems. The increased withdrawal of water from surficial aquifers and the alteration of natural sheet flow from development have direct and indirect effects on the hydrology of natural systems. Hydrology is probably the single most important determinant for establishment and maintenance of the specific types of wetlands and wetland processes yet the effects of hydrologic change or hydrologic disturbance on wetlands are subtle and complex, being influenced by both regional and local processes and impacts (Gosselink et al., 1994). Several authors discuss how hydrologic disturbance and water level drawdown can affect the vegetation changes in south Florida flatwoods marshes (Kushlan, 1990; Mortellaro et al., 1995; Gosselink et al., 1994). However, a great deal remains unknown about the biological communities of wetlands, especially hydric pine flatwoods of southwest Florida (Beever and Dryden, 1993).

Increasing or decreasing wetland hydroperiods and altering the timing of inundation can cause shifts or extirpation of breeding amphibians (Mazzotti et al., 1992). The management of water levels in marshes of the Everglades and Water Conservation Areas has been shown to cause rapid and dramatic changes in fish communities (Loftus and Eklund, 1994; Fury et al., 1995). Reductions in hydroperiods or lowering water tables in ephemeral systems could lead to the extirpation of fish and amphibians before any noticeable change in plant communities is observed. Freshwater fishes are important components of marsh systems, filling niches in the aquatic food web from primary consumers of vegetation and detritus through intermediate levels as predators on aquatic insects, crustaceans and other fish. Fishes, in turn, are prey for a myriad of predators and scavengers (Loftus and Ecklund, 1994). Main et al. (1997) recently described the following three major functional feeding groups and habitats of wetland fish species in the isolated wetlands of the South Florida Water Management District:

1. Small omnivorous fishes – shallow, ephemeral wetlands.
2. Small predatory fishes - wetlands with deepwater refugia.
3. Large predators and open-water fishes - semi-permanent, deepwater wetlands.

Functional feeding groups 1 and 2 include fish that have adapted to the relatively harsh extremes found in natural wetlands of south Florida. When these natural extremes are amplified by anthropogenic disturbances, we can expect to see shifts in fish community structure and possibly the loss of certain species. The loss of small fish and aquatic invertebrates from isolated wetlands will disrupt food chains and affect wading bird populations by reducing forage habitat. For example, the availability and quality of forage, primarily wetland fish and decapod crustaceans (crayfish and prawns), is the limiting factor for successful reproduction in several wading bird species, controlling both nest initiation and abandonment of wood storks and white ibis (Frederick and Spalding, 1994). The objectives of this study were: 1) to survey the fish community structure, species richness and abundance in three isolated hydric flatwood wetland systems using clear plastic fish traps (Breder, 1960) and; 2) to evaluate the potential of wetland fish communities, species assemblages and individual species as indicators of hydrologic disturbance in hydric flatwoods.

STUDY AREA

This study was conducted in Section 33, Township 46S and Range 26E, of Lee County, Florida (Figure 1). Section 33 is located at the northern tip of the Corkscrew Regional Ecosystem Watershed (CREW), a 60,000-acre conservation acquisition area in Lee and Collier Counties. The Lee County portion of CREW is known as the Flint Pen Strand and consists of approximately 15,000 acres. The Flint Pen area is a mosaic of open pine flatwoods, wet prairies, cypress domes and sloughs that was historically used to graze cattle. Habitats in Section 33 include cypress slough, cypress dome, hydric flatwoods, upland pine flatwoods, wet prairie, and flag pond marsh. Four of these cypress dome habitats were surveyed for fish (Main et al., 1997) and macroinvertebrates (Stansly et al., 1997) in 1996. Our study focused on three transects through the habitat gradients between the cypress domes/sloughs and the upland pine flatwoods. For the purposes of this study the habitat gradient is referred to as hydric flatwoods. This gradient consisted of cypress, *Taxodium ascendens*, with scattered slash pine, *Pinus elliottii* var. *densa*, on the deeper side near cypress domes, to pine-cypress mixed in the center, and pine-palmetto on the outer shallow wetland fringes.

MATERIALS AND METHODS

Shallow water habitats of three wetlands (FP6, FP7, and FP9) were quantitatively sampled using clear Plexiglas ™ fish traps (Breder, 1960). A Breder trap (Figure 2) consists of two parts, a rectangular funnel, which directs fish into the trap and a box (30 cm x 15 cm x 15 cm), where they are held until collection. Breder traps were selected for this study since they have been effective in shallow water wetlands with dense vegetation, are nondestructive (Main et al., 1997) and have the least amount of sampling bias when compared to other techniques (Sargent and Carlson, 1987).

Three distinct vegetation zones along a gradient were sampled simultaneously within each wetland (FP6, FP7, and FP9) using six traps in each zone. Vegetation zones, from deepest to shallowest, typically consisted of: (A) cypress dominated canopy with scattered pine; (B) slash pine with cypress mix and; (C or D) pine dominated with scattered cypress and/or saw palmetto. This stratified sampling technique was intended to characterize the fish communities of each major vegetative and water depth zone within the flatwoods adjacent to the previously surveyed cypress domes (Main et al., 1997).

Sampling within each zone was conducted within 10 meters of an arbitrarily selected center point, marked with a stake. Six Breder traps were evenly spaced inside this 10 meter circle in an effort to sample microhabitats within each zone. The funnel opening to each trap was placed toward open water to increase catch efficiency. Traps remained in the water for a period of 2 hours then retrieved. Sargent and Carlson (1987) conducted Breder trap "soak time" experiments in salt marsh and mangrove wetlands and suggested 2-3 hours "soak time" for best results. From our experience and from Main et al. (1997),

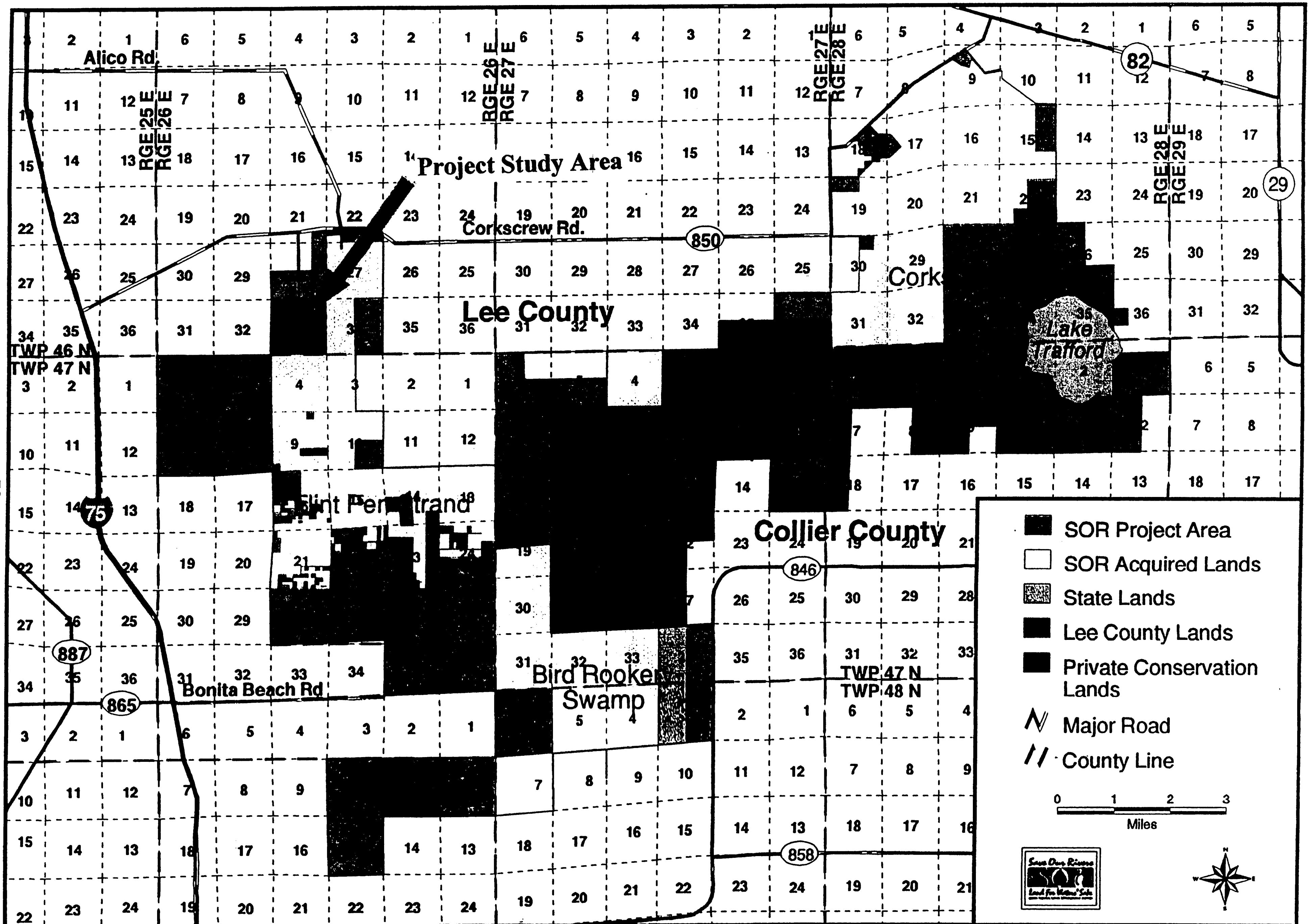


Figure 1. General location map of Section 33 study area (red) in the Flint Pen Strand portion of the Corkscrew Regional Ecosystem Watershed Boundary.

Drawn by P.S.Ellis - 05/29/98

2 hours is sufficient to obtain a representative sample in shallow, non-tidal freshwater marshes. All fish collected were identified to species level, enumerated and most were released. A small number (5-10) of each species were preserved in 10% formalin for voucher specimens and to identify stomach contents. This quantitative sampling was repeated three times during 1998.

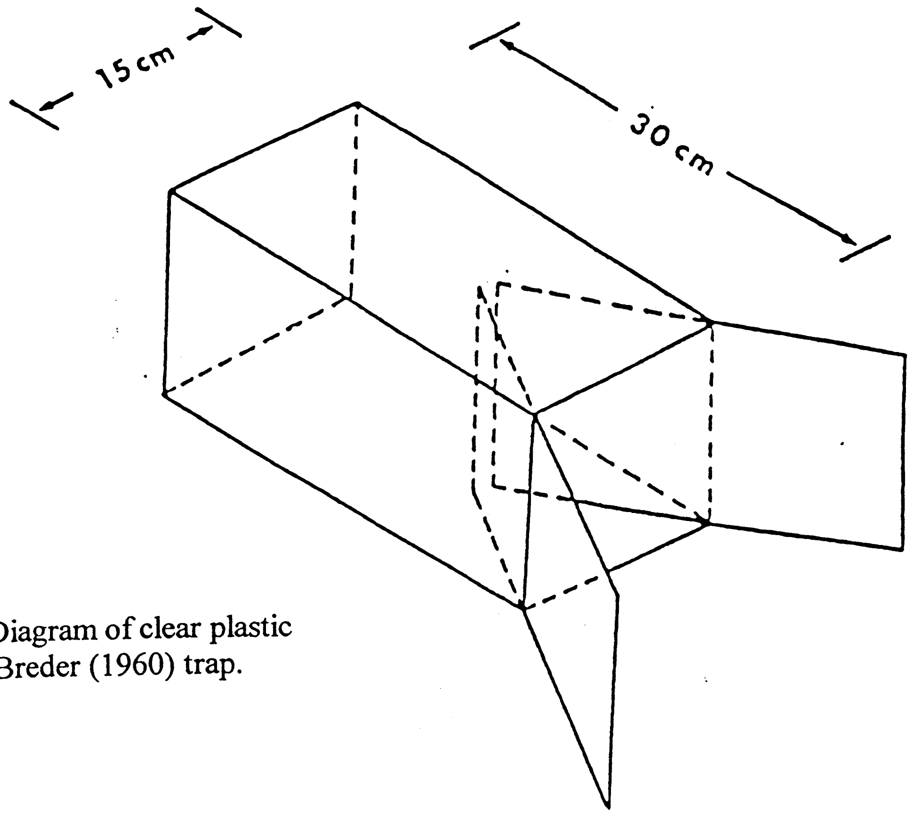


Figure 2. Diagram of clear plastic Breder (1960) trap.

Water quality sampling was conducted using a YSI™ model 57 dissolved oxygen meter and YSI™ model 33 SCT meter. Weather conditions, habitat type (vegetation), sediment type, water temperature, specific conductance, salinity, water depth and dissolved oxygen readings were collected from each sampling zone and recorded on the field data form prior to retrieving traps and were included in the statistical analysis.

Statistical and Graphical Analyses

Field data was entered into "Access 97"™ database management system, downloaded to "Excel" ™ spreadsheet for graphical presentation and statistical analysis using "SYSTAT"™. The six, two-hour Breder trap samples were composited for statistical analysis. Graphical presentation of data included cluster diagrams based on species abundance (standardized and non-standardized) using Pearson's Product Correlation Coefficient (PPC) matrix and Euclidean distance matrix. Both were clustered using Ward's (UPGMA) clustering algorithm. Principal Components Analysis (PCA) and

Common Factor Analysis (iterated principal axis), displaying the first three factor loadings based on species abundance, were graphed for visual interpretation. PCA of the independent variables based on species abundance was also graphed. PPC (r), multiple (interactive) stepwise regression (forward and backward), species diversity (H'), percent similarity, and Jaccard association index were methods used to analyze data in this study.

RESULTS

Unseasonable rainfall events late in 1997 resulted in an extended (or second) "wet season" within the same year. Sampling schedules were adjusted in order to collect fish during the "dry season", after the beginning of the "wet season", and following extended high water levels near the end of the "wet season". In this study, those sampling events were conducted in April, September, and February of 1998, respectively. According to hydrographs provided by the South Florida Water Management District and our field observations, when surface water levels dropped below 16.5 ft. NGVD, the hydric flatwoods were dry. Based on these data and observations the hydroperiod in the "hydric flatwoods" sampling sites ranged between 251 and 267 days during 1998.

Fish sampling began on 6 and 7 February 1998 after the study sites had been continuously flooded for approximately 70 days. During the 17-18 April 1998 sampling trip, water levels had receded and five of the sampling zones (FP6B, FP7B, FP7C, FP9B and FP9C) had no water at the surface to sample. Surface water data indicate that most (or all) sampling sites were dry or only saturated to ground level from late April through late July. The final round of quantitative Breder trap sampling was completed on 1 October, following approximately six weeks of water levels above 16.5 ft. NGVD.

Fish Sampling Results

A total of twelve fish species, representing six families were collected by Breder trap from three wetlands combined (Table 1). Small fish were easily collected, identified, enumerated, and released alive with minimal or no handling to cause stress or mortality. Total species, species richness, and abundance for each wetland zone are presented in Table 2. The most abundant fish was the eastern mosquitofish, *Gambusia holbrooki* (2021 individuals); collected at every site and during each sampling event. Also abundant and widely distributed were flagfish, *Jordanella floridae* (234), least killifish, *Heterandria formosa* (229), and golden topminnows, *Fundulus chrysotus* (184). Sailfin molly, *Poecilia latipinna* (102) were only found in abundance at FP9, with only 3 and 15 individuals collected from wetlands FP6 and FP7 respectively. Marsh killifish, *Fundulus confluentus* (45) were not abundant at any of the wetland sites. However, qualitative dip net sampling of roadway puddles near wetlands FP7 and FP9 produced large numbers of juvenile and adult marsh killifish as water levels dropped in April. Everglades pygmy sunfish, *Elassoma evergladei* (218), were found only at FP6 with the exception of one individual collected at FP7A. An isolated pool at FP6A was all that remained on 17 April 1998 for sampling. A total of 166 *E. evergladei* and 225 *G. holbrooki* were collected from six Breder traps with 82 *E. evergladei* and 73 *G. holbrooki* collected in a single trap.

Centrarchid sunfish species of the genus *Lepomis* were for the most part restricted to deeper water areas of FP7. The dollar sunfish, *Lepomis marginatus* (30), appeared to utilize shallow zones more than other sunfish species. The only non-native fish collected during the study was the black acara, *Cichlasoma bimaculatum* (3), and it was only collected at FP6. Black acara are generally found in deepwater wetlands, ponds and canals in south Florida. Black acara were collected from the cypress dome ponds near FP6 during this study and the study conducted by Main et al. (1997).

Table 1. Fish Species Collected by Breder Trap, Flint Pen Strand Wetland Sites.

Family	Scientific Name	Common Name
Cyprinodontidae		
Pupfishes	*Jordanella floridae*	flagfish
Fundulidae		
Topminnows	*Fundulus chrysotus*	golden topminnow
& Killifish	*Fundulus confluentus*	marsh killifish
	Lucania goodei	bluefin killifish
Poeciliidae		
Livebearers	*Gambusia holbrooki*	eastern mosquitofish
	Heterandria formosa	least killifish
	Poecilia latipinna	sailfin molly
Centrarchidae		
Sunfishes	*Lepomis gulosus*	warmouth
	Lepomis marginatus	dollar sunfish
	Lepomis punctatus	spotted sunfish
	Lepomis sp. (juvenile)	
Elassomatidae		
Pygmy sunfish	*Elassoma evergladei*	everglades pygmy sunfish
Cichlidae		
Cichlids	*Cichlasoma bimaculatum**	black acara

* = Non-native, introduced species

Fish species diversity was calculated using the natural logarithm of the Shannon diversity index (H') and based on species abundance in each sample by date and site. The diversity (H') values in this study were from 0.261 to 1.542. The highest H' values, 1.542 and 1.414 were at FP6B (8 species) and FP7C (7 species) on 30 September. The two sites with the highest fish diversity represent the middle and outer fringe of hydric pine flatwoods respectively. Both of these sites were completely dry during the April sampling event and were not re-flooded until approximately six weeks prior to the final sampling. Mean water depths at during this September sampling event were 16.8 cm (6.6 inches) and 9.8 cm (3.8 inches) for sites FP6B and FP7C respectively.

	Combined Fish Sampling Results by Site, Breder Trap								
	Wetland FP6			Wetland FP7			Wetland FP9		
Fish Species	**FP6A**	**FP6B**	**FP6D**	**FP7A**	**FP7B**	**FP7C**	**FP9A**	**FP9B**	**FP9C**
Jordanella floridae	14	25	28	33	12	40	23	28	31
Fundulus chrysotus	25	20	13	49	24	26	17	2	8
Fundulus confluentus			3	10	2	7	5	5	13
Lucania goodei				1					
Gambusia holbrooki	486	261	51	298	198	125	318	136	148
Heterandria formosa	66	28	18		8	20	25	44	20
Poecilia latipinna		1	2	6		9	10	55	19
Elassoma evergladei	166	1	50	1					
Lepomis gulosus				3		1	1	1	
Lepomis marginatus				18	11		1		
Lepomis punctatus			1						
Lepomis sp. (juv.)		1		3					
Cichlasoma bimaculatum		1	2						
Species Richness/Site	5	8	9	10	6	7	8	7	6
Total Species Richness	10			11			8		

Table 2. Summary of Breder Trap sampling results for Wetlands FP6, FP7 & FP9

Stepwise (interactive) multiple linear regressions were used to construct predictive models of a dependent variable (number of species, number of individuals, and species diversity) using one or more independent variables. Forward selection procedures indicated that about 24% (r^2=0.236) of the variance in the number of species collected at each site could be attributed to habitat type/vegetation. Specific conductance (12%), temperature (8%), sediment (4%), and dissolved oxygen (DO)(3%) appear to be less associated with the number of species collected, but when combined account for 51% of the variance in the predictive model of number of species. In a predictive model of number of individuals collected, water depth (r^2=0.178) combined with sediment, time of day, DO, and conductance explained approximately 50% (r^2=0.498) of the variance. In a predictive model of species diversity (H') sediment type (r^2=0.200), DO, water depth, time, and habitat type contributed to explaining about 38% (r^2=0.375) of the variance. The results of these regressions indicate that habitat type/vegetation, water depth, sediment type and to a lesser extent conductance are some primary factors that are associated with number of species, number of individuals, and species diversity.

The Pearson Product Correlation Coefficient (r) between all variables (both dependent and independent) is presented in the form of a matrix (Appendix). In this data set there are few strong associations as evidenced by this analysis, however, there are some notable exceptions. A high, positive correlation (r = 0.892) existed between the abundance of *Gambusia holbrooki* and the total number of individuals of all species. This is to be expected, as *G. holbrooki* was the most abundant fish present and clearly contributed to the total number of fish collected at each site. Between species there was high positive correlation (r = 0.703) between *Elassoma evergladei* and *Heterandria formosa*. This may reflect their similar habitat preference for waters containing dense vegetation. Several (weak) negative correlations were calculated between both *G. holbrooki* and *H. formosa,* and several other fish species abundance, most of which were sunfishes. This might indicate that *G. holbrooki* and *H. formosa* were often not present when other species were abundant due to predation. Similarly, it could indicate that the shallowest habitats were suitable for *G. holbrooki* and *H. formosa* but unsuitable for other species.

Graphical presentations of the data were used to help visualize associations between and among dependent and independent variables. Two-dimensional cluster analysis was used to help depict fish species and habitat attribute associations (Figure 2). A graph of Principal Components Analysis (PCA) using the first three factor loadings provides a three dimensional view that illustrates how the first three independent variables interact with or, are associated with, fish species abundance (Figure 3).

Lepomis marginatus, Lepomis gulosus, Lepomis sp. and *Lucania goodei* cluster together which is to be expected. *L. gulosus* and *L. marginatus* are the most common sunfish in freshwater wetlands of southwest Florida (Cox and Ceilley, 1995; Main et al., 1997). While only one *L. goodei* was collected in this study, Kushlan (1980) found in the Everglades that *L. goodei* populations increased along with several species of *Lepomis* during a period of extended high water. There is a close association between *Elassoma evergladei, Heterandria formosa, Gambusia holbrooki,* and *Fundulus chrysotus*.

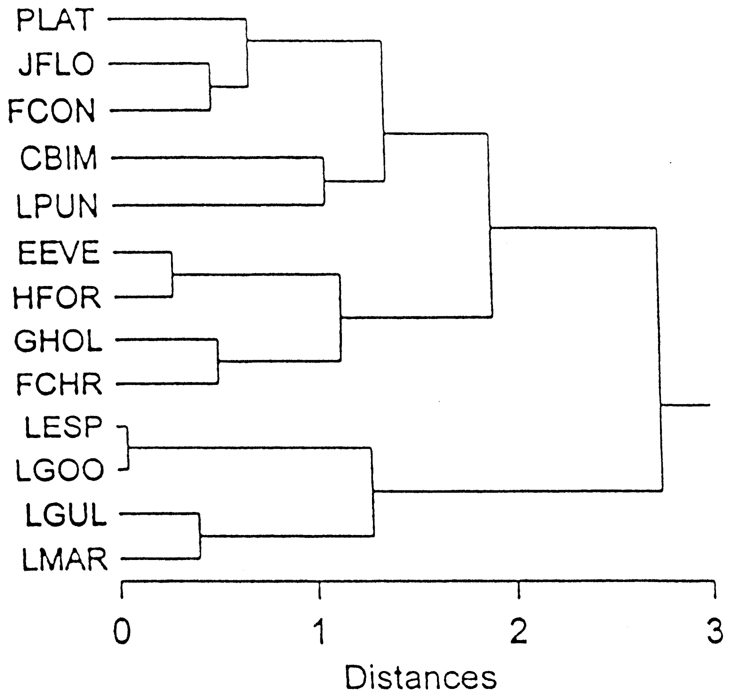
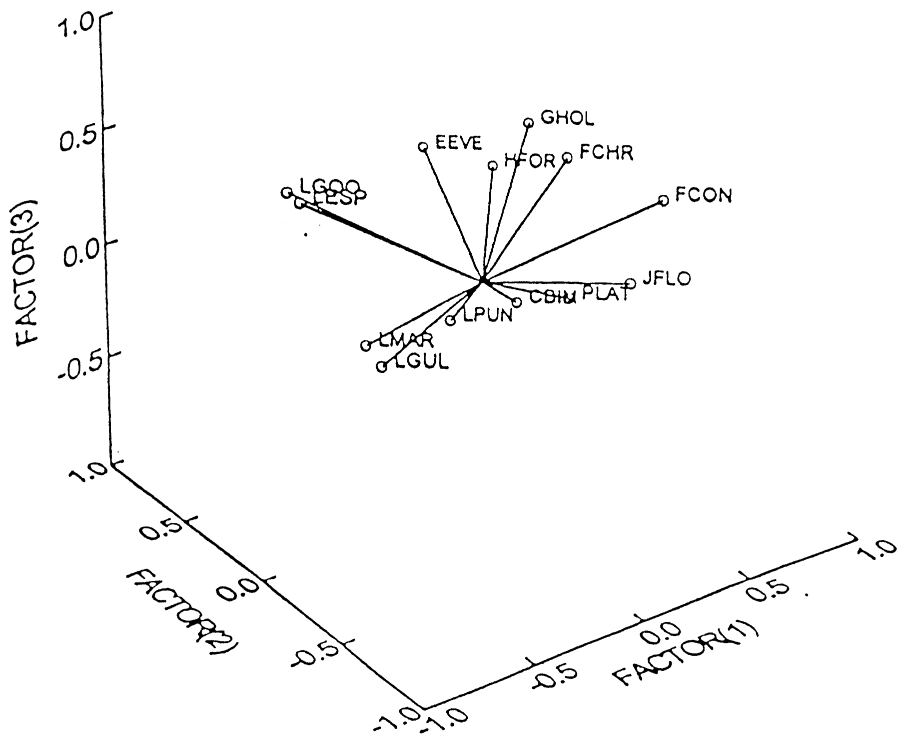


Figure 3. A species cluster diagram based on the standardized species abundance using the Pearson Product Correlation Coefficient matrix and using Ward's (UPGMA) clustering algorithm.

Figure 4. Factor Loading Plot using Principal Components Analysis based on species abundance displaying the first three factor loadings.



However, *E. evergladei* populations respond positively to extended periods of high water while *G. holbrooki, H. formosa*, and *F. chrysotus* typically decrease in number following such periods (Kushlan, 1980; Fury et al., 1995). The *G. holbrooki, H. formosa*, and *F. chrysotus* association is supported by observations in other areas of southwest Florida where these species dominate wetland fish collections (Cox and Ceilley, 1995: Main et al., 1997) along with *Jordanella* (Carlson and Duever, 1977). *Cichlasoma bimaculatum* and *Lepomis punctatus* are loosely associated with each other. Both species prefer deepwater habitats of ponds, canals or large marshes and are uncommon or rare in flatwoods. *C. bimaculatum* is an exotic species that is intolerant of cold water and therefore, limited in distribution to subtropical areas in Florida. *Poecilia latipinna* clustered closely with *Fundulus confluentus* and *Jordanella floridae*. This might be explained by the fact that *P. latipinna* and *F. confluentus* are eurihaline species, considered by some authors to be estuarine species (Dunson et al., 1997; Robins et al., 1986). *J. floridae* is primarily a freshwater pupfish species but enters brackish water (Page and Burr, 1991). In addition, *F. confluentus* and *J. floridae* both have eggs that can withstand some periods of desiccation or severely reduced moisture (Lee et al., 1980)

Water Quality

Water quality parameters measured in this study appeared to have little effect on fish species distribution or abundance. Specific conductance ranged broadly from 30 to 410 µS/cm between sites and seasons. Conductance was lowest during the February monitoring event after recent heavy rains when water levels were highest. Conductance was highest during the April event when receding water concentrated dissolved cations. Daytime dissolved oxygen (DO) concentrations ranged from 1.0 to 17.5 mg/l (supersaturated). DO concentrations were not correlated with fish species presence/absence or abundance. Surprisingly, low DO concentrations did not appear to effect survival of larger predatory sunfish; for example, warmouth (*Lepomis gulosus*) were collected from areas with the lowest DO concentrations.

DISCUSSION AND CONCLUSIONS

The distribution of fishes in aquatic environments in south Florida is dependent on several factors including water chemistry, protective cover, connectivity to other bodies of water, and hydrology (Carlson and Duever, 1977; Hoyer and Canfield, 1994; Kushlan, 1973; 1980; Dunson, 1997). In south Florida's isolated wetlands, hydrologic patterns are considered to be the most important factor influencing fish community composition (Main et al., 1997; Kushlan, 1980). Based on our observations and grab samples of water quality, water temperature and DO did not appear to limit species richness or abundance at any of the sites. Diurnal temperature and DO fluctuations are dramatic in these shallow wetlands, yet several small fishes thrive there. Water depth, hydroperiod duration, and connection to deep-water refugia appear to be more important in determining fish community structure. Each of these may be negatively affected by water table drawdown. Habitat type, water depth, sediment type, and specific conductance appeared to be the primary factors associated with species presence/absence, abundance and diversity in this study. Taken together, these independent variables are descriptive of ecological zones or microhabitats within the flatwoods complex that are directly influenced by hydrology, climate, and geology.

Cypress Domes and Hydric Flatwoods Fishes

Table 3 compares the fish communities found in the cypress domes (Main et al., 1997) with those collected in this study from the adjacent hydric flatwoods. None of the fishes from functional group 3 were collected from the flatwoods sampling sites while representatives of all three functional groups were collected from the adjacent cypress dome, FP6. This FP6 cypress dome contained a gator hole that contains water year round and apparently serves as a local dry season refugia for many fish species.

During the wet season hydric flatwoods wetlands were shallow (4-20cm deep) and broad, but contiguous with and surrounding much smaller and deeper (50-180± cm) cypress dome wetlands. The high diversity and abundance of fish collected from the shallow hydric pine flatwoods is somewhat surprising when compared to other wetland sites in the SFWMD. Overall fish species richness, family richness (Table 2), and diversity (H') were highest in the pine and mixed pine-cypress canopy habitats than in the deeper cypress dominated fringes sampled in this study. Generally speaking, the shallowest zones sampled contained a high proportion of small juveniles (especially *G. holbrooki, H. Formosa, J. floridae*, and *F. chrysotus*) and few mature adults while deeper zones contained mature adults and few small juveniles. This habitat partitioning by size may be a function of foraging, predation, predator avoidance, and reproductive strategies or most likely combinations thereof. Under normal hydrologic conditions, cypress domes and strands are not biologically isolated in terms of aquatic fauna from surrounding habitats especially the hydric flatwoods of south Florida. As water levels rise during the rainy season and hydric flatwoods re-flood, fishes migrate from dry season refugia into adjacent habitats. Kushlan (1980) stated that this movement probably represents spawning migrations for many species. In addition, certain species like the marsh killifish (*F. confluentus*) and flagfish (*J. floridae*) have unique reproductive strategies including egg stages that are adapted to survive some periods of desiccation (Harrington, 1959; Lee et al., 1980). This allows these species to re-colonize ephemeral wetlands or systems that experience dry periods then become re-hydrated during the rainy season. Additional research will be needed to determine the minimum hydroperiod required for survival or how long these eggs can survive in sediments without inundation.

The severance of this seasonal aquatic continuum near the cypress dominated edge by ditches and dikes, agriculture, and development disrupts the seasonal movement of several small fish species (functional groups 1 and 2) into the shallow flatwoods where many would normally live and propagate during much of the year. This results in the direct loss of important feeding, nesting, and nursery habitat for numerous native fishes. In addition, by confining small forage fish to deepwater zones (cypress domes) year-round we may expect increased mortality through predation by large piscivorous fish and other fauna.

	Functional Group	Cypress Domes*		Hydric Flatwoods		
Fish Species		**FP6**	**FP7**	**FP6**	**FP7**	**FP9**
Fundulus confluentus	1	X	X	X	X	X
Gambusia holbrooki	1	X	X	X	X	X
Heterandria formosa	1	X	X	X	X	X
Jordanella floridae	1	X	X	X	X	X
Poecilia latipinna	1	X	X	X	X	X
Enneacanthus gloriosus	2	X	X			
Elassoma evergladei	2	X	X	X	X	
Fundulus chrysotus	2	X	X	X	X	X
Lepomis gulosus	2	X	X		X	X
Lepomis marginatus	2	X			X	X
Lepomis punctatus	2			X		
Lepomis sp. (juv.)	2			X	X	
Lucania goodei	2	X	X		X	
Ameiurus nebulosus	3	X				
Labidesthes sicculus	3	X				
Lepisosteus platyrhincus	3	X				
Lepomis microlophus	3	X				
Cichlasoma bimaculatum	NA	X	X	X		
Species Richness	18	16	11	10	11	8
Functional Grps. Present	1,2,3	1,2,3	1,2	1,2	1,2	1,2

Table 3. A Comparison of Fish Collections from Cypress Domes* and adjacent Hydric Flatwoods in the Flint Pen Strand, Lee County, Florida.

Functional Feeding Groups and Associated Habitats*

1. Small omnivorous fishes – shallow, ephemeral wetlands.
2. Small predatory fishes – wetlands with deepwater refugia.
3. Large predators and open-water fishes – semi-permanent, deepwater wetlands.

* Main et al. (1997)

Potential Indicator Species

Assessing the fish community structure of wetland habitats is a cost-effective method of measuring functional attributes and may serve as a valuable tool for monitoring hydrologic alteration over time. Main et al. (1997) suggested using the "functional group" approach to evaluate hydrologic conditions of wetlands throughout the South Florida Water Management District. These functional groups are helpful for identifying general hydrologic conditions of wetland habitat types and gross changes in hydroperiods over time. For evaluating regional wetlands and specific habitat types (e.g. southwest Florida flatwoods) we recommend using individual fish species presence/absence, relative abundance, and community assemblages to detect more subtle changes in hydrology.

Fishes within a single functional group have a variety of adaptations and strategies to survive in the dynamic conditions of Florida's freshwater wetlands. With monitoring information on fish community structure, rainfall, topography, and climate these specific adaptations can be used by wetland scientists to evaluate hydrologic conditions and identify levels of disturbance.

Due to their unique life history requirements the following (common and widely distributed) species may serve as indicators of hydrologic conditions or disturbance in SW Florida wetlands:

1. The most abundant centrarchid in the hydric flatwoods was the dollar sunfish, *Lepomis marginatus*. Dollar sunfish have been observed constructing and defending nest sites in the slash pine-*Hypericum* zones of flatwoods during the wet season in southwest Florida (Ceilley and Cox, 1995). The dollar sunfish appeared to thrive in these shallow zones where no other *Lepomis* species are found. The use of shallow hydric pine flatwoods and wet prairies by dollar sunfish indicates that populations could be negatively affected by surface water drawdown especially if deepwater refugia nearby is also impacted by draw-down or contains high concentrations of other fish competitors and predators. The dollar sunfish, by virtue of it's preference for shallow wetland systems (Main et al., 1997; Fury et al., 1995; Kushlan and Lodge, 1974), wide distribution, and life history (Lee et al., 1980), may have value as an indicator of hydroperiod conditions in many southwest Florida wetlands (i.e., cypress domes with flatwoods).

2. The golden topminnow (*F. chrysotus*) and the marsh killifish (*F. confluentus*) have similar habitat requirements in terms of vegetation, water depth, and sediment and appear to prey on similar items (ostracods, dipterans, small snails). However, the reproductive strategies of these species are quite different. *F. chrysotus* requires permanent water to survive, lays eggs in submergent vegetation, and colonizes very shallow zones after inundation as they migrate out of deepwater refugia. Conversely, *F. confluentus* adults appear to breed in shallow water as water levels recede, laying eggs in muddy pools, with delayed hatching after the dry season as water levels rise. Excessive desiccation from drought or water table drawdown would likely inhibit reproductive success of *F. confluentus*.

3. Flagfish , *Jordanella floridae*, are endemic to peninsular Florida and seem to prefer heavily vegetated ephemeral waters (Lee et al., 1980). Their reproductive strategy is similar to that of *F. confluentus*. However, *F. confluentus* is mainly limited to the Everglades and freshwater and brackish coastal areas of Florida (Lee et al., 1980) while *J. floridae* is more widely distributed throughout Florida's freshwater wetlands and lakes with an affinity for alkaline, low nutrient waters with abundant vegetation (Hoyer and Canfield, 1994). In the wet prairie habitats of Corkscrew Swamp Sanctuary, Carlson and Duever (1977) found that *J. floridae* dominated collections (25-60% by number and 20-85% by weight). Both *F. confluentus* and *J. floridae* appear to have great potential as hydroperiod indicators due to their habitat preferences for shallow systems and reproductive strategies that are dependent on natural water cycles (i.e., seasonal flooding and drying of wetlands). Their reproductive success is directly affected by water level fluctuations that regulate both egg deposition and delayed hatching.

4. Everglades pygmy sunfish (*E. evergladei*), bluefin killifish (*Lucania goodei*), and warmouth (*Lepomis gulosus*) populations responded favorably to extended periods of high water in the Everglades water conservation areas indicating that they may prefer longer hydroperiods and higher water levels (Fury et al., 1995). This is supported by our observations and other wetland fish studies (Main et al., 1997). Together these species may serve as indicators of hydroperiod conditions in other wetlands of south Florida.

5. Eastern mosquitofish (G. holbrooki) is the most ubiquitous and abundant fish in south Florida wetlands. Mosquitofish may have value in evaluating hydroperiod condition since they tend to dominate collections, in terms of total numbers of fish collected, following periods of drought (Fury et al., 1995).

Additional investigation into the seasonal use of hydric pine flatwoods by small omnivorous fish species is warranted. In order to develop better predictive models we recommend larger quantitative samples be taken in the future. By evaluating wetland fish species presence/absence, overall diversity, and community structure, we should be able to detect subtle changes in hydroperiods rather quickly. Alternate seasons (or cycles) of flood and drought conditions are normal in the flatwoods and typically follow the summer/fall wet season and winter/spring dry season, respectively. In this relatively harsh environment for aquatic fauna, many fish species are adapted in a variety of ways to survive, and thrive under, these extremes. However, anthropogenic manipulations of hydroperiod cycles and resultant extremes of either flood or drought can exceed the tolerances of even these hardy fish species. Due to their expansive shallow surface waters, it is likely that the hydric flatwood habitats will be the first areas to show biological evidence of water table drawdown when it exceeds natural seasonal fluctuations. Fish species presence/absence and relative abundance (diversity) and community composition may therefore be an effective indicator of annual hydroperiod and whether or not conditions have been impaired or degraded to the point that wetland functions are lost (e.g. extirpation of species, disruption of food chains).

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APPENDIX
Statistical Tables & Matrices

Table 6. Summary of stepwise (interactive) multiple linear regression

Summary of Forward Selection Procedure for Dependent Variable: Number of Species (NO_SP)

Step	Variable Entered	Number In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	HAB_CODE	1	0.2356	0.2356	4.5437	6.1651	0.0220
2	CD	2	0.1198	0.3554	3.0116	3.5299	0.0757
3	T	3	0.0802	0.4356	2.6463	2.5576	0.1272
4	DO	4	0.0321	0.4677	3.6989	1.0259	0.3253
5	SED_CODE	5	0.0382	0.5059	4.5724	1.2369	0.2825

Summary of Forward Selection Procedure for Dependent Variable: Number of Individuals (NO_IN)

Step	Variable Entered	Number In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	WD	1	0.1780	0.1780	5.1843	4.3318	0.0505
2	SED_CODE	2	0.1458	0.3238	3.0727	4.0960	0.0573
3	ST	3	0.0642	0.3880	3.2627	1.8872	0.1864
4	DO	4	0.0851	0.4731	2.8629	2.7449	0.1159
5	CD	5	0.0245	0.4976	4.1720	0.7801	0.3902

Summary of Forward Selection Procedure for Dependent Variable: Species Diversity (H_PRI)

Step	Variable Entered	Number In	Partial R**2	Model R**2	C(p)	F	Prob>F
1	SED_CODE	1	0.2004	0.2004	0.0354	5.0110	0.0367
2	ST	2	0.0357	0.2361	1.2300	0.8881	0.3578
3	WD	3	0.0424	0.2784	2.2742	1.0572	0.3175
4	DO	4	0.0718	0.3503	2.6544	1.8791	0.1883
5	HAB_CODE	5	0.0249	0.3752	4.0923	0.6382	0.4360

Legend for Independent Variables

CD = Specific Conductance
DO = Dissolved Oxygen
HAB_CODE = Habitat Type/Dominant Vegetation
SED_CODE = Sediment Type
ST = Start Time
T = Temperature
WD = Water Depth

Pearson correlation matrix

	M	WD	DO	T	CD
M	1.000				
WD	0.216	1.000			
DO	-0.525	-0.284	1.000		
T	0.842	0.105	-0.199	1.000	
CD	0.279	-0.280	-0.324	0.002	1.000
NOSP	0.464	0.053	-0.155	0.397	0.208
NOIN	-0.229	-0.422	0.195	-0.070	0.023
H	0.080	-0.261	0.018	0.101	0.066
CBIM	0.320	-0.057	-0.114	0.539	-0.186
EEVE	-0.112	-0.150	-0.290	-0.045	-0.052
FCHR	0.015	-0.344	0.555	0.348	-0.084
FCON	-0.235	-0.527	0.506	-0.199	0.306
GHOL	-0.213	-0.310	0.323	-0.044	0.031
HFOR	-0.398	-0.453	-0.072	-0.405	-0.075
JFLO	0.223	-0.305	0.189	0.258	0.041
LESP	0.300	0.404	-0.220	0.246	-0.048
LGOO	0.234	0.401	-0.213	0.097	0.008
LGUL	0.245	0.455	-0.089	0.103	-0.074
LMAR	-0.200	0.501	0.196	-0.154	-0.137
LPUN	-0.088	0.302	-0.272	-0.160	-0.082
PLAT	0.146	-0.397	-0.008	-0.076	0.418
	NOSP	NOIN	H	CBIM	EEVE
NOSP	1.000				
NOIN	-0.343	1.000			
H	0.578	-0.219	1.000		
CBIM	0.303	-0.231	0.388	1.000	
EEVE	-0.230	0.667	0.056	-0.081	1.000
FCHR	0.191	0.526	0.092	0.128	0.229
FCON	0.210	0.200	0.237	-0.005	-0.187
GHOL	-0.437	0.892	-0.521	-0.287	0.326
HFOR	-0.278	0.641	0.236	-0.174	0.703
JFLO	0.542	-0.053	0.469	0.273	-0.317
LESP	0.421	-0.179	0.087	0.070	-0.076
LGOO	0.282	-0.125	-0.028	-0.065	-0.061
LGUL	0.231	-0.309	0.277	-0.151	-0.142
LMAR	-0.007	-0.236	0.154	-0.120	-0.112
LPUN	0.100	-0.175	-0.131	-0.065	0.234
PLAT	0.170	0.021	0.305	-0.111	-0.161
	FCHR	FCON	GHOL	HFOR	JFLO
FCHR	1.000				
FCON	0.469	1.000			
GHOL	0.480	0.198	1.000		
HFOR	0.020	0.028	0.337	1.000	
JFLO	0.216	0.492	-0.097	-0.082	1.000
LESP	-0.072	-0.191	-0.162	-0.169	-0.048
LGOO	-0.127	-0.149	-0.091	-0.146	-0.099
LGUL	-0.212	-0.290	-0.330	-0.258	0.044
LMAR	-0.093	-0.265	-0.211	-0.214	-0.241
LPUN	-0.151	-0.149	-0.286	-0.118	-0.126
PLAT	-0.156	0.298	-0.063	0.158	0.397
	LESP	LGOO	LGUL	LMAR	LPUN
LESP	1.000				
LGOO	0.947	1.000			
LGUL	0.249	0.295	1.000		
LMAR	0.196	0.233	0.591	1.000	
LPUN	-0.061	-0.048	-0.111	-0.087	1.000
PLAT	-0.154	-0.127	0.118	-0.228	-0.127
	PLAT				
PLAT	1.000				

Number of observations: 22

Pearson correlation matrix

	CBIM	EEVE	FCHR	FCON	GHOL
CBIM	1.000				
EEVE	-0.081	1.000			
FCHR	0.128	0.229	1.000		
FCON	-0.005	-0.187	0.469	1.000	
GHOL	-0.287	0.326	0.480	0.198	1.000
HFOR	-0.174	0.703	0.020	0.028	0.337
JFLO	0.273	-0.317	0.216	0.492	-0.097
LESP	0.070	-0.076	-0.072	-0.191	-0.162
LGOO	-0.065	-0.061	-0.127	-0.149	-0.091
LGUL	-0.151	-0.142	-0.212	-0.290	-0.330
LMAR	-0.120	-0.112	-0.093	-0.265	-0.211
LPUN	-0.065	0.234	-0.151	-0.149	-0.286
PLAT	-0.111	-0.161	-0.156	0.298	-0.063

	HFOR	JFLO	LESP	LGOO	LGUL
HFOR	1.000				
JFLO	-0.082	1.000			
LESP	-0.169	-0.048	1.000		
LGOO	-0.146	-0.099	0.947	1.000	
LGUL	-0.258	0.044	0.249	0.295	1.000
LMAR	-0.214	-0.241	0.196	0.233	0.591
LPUN	-0.118	-0.126	-0.061	-0.048	-0.111
PLAT	0.158	0.397	-0.154	-0.127	0.118

	LMAR	LPUN	PLAT
LMAR	1.000		
LPUN	-0.087	1.000	
PLAT	-0.228	-0.127	1.000

Number of observations: 22

Appendix 3 Legend for Abbreviations

Fish Species Codes

CBIM = *Cichlasoma bimaculatum*
EEVE = *Elassoma evergladei*
FCHR = *Fundulus chrysotus*
FCON = *Fundulus confluentus*
GHOL = *Gambusia holbrooki*
HFOR = *Heterandria formosa*
JFLO = *Jordanella floridae*
LESP = *Lepomis sp. (juv.)*
LGOO = *Lucania goodei*
LGUL = *Lepomis gulosus*
LMAR = *Lepomis marginatus*
LPUN = *Lepomis punctatus*
PLAT = *Poecilia latipinna*

Independent Variables

M = Date
WD = Water Depth
DO = Dissolved Oxygen
T = Temperature
CD = Specific Conductance

Dependent Variables

NOSP = Number of Species
NOIN = Number of Individuals
H = Species Diversity

DESIGN AND CONSTRUCTION OF A FLOATING LIVING MACHINE

Peter Yaron, Michael Walsh, Chris Sazama, Ryan Bozek, Christine Burdette, Alex Farrand, Chris King, Jay Vignola and Patrick Kangas

Natural Resources Management Program
University of Maryland
College Park, Maryland 20742-2315

ABSTRACT

A number of different types of ecosystems have been created for wastewater treatment including microbial reactors, algal tanks and scrubbers and constructed wetlands. Treatment is performed by these ecosystems through physical/chemical processes such as soil absorption and through metabolic processes such as denitrification. A set of constructed ecosystems that is connected in a sequence to provide treatment of a waste stream that flows through it is sometimes referred to as a living machine. In this presentation the design of a floating living machine is described as the product of an educational experience by a group of senior-level university students. It is an example of the lake restorer living machine concept, developed by John Todd, which improves water quality of a pond or lake by the continuous pumping of water through the system. Our lake restorer consists of a set of five different ecosystems in plastic containers that are connected together on a raft with dimensions of 1.7 meters (5 1/2 feet) by 2.3 meters (8 feet). Biofilms on three kinds of substrates along with cells of emergent and floating-leaved wetland plants are included. The system has been tested on a stormwater retention pond at the University of Maryland campus. Water is pumped onto the raft and then moves by gravity flow through the series of ecosystems to the end of the raft where it is discharged back to the pond. Power for the pump is provided by a solar panel mounted on the raft so that the system can operate remotely with minimal human maintenance. The system is constructed of locally available materials and the total cost is about $820. Design issues and progress are described along with aspects of the educational value of the experience.

INTRODUCTION

There is a continuing need for new wastewater treatment technologies in order to handle increasing loading rates and to improve environmental quality. Ecological engineering is a relatively new approach to developing these technologies that combines conventional engineering and living ecosystems (Mitsch 1996). The best examples of ecologically engineered wastewater treatment systems are probably treatment wetlands (Kadlec and Knight 1996, Campbell and Ogden 1999), which number in the thousands across the United States and in European countries. However, other examples are being studied and implemented including various biofilter ecosystems along with algal-based systems and others that incorporate soil beds and higher plants. Sometimes these technologies are called living machines due to their hybrid nature.

A whole new approach to design is required for ecologically engineered technologies because they combine living and non-living components. Clearly, traditional engineering problem solving is required but the ecological side of the systems creates additional design problems. These interdisciplinary challenges make ecological engineering an exciting field.

Because it is a new approach, few universities are offering coursework or curricula in ecological engineering. Much trial-and-error type testing is being done, which is probably appropriate for the current state of the art of the development of both technologies and educational programs. The purpose of this study is to describe a senior-level capstone course for undergraduate students who designed, built and operated a living machine treatment system. This kind of course represents one approach to design education in ecological engineering, which can be used as a model for constructive criticism and further improvements.

The Living Machine Concept

Living Machines are a set of patented and trademarked ecologically engineered technologies developed by John Todd (1991). Although these systems are usually employed for wastewater treatment, they potentially can support other functions such as production of food and biomass fuels. The living machines developed by Todd represent a high level of ecological engineering design because of the intimate connections and balance between the living and non-living parts of the systems. A number of these systems have been built and operated and principles for their design have been developed (Todd and Josephson 1996). Todd is one of the pioneers of the field and the record of his experiences in developing the living machine concept (Todd and Todd 1994) is a valuable resource for ecological engineering education.

Todd's living machines evolved from his work with sustainable aquaculture and the design of multifunctional architectural structures, called "arks". The concept involves constructing a sequence of tanks through which wastewater passes. Each tank in the sequence is designed to contain a different kind of ecosystem that contributes to the overall treatment process. In this way the separate tanks correspond to the unit processes in a conventional wastewater treatment plant, though in the living machine they are multifunctional. The ecosystems are developed by multiple seeding techniques so that they self-design a species composition matched to the water chemistry of the wastewater stream at any point in the treatment sequence. Conventional engineering design comes into play in various ways such as the sizing of the pumps and tanks and in the choice of materials of the structure. Thus, the overall system is a hybrid of ecology and engineering.

The University of Maryland Lake Restorer Project

As an educational project, a special type of living machine was designed and built by a group of undergraduate students from the University of Maryland at College Park (UMCP). The intention was to provide the students with an ecological engineering experience by drawing on the published work about the living machine concept. The project was initiated as a formal course, NRMT 470, which is the senior capstone course within the Natural Resources Management Program at UMCP. All of the students who participated are listed as co-authors on this manuscript. The course took place during Fall Semester in 1999. Three students (the first co-authors) continued the work as an independent study course (NRMT 489) during Spring Semester in 2000.

The decision was made to construct a "lake restorer" living machine. This is a living machine that floats on a raft on a water body and acts to improved water quality by re-circulating water through the system. Students read relevant literature from Todd's group (Boylan 1998, Graziano 1998, Josephson 1995, Josephson 1996, Todd 1996, Todd et al. 1997) as part of the required coursework and developed a design based on this information. To facilitate the work, the lake restorer was designed to operate on a stormwater management pond on the UMCP campus. This is a 1/2-acre pond whose volume varies with stormwater inputs. The project's lake restorer was therefore sized with dimensions in relation to this pond.

Figures 1 through 3 show the design for the lake restorer including dimensions, substrates and plumbing arrangements. Plastic and PVC parts were used as much as possible to keep the overall weight low and to minimize corrosion that might occur from the use of metals. Adequate floatation is critical for the function of the lake restorer, since it must float on the water surface. A 3" PVC frame was attached to the underside of the circumference of the lake restorer to provide buoyancy along with additional foam floats, which were attached between the cells. The frame was constructed by using 1 1/2" schedule 40 PVC tubing and it was partitioned into ten cells. A 24-Volt DC pump and a 22-watt solar panel (Sunmotor International Ltd.) provided power for the lake restorer. The pump is capable of producing a flow rate of four gallons per minute with a lift of two feet. The solar panel was mounted on a pressure treated wood frame that was securely mounted on to the PVC. The solar pump was submerged in a 5-gallon bucket that contained 3 rows of 1/2" diameter holes with screening, to ensure that the pump would not get clogged or damaged by debris in the water.

The philosophical basis of the ecological side of the design was to incorporate many microhabitats, which would support a wide variety of biodiversity to be involved in the water treatment process. These are contained in cells which are plastic containers that are placed within the frame of the lake restorer raft. The first three cells are filled with different media that provide surfaces for biofilms of bacteria and other microbes: Cell #2 contains pumice rocks and broken concrete approximately 2" diameter, Cell #3 contains shredded milk cartons and rings cut from PVC tubing, and Cell #4 contains oyster shell. The microbial metabolism of the biofilms mediates various chemical reactions that transform nutrients and other compounds in the water flowing through the lake restorer to

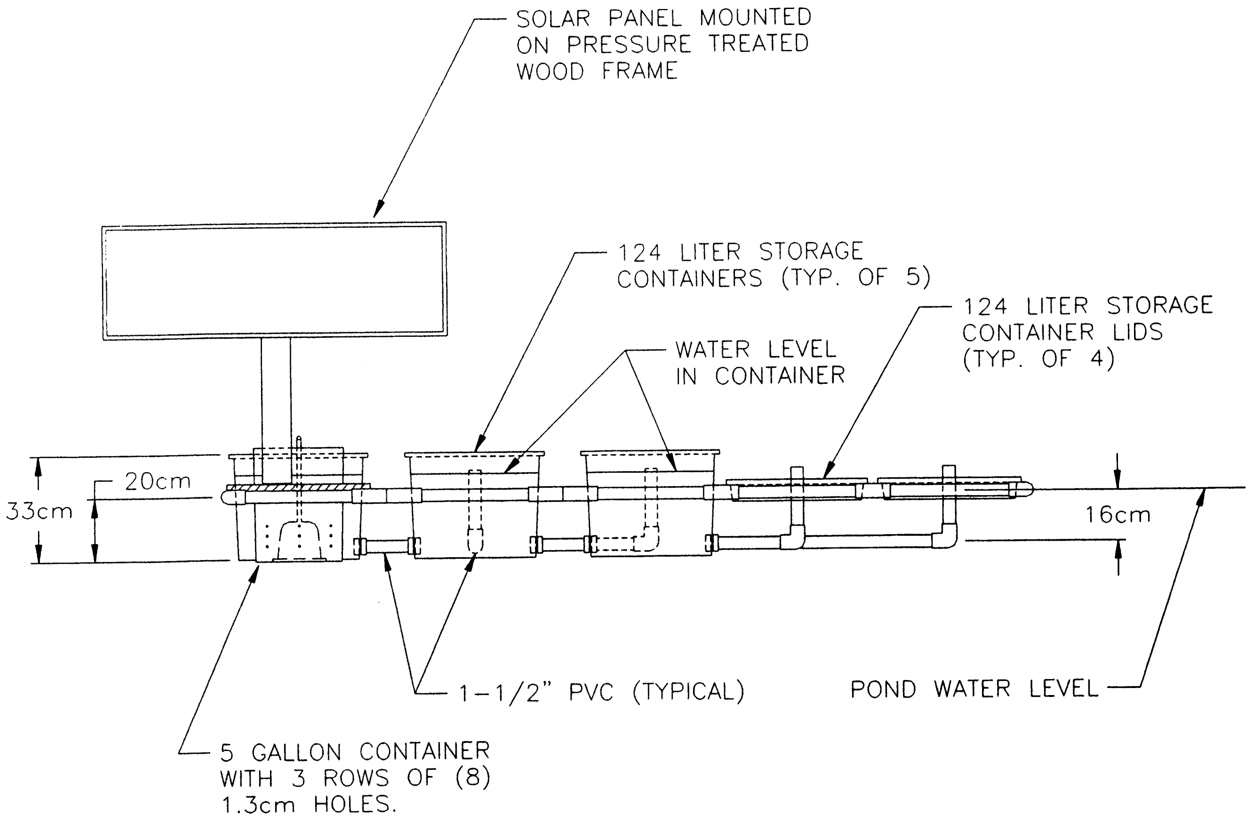

Figure 1. Side view of the Lake Restorer

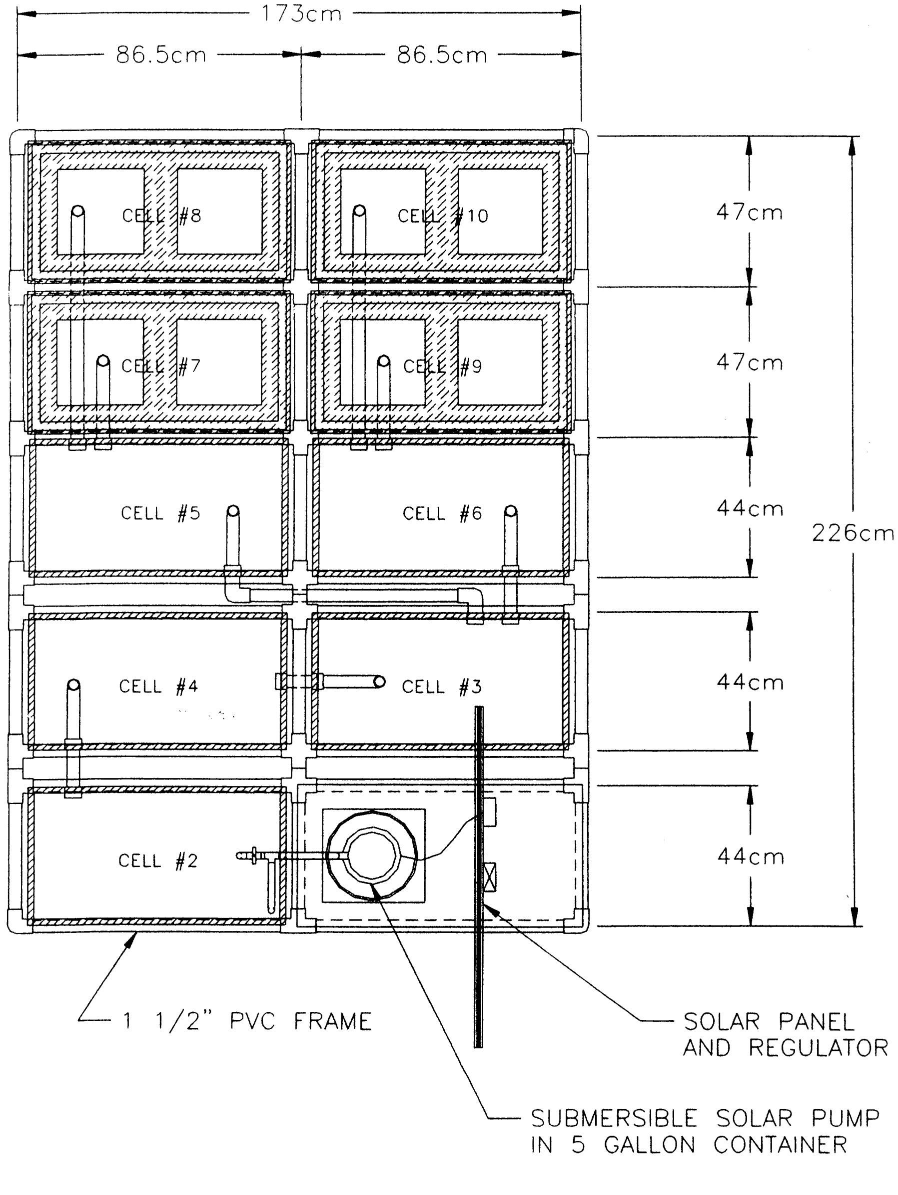

Figure 2. Plan view of the Lake Restorer

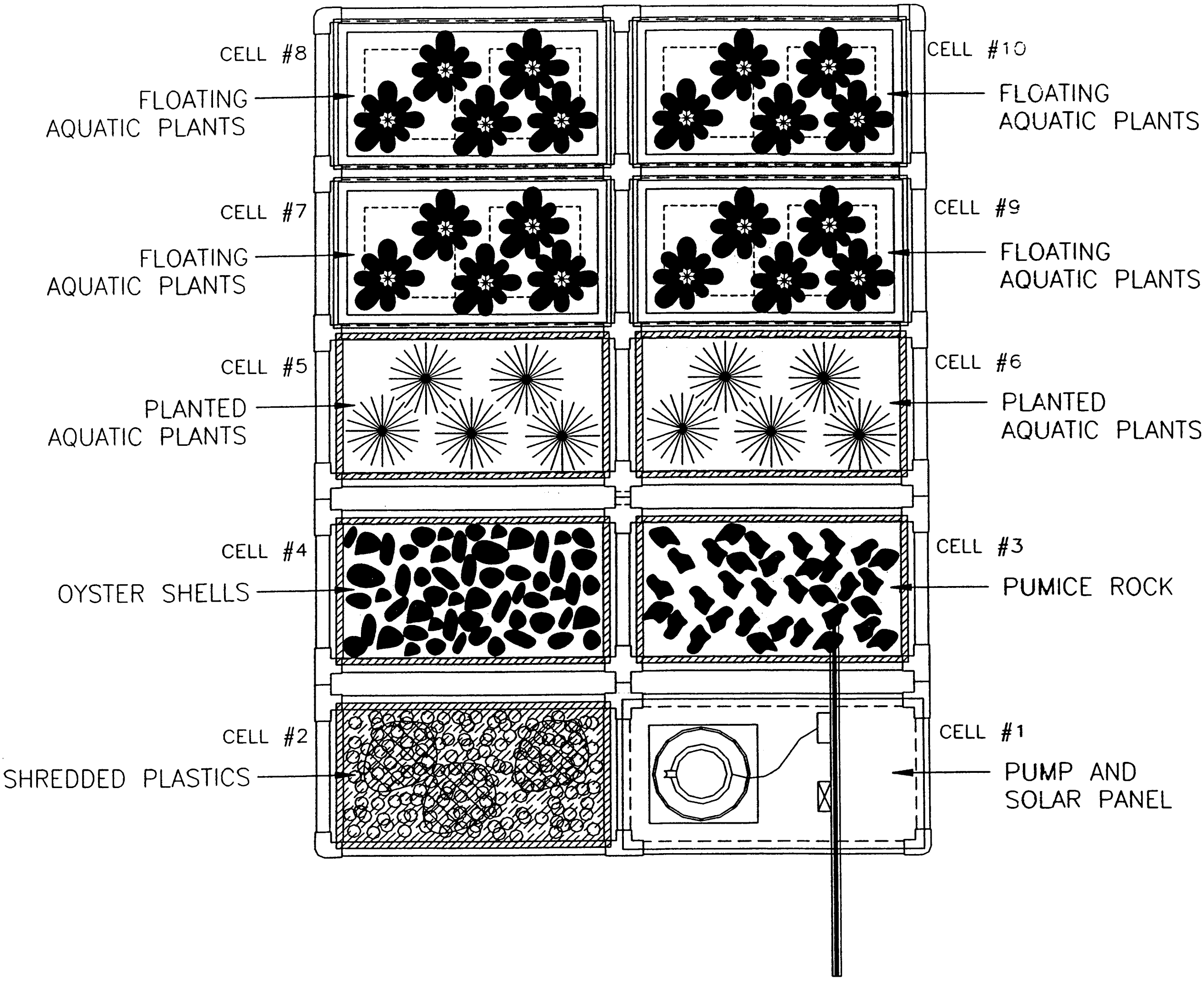

Figure 3. Layout of cells within the Lake Restorer

Table 1. Weights of components of the lake restorer living machine. Re-design between Fall 1999 and Spring 2000 provided a weight reduction that improved buoyancy and stability of the system.

component	Fall 1999 Weight Kilograms (lbs.)	Spring 2000 Weight Kilograms (lbs.)
oyster shell	21.26 (46.87)	21.26 (46.87)
pumice and concrete fragments	33.50 (73.85)	14.04 (30.95)
cut PVC rings	3.62 (7.98)	5.31 (11.71)
shredded plastic milk containers	1.04 (2.29)	0.69 (1.52)
pea gravel	46.74 (103.04)	0
herbaceous plants	29.95 (66.03)	30.50 (67.24)
frame with containers and piping	42.28 (93.21)	42.28 (93.21)
wood brackets	0	3.08 (6.79)
styrafoam ballast	2.86 (6.31)	0
4" PVC ballast	7.36 (16.23)	7.36 (16.23)
wood stand	7.23 (15.94)	7.23 (15.94)
solar panel and pump	7.07 (15.59)	7.07 (15.59)
pump bucket	1.05 (2.32)	1.05 (2.32)
TOTAL	203.96 (449.66)	139.87 (308.37)

provide treatment functions. Higher aquatic plants are maintained in the remaining cells of the lake restorer. Cells #5 and #6 are planted with emergent wetland plants (including *Typha sp.*, *Pontederia cordata*, *Peltandra sp.* and *Juncus effusus*) while Cells #7- #10 contain floating plants (*Eichhornia crassipes*). These plants facilitate the treatment process directly through uptake of nutrients and other elements and indirectly through metabolism by the bioflims attached on their roots.

All water flow connections between the cells were made with 1 1/2" PVC tubing and gasketed with rubber washers to minimize leakage. The placement of the openings of the pipes allowed for a slow gravity flow throughout the lake restorer once water is pumped up on to the raft. The intention was to maintain a flow rate of about 1 to 2 gallons per minute during daylight hours.

The system was initially completed and operated on the stormwater pond in November-December 1999. During this period problems with the original design were identified which included the total weight of the system and its distribution on the raft. These problems were addressed during a re-design phase in Spring 2000 when the system was removed from the pond and modified. The system was operated on the pond again in April-June 2000 with improved floatation and stability. The re-design effort reduced the total weight of the system by more than 30% (Table 1).

Total cost of the system was about $820 (Table 2). The cost of the solar pump ($400.00) dominated the total cost, followed by the emergent plants which were purchased both in the Fall and the Spring. The system took approximately two full work weeks to design and to build, spread out over two semesters. This time period included modifications and improvements to the design, as the lake restorer was being assembled in the Fall and re-assembled in the Spring. Only hand tools were used in construction, such as screwdriver, hacksaw, utility knife, tape measure and keyhole saw, and all materials, except for the solar panel, were purchased from local hardware supply stores.

CONCLUSIONS

The undergraduate courses described in this paper were successful in terms of designing and building a floating living machine. The system that was constructed appeared to function properly based on the vigorous growth of the plants and biofilms on substrates, especially during Spring 2000. Much learning took place because of the goal-oriented, hands-on approach of the courses. One important lesson that emerged from the experience was the iterative nature of the design process. While the original design was improved in terms of weight reduction, further refinements were envisioned such as testing of different geometric forms of the raft for weight redistribution and modification of the solar pump to minimize clogging.

Unfortunately, it was not possible to make measures of system performance due to time constraints of the courses. Some preliminary water quality measurements were made in the stormwater management pond during this study but there was not sufficient time to

Table 2. Costs of components and parts of the lake restorer.

component or part	quantity (no. of items)	unit cost ($/item)	total ($)
32 gallon tupperware containers	3	17.00	51.00
32 gallon tupperware containers	2	19.99	39.98
1 ½" PVC	10	2.29	22.29
4-way 1 1/2" PVC joints	8	2.88	23.04
PVC elbows	13	0.66	8.58
1 ½" PVC T-joints	12	1.13	13.56
4-way 1 ½" PVC joints	2	2.88	5.76
PVC plug	2	0.44	0.88
4" PVC elbows	2	1.97	3.94
4" PVC	3	3.47	10.41
PVC drain cap	4	0.94	3.76
PVC plug	2	0.44	0.88
PVC primer	2	1.97	3.94
PVC cement	1	3.41	3.41
Marine goop	3	4.97	14.91
Screws	1	3.69	3.69
Adapter	12	0.69	8.28
Adapter	20	0.59	11.80
Ties	3	3.96	11.88
Ties	3	4.47	13.41
Valve	1	6.96	6.96
Plants	63	1.60	100.80
Pond plant pp-1699	3	8.49	25.47
Pond plant pp-399	4	1.99	4.99
Pond plant pp-999	2	4.99	9.98
Fitting	3	2.42	7.26
Sheeting	6	0.91	5.46
Solar pump	1	400.00	400.00
	TOTAL		816.32

record changes due to the operation of the lake restorer. Based on the results of John Todd's work, reductions in nutrient concentrations, increased water clarity and other improvements can be expected from the continuous actions of the lake restorer living machines. Some maintenance is required, but to a large extent, these kinds of systems can operate remotely due to their use of renewable power sources. Results of this study demonstrate that a basic lake restorer living machine can be relatively inexpensive to construct, which may facilitate future testing and implementation of this interesting example of ecologically engineered technology.

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MOIST-SOIL IMPOUNDMENTS FOR WETLAND WILDLIFE

John J. Lane, Tennessee Technological University

Kent C. Jensen, ERDC

ABSTRACT

The term and concept of "moist-soil" plant production, introduced by Frank Bellrose in the 1940s, refers to plant species that grow on exposed mud flats after surface water retreats in spring or summer. The purpose of moist-soil management has been to increase wetland productivity and waterfowl use on migrating and wintering grounds. The current goal of wildlife managers utilizing moist-soil techniques is to maximize production of naturally occurring wetland vegetation in order to optimize use of wetland habitats by wildlife. Moist-soil management promotes the production of naturally occurring wetland vegetation by emulating and manipulating natural wetland functions (e.g., hydrology and successional stage).

In the United States, moist-soil management procedures have been most widely applied to waterfowl management in areas of migrational and wintering habitat. Although moist-soil management technology was initially developed and extensively tested in the upper Midwest and Mississippi Alluvial Valley, the practice has potential application in other areas. Moist-soil management is used to some extent throughout the Southeast, including portions of Georgia, and the Chesapeake Bay and North Carolina sounds region. Various levels of moist-soil management have also been applied in the western states, including the Southern High Plains of Texas.

INTRODUCTION

As wetland acreage continues to decline in the conterminous United States (Dahl 1990), intensive management of remaining habitat to meet the biological needs of wetland wildlife (especially waterfowl) has become increasingly important (Reid et al. 1989). Changes in policy emphasis, such as management of nongame wildlife species, natural habitats, and biodiversity also confront wildlife managers (Faaborg 1986, Fredrickson and Reid 1986, Sweeny and Henderson 1986). Budgetary constraints continue to increase, thus demanding that managers gain the greatest benefit for the least expenditure (Mangun 1986). Moist-soil management provides managers with a mechanism to meet these challenges. The term and concept of "moist-soil" plant production, introduced by Frank Bellrose in the 1940s, refers to plant species that grow on exposed mud flats after surface water retreats in spring or summer (Fredrickson and Taylor 1982). Bellrose observed that waterfowl often concentrated on these sites and consumed natural foods. The purpose of moist-soil management has been to increase wetland productivity and waterfowl use on migrating and wintering grounds (McEwan 1979, Fredrickson and Taylor 1982, Bolen et al. 1989, Kadlec and Smith 1989). The current goal of wildlife managers utilizing moist-soil techniques is to maximize production of naturally occurring wetland vegetation in order to optimize use of wetland habitats by wildlife. Moist-soil management promotes the production of naturally occurring wetland vegetation by emulating and manipulating natural wetland functions (e.g., hydrology and successional stage).

Study Sites

Managed moist-soil habitats are shallow-water areas impounded by levees, which contain water-control structures that enable flooding during fall and winter and dewatering during spring and summer. Flooding provides foraging habitat and cover for diverse communities of migrating and wintering waterfowl and other waterbirds (Fredrickson and Taylor 1982, Reid 1989, Reid et al. 1989, Reinecke et al. 1989). Drawdowns (dewatering to mud flat conditions) promote germination and growth of plants adapted to moist or shallowly flooded sites (Low and Bellrose 1944, Fredrickson and Taylor 1982). These plants produce rich food sources of aquatic invertebrates, seeds, tubers, and browse for waterfowl, shorebirds, other waterbirds, and some upland wildlife (Reid 1983, Reinecke et al. 1989, Krapu and Reinecke 1992). Although moist-soil management is most often applied to man-made impoundments (Fredrickson and Taylor 1982), natural wetlands with modified hydrology or degraded habitats can be enhanced, and value for wildlife can be increased by utilizing moist-soil management techniques (Reid et al. 1989). Sites too wet for consistent production of row crops or establishment of upland vegetation, yet too dry for the management of aquatic plants, are especially well-suited for development of moist-soil impoundments (Fredrickson and Taylor 1982). From 1968 to 1982, the concepts and techniques of moist-soil management were developed at Mingo National Wildlife Refuge in southeastern Missouri and published by Fredrickson and Taylor (1982). The information in this report has been drawn predominantly from their work, with the integration of additional findings since 1982.

MATERIALS AND METHODS

Wetland hydrology is usually controlled by constructed water delivery, control, and discharge systems. The successional stage of an area is manipulated by soil or vegetative disturbances or prolonged inundation. Vegetative composition and density of a moist-soil site are influenced by altering the timing and duration of drawdowns and stage of succession. To maximize habitat availability and utilization, depth and timing of flooding are manipulated according to the habitat requirements and migration or breeding phenology of wildlife species (Fredrickson and Taylor 1982). Through precise control of hydrology and manipulation of plant succession, wildlife managers can achieve desired plant communities and provide habitat requirements for a variety of wildlife species throughout their annual cycles.

Moist-soil management techniques provide a mechanism for enhancement of established wetlands, restoration of former wetlands, and creation of new wetland habitat. Enhancement of wetlands occurs in areas where hydrology and habitat have been degraded and active management is required to renew wetland functions and improve value as wildlife habitat. Areas where wetlands previously existed are often unproductive for alternative land uses because of altered hydrology but are well-suited for restoration. Creating wetlands where none previously existed helps offset wetland habitat losses (Weller 1990).

Moist-soil management contributes to increasing and maintaining the biodiversity of an area. Moist-soil impoundments more closely resemble natural habitats and provide required habitat parameters for a larger variety of game and nongame wildlife species than monotypic agricultural row crops (Taylor 1977, Rundle and Fredrickson 1981, Fredrickson and Taylor 1982, Fredrickson and Reid 1986).

RESULTS

Over 80 percent more species have been found to occur in moist-soil impoundments than in adjacent row crops and include invertebrates, herpetofauna (amphibians and reptiles), prairie and marsh passerines (small- to medium-sized perching birds), shorebirds, wading birds, waterfowl, gallinaceous birds (e.g., pheasants, wild turkeys), raptors, and mammals (Table 1) (Fredrickson and Taylor 1982). Fredrickson and Reid (1986) observed >150 avian species on moist-soil impoundments on the Ted Shanks Wildlife Area and Mingo National Wildlife Refuge, Missouri. Areas managed for upland wildlife attract ring-necked pheasants, wild turkeys, and northern bobwhites, which use the sites for brooding and feeding. White-tailed deer forage in moist-soil habitats and use areas of abundant, dense vegetation as nurseries when impoundments are dry. Rabbits and other small mammals find food, cover, and nesting sites during dry periods, and passerine birds are attracted to the new vegetative growth (Fredrickson and Taylor 1982). Furbearers such as raccoons, minks, and muskrats benefit from wetland conditions provided by moist-soil impoundments.

Table 1
Birds and Mammals that ave Responded to Moist-Soil Management in the Midwest 1

Pied-billed grebe	Golden eagle	Barred owl
American bittern	Northern harrier	Short-eared owl
Least bittern	Red-shouldered hawk	Common nighthawk
Great blue heron	Red-tailed hawk	Chimney swift
Great egret	Wild turkey	Belted kingfisher
Snowy egret	Northern bobwhite	Eastern kingbird
Little blue heron	Ring-necked pheasant	Tree swallow
Cattle egret	King rail	Bank swallow
Green-backed heron	Virginia rail	Barn swallow
Black-crowned night heron	Sora	American crow
Yellow-crowned night heron	Common moorhen	Sedge wren
Tundra swan	American coot	Marsh wren
Snow goose	Killdeer	Common yellowthroat
Canada goose	Greater yellowlegs	Indigo bunting
Wood duck	Lesser yellowlegs	Dickcissel
Green-winged teal	Solitary sandpiper	Song sparrow
Blue-winged teal	Willet	Swamp sparrow

American black duck	Spotted sandpiper	White-throated sparrow
Mallard	Least sandpiper	White-crowned sparrow
Northern pintail	Pectoral sandpiper	Red-winged blackbird
Northern shoveler	Dunlin	American goldfinch
Gadwall	Common snipe	Muskrat
American wigeon	American woodcock	Raccoon
Ring-necked duck	Mourning dove	Mink
Hooded merganser	Barn owl	White-tailed deer
Bald eagle	Great horned owl	Rabbits
1 Sources: Fredrickson and Taylor (1982), Fredrickson and Reid (1986).		

Moist-soil management is a more cost-effective technique than row-cropping for providing food and cover for a variety of wildlife species (Fredrickson and Taylor 1982). Productive row-cropping requires annual seeding and periodic applications of fertilizer, herbicides, and pesticides. Moist-soil management has been productive without these applications (Fredrickson and Taylor 1982); however, seed bank establishment may berequired at highly degraded sites (van der Valk and Pederson 1989), and herbicide application may be required in extreme cases. Return of energy (kilocalorie of food in the form of seeds) for each unit of energy input (kilocalorie of fuel, chemicals) for moist-soil plant production is regularly 7.17 kilocalories (Fredrickson and Taylor 1982). This does not include root, tuber, browse, herpetofauna, or invertebrate production, which would increase this figure. The national average energy return for corn is 2.82 kilocalories. Many wetland plant seeds also resist deterioration longer when flooded than do cereal grains (Neely 1956, Shearer et al. 1969). Neely (1956) showed that after 90 days of continuous inundation, soybeans and corn deteriorated 86 and 50 percent, respectively, while saltmarsh bulrush and smartweed deteriorated 1 and 21 percent, respectively. Many wetland plant seeds may persist for several months or even years while flooded (Fredrickson and Taylor 1982). Adverse weather conditions may reduce row crop production but have less effect on natural vegetation because of the diversity of plant species adapted to wetland conditions (Figure 1).

Agricultural row crops are important sources of high-energy foods for large concentrations of migrating and wintering waterfowl, mainly geese and mallards[1] (Gilmer et al. 1982, Reid et al. 1989, Reinecke et al. 1989, Ringelman 1990), but fail to provide adequately for many other waterfowl and wildlife species (Fredrickson and Taylor 1982, Heitmeyer 1985, Reid et al. 1989). The value of wetland plants for waterfowl foods is well-documented (Martin and Uhler 1951, Wright 1959, Wills 1971, Heitmeyer 1985, Delnicki and Reinecke 1986, Combs 1987, Fredrickson and Reid 1988a). Many wetland plants have higher overall nutritive qualities, contain more essential amino acids, and provide more cover than cereal grains (Burgess 1969, Fredrickson and Taylor 1982, Fredrickson and Reid 1988a, Heitmeyer and Fredrickson 1990, Laubhan 1992). Moist-soil impoundments also contain a variety of aquatic invertebrate species (Wiggins et al.1980, Reid 1983) that are critical to waterfowl diets during periods of the annual cycle (Chura 1961; Swanson and Meyer 1973, 1977; Krapu 1974, 1979; Drobney and Fredrickson 1979; Eldridge 1990). Consequently, a more diverse waterfowl population is attracted to moist-soil impoundments than to flooded agricultural row crops (Taylor 1977).

[1] Common and scientific names of animal species are given in Appendix A.

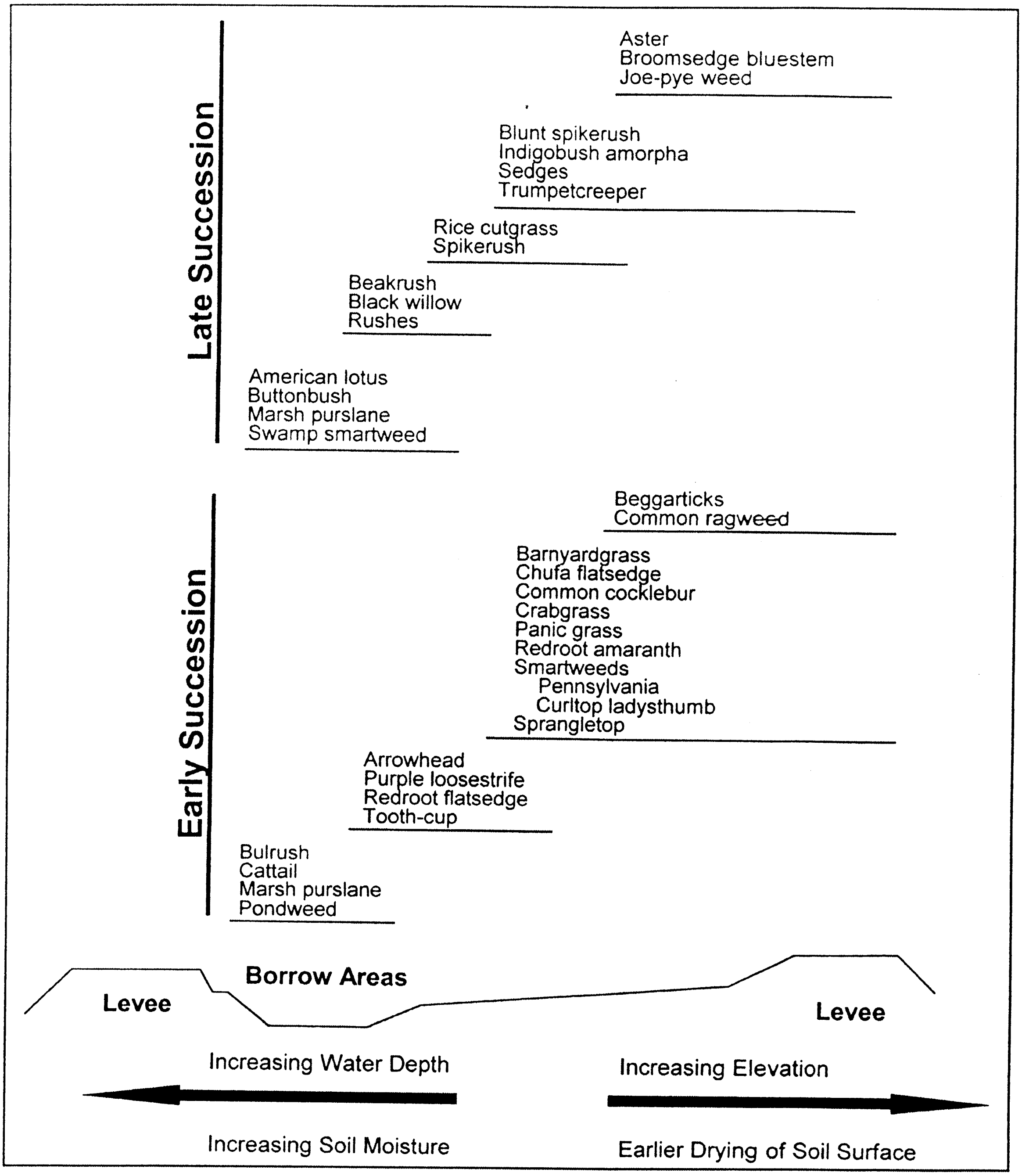

Figure 1. Distribution of common moist-soil plants along a flooding gradient (Fredrickson and Taylor 1982)

DISCUSSION AND CONCLUSIONS

Moist-soil management procedures have been most widely applied to waterfowl management in areas of migrational and wintering habitat. Although general ecological and management principles of moist-soil habitats have broad applications, specific techniques (e.g., timing of draw-downs and flooding) and their results vary with changes in latitude because of various aspects of wetland plant distribution and seed germination traits. To be successful, wetland managers must duplicate hydrologic conditions of their regions, monitor plant and animal responses, and adjust management to conditions at their specific locations (Fredrickson and Taylor 1982).

Although moist-soil management technology was initially developed and extensively tested in the upper Midwest and Mississippi Alluvial Valley, the practice has potential application in other areas. Moist-soil management is used to some extent throughout the Southeast to stimulate growth of waterfowl food plants (Johnson and Montalbano 1989; Gordon et al. 1989), but little experimental work has been published on the effectiveness of moist-soil management in the south-central United States where the growing season is long, the climate is warmer, and southern plant assemblages are involved (Polasek et al. 1995). Preliminary studies indicate that moist-soil management can potentially improve waterfowl habitat in portions of Georgia (Larimer 1982; Jensen and Reynolds 1997). Partial drawdowns, drawdown timing, and soil disturbance were effective tools in creating diverse habitats in shallow impoundments in northern Texas (Polasek et al. 1995).

Several National Wildlife Refuges in the Chesapeake Bay and North Carolina sounds region have recently been using moist-soil management along with other traditional practices to improve waterfowl habitat (Hindman and Stotts 1989). In North Carolina, moist-soil impoundments are drawn down in April to encourage annual plants, such as barnyard grasses, panicums, American bulrush, squarestem spikerush, smartweeds, redroot flatsedge, and beggarticks. Impoundments are reflooded in October-November to make food resources available to migratory waterfowl. Various levels of moist-soil management have also been applied in the western States. Mushet et al. (1992) stated that wildlife managers in the Central Valley of California use various water-management techniques to maximize waterfowl use during winter and periods of migration. These managers follow the general pattern of flooding wet areas in late summer and early fall, keeping them flooded in winter, and draining them in spring to stimulate germination of moist-soil annuals. Swamp timothy is considered a target moist-soil species in many Central Valley wetlands; other important waterfowl food and cover plants in the Sacramento Valley are prickle grass, common barnyard grass, and sprangletop. Moist-soil management is being used to promote germination, growth, and seed production of mud flat annuals for wintering waterfowl in playa (desert basin) wetlands (Haukos and Smith 1993, 1996). The effects of moist-soil management were evaluated on soils of eight playa wetlands in the Southern High Plains of Texas. Wetland flooding occurred primarily from overland runoff of precipitation and secondarily from runoff of irrigation operations. Moist-soil management reduced soil resistance for germination and raised pH closer to neutrality but had no effect on soil moisture in the top 4 cm of soil. Nitrogen and phosphorus levels in playa soils were not affected during the two seasons of study. Haukos and Smith (1996) stated that moist-soil management is a sustainable and compatible practice for playa wetlands because it enhances naturally occurring events.

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THE ALLEN'S CREEK WATERSHED MANAGEMENT PLAN PINELLAS COUNTY, FLORIDA

Mariben Espiritu-Andersen
Scheda Ecological Associates, Inc.
4013 Fowler Avenue, Tampa, Florida 33617

Donald D. Moores
Pinellas County Department of Environmental Management
512 South Fort Harrison Avenue, Clearwater, Florida 33756

ABSTRACT

The Allen's Creek watershed is a typical urban stream located in the central portion of Pinellas County, Florida. In 1986, Pinellas County, the City of Largo and the City of Clearwater agreed to fund and develop a watershed management plan to address the problems of the creek. A baseline study was completed in 1991 identifying the problems of the creek. The watershed management plan was completed and adopted by local governments in 1996 and 1997. Programs and proposed projects were evaluated by County and City staff for possible funding and implementation.

In 1997, a set of computer models that will simulate the effects of potential projects on the creek was completed. Projects and Best Management Practices are evaluated using this tool. The model is used to simulate project conceptual designs ensuring that base flows are maintained and water quality is improved.

During the development of the plan, projects that would benefit the creek were identified. These projects included the development of educational materials, public outreach programs, and demonstration sites for habitat restoration, exotic plant removal, native landscaping and stormwater treatment. Where possible, projects addressed stormwater treatment, water quality, flooding and habitat restoration and enhancement integrating public education. These projects used the stakeholder concept of involving neighborhoods and schools in project planning and design, implementation and monitoring.

Today, only three years after adoption of the Allen's Creek Watershed Management Plan several projects have been completed and the plan is used as an example for other watershed management plans throughout the state. Details of each project will be discussed.

INTRODUCTION

Allen's Creek is a typical urban system in Pinellas County, Florida where fish kills and algal blooms are common and recreational fishing is poor (Figure 1). In 1986, Pinellas County, the City of Clearwater and the City of Largo with the assistance from the Florida Department of Environmental Regulation entered into an agreement to jointly resolve the problems of Allen's Creek in response to a complaint filed with the United States Environmental Protection Agency. An 18 month baseline study was conducted to collect data on the watershed and identify the problems in the creek. The results of this study are discussed in detail in the Allen's Creek Phase One Report. Efforts to develop a watershed management plan for the Allen's Creek basin commenced in 1991. Target conditions were established and a problems and solutions matrix was developed to address concerns in the creek in many specific areas. The goals of the watershed management plan include:

1. stormwater management and water quality improvement;
2. flood management;
3. habitat restoration; and
4. wildlife management.

The watershed management plan for the Allen's Creek basin was completed and adopted by the Board of County Commissioners in October 1996 and by the Largo Commission in May of 1997. Programs and proposed projects in the plan were evaluated by County and City staff for possible funding and implementation.

In 1997, a County-hired consultant developed and completed a set of computer models that will simulate the effects of potential projects on water quality, and on hydraulic and hydrologic conditions of the creek. The model enables County and City staff to evaluate potential structural projects and Best Management Practices within the watershed.

IMPLEMENTED PROJECTS

During the development of the plan, projects were identified and implemented. These projects included the development of educational materials and demonstration sites for habitat restoration, exotic plant removal and stormwater treatment. The following sections gives a summary of each project.

Oligohaline Habitat Restoration Project

This is the first structural project that was implemented within the watershed. Pinellas County and the Southwest Florida Water Management District (SWFWMD) signed a cooperative agreement to jointly fund the design and construction of this project in November of 1995. Oligohaline or low salinity habitat is scarce in the creek, as in most urban tidal creeks. A preliminary evaluation of wetlands in the watershed indicates 67% of oligohaline wetlands have been filled and developed since 1926. This project aimed to restore low salinity wetlands and enhance habitat for aquatic species use including snook, redfish, spotted seatrout and blue crabs. Design plans were completed in 1997 and construction was completed in March 1997. More than 200 student, teacher and parent volunteers with County, City and District staff planted the site in April 1997 with 3500 upland and salt tolerant wetland plants. St. Paul's School students have adopted the project site and are observing bird activity and conducting periodic clean ups. Their participation in this project inspired them to restore the school's own creek shoreline which was partially completed in 1998. County staff monitored fish population abundance and diversity every six weeks from March through December for 1997, 1998 and 1999. Monitoring prior to restoration of the low salinity marsh captured snook. Juvenile target species including snook, redfish and spotted seatrout were captured and released during the monitoring events after restoration was completed. Monitoring will resume in 2004 to assess fisheries diversity and abundance.

Maple Swamp Habitat Restoration Project

This is the second structural project that was implemented within the watershed. The project combined stormwater treatment, habitat restoration, and educational and recreational use at a single site in the central portion of the watershed. The SWFWMD, the City of Clearwater and Pinellas County signed an interagency agreement to jointly fund the design and construction of the project in May of 1995. Design of the project commenced in 1996 and was completed in December 1997. Project construction was completed in September 1999. More than 250 student, teacher and parent volunteers, together with County and City staff planted the site with native wetland vegetation.

Students at Plumb Elementary School have been assisting County staff by monitoring wildlife activity at Maple Swamp since April of 1997. Clearwater Audubon Society members conducted two annual bird surveys of the project site (1997 and 1998). This information serves as baseline data that will be compared to wildlife use after the restoration project is completed. Wildlife monitoring at the project site resumed in August 1999. The monitoring will continue tri-annually (April, June and September) until 2001. The residents fully support the project and use the walking trails on a daily basis. Wildlife activity especially bird utilization has increased. This project won an honorable mention at the 1999 Future of the Region Award for Tampa Bay.

Belcher School Nature Center and Transitional Habitat Restoration Project

Another project enhanced a freshwater and upland system than runs along the eastern border of the Belcher Elementary School property near the head waters of the creek. County staff and the Florida Yard and Neighborhoods Program have been working with Belcher Elementary teachers and parents on the Belcher Backyard Nature Center. The Center aims to provide an opportunity for teachers, students and the community to observe, learn about, and respect nature by maintaining a natural habitat within the schoolyard environment. Project design and construction for phase one, upland habitat enhancement, were completed in May 1997. Activities and lessons using the Center were developed and integrated into classroom curricula in 1998. Phase two, wetland habitat enhancement, was also completed the same year (1998). Additionally, garden plots were planted between classrooms to increase plant diversity on school grounds. Students compare different habitats and utilize the nature center on a daily basis. After-school classes on Florida habitat are offered to interested students and funded by the Belcher Elementary Parent Teacher Association. The Nature Center has won several awards and has been visited by other teachers interested in creating their own outdoor classroom.

Dry Pond Enhancement Project
Pinellas County funded a Dry Pond Demonstration Enhancement Project at Largo Fire Station 42. This is a project that illustrates how dry ponds can be an amenity to a community and enhance wildlife habitat. This project was designed by City of Largo and County staff. The site was planted in late 1997 by St. Paul's School students as well as County and City staff. The City of Largo Parks and Recreation Department staff maintains the site. Local firefighter reports avifaunal and butterfly activity at the pond.

Storm Drain Marking Project
This is the first community involvement project within the watershed. The Allen's Creek Storm Drain Stenciling Program had it's first training class for volunteers in November, 1995. Eighth grade students, teachers and residents have volunteered to paint "Don't Dump! Drains to Allen's Creek (Fish Logo)" on storm drains in their neighborhoods. This project then evolved to marking storm drains with the plastic plaques by using concrete adhesive. Since it's inception, several student groups, residents, local citizen groups and city staff have marked more than 80% of the stormdrains in the watershed. Youth volunteers also serve as ambassadors speaking with residents about environmental friendly ways to help the watershed. This project was implemented countywide in 1998. The instruction manual for this project is used as a template by other local governments throughout Florida.

Septic Tank Maintenance Booklet
Pinellas County also produced and distributed "You and Your Septic Tank" booklets to Allen's Creek residents with septic tank systems to address groundwater nutrient loading. The booklet contains information on the function, operation and maintenance of septic tank systems. Copies of the booklet were made available to the public through several County offices and the Pinellas County Public Health Unit.

Naturescape
"Naturescape: the Allen's Creek Urban Wildlife Enhancement Program" was completed for distribution to the public in 1996. The booklet contains information on plant species native to Pinellas County, artificial supplies for wildlife and tips on yard maintenance. Naturescape promotes urban wildlife enhancement by educating the public on actions they can take to provide food and shelter for wildlife, increase vegetative cover, and increase native and naturalized plant density. This booklet is distributed by the Pinellas County Department of Environmental Management and the Pinellas County Cooperative Extension Service.

CURRENT STATUS
For the year 2000, the Lancaster Habitat Restoration project is expected to be designed enhancing 14 acres of wetland and upland communities. This project is adjacent to Belcher Elementary School and is located along the main channel of the creek. The project site offers opportunities to create oligohaline wetlands, a freshwater marsh and demonstrations for

shoreline restoration and stormwater treatment. All the educational and monitoring projects that are related to the restoration projects are ongoing and receive much public support.

CONCLUSIONS

In summary, all the projects contributed to the goals of the Allen's Creek watershed management plan by improving water quality, increasing floodplain area and providing enhanced opportunities for wildlife. This is also consistent with the goals of the Pinellas County Comprehensive Management Plan and the Tampa Bay Estuary Program Comprehensive Conservation and Management Plan which is a baywide plan to improve Tampa Bay. In addition, all the projects contribute to the social and public education components of the watershed management plan.

Incorporating community involvement as part of these habitat restoration projects provides an avenue to increase environmental awareness, expose students and residents to different Florida habitat and increase public acceptance and participation. Local residents develop a sense of ownership by supporting and participating in the projects and keeping a watchful eye on the site. The strong community involvement helps ensure the long-term success of these projects.

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LAND MANAGEMENT PLANNING AND IMPLEMENTATION PURSUANT TO WETLAND RESTORATION IN A REGIONALLY SIGNIFICANT WATERSHED IN POLK COUNTY, FLORIDA

Harry V. Neal, Jr., PWS
Joel Thomson
PBS&J
1560 North Orange Avenue
Winter Park, Florida 32789

Bill Barnard
Greater Orlando Aviation Authority
One Airport Boulevard
Orlando, Florida 32827

ABSTRACT

In 1996, the Greater Orlando Aviation Authority (GOAA) was in need of mitigation opportunities caused by the need for additional runway construction at the Orlando International Airport (OJA). Due to on-site property constraints, the choice was to seek off-site mitigation. Two tracts of land with mitigation potential were chosen in the Reedy Creek/ Lake Marion Creek watershed in Polk County, Florida. This is an environmentally sensitive area that, along with previous GOAA acquisitions, contributes to a conservation effort of regional significance.

After purchasing the mitigation tracts, staff ecologists evaluated the properties and prepared a land management plan (the Plan). The Plan focused on enhancing and restoring wetlands that had been impacted by anthropogenic disturbances, as well as preserving the remaining wetland communities. Examination of historical aerials (1941) provided a template on which restoration activities were based.

Upon implementation of the Plan, state-of-the-art land management techniques were evaluated and applied where their efficiency could be maximized. These included hydrologic restoration, elimination of cattle grazing, control of exotic-, nuisance- and invader-vegetative and faunal species, reintroduction of a fire regime, protection of cultural resources, facilitation of research and security and upkeep of the property. Industry-approved methods were used to monitor and evaluate the effectiveness of ongoing operations.

To date, both qualitative and quantitative monitoring have documented a transition of the target areas from upland to wetland communities. An increase in wildlife utilization has also been noted. Further years of increased inundation due to hydrologic alterations should ensure their existence as functional wetlands.

INTRODUCTION

As the Central Florida area continues to grow in population (both resident and seasonal), the need for expanded operations was recognized by the Orlando International Airport (OIA) and its governing board, the Greater Orlando Aviation Authority (GOAA). Pursuant to this realization, the permitting process was initiated to begin mitigating for construction activities at the OIA (buildout which includes the South Terminal and runways). Due to on-site property constraints, approximately 809 hectares (named the London Creek and McKinney Tracts) were purchased in Polk County, Florida. These tracts were donated to the South Florida Water Management District (the District) for inclusion in the Save Our Rivers Program. They joined 1,631 hectares previously donated to form a regional conservation area. All GOAA mitigation lands are located within the Reedy Creek/Lake Marion Creek watershed, a 101,172-hectare area of considerable ecological significance. This watershed is located in the upper Kissimmee Chain of Lakes, the headwaters of the Kissimmee River system that eventually supplies the Everglades with much of its water.

After the tracts were acquired, GOAA retained the services of PBS&J. Chosen through the bid-selection process, PBS&J supplemented its various land management services with job-specific subcontractors (presented in the Acknowledgements section). The property was analyzed with regard to historical conditions (1941), vegetative community structure, habitat and biotic diversity, presence of protected plant and animal species and valuable cultural, recreational and water resources. Guidelines were established that, upon implementation, would preserve, restore and/or enhance the subject properties, and were included in a document entitled "Management and Restoration Plan: GOAA Mitigation Lands, London Creek and McKinney Tracts" (the Plan). The Plan sought to maximize mitigation credits through the application of state-of-the-art land management techniques. The District approved of the Plan on December 11, 1997, in Permit Modification #48-00063-S. Public transfer of the two tracts is scheduled for January 1, 2002, upon successful fulfillment of the Permit's general and special conditions.

STUDY SITE

The study site consists of two properties: the London Creek and McKinney Tracts. The two tracts are adjacent to or adjoining the Disney Wilderness Preserve (DWP), a preserve owned and managed by The Nature Conservancy (TNC) just southwest of Lake Tohopekaliga. The properties are located in east central Polk County between Lake Hatchineha and Lake Russell, with the Reedy Creek swamp and the Dead River to the east and Lake Marion to the west.

The 561-hectare London Creek Tract, lying just west of the central portion of the DWP, is surrounded on three sides by private ranch land and bounded by Lake Hatchinha to the south. This tract includes areas adjacent to London Creek and Lake Marion Creek. More specifically, this tract lies in portions of Sections 5, 6, 7, 8, 17 and 18 of Township 28 South, Range 29 East, Sections 1, 11, 12, 13 and 14 of Township 28 South, Range 28

East, and Section 36 of Township 27 South, Range 28 East. This tract is accessed from the north through the former Fisher-London Creek Ranch, and from the southeast through the DWP.

The 242-hectare McKinney Tract lies just east of DWP. The site is bounded on two sides by private ranch lands, to the north by the Reedy Creek Swamp and to the east by the Dead River. More specifically, this tract lies in portions of Sections 1, 12 and 13 of Township 28 South, Range 29 East and Sections 7 and 18 of Township 28 South, Range 30 East. Access to the property is obtained from the west through the DWP and across a small portion of the J & L McKinney Ranch.

MATERIALS AND METHODS

Upon implementation of the plan, a baseline vegetative monitoring event was conducted to document existing vegetation. Monitoring transects were installed (marked with rebar and PVC) and surveyed, with their placement preferentially located to reflect changes in active restoration and/or enhancement areas. Both qualitative and quantitative data were recorded in various vegetative strata. Additionally, piezometer monitoring wells were installed along transect lines to document changes in groundwater elevations.

During the first year of active implementation (1998), the Plan timeline called for certain construction activities to be accomplished. These included the following: reclamation of an approximately 1.6 kilometer ditch-and-berm complex, property boundary clearing and fence line installation, installation of ditch-blocks, installation of water level stage recorders, fireline clearing and the removal of approximately 32 hectares of timber.

Once the construction phase was completed, active land management continued on-site. As part of the permitted Plan, a nuisance/exotic floral and faunal management was initiated. Cattle were removed from grazing lands once the fence installation was completed. A trapping regime for feral hog *(Sus scrofa)* was initiated, as well as a control plan for coyote *(Canis latrans)* and armadillo *(Dasypus novemcinctus)* due to their detrimental effects on native wetland species. A vegetative contractor began systematic treatments (utilizing mechanical and herbicidal mechanisms) on both sites for vegetative species which are considered exotic or have the potential to out-compete native beneficial species.

The reintroduction of a fire regime was also essential, as many wetland plant species are dependent on fire for propagation. The properties were subdivided into burn blocks based on community types, property boundaries and hydrologic and morphological constraints. Numerous prescribed burns have been conducted on-site, primarily for fuel reduction purposes.

Due to the secluded location of the sites, and their accessibility to airboats via rivers and creeks, security personnel were hired to patrol and protect the tracts' various resources. Primarily, the officers' focus is to deter the illegal hunting (poaching) of deer, turkey and other wildlife, of which there are abundant populations. They also protect the on-site office trailer and associated land management equipment, as well as monitor the posted fence line for trespassers.

Additional ongoing activities include wildlife surveys (both diversity and estimated abundance, primarily consisting of aviafauna, herpetofauna and icthyofauna), maintenance and monitoring of hydrological conditions through monthly piezometer and river stage data collection, fence line maintenance and implementation of prescribed fire (weather permitting).

RESULTS

To date, the restoration activities appear to be successfully transitioning targeted areas to historical wetland conditions. Data from the last monitoring event show sampling plots ranging from 2.7% to 100% coverage by beneficial (obligate or facultative wet) wetland species. All monitoring and hydrologic data, as well as a summary of each year's management activities, are presented to the District in an Annual Monitoring Report.

DISCUSSION

While the varied land management activities have shown a trend toward meeting restoration goals, there have been limitations in their effectiveness. Primarily, weather patterns associated with La Nina' have brought extremely dry conditions to the region, and the site in particular. This plays a major role in the restoration of wetland plant communities by limiting the beneficial effects of hydrologic alterations. Additionally, it has severely altered the growing-season burn schedule associated with the prescribed fire plan (through the state-issued "Burn Bans and Red Flag Conditions"). Despite these barriers, both sites are visibly moving toward the outcomes predicted in the land management plan. Future years of active management and subsequent monitoring will demonstrate our ability to ameliorate man's detrimental effects on these historical wetland communities.

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