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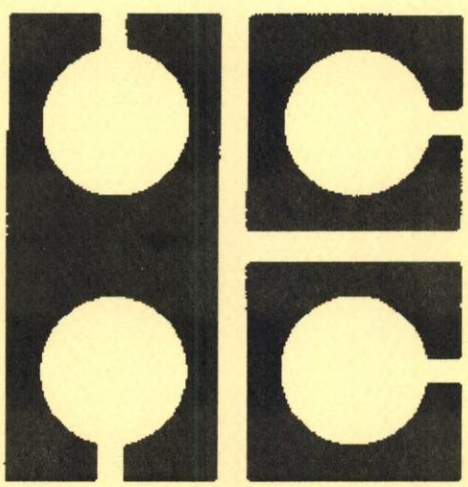
May, 1997



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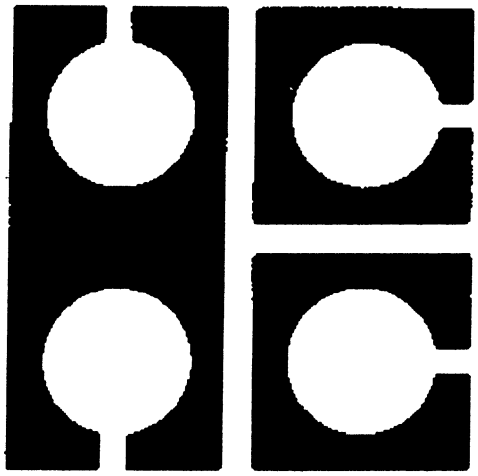

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Proceedings of
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INTRODUCTION

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 Fourth 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 four years ago. We are grateful for his help and participation. Appreciation is also extended to Charles Duesner and Fred Webb for providing administrative support for the conference.

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Thanks are extended to the staff of the **Environmental Lands Acquisition and Protection Program** 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.

IMPLEMENTATION OF ADAPTIVE MANAGEMENT TO RESTORATION OF DIKED SALT HAY FARMS TO NATURAL MARSHES

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ABSTRACT

Fifty years of diking have reduced marsh plain elevations, obliterated tidal channels, reduced *Spartina alterniflora* and increased *Phragmites australis* in marshes on the Delaware River Estuary. Prior to diking, the marshes were dominated by *Spartina alterniflora* and *Spartina patens*. Salt hay farming exacerbated the invasion of Phragmites and converted the marshes into *Spartina patens* marshes. The restoration goal is to obtain a mixed salt marsh ecosystem dominated by *Spartina alterniflora* but with significant areas of *Spartina patens* high marsh. The restoration construction of the first six hundred acres of salt hay farm is complete and the restoration construction at two other sites is ongoing. The restoration philosophy and the applications of adaptive management at three salt hay farm marsh restoration sites are discussed. In addition, applying adaptive management to resolve conflicts between construction and restoration goals is outlined.

INTRODUCTION

The project involves the restoration of three diked salt hay farms in the Delaware River Estuary. Each of the farms present distinct restoration challenges based on their differing sizes, locations, and conditions at the beginning of restoration. The restoration of diked salt hay farms within the Delaware River Estuary is not a historic undertaking nor is it the first attempt at restoring such sites (Weishar et al. 1996). The basic restoration concept is to remove the dikes and convert the artificially maintained high marsh areas dominated by *Spartina patens* to low marsh areas dominated by *Spartina alterniflora*. Nature and the New Jersey Department of Fish and Game

(NJDF&G) have been slowly returning salt hay farms to low marsh areas by either allowing storms to breach the dikes or purposefully breaching the dikes, thus returning tidal flows to the salt hay farms. The restoration is then allowed to occur naturally.

The establishment of restoration goals and objectives is important for large restoration projects. The mere return of marsh waters to the formerly diked salt hay farms could be viewed as a successful restoration. However, establishment of marsh channels and of low marsh species are the general goals for this project. The salt hay farms "naturally restored" either by nature or the NJDF&G exhibit widely different time courses on their way toward the desired goals. The re-establishment of low marsh species and the necessary functioning tidal channels and sub-channels required to return the farm fields to a healthy, fully functional marsh has taken as long as 20 years. In some instances, marsh sediments were eroded to leave open water over large areas of the newly opened sites. While this does not indicate that these marshes are not on a restoration path, it does mean that the establishment of *Spartina alterniflora* will take decades, determined by the current rate of sediment deposition.

The goal of the restoration of the three salt hay farms is to re-introduce tidal waters to the marsh plain, provide channelization throughout the salt hay farm (sufficient to fully wet and dry the marsh plain twice daily), reduce *Phragmites australis* coverage to less than 10%, have no more that 10% open water areas within the restoration area, and establish low marsh vegetation dominated by *Spartina alterniflora* within five years. To accomplish these goals, an aggressive plan was adopted that used numerical modeling, engineering, and adaptive management to accelerate marsh evolution in such a manner that large open water areas would not form and a natural mosaic of high and low marsh areas dominated by *Spartina* species would develop within 10 years.

PROJECT REQUIREMENTS

The restoration and preservation of over 5868 ha (14,500 acres) of degraded salt marshes within the Delaware River Estuary is required by a permit issued to the Salem Generating Station (Fig.1). The permit, which became effective in September 1994, also requires a limitation of cooling water withdrawn from the

Delaware Estuary; the installation of improved cooling water intake screen technology to increase fish survivability at the Station; studies to investigate new technology to deter fish from the station's intake area; construction of five fish ladders to eliminate barriers that prevent fish from migrating into tributary freshwater spawning areas and implementation of an expanded biological monitoring program.

Public Service Electric & Gas Company's (PSE&G) established the Estuary Enhancement Program (EEP), as an environmental improvement program designed to provide long-term benefits to the ecology of the Delaware Estuary. The mission of the EEP is to minimize potential losses of fish due to the operation of the Salem Generating Station (Station) and to facilitate production of fish and other aquatic species by expanding and protecting habitat for fish and other aquatic organisms. Overall, this initiative will contribute to the restoration, enhancement and preservation of more than 8,300 ha (20,500 acres), or more than 83 square kilometers (32 square miles), of salt marsh and uplands along the Delaware Estuary.

The combination of abundant food, warm shallow summer habitat, and refuge from predators makes salt marshes an ideal environment for species of fish that live their entire lives there and for the young of other species that use the marsh as a nursery. In this way salt marshes boost the productivity and growth of commercially and recreationally valuable fishes.

SALT HAY FARMS CHARACTERISTICS

The first phase of the marsh restoration project involved the restoration of three salt hay farms. The EEP program acquired approximately 2,400 ha (6,000 acres) of salt hay farms which are surrounded by perimeter dikes. Within the salt hay farms, the marsh plain subsided over the years following diking. Much of the original tide plain now ranges from mean tide level to mean high water. The majority of the three salt hay farms were diked in this century and have been in continuous agriculture since the early 1950's. They are located in Dennis, Commercial, and Maurice River Townships in southern New Jersey (Fig.1). The Dennis salt hay farm restoration site consists of approximately 227 ha(560 acres) of degraded coastal salt marsh, fresh water wetlands and uplands.

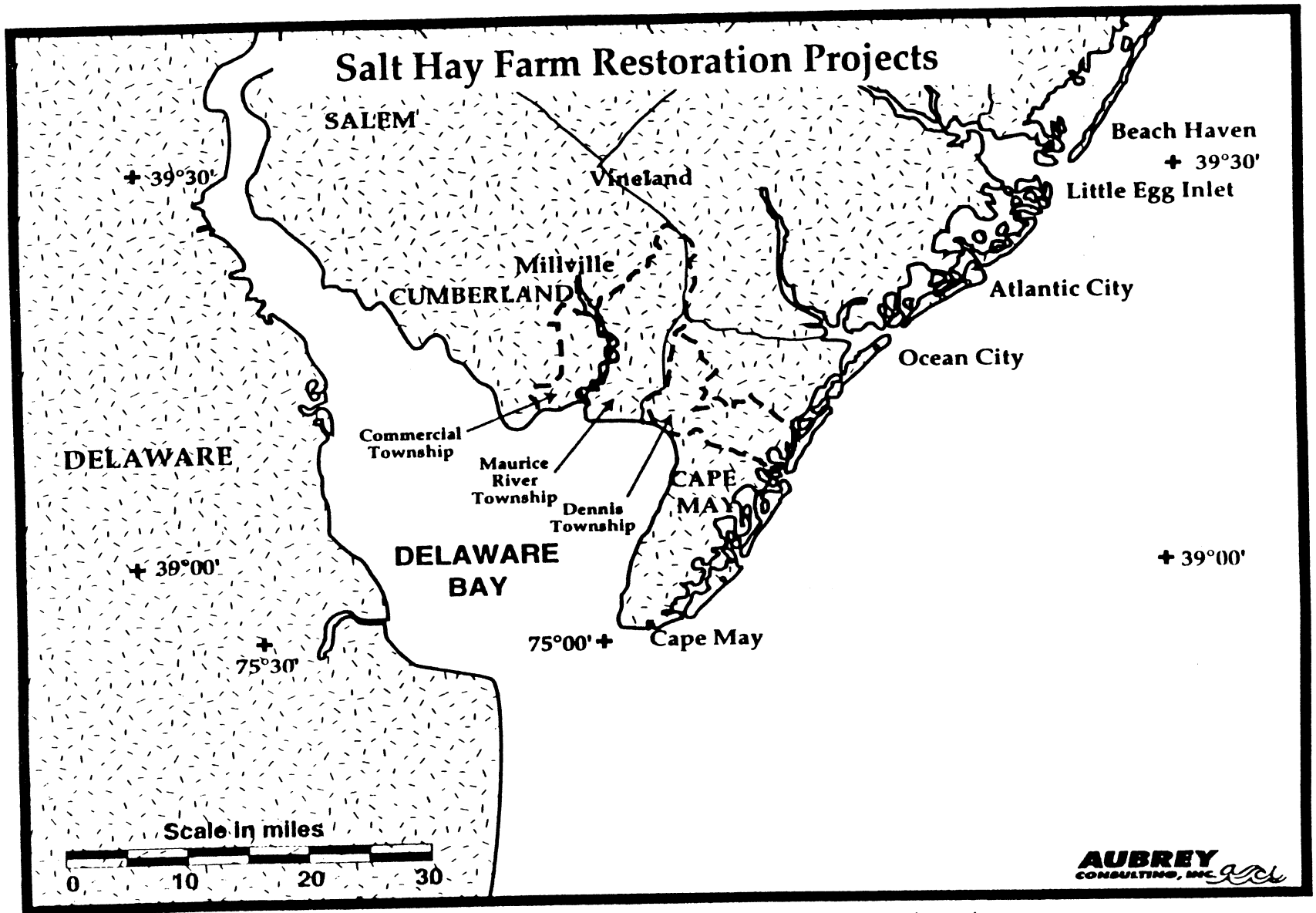

Figure 1: Location of Salt Hay Farm restoration sites.

The completion of the project will restore approximately 148 ha (365 acres) of degraded coastal wetlands. Construction of the site was completed in August 1996 with the breaching of the perimeter dikes and return of tidal flows to the salt hay farm. Construction of the tidal channels within the site was relatively easy compared with Maurice River and Commercial restoration sites because the site is relatively small and the perimeter dikes were in good repair. The size of the site minimized logistical problems associated with moving construction equipment across long distances of marsh plain. The good condition of the perimeter dikes helped insure that the construction was not adversely impacted by tides and storms. As a result, the site was kept relatively dry during construction which also minimized construction logistics.

The Maurice River salt hay farm restoration consists of approximately 445 ha (1,100 acres) of degraded coastal wetlands all of which will be restored. The dikes at this site breached during a series of severe winter storms in 1994 resulting in the flooding and impoundment of tidal waters on the marsh plain. Most of the marsh plain remained flooded throughout the tidal cycle because the drainage ditches were too small to carry enough water during a normal ebb tidal cycle. As a result this site remained inundated most of the time resulting in the loss of almost all of the vegetation on the site. Inundation of the site has presented many logistical problems associated with construction of the large main stem channels and moving equipment around the site. Construction at this site is currently underway with an expected completion date of December 1997.

The Commercial salt hay farm restoration site consists of approximately 2430 ha (6,000 acres) of degraded coastal wetlands, fresh water wetlands, and upland. At the conclusion of the project, approximately 1600 ha (3,950 acres) of degraded coastal wetlands will be returned to functioning salt marsh. Construction at this site is a challenge because of the size of the site and the associated time required to move construction equipment about within the site. Additionally, water management associated with dredging within a closed system continually presents a challenge. The key to efficient construction and dredging at this site is to maintain adequate water levels for efficient dredging operations but low enough to facilitate transport of equipment across the site. Construction at the Commercial site is scheduled for completion in December 1997.

ADAPTIVE MANAGEMENT

Adaptive Management involves setting goals for a project, following the projects progress and modifying oversight and intervention as necessary to achieve those goals (National Research Council 1992). The foundation of our Adaptive Management (ADM) is an understanding of tidal marsh ecology and hydrology based on experience, current literature and historical observations. For the restoration projects discussed here, we set up goals that consisted both of final ecological states in the restored marshes and trajectories along which we expected the restoration to progress toward those final conditions. Both the final states and trajectories were set up as ranges to allow for the natural variability in marsh systems and for accidents of weather and biological variability that will occur during the restoration period. Data from other marshes, both relatively unmodified and naturally restored, obtained from historical aerial photos established the necessary bounds of acceptability (success criteria) for the project (Fig. 2, Weinstein et al 1997).

The success criteria include the reduction of the undesirable *Phragmites australis*, the increase of desirable *Spartina* species and the amount of open water established. Two sets of criteria, interim and final, were developed. The interim criteria were established to satisfy regulatory requirements for the necessary permits (construction, wetlands, etc.) needed for each site. The interim success criteria for diked salt hay farms consist of > 36% coverage by *Spartina*species in seven years and the establishment of a natural hydroperiod (daily tidal inundation without prolonged inundation). On *Phragmites* dominated sites the criteria is >36% coverage by *Spartina* species in six years.

In situ observations of critical parameters, comparisons, and actions are all undertaken on an ongoing basis by a advisory team of four experts. Their observations and actions will be reviewed periodically by a larger group of experts less intimately involved with the restoration so to bring a wider point of view into the ADM process. The observations are measurements of parameters critical to wetlands restoration success. Their magnitude provides the thresholds (the "triggers"), that when exceeded, may require corrective actions to supplement the basic restoration activities.The triggers briefly are:

- Excessive ponding of water on the marsh plain;
- Upland flooding beyond that that would have occurrred without

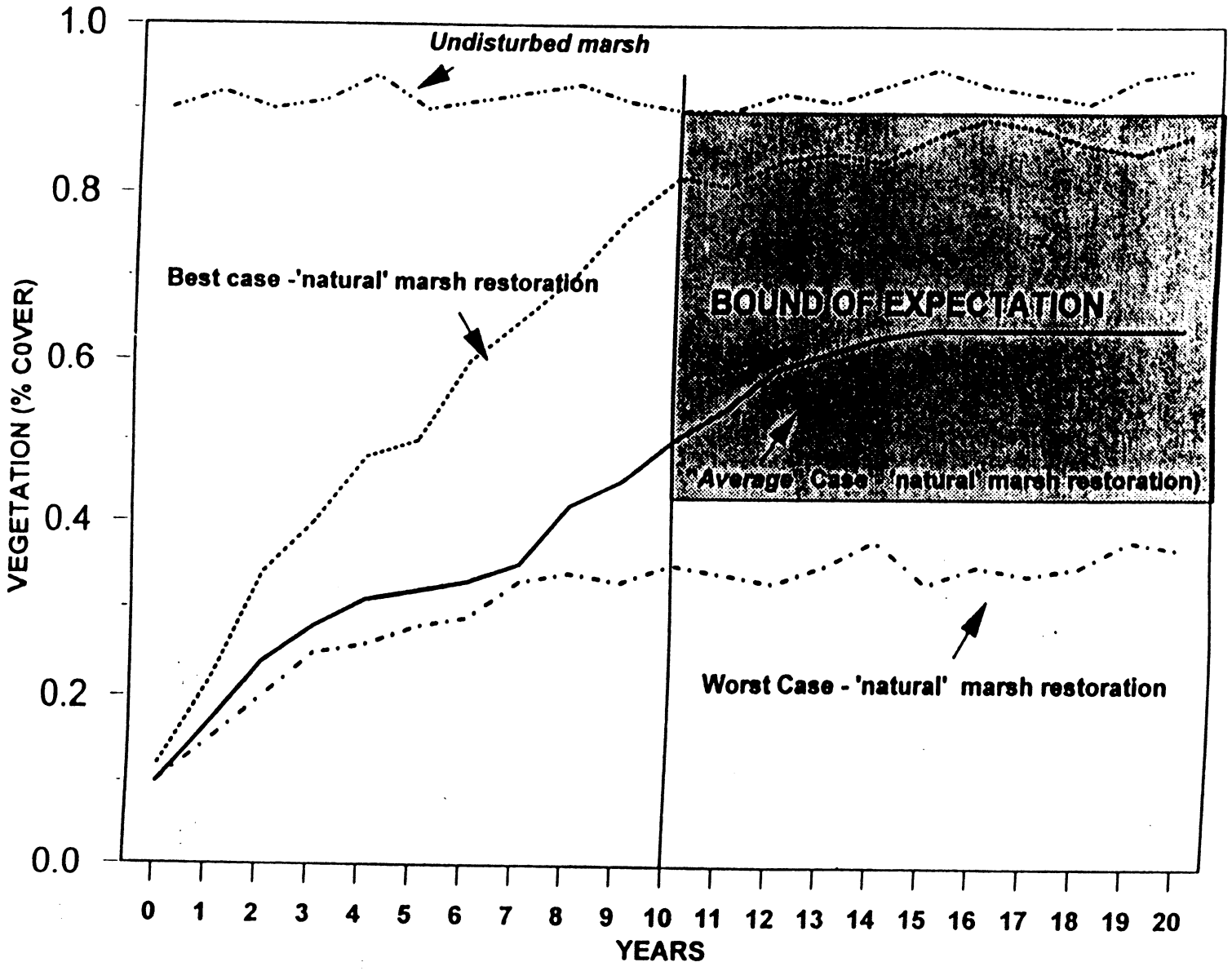

Figure 2: Hypothetical curves for marsh restoration end points, (After Weinstein et al., 1997).

the restoration
- Occlusion of the channels by which normal tidal exchange should occur;
- Re-establishment of *Spartina* spp. at less than approximately 9% per year after a one or two year lag and;
- A reduction in *Phragmites australis* coverage of less than 10% per year

Actions would be automatically taken if the triggers were observed. The actions affecting hydrology could include excavating additional channels; enlarging existing channels; providing additional breach sites on existing dikes; filling existing tidal channels (where tidal exchange is detrimental to vegetation recolonization); and stabilizing existing breaches. Hydrologic alterations also affect vegetation but planting or use of herbicides could also be called for. In some cases, based upon the knowledge and observations of the ADM team, the first action could be waiting, coupled with more intensive monitoring, to see whether the situation would be self correcting. The regular monitoring by the advisory team involves monthly visits to the restoration sites to examine:

- vegetation coverage and condition;
- evidence of herbivory;
- marsh plain drainage;
- formation of lower order tidal creeks;
- shape and changing configuration of the larger, higher order channels; sediment accumulation and/or subsidence; and
- condition of the upland dikes and drainage.

The team has established transects that will be recorded photographically each summer at about the time of maximum vegetation. The photographs will provide a visual record of the progress in re-establishing the normal marsh vegetation and provide data to track the restoration trajectory.

APPLICATION OF ADAPTIVE MANAGEMENT

Four adaptive management examples have been chosen to show its application and to demonstrate how the process was used to balance construction and restoration goals.

Channel Straightening

During construction several design changes were required after the construction engineer attempted to implement the design and determined that it was not possible without modifications (Fig. 3). Once this situation was encountered, the adaptive management was applied to rectify the conflict between the design and construction.

The original channel design called for making maximum use of the existing drainage within the salt hay farm. The rational for this design constraint was that utilizing exiting channels would minimize the required dredging and accompanying destruction of the marsh plain. The design embraced the concept of ecological engineering which assumed that in time micro-topography would establish the small drainage channels and establish channel meanders. In some cases the dredger determined that the channel design meanders had a turning radius smaller than the dredge could accommodate. This required a closer look at the two locations to determine if loss of the natural meander would have an adverse impact on the initial design conditions and if the channel straightening would result in a loss of initial habitat.

The new channel would cut-off the channel meander and would remove the tight channel turn. The new channel alignment and location was determined by examining the topography, discussions with the dredger, and an examination of the adaptive management implications.

An examination of the topographic maps and a walk of the proposed new channel location quickly determined there were no local topographic impediments such as shell road or drainage channel levies which would inhibit channel formation. Discussions with the dredger resulted in a new channel configuration which the dredger was confident that he could construct with no change in the project scope.

The last step in the process was to examine the implications of the proposed project change within the adaptive management frame work. One of the project goals in laying out the channel design was to include sinuosity in the larger drainage features and to avoid a rectilinear pattern. Therefore, the new channel was configured with a gentle curvature which facilitated the dredging requirements for greater maneuverability and the restoration goals by increasing

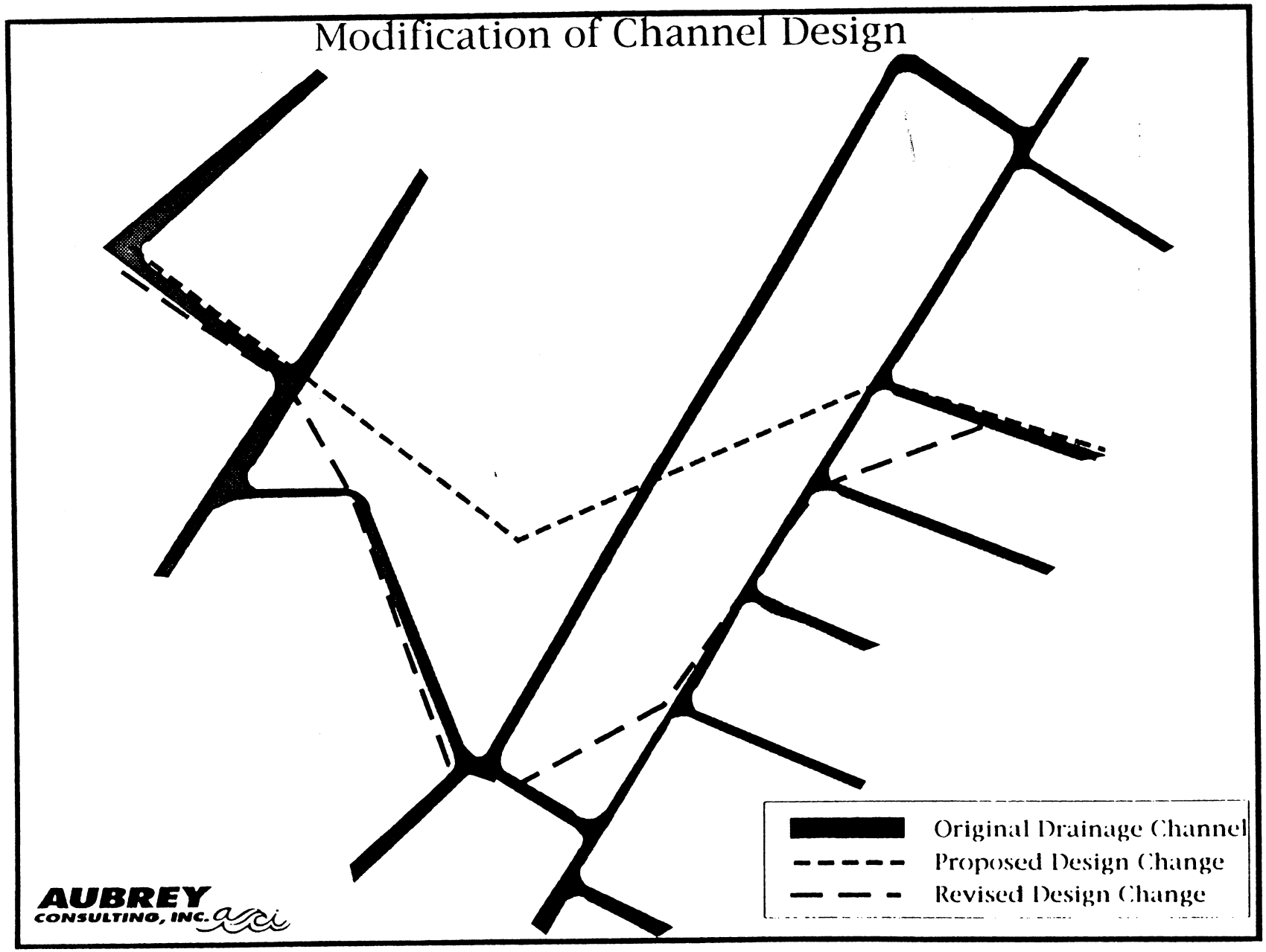

Figure 3: Application of adaptive management to channel construction.

biological and hydrological benefits of sinuous over straight channels. Sinuous channels provide greater habitat for fishes because sub-aqueous and sub-tidal channel deeps and shallow sections naturally evolve along with channel curvatures and bends. These areas provide better habitat for juvenile fishes and benthic infauna.

The application of adaptive management was successful in examining construction and habitat requirements, and balancing the multiple demands of the project First, the construction of the new channel was made easier, which eliminated a possible delay in the construction schedule and made the project more constructable. This had the benefit of showing the construction contractor that the management team was willing to work out potential design oversights to keep the project on schedule. Second, the overall habitat was increased because the existing bend in the drainage was maintained as an oxbow. The oxbow provided habitat and shallows immediately for benthic fish and fauna which were not included in the original project design.

Dennis High Marsh Notching

Dennis Township salt hay farm construction was completed and the restoration project was opened to tidal waters in August 1996. This restoration project disposed of dredged materials in containment areas designed to be high marsh. These high marsh areas were filled with dredged material and the berms were mechanically lowered to the desired high marsh elevations immediately prior to breaching the perimeter dikes. The restoration design called for the site to naturally accrete by trapping sediments from the river and bay. Additionally, the site was opened in the fall when it was anticipated that there would be a plentiful source of *Spartina* seeds from adjacent marshes. In early January 1997 there were significant areas of ponded water on the site. These ponded areas resulted from the poor connection of the marsh plain to the dredged channels. There were several reasons for this lack of connectivity. First, many of the pre-restoration drainage ditches were inadvertently blocked by the construction of the main channels eliminating one of the main drainage pathways for the marsh plain. Second, the design of the drainage channels simply did not connect to several areas. The application of ecological engineering called for construction of primary and secondary channels only. Third, drainage into the pre-restoration ditches was inhibited by the presence of levees along the ditches. The levees were formed when the ditches were cleaned-out by the salt hay

farmers and the material was disposed of along the ditch margins.

In early spring a plan was formulated to hydraulically notch (open) these areas using a small water pump and a discharge hose to generate a high pressure discharge to excavate a small notch through the material blocking the ditches or through the ditch levies. The small notch would provide a small drainage pathway to help the formation of natural drainage features. After the January reconnaissance it was estimated that there were between fifteen to twenty locations which would require notching to ensure that the marsh plain could begin to drain properly. However, when the adaptive management team prepared to hydraulically notch the blocked areas in May of 1997, nature had opened all but six of the locations areas identified for notching. The remaining six areas were notched and drainage was established using a minimum of personnel and equipment.

Sedimentation and Plant Recruitment

The permit for the Dennis Township salt hay farm restoration called for planting sections of both high and low marsh. However, the restoration design employed ecological engineering to minimize the need for planting by raising the marsh plain through natural sedimentation and establish conditions favorable for recruitment of *Spartina* seeds. To facilitate ecological engineering, the primary and secondary channels were designed to be large enough to fully wet and dry the marsh plain and to have maximum average velocities below .75 m/s. The design criteria was established to help ensure that there would be minimum of high velocity sheet flow off the marsh plain. If this design condition could be attained, sediment laden tidal waters would flood the marsh plain during flood tide and allow the suspended sediment and associated seeds to be deposited on the marsh plain prior to flowing of the marsh plain during ebb tide.

In January 1997 sedimentation was observed in many areas of the site although access was limited due to weather and lack of a suitable vehicle to traverse the marsh. By the second reconnaissance in May of 1997 the weather was good and a suitable vehicle to traverse the marsh plain had been acquired. Observations of sedimentation and recruitment of seedlings in the interior of the site were then possible. From 3 to 10 centimeters of sediment containing *Spartina alterniflora* seeds had accreted on the marsh plain. The seeds had germinated

and were growing vigorously in most areas. While new seedlings were observed in most locations across the site, the densest seedling concentrations were seen in locations which had accreted the most sediment. These areas were most evident along the base of the perimeter dikes, head waters of the newly dredged channels, and remnant open water areas which had formerly ponded water.

These observations provided initial validation of the ecological engineering concept. The design had provided the conditions necessary to accrete sediment and provide the conditions necessary to trap seeds from the surrounding estuarian system.

Channel Construction Methodologies (Evaluation of Channel Sloping vs. Side Cut)

Channels in marsh systems provide the conduit for tidal waters to move into and out of the marsh, transport for nutrients and sediments, substrate for algal growth, pathways for the export of detritus and conduits and habitat for fish and benthic organisms. One of the primary reasons channels provide such a good habitat for micro and macro species is their diverse combination of sub- and inter tidal areas. Once all of these conditions were recognized, the restoration challenge was to derive a combination of engineering and construction techniques which provided the initial habitat. The easiest channel configuration to construct using a hydraulic dredge is a box cut (Fig. 4). A box cut allows the dredge operator to construct the channel with the minimum number of passes, saving time and reducing costs. However, this channel configuration leaves the entire channel (except for the sides) sub-tidal. No shallows or point bar habitats are exposed during low tide. Therefore our challenge was to determine a cost effective construction methodology to provide an initial inter-tidal habitat within the channels.

We evaluated four channel construction methodologies (Fig. 4) used along selected channel sections. Once completed, the sections were evaluated for effectiveness of the habitat they produced. The first technique was a simple box cut with a uniform cross-section. The box configuration required the least construction time. The cross-section was uniformly deep with fairly steep channel side slopes (Fig.4) which were not vertical due to dredge inconsistencies and slumping after dredging. Use of this technique left a uniform

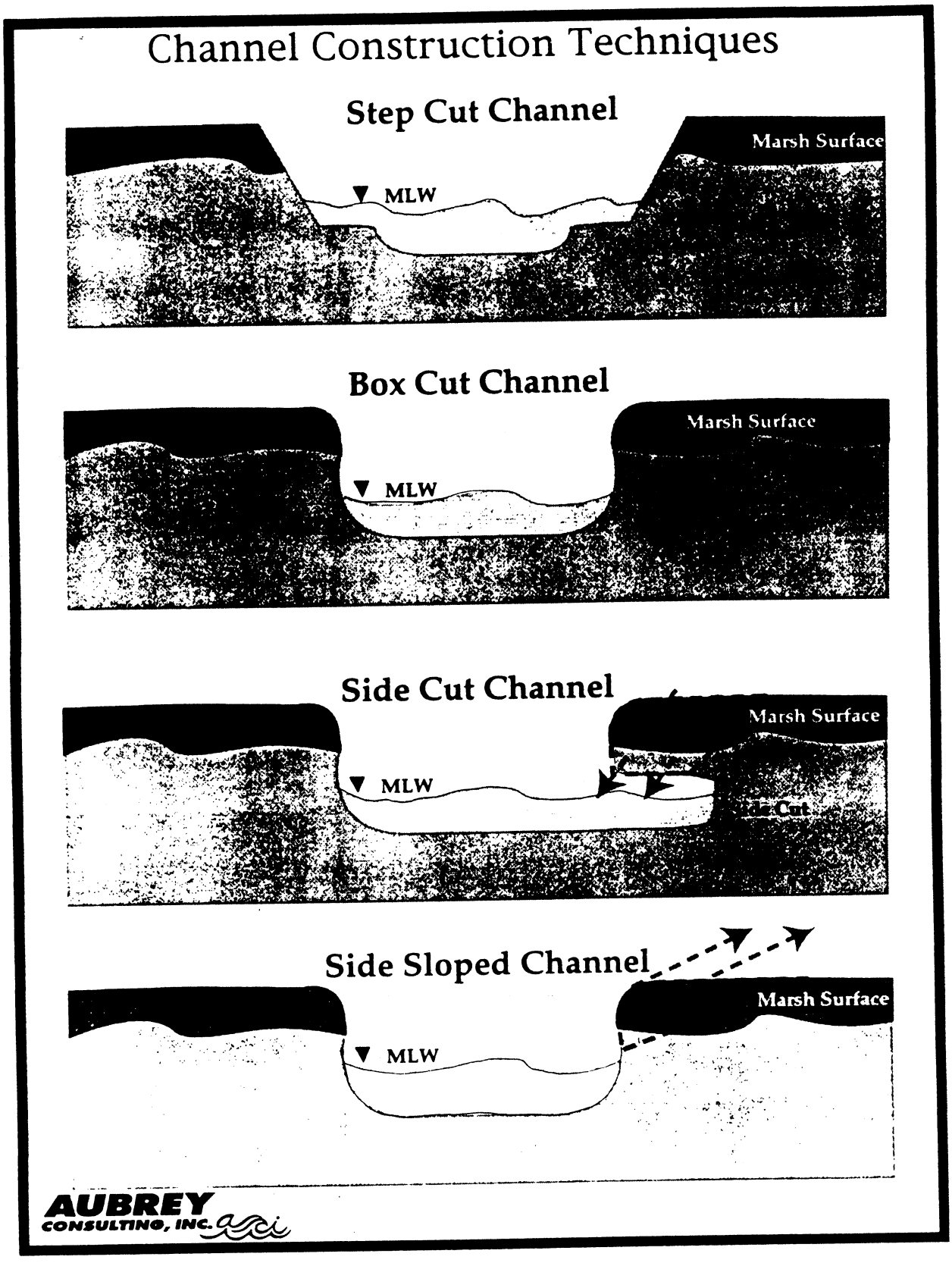

Figure 4: Channel Construction techniques evaluated during the construction process.

channel bottom which had a minimum of channel bottom nonconformity's. The side slopes evolved very quickly as the result of the channel margins cleaving in large linear sections and slumping into the channels forming small inter-tidal habitat with nooks and crannies for benthic flora and fauna.

The second channel configuration was a side sloped channel, a modified box cut. After the box cut was completed by the dredge, an excavator was used to mechanically side slope the channel sides. Placing the excess dredged material along the channel margins was not desirable because it formed a channel levee which would inhibit formation of smaller channels. Therefore, the excavated material was pushed into the channel bottom. The technique gave an artificial roughness to the channel bottom. The material was in chunks and it remained as habitat because it was not immediately flushed out of the channel once the channels were opened to tidal flows.

The third construction technique evaluated was the side cut channel. The step cut channel was initially dredged using a box cut. Once the box cut was completed the dredge made one final pass to undercut one of the channel edges (Fig. 4). The undercut channel did not immediately fall into the channel leaving a ledge waiting to collapse. As this presented a hazard to both equipment and personnel, the technique was abandoned and the ledge was pushed down using the excavator to prevent an accident.

The fourth technique evaluated was the step cut. This channel construction technique dredged the channel in two steps. The upper section of the channel was dredged wider than the bottom section of the channel. The resulting channel cross-section had a step formed which provided subaqueous habitat and limited inter-tidal habitat after the channels were opened to tidal flows.

We selected the step cutting processes as the preferred construction technique. The side slope technique required the use of additional equipment, an excavator or drag line, to form the side slopes. These are slow to move along the channel margins increasing the cost of channel construction. The step cut technique could be completed with a single piece of construction equipment, did not impose significant construction delays associated with the additional channel dredging required, and provided habitat for fishes immediately upon opening of the channel to tidal flows. An additional consideration in selecting this

construction technique was that the channel margins began to slump within several months of the opening of the channels, forming quite natural side slopes.

CONCLUSION

Use of adaptive management process helped facilitate both construction and restoration goals. It will be necessary to continue the process of following the development of the restored marshes until a satisfactory conclusion is reached. We believe the process, as illustrated by these examples, shows how a successful restoration should be carried out.

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A TAXONOMY OF SPATIAL FORMS OF MANGROVE DIEOFFS IN SOUTHWEST FLORIDA

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ABSTRACT

Patches of dead mangroves occur throughout the coastal zone of southwest Florida. These dieoffs range in size from tens of square meters to hundreds of hectares and are of concern to environmental managers and regulators. Although the causes of some of the dieoffs seem to be known, others lack obvious explanation. Both natural and human induced stressors are involved, but more information on the dieoffs would be helpful for decision making on the appropriateness restoration actions. In this presentation we propose a classification of spatial forms of mangrove dieoffs based on aerial views. we relate the classification to possible causes by using form as a guide.Characteristics such as size, shape and appearance of dead trees in a dieoff are included in the classification and it is presented as a type of taxonomic key. The literature on forest dieoffs with special emphasis on mangroves is reviewed as a context for the classification and its use. Litterfall, leaf area index, forest structure, and soil chemistry data for a declining (approaching dieoff stand type) mangrove forest are presented as well as a temporal sequence of events and conceptual model for large black mangrove dieoffs. Recommendations for future research on mangrove dieoffs are proposed based on the classification of spatial form, declining forest data, and the literature review.

INTRODUCTION

The death of a tree can be a long process that results from the cumulative impacts of a number of different stressors. For example, Franklin et al. (1987)

describe death of a Douglas-fir tree with a series of stressors positioned along a spiral that leads from a healthy tree to death. In this "mortality spiral" the tree sequentially experiences competition, suppression, defoliation, bark beetle attack, fungus infection, and finally death. Although key stressors that cause tree death often can be identified (Table 1), in some cases it is difficult to determine a single cause or the sequence of multiple causes in cumulative effects. The causal basis of large scale dieoffs of trees is especially critical since the role of anthropogenic stressors needs to be identified and mitigated (Loehle 1988, Klein and Perkins 1987, 1988, Mueller-Dombois 1986, 1987).

Patches of dead mangroves, ranging in size from tens of square meters to hundreds of hectares, occur throughout the coastal zone of southwest Florida. These dieoffs are of concern to environmental managers and regulators who need to determine the role of human impacts on mangroves. Although there are many potential causes of mangrove tree death (Jimenez and Lugo 1985), the causal basis for any particular dieoff is difficult to determine without detailed study.

In this paper a classification of the spatial forms of mangrove dieoffs in southwest Florida is presented. Possible causes of the dieoffs then are inferred by using form as a guide. A case study of a dieoff near Goodland, Florida is described with aerial photos and field data to provide perspective on the classification and the inference of form as a guide to cause. Although it is hoped that the classification can help environmental decision-makers to identify causes of dieoffs, it is not intended as a substitute for detailed study. In fact,

Table 1. Examples of tree kills.

Forest Type	Key Cause of Mortality	Reference
Temperate Floodplain	flooding	Gates and Woolett 1926, Kozlowski 1984, Schwintzer 1978, Harms et al. 1980
Temperate Uplands	insect outbreaks	Barbosa and Scultz 1987, Campbell 1979, Landsberg and Ohmart 1989, Mattson and Addy 1975
Tropical	hurricane damage	Lugo et al. 1983, O'Brien et al 1992, Boucher et al. 1990, Baldwin et al. 1995, Smith et al. 1994, Doyle et al. 1995
Northern and Temperate Uplands	air pollution	Eagar and Adams 1992, Society of American Foresters 1984, Johnson and Siccama 1983, Pitelka and Raynal 1989
Forested Wetlands	aquatic pollution	Richardson et al. 1983, Lewis 1990

recommendations are made for research that will identify causes thereby assist with the restoration of mangrove dieoffs.

STUDY SITE

Mangrove forests on the southwest coast of Florida from Wiggins Pass (just North of Naples) South to the Chatham River area were surveyed as part of this study. In this range, the forested areas observed were within an estuarine gradient from the Gulf of Mexico landwards to U.S. Highway 41 (Tamiami Trail).

MATERIALS AND METHODS

Aerial Surveys

The taxonomic key of mangrove forest types was constructed from a series of photographs taken from a Cesna 172 at 150-350 m above the forests. Flights were conducted from August 1992 to May 1997. In most cases, ground truth verification surveys were made by boat to the various dieoff sites.

Forest structure

Data for forest structure was gathered in October 1992 from 15 - 1000 m^2 quadrats in which all trees were identified to species and measured for DBH (diameter at breast height 1.35m). Height measurements were obtained as an average of the tallest tree in each of the 15 quadrats.

Leaf area index

Leaf area index (LAI) is used to quantify the one sided leaf surface area of the forest canopy per unit area of ground. The plumb-bob method (Cintron and Schaeffer-Novelli 1984) was used. A telescoping fiberglass pole was extended with plumb-bob and string above the canopy. The bob and string is slowly lowered through the canopy and the number of leaves in direct contact with the string is the LAI value. The process was repeated 50 times for each measurement date. In addition to LAI, mangrove canopy cover (CC) was evaluated from the plum-line measurements (Cintron and Schaeffer-Novelli 1984) where CC = (Total # of drops - # of drops where no leaves intercepted /

Total # of drops) X 100).

Litterfall

Litterfall collectors were constructed from PVC pipe which was joined to form a 0.25m^2 square and was supported 1.4 m above the forest floor by PVC poles at each corner. The inside of the square was lined with plastic window screening (mesh size 1 mm^2) which was gathered by a quick release tie to form a downward pointing funnel. Ten collectors were harvested monthly at each of the two black mangrove forest sites beginning in November 1992 for site 1 and from May 1993 for site 2; collections continue to date. Samples were dried to a constant weight at 70^0 C for 72 hr., and weighed to the nearest 0.1 g.

Soil Chemistry

A preliminary examination of soil chemistry was performed at the University of Maryland Soil Testing Laboratory, College Park, Maryland. Dried soil samples were ground and analyzed for Mg, P, K and Ca following the Mehlich I procedure with extracts evaluated on a Technicon Autoanalyzer 2. Soil C and N content was measured on a LECO CHN-600 Carbon/Hydrogen/Nitrogen Determinator. Soil pH measurements were performed in the field on fresh samples with a handheld meter and glass electrode using the wet paste method.

RESULTS AND DISCUSSION

Spatial Forms of Mangrove Dieoffs

A classification of mangrove dieoffs is presented as a taxonomic key in Table 2. It is based on observations of dieoffs from the air and on the ground and it uses a hierarchical series of indicators to infer cause. The classification relies on the overall principle that "form follows function" or, in this case, form follows cause. This principle has been used in other applications, especially to interpret wetland hydrology (Radforth 1977, Radforth and Bellamy 1973, Kangas 1990). The hierarchical series of indicators proceeds from shape of dieoff to size of dieoff and finally to morphology of dead trees. Fifteen different kinds of dieoffs are included in the classification with key causes ranging from hurricanes to boating accidents. The classification is actually a set of hypotheses about the causal basis of mangrove dieoffs and it is hoped that it will stimulate research while acting as a preliminary tool for environmental decision-

makers.

Three main forms of mangrove dieoffs were found: circular, linear, and irregular. circular dieoff types (Fig.1) have a sharp circular outline. The most common dieoff type encountered was a small size, usually consisting of only a few trees. Florida has the highest rate of lightning strikes in the US (Michaels et al. 1987). The landscape displays a high density of circular gaps at random in the forests (Fig. 1A) that have been positively related to lightning strikes (Craighead 1971, Fig.1B) and are known to have important functional attributes (Smith et al. 1994). Another type of circular dieoff found was larger with standing water. The rim of the dieoff is higher and the dieoff area becomes deeper towards the center (Fig. 1C). We term this type a depressional dieoff. The depressional dieoffs were found in areas well removed from human activities and are therefore considered to be a natural feature of the landscape. Depressional dieoffs were found in various stages of formation: from standing dead trees to tree stumps in water to shallow open water areas. There may also be important functional attributes associated with this dieoff type as it increases diversity in the landscape and would be an interesting area for study.

The second spatial form of dieoffs presented in the key is linear. We divided linear dieoffs into those found near a shoreline and those located away from open waterways. Mangrove forests which are directly exposed to the Gulf of Mexico experience linear erosional and depositional dieoffs caused by storm surge. Wave action may remove sand and peat, exposing root systems and occasionally completely uprooting trees. Alternatively, storm action may deposit large amounts of sediments smothering root systems. Figure 2A shows both an erosional dieoff in the foreground and a depositional (sand berm) dieoff from storm action on Kice island.

Linear blowdown dieoffs are most commonly found adjacent to large open water bodies where mangroves may encounter high wind speeds. Blowdown dieoffs are characterized by tree trunks being snapped and trees felled primarily in one direction. Figure 2B is a blowdown dieoff on Pumpkin Bay caused by a storm in March 1993. Linear dieoffs of unknown etiology are occasionally found such as the one in Figure 2D. Trees appear normal in that there are no broken trunks or branches and the soil surface has not been eroded or filled. It is hypothesize that strong wind action may have defoliated the trees to such an

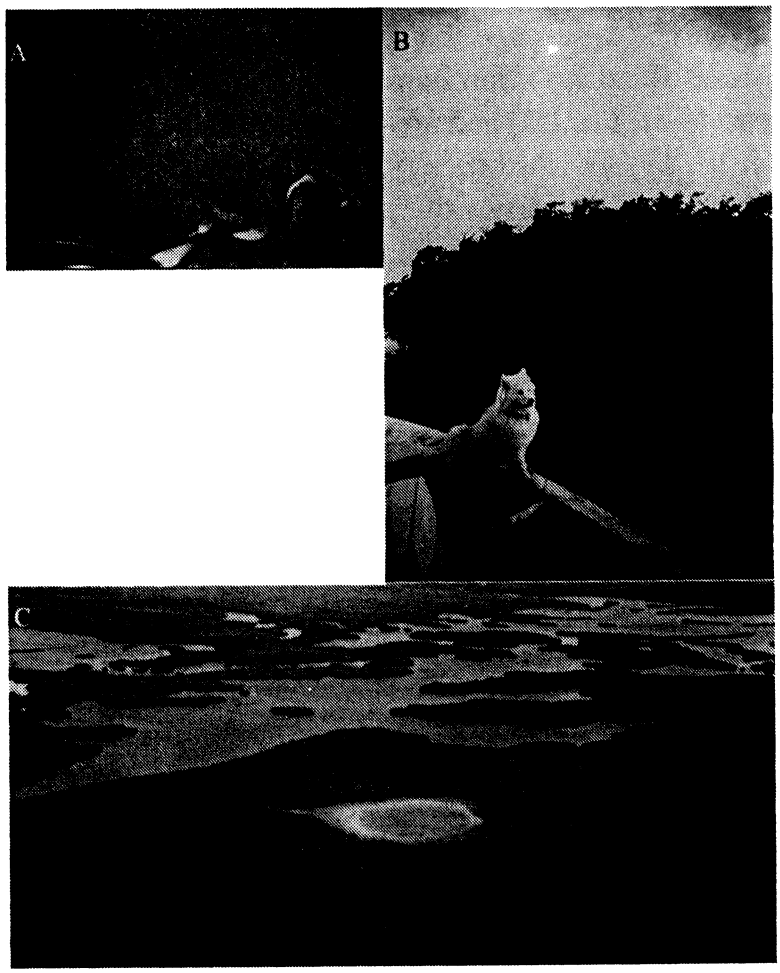

Figure 1. Circular mangrove dieoffs. A. lightning strike dieoffs as a natural landscape feature, B. ground truth verification of mangrove dieoffs, C. depressional dieoff showing standing water in center.

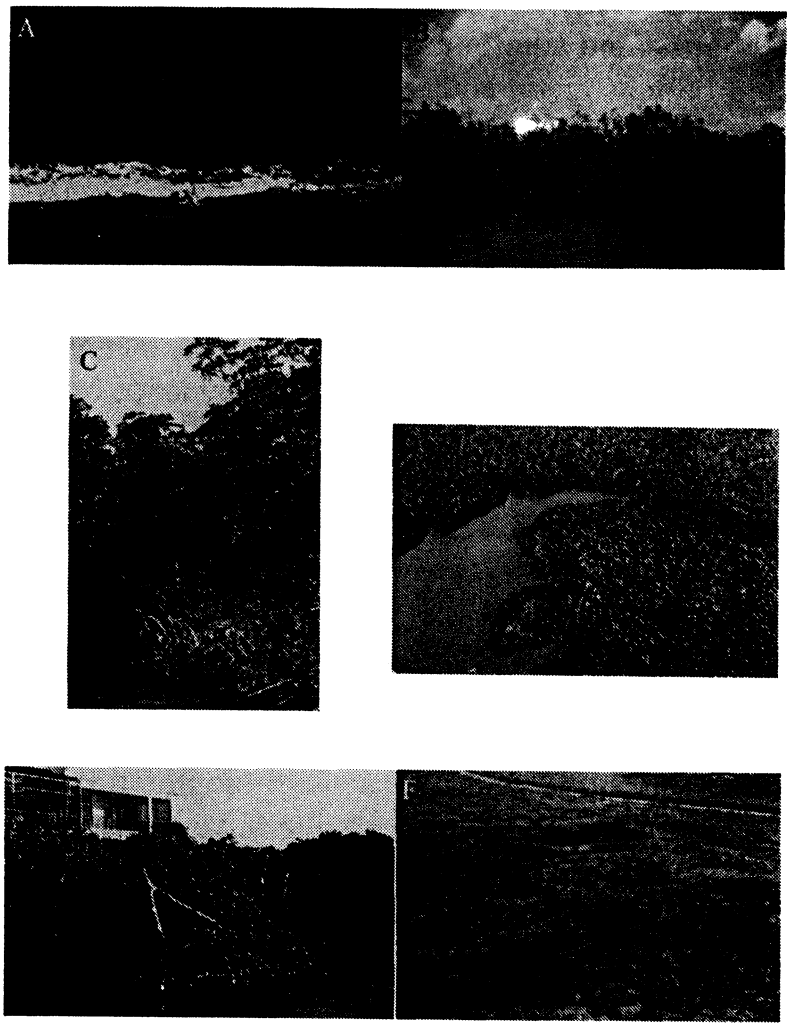

Figure 2. Linear mangrove dieoffs. A. erosional dieoff in foreground with depositional dieoff from sand berm formation, B. blowdown dieoff, C. boating accident dieoff, D. linear dieoff of uncertain etiology, E. alteration (pruning) dieoff, F. improved access (background) and at grade access (center) dieoffs.

extent that recovery was not possible.

Five linear dieoff types which can be directly attributed to human activity include boating and automobile accidents, alteration from pruning for water views and both at grade and improved access (roadways) dieoffs. Boating accident (Fig. 2C) and automobile accident dieoffs are characterized by the knockdown of trees in several different directions. The dieoff often continues into the forest and stops abruptly at a large tree. Red mangroves do not recover well from heavy pruning of the main trunk. Alteration dieoffs (Fig. 2E) are characterized by dead trees with stumps of uniform height, are a common feature of waterside home sites. Black and white mangroves often recover from severe alteration and require continual maintenance or stump removal. Figure 2F displays both at grade (foreground) and improved (road at top of photo) access dieoff types. These dieoffs are characterized by having trees removed. Fill is added to improved access dieoff sites which prevents forest recovery. At grade access dieoffs will recover if activity along the site stops.

The third dieoff form identified is large, to hundreds of hectares, with irregular shape. Dieoffs of this type are caused by hurricanes, cold storms and human impact. Frost dieoffs are characterized by standing dead trees which have dead leaves attached to the stems for several months following the freeze event. Figure 3A shows a vast expanse of white and red mangroves damaged from the freeze of January 18, 1997. Some of the trees effected are now showing signs of possible recovery with basal shoots and adventitious branching but need to be monitored. Frosts are an important structuring force between salt marshes and mangroves throughout southwest Florida. Dieoffs which have large numbers of standing dead but did not retain dead leaves are long term stress dieoffs (Fig. 3B). This dieoff type will be explained in detail below. With age, long term stress dieoff trees will eventually fall in different directions.

Large dieoffs characterized by having trees fallen primarily in one direction, within 90 degrees (Doyle et al. 1995), were caused by severe storm activity. Hurricane Andrew (August 24, 1992) caused extensive damage to the mangrove forests around Chatham River. Figure 3C shows the uniform direction of hurricane downed trees in this area nearly five years later. The forests in this area are not recovering rapidly perhaps due to the vast area which was affected.

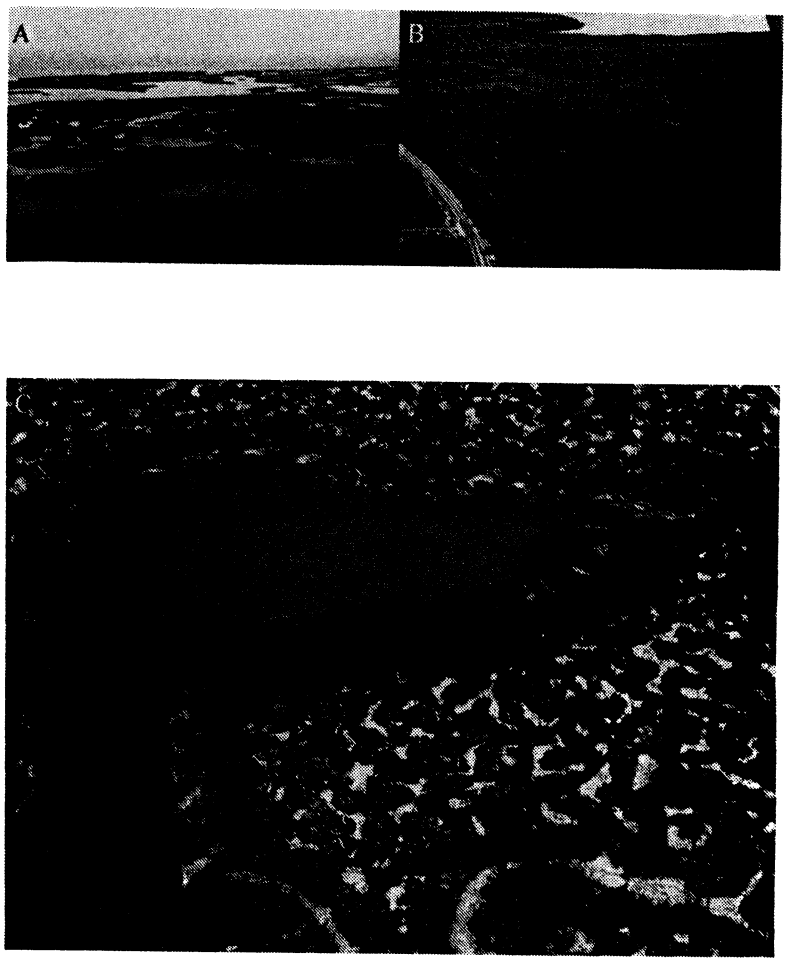

Figure 3. Large irregular shaped dieoffs. A. frost dieoff, B. Long term stress dieoff, C. storm (hurricane) damage dieoff.

Accelerated soil subsidence within large dieoff areas may present one obstacle to natural colonization or restoration efforts and should be measured.

Table 2. Taxonomic key to mangrove forest dieoffs

1. Dieoff has sharp circular outline 2
1. Dieoff non-circular.....3
2. Dieoff area small, only a few trees.....1. Lightning strike dieoff
2. Dieoff area large, < 100 m .....2. Depressional dieoff
3. Dieoff has distinctly linear outline.....4
3. Dieoff not linear in outline.....7
4. Dieoff at shoreline.....5
4. Dieoff not by shoreline.....6
5a. Dead trees with roots exposed.....3. Erosional dieoff
5b. Dead trees with mound covering roots.....4. Depositional dieoff
5c. Dead trees with trunks snapped in one direction.....5. Blowdown dieoff
5d. Dead trees with trunks snapped in more than one direction ..6. Boating accident
5e. Dead trees standing, roots appear normal.....7. Unknown
5f. Dead trees with stumps of uniform height.....8. Alteration dieoff
6a. Dieoff by roadside, dead trees fallen.....9. Automobile accident
6b. Dieoff with trees removed, fill material present ...10. Improved access dieoff
6c. Dieoff with trees removed, no fill present.....11. At grade access dieoff
7. Dieoff has an irregular outline, dead trees standing.....8
7. Dieoff has an irregular outline, dead trees fallen.....9
8a. Dead leaves remain attached for month(s) .....12. Frost dieoff
8b. Dead leaves not remaining attached for months.....13. Long term stress dieoff
9. Dieoff fallen trees in more than one direction .....14. Old long stress dieoff
9. Dieoff fallen trees primarily in one direction.....15. Storm damage dieoff

Long Term Stress Dieoff: Field Study and Conceptual Model

Large areas of basin mangrove forests in southwest Florida have experienced long term stress dieoff beginning at least since 1992 and continuing to the present, expanding into new areas all the while. One such area has been studied on Marco Island since Oct. 1992. In 1992 the forest appeared healthy and was chosen as a forest for structural and functional examination because there was little damage from hurricane Andrew. In the years that followed, the forest declined and several large areas of forest nearby collapsed. The study site lies on the edge of a dieoff and presented a unique opportunity to follow the dieoff over time. From our observations and forest structural/functional studies, three stressors have been identified as well as a temporal sequence of events leading up to the forest dieoff.

Forest structure was evaluated in December 1992 and is compared to other mangrove forest types in the area (Table 3). At this time the forest had a moderate to high stem density, indicative of a young age stand, and average basal area and tree height. The forest had the highest density of standing dead, with 29% of all individuals and 37% of the site's basal area. Since 1992 there has been considerable change in the forest and we expect to find even higher amounts of standing dead and decreased basal area when the site is remeasured in 1997.

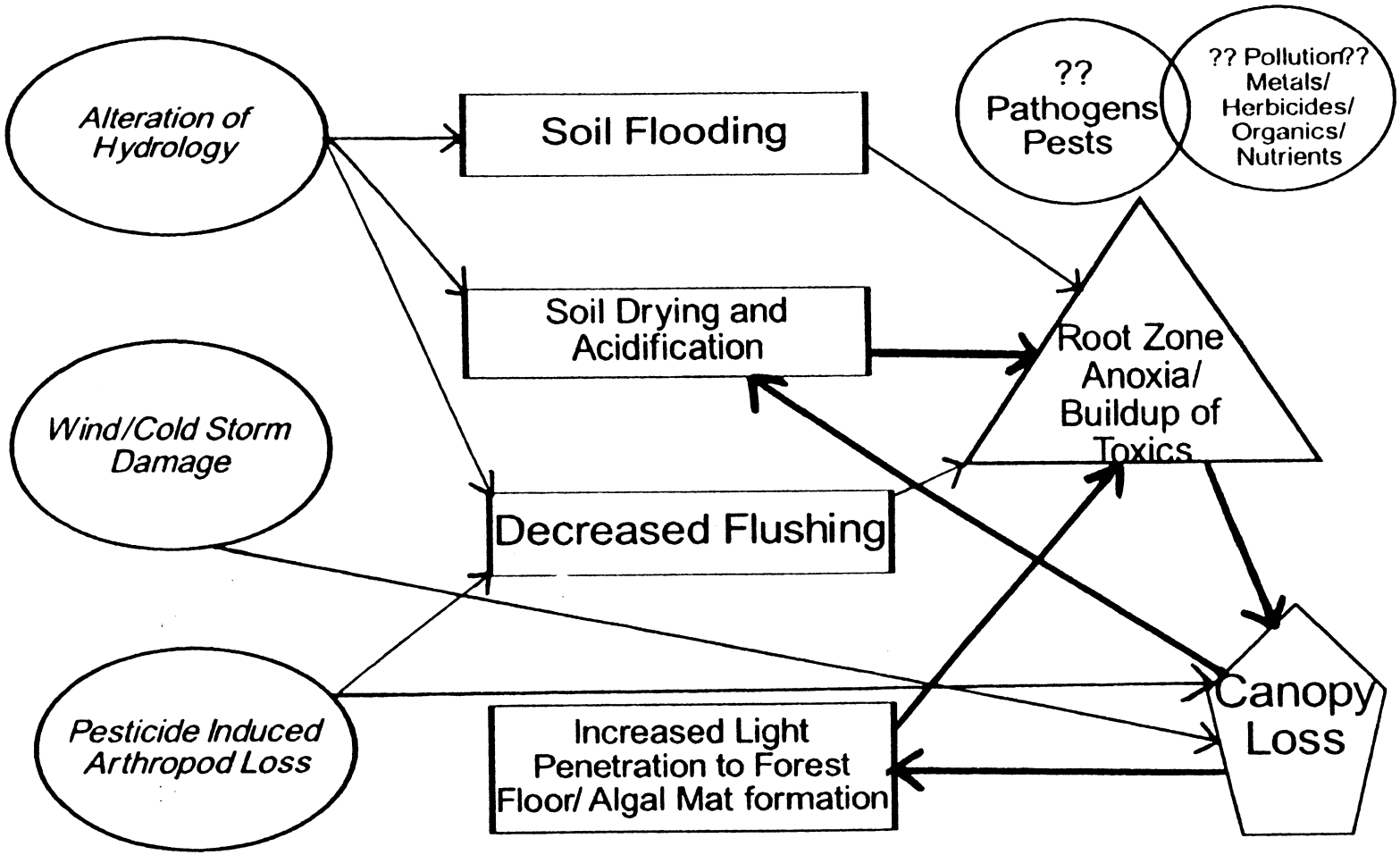

Figure 4. Causal factors, pathways and feedback loops for basin mangrove forest long-term stress induced dieoffs

Table 3. Overall comparison of Florida mangrove forests

Stand Type	Basal Area (m^2/ha)	Density (live/ha)	# of Species	Height (m)	Complexity Index* (CI)
Fringing Red Mangrove	22.5	3613	3	9.4	22.9
Overwash Red Mangrove	24.7	2580	3	9.8	18.7
Inland Black Mangrove	26.0	4500	3	9.8	34.4
Inland White Mangrove	30.6	16760	2	9.5	97.4

A conceptual model is presented (Fig. 4) which incorporates the three stressors and several effectors which bring about forest canopy loss. The model framework may be applied to all of the long term stress dieoffs known. one universally accepted stressor is altered hydrology. Roads were constructed which interrupted the natural flow of water into and out of the forest. Although culverts were placed under the roads, water movement was restricted. This creates periods of flooding as well as drying and decreases the total amount of tidal flushing. Under these conditions, soils may become more anoxic and toxic substances are formed and allowed to concentrate.

Preliminary soil analysis showed that sediments were a heavy peat with a total carbon content of 31%. Peat soils that are allowed to dry out will become acidified (Pannier 1984). Soil pH was very low (4.9 to 5.1). Low pH combined with decreased flushing may be responsible for the release and concentration of soil *N*, K, Mg and Ca to levels 3-5 times higher that other mangrove forests in the vicinity (Finn 1996). Root system stress and eventually death results, which are both followed by loss of leaves.

Leaf area index (LAI) measurements performed from August 1993 to December 1996 (Fig. 5a.) show a relatively open canopy with approximately 30-50% decrease in LAI when compared with a healthy forest (Finn 1996, Pool 1973). In addition to LAI, total litterfall was measured from November 1992 to March 1997 at a moderately effected site in the forest (Fig. 5b.) and from May 1993 to March 1997 at a moderately to severely effected site within the dieoff area (Fig. 5c.). Litterfall rates and seasonal fluctuation were lessened with increased dieoff

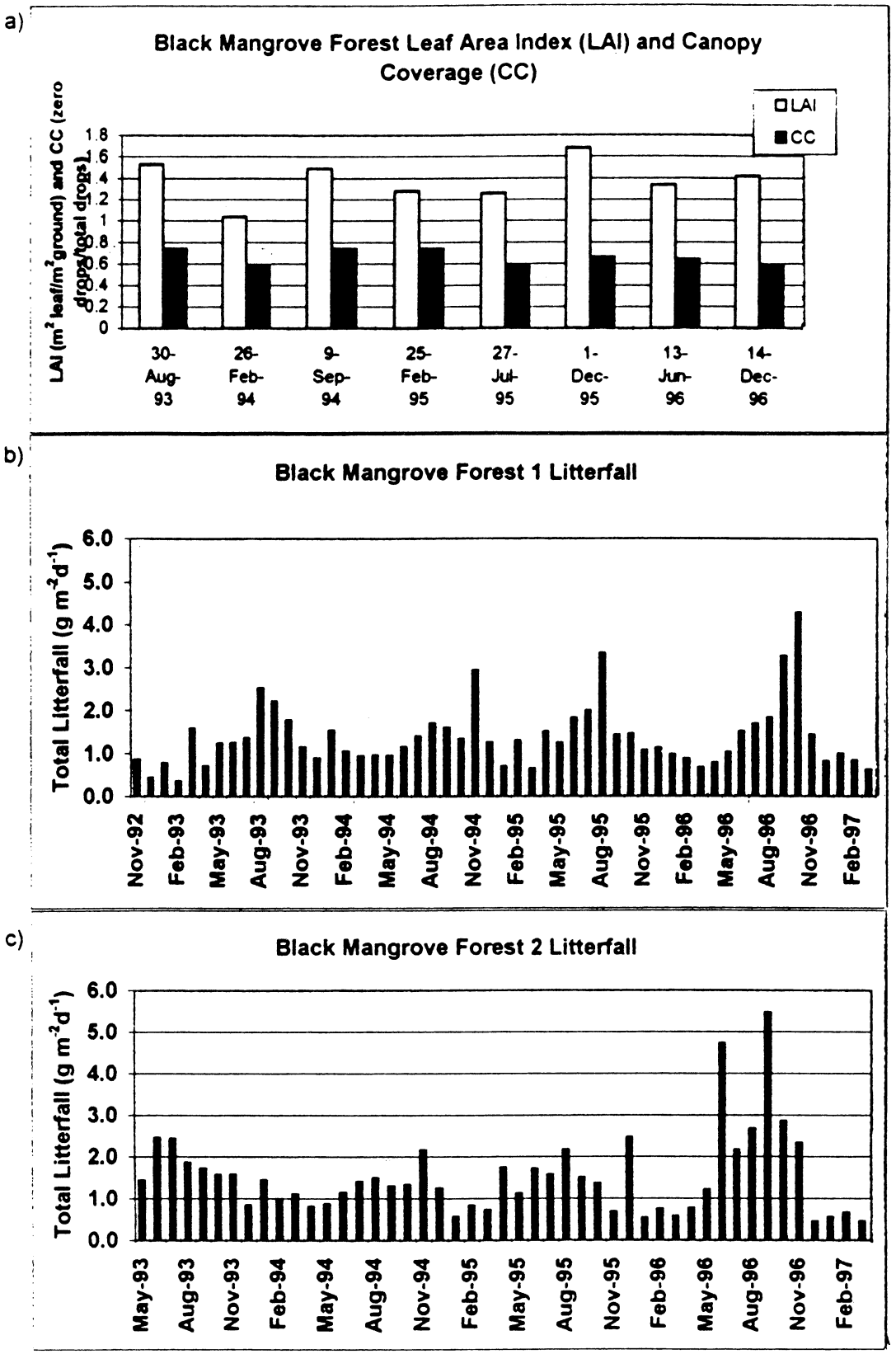

Figure 5. (a) Leaf area index and canopy coverage (b) Total litterfall in a moderately stressed black mangrove forest (c) Total litterfall at a severely effected site

severity. Reproductive litterfall was also decreased in the dieoff sites. As the dieoff progressed, spikes in litterfall were observed (Fig. 5c, 1996) from an increase in wood fall (branches) which is followed by very low litterfall rates (Fig. 5c, 1997).

Wind and cold storms may directly cause canopy loss and defoliation, increasing light penetration to the forest floor which permits the formation of green algal mats and causes soils to dry faster. Two positive feedback loops were found. One in which the mats of algae smother pneumatophores creating root zone anoxia leading to canopy loss, greater light penetration, more algal growth and pneumatophore smothering. A second loop occurs from soil drying as a result of altered hydrology or other causes of canopy loss which permits increased light penetration to the forest floor, further drying of soils, harsher root zone conditions and more loss of canopy (Fig.4).

Basin mangrove forests which are dying from long term stress are all in the vicinity of developed areas and are subjected to aerial spraying of insecticides for mosquito control. The sprays kill many non-target arthropods. Burrowing crabs are especially susceptible and the removal of crab burrows decreases soil flushing with resultant increased anoxia and toxins. Insecticide applications may also alter predator/prey guilds with the possibility of pest insect population increase.

Trees in the large black mangrove dieoff sites were found to follow a series of morphological changes. Early black and white aerial photographs clearly show a lightened area which precedes the dieoff by one to two years. The lightened image is due to initial loss of leaves from the canopy. As the dieoff progresses, increased light penetration creates green algal mats which cover pneumatophores. Pneumatophores which are not killed by the algae become bifurcated, with two growing points arising from the original single pneumatophore. There is widespread loss of pneumatophores which is followed by a dramatic loss of crown foliage. Trees which are not directly killed exhibit a partial regrowth with adventitious branches formed along the main trunk. Algal mat formation continues to smother pneumatophores, bark of the main trunk begins to peel and adventitious branches wither, killing the remaining live trees.

CONCLUSION

Mangrove dieoffs have been shown to be caused by natural forces, human induced changes and a combination of both. In most cases, dieoffs are natural events which may have positive effects. Large scale dieoffs, from factors such as frost, hurricanes or human impacts, can create a barren landscape which is slow to reforest. Several methods for evaluating mangrove forests (aerial analyses with ground truth verification, forest structure, LAI, litterfall, soil chemistry) have been demonstrated and should be employed especially in forest areas which are at risk from human activities. Study of the effects of human impacts such as altered hydrology and pesticide induced arthropod loss on plant and animal communities is needed. Additionally, rates of soil accretion and subsidence need to be monitored as increased soil subsidence may hinder forest restoration. integrated study of forest structure, function and biogeochemistry with associated animal communities is needed to gain insight into direct and indirect effects of human impacts on this complex and economically important ecosystem.

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RESTORING WEST LAKE: FISH, SHOREBIRD HABITAT, TIDAL POOLS AND MANGROVES RESTORED IN A 1,500 ACRE MANGROVE PRESERVE WITHIN DENSELY POPULATED BROWARD COUNTY, FLORIDA

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EXPANDED ABSTRACT

During the period of 1985 through 1996, the West Lake Park Project, one of the largest mangrove restoration programs in the United States, converted 607 ha (1,500 acres) of disturbed land area into productive, ecologically sound mangrove habitat. This project required the cooperative efforts of local, State and Federal regulatory agencies, the Broward County Commission through its Parks and Recreation Division, and a private developer for completion. Located in the Fort Lauderdale, Florida area, West Lake borders the Atlantic Intracoastal Waterway for 2.5 miles and is approximately one mile in width. Once a freshwater ecosystem, the area was dredged, filled, and divided in 1924-26 into more than 654 outparcels, ready for development. Using $12,000,000 in State of Florida Conservation and Recreation Lands (CARL) funds and $8,000,000 in County funds, the land was purchased and preserved. Working with the State of Florida, Broward County, the City of Hollywood, a large private development firm, and concerned environmental groups, 82.2 ha (203 acres) of mangrove re-creation was accomplished from previously disturbed Australian

pine (Casaurina spp.) habitat. The project involved obtaining public ownership of all parcels, establishing the funds to accomplish the $6,000,000 restoration program, providing scientific research for successful natural mangrove propagule establishment and significantly modifying the regulatory agencies' original mitigation design.

Broward County had concerns about the final construction scrapedown elevation for mangroves (+0.6' NGVD) in relation to natural propagation, which was the permit requirement in West Lake. To assist, Mr. Robin Lewis, President, Lewis Environmental Services, Inc. was hired to provide direction to one of the largest wetland mitigation projects ever attempted in the United States. An 1100 foot zone of 25 one-meter test plots was designed by Mr. Lewis and monitored for 3½ years. The results showed that the design scrapedown elevation should be modified slightly higher (+0.9 - 1.4' NGVD) for the entire project.

With this information, the permits were modified and the mangrove creation project was constructed at the revised elevation. Outstanding natural recruitment has occurred throughout the 2.5 mile ecosystem. In addition, a 4.05 ha (10 acre) tidal pool and mudflat zone was constructed with elevations at +0.0' to +0.5' for mudflats, -4.0' for tidal pools, and -2.0' for connecting channels. This zone has been very productive in providing a diversified feeding habitat for shore and wading birds.

Being the largest mangrove preserve in an approximate 140-mile stretch of the urban Gold Coast of Florida, West Lake is home or utilized by 91 species of fish and 135 species of birds. Public access has been integrated, designed to be consistent with the natural resource preserve, through a $10,500,00 nature center complex and canoe marina funded by Broward County.

A COMPARISON OF FISH COMMUNITIES IN RESTORED AND NATURAL SALT MARSHES IN TAMPA BAY, FLORIDA

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ABSTRACT

Four restored salt marshes and one natural marsh in Tampa Bay, Florida were sampled regularly for two years to compare fish colonization and community structure. Fifty-six species of fish (86,024 total individuals) representing 25 families were caught and released during the study period. The numerically dominant species (those species which individually comprised more than 5% of the overall catch) were Menidia beryllina (27-.), Anchoa mitchili (12%), Lucania parva (9%), Poecilia latipinna '(8-.), Cyprinodon variegatus (7%), Fundulus grandis (6%), Brevoortia smithi (6%), and Adinia xenica (5%). Peak densities typically occurred during early spring and late fall months, however, mean fish density did not change significantly over time. Marshresident species dominated the overall catch and were found in greater densities than transient and nursery species. We found no significant differences in fish density between restored and reference marshes, however, there were significant ($p < 0.05$) differences in numbers of species between sites. Species of economic importance including spotted seatrout (Cynoscion nebulosus), common snook (Centropomus undecimalus), red drum (Sciaenops ocellatus), spot (Leiostomus xanthurus), and striped mullet (Mugil cephalus) were typically found as juveniles in all marshes and in equal or greater densities at restored marshes than at the reference marsh.

INTRODUCTION

Extensive shoreline development has cost the Tampa Bay coastal ecosystem an estimated 45% of its natural salt marsh habitat over the last century. Concurrently, declines in the populations of recreationally and commercially important fish species have occurred due, in part, to the loss of critical nursery and foraging habitats which include intertidal marshes and mangrove-rimmed shorelines. These coastal communities are highly productive and valuable ecosystems since they are a source of primary and secondary productivity and provide structural refugia for resident, nursery, and transient fish and shellfish species (Gilmore et al., 1983; Rakocinski et al., 1992; Robertson and Duke, 1987; Shenker and Dean, 1979; Sheridan, 1992).

In the Tampa Bay area, coastal habitat restoration projects have been implemented since the early 1970's and continue to be constructed as part of an overall plan to restore the balance of ecosystems lost during the last decade (Tampa Bay National Estuary Program, 1997). In fact, more than 46 hectares (113 acres) of estuarine marsh have been restored or created by public agencies in the Tampa Bay area over the past five years (Treat, In press). Few studies, however, have addressed the impacts of habitat restoration, enhancement, or creation on estuarine fish communities. This study was conducted to evaluate the fish communities that colonized restored salt marshes and to compare these communities with those from a natural salt marsh system. Specifically, fish density, species diversity, and community similarity were compared between five different marshes in Tampa Bay.

MATERIALS AND METHODS

Study Locations

Tampa Bay is located in the east-central region of the Gulf of Mexico and is Florida's largest open water estuary with a surface area of approximately 1,040 km^2 (Figure 1). Historically, Tampa Bay has supported a complex and diverse

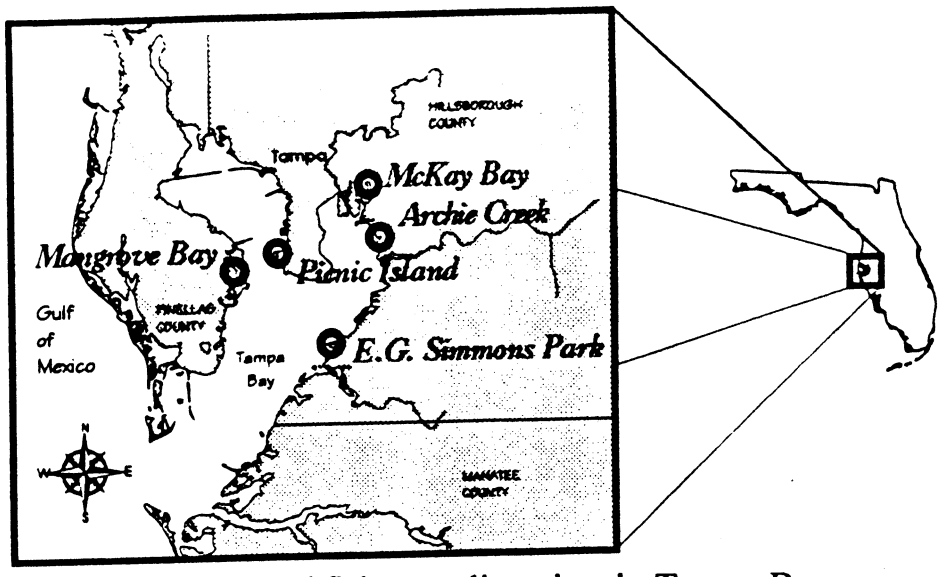

Figure 1. Locations of fish sampling sites in Tampa Bay.

assemblage of coastal habitats including mangrove forests, salters, oligohaline and intertidal marshes, seagrass beds, mud flats, and hard bottom. In recent decades, dredge and fill activities prevalent along the western and northern shores of Tampa Bay have resulted in significant losses of natural habitat. In an attempt to reverse these declines, over twenty-five marsh restoration projects have been completed in Tampa Bay during the last decade.

Five marsh systems were sampled during this study and included four restored/created marshes and one natural marsh that served as a reference site (Table 1). All four restored marshes were located in the middle and upper Tampa Bay regions and had topographical and vegetative similar to the reference marsh. Each of the marshes was cooperatively constructed by the Improvement and Management (SWIM) Program of Florida Water Management District and one of government agencies including Hillsborough County, the City of St. Petersburg, and the City of Tampa.

Table 1. Descriptions of the five marsh sites in Tampa Bay.

Site	Year Completed	Size (ha)	Salinity Range (ppt)	Total Area Sampled (m^2)
Picnic Island	1993	3.2	11-31	1,377
McKay Bay	1991	1.6	0-26	258
Mangrove Bay	1991	5.3	8-30	754
E.G. Simmons Park	1990	5.7	15-33	1,094
Archie Creek (reference marsh)	Historic	>25	2-27	558

Experimental Design

Each of the five marsh sites described in Table 1 was sampled monthly from January 1994 to December 1994. Due to logistical constraints, Picnic Island and Mangrove Bay were sampled quarterly in 1995 while the remaining marshes continued to be sampled monthly. No samples were taken in March or December 1995 from any of the five sites. A 15.2 m wide by 1.2 m high bag seine with 0.6 cm mesh was used for sampling at restored and reference sites. To control for the effects of tidal height variability, every effort was made to sample each area at approximately 0.5 m above mean low tide (MLLW). At this tidal height, platform areas adjacent to sampling stations were usually drained of water, concentrating the fish in channels where they could be collected with the seine. Sampling at each marsh was performed at fixed stations in both open water and channel areas.

Fish were enumerated alive, identified to species and released. Large catches were held in five-gallon containers until they could be recorded and released. Species of economic importance such as snook (Centropomus undecimalus), red drum (Sciaenops ocellatus), spotted seatrout (Cynoscion nebulosus), and mullet (Mugil cephalus) were measured to the nearest centimeter total length. Salinity (ppt) and temperature (^{0}C) were recorded using a refractometer and mercury thermometer, respectively, during each sampling event.

Statistical Analysis

Overall trends in fish abundances and species are presented using untransformed data. For statistical comparisons between sites, fish density (i.e., catch per square meter) values were used since the total area and number of seine hauls differed between sites. Fish density values were calculated by combining data from all stations sampled within a site and dividing by the total area (ml) sampled. Fish density data were then normalized by log + 1 transformation to meet the normal distribution assumptions for parametric analysis. A general linear models procedure (PROC GLM, SAS Institute, 1989) was used since sample sizes differed among sites. Untransformed temperature and salinity data were analyzed separately using one-way ANOVA. A Student Newman Keuls (SNK) test was used for post-hoc analyses.

To compare and describe trends in fish community structure, species similar in their functional use of the marsh ecosystem were grouped into three separate guilds: nursery, resident, and transient. Nursery species were grouped as those using marsh habitat during an important early life history stage. Resident species were grouped as those using marsh habitat during most or all stages of their life history. Transient species were classified as using marsh habitats periodically for foraging or infrequently for refuge. Cluster analysis (nearest neighbor method) was used to generate a hierarchical tree, which identified the relative similarity among sites based on abundances of each of these three guilds.

RESULTS

A total of 86,024 fish representing fifty-six species and twenty-five families were collected over the 24-month study period from the five marsh sites (Table 2). Dominant species (abundances >5% of the total population sampled), in order of greatest total abundance, were Menidia beryllina (27%), Anchoa mitchili (12%), Lucania parva (9%), Poecilia latipinna (8%), Cyprinodon variegatus (7%), Fundulus grandis (6%), Brevoortia smithi (6%), and Adinia xenica (5%). Mean number of species per sampling event was significantly different ($df = 4$, $F = 19.96$, $p = 0.0001$) among sites. Greatest mean number of species was found at Picnic Island (18.8 ±4.7 species) followed by E. G. Simmons Park (14.8 ±5.9), Mangrove Bay (11.1 ±3.3), Archie Creek (9.8 ±4.8), and McKay Bay (9.0 ±4.5).

Mean fish densities for all species combined were calculated from greatest to least as follows: McKay Bay (1.96 fish m^2) , Archie Creek (1.48 fish m^2), Mangrove Bay (1.29 fish m^2) , Picnic Island (0.89 fish m^2) , and E.G. Simmons Park (0.87 fish m^2) . These differences, however, were not significantly different between sites ($p > 0.05$). When data were segregated by guild, marsh resident fish densities were significantly greater than both transient and nursery fish densities ($df = 2$, $F = 50.15$, $p < 0.0001$) for data pooled from all sites.

For comparisons between marshes, mean densities of marsh resident fish were significantly greater ($p < 0.05$) at Mangrove Bay than Picnic Island. Mean densities of nursery species were greatest at McKay Bay (0.22 fish m^2) and

least at Mangrove Bay (0.06 fish m^2) , however, differences between sites were not significant ($p > 0.05$). Densities of nursery species were significantly different among months ($df = 11$, $F = 2.38$, $p = 0.01$) with greatest densities occurring in February and March. Transient fish densities were significantly different among sites (df 4, $F = 14.27$, p 0.0001) and were greatest at Picnic Island (0.76 fish m^2) followed by McKay Bay (0.49 fish m^2) E. G. Simmons Park (0.07 fish m^2) , Archie Creek (0.02 fish m^2) and Mangrove Bay (0.0007 fish m^2) . Densities of transient fish differed significantly between months ($df = 11$, $F = 14.27$, $p = 0.0001$) and were greatest in April than any other month.

Data for economically important species were pooled among all sites to calculate mean total length values. A total of 204 snook, 491 red drum, 75 spotted seatrout, 2,576 spot, and 2,547 mullet were caught over the study period. Snook total length values ranged from 20-590 mm with a mean length of 99.3 mm (Figure 2). Total length values for red drum ranged from 20-210 mm with a mean of 59.4 mm. Spotted seatrout total lengths ranged from 40-120 mm with a mean of 74.5 mm. Total length values for mullet ranged from 10-210 mm with a mean of 28.3 mm.

Densities of economically important fish species were analyzed separately for comparisons between sites. Mean densities of snook were greatest at Mangrove Bay (0.0052 fish m^2) and least at the natural marsh at Archie Creek (0.0009 fish m^2) . However, snook densities were not statistically different between sites ($p > 0.05$) nor between months ($p > 0.05$). Mean densities of red drum were significantly greater at Archie Creek (0.018 fish m^2) than any other site ($df = 4$, $F = 5.61$, $p = 0.001$) (Figure 3). Red drum densities also differed significantly ($df = 11$, $F = 4.58$, $p = 0.0002$) between months with greatest densities occurring in December and January at both Archie Creek and McKay Bay. Mean densities for spotted seatrout were greatest at Archie Creek (0.0014 m^2) and least at Mangrove Bay (0.0002 fish m^2). Spotted seatrout densities were not statistically different ($p > 0.05$) between sites nor between months. Mean densities for mullet were significantly different ($df= 4$, $F=2.94$, $p=0.03$) between sites with greatest densities at McKay Bay (0.1682 fish m^2). No significant differences ($p > 0.05$) in mullet densities were found between months.

Salinity values were significantly different between sites ($df=4$, $F=37.75$, $p < 0.05$) and ranged from 0.0 - 33.0 ppt for all sites combined. Lowest salinities

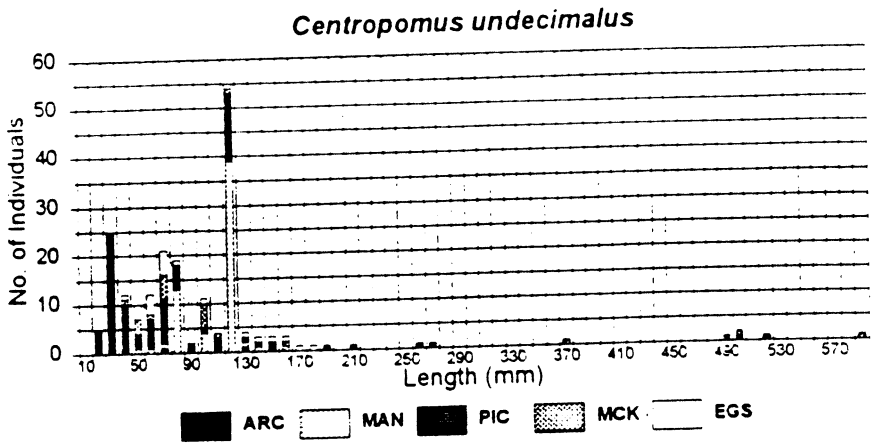

Figure 2. Length frequency distribution of snook at the five study marshes in Tampa Bay (ARC = Archie Creek, MAN = Mangrove Bay, PIC = Picnic Island, MCK = McKay Bay, EGS = E. G. Simmons Park).

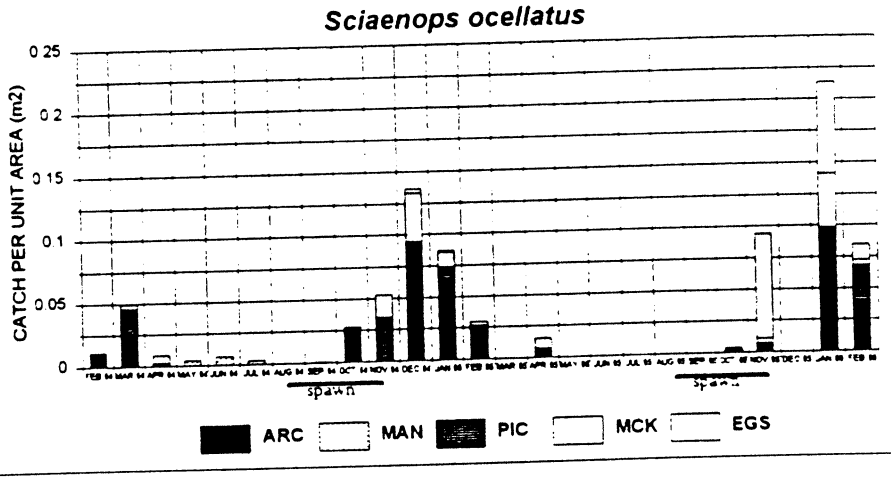

Figure 3. Mean densities of red drum at the five study marshes in Tampa Bay.

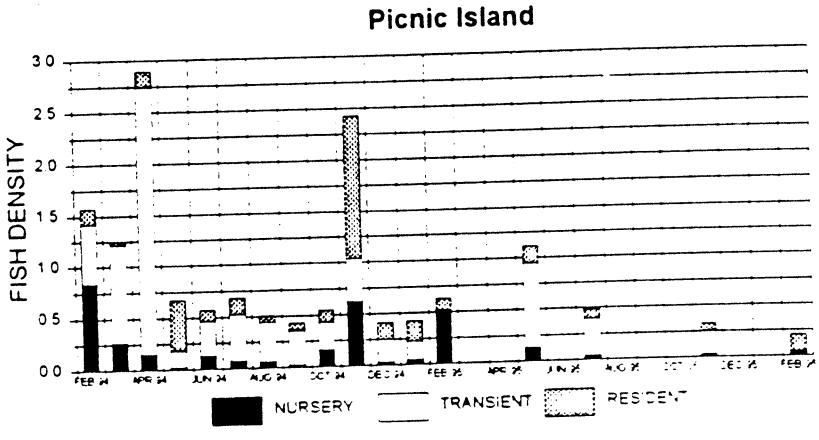

Figure 4. Mean monthly fish densities by guild for Picnic Island.

occurred at McKay Bay, followed by Archie Creek, Mangrove Bay, E.G. Simmons Park, and Picnic Island. Temperatures throughout the study area ranged between 15 - 38 'C and were not significantly different between sites during any given month (df=4, F=0.28, p = 0.89) .

Total fish densities (all species combined) were not significantly correlated with temperature but were positively correlated with salinity ($r^2 = 0.16$, $p = 0.0001$) Densities of red drum, trout, and mullet were not significantly correlated with temperature. Snook densities were positively correlated with temperature ($r^2 = 0.15$, p 0.05) and spotted seatrout densities were negatively correlated with salinity ($r^2 = 0.21$, $p = 0.04$).

Fish community similarity was measured using cluster analysis and was used to group the most similar sites based on mean monthly densities of the three guilds (nursery, resident, transient) at each site. Nearest-neighbor (Euclidean distance) values were shortest between Mangrove Bay and Archie Creek indicating that these sites were most similar in guild composition. Picnic Island and E.G. Simmons Park also were relatively similar while McKay Bay ranked between both of these two clusters.

DISCUSSION

Previous studies of natural marshes in the Gulf of Mexico have established considerable descriptions and species lists of fish communities (Subrahmanyam and Drake 1975; Subrahmanyam and Coultas 1980; Peterson and Ross 1991; Rakocinski et al. 1992). We observed similar dominant species and overall fish community structure as those found in other west Florida marshes in both the restored and natural marshes we sampled in Tampa Bay. However, we also found significant differences in the proportions of resident, nursery, and transient species among the five study sites.

Marsh resident species comprised more than 50% of the total catch at three of the four restored marshes (Mangrove Bay, E. G. Simmons Park, and McKay Bay) and the reference marsh. These four sites are all located in relatively protected, quiescent (low wave energy) areas away from the open waters of Tampa Bay; conditions typically favored by many marsh resident species.

Conversely, Picnic Island is located in the middle reaches of the bay and is exposed to large-scale, semi-diurnal tidal currents that are capable of transporting a wide variety of larval and juvenile fish species into the bay from offshore spawning areas in the Gulf of Mexico. Transient fish densities comprised approximately 55% of the catch at Picnic Island (Figure 4). We believe that the reason Picnic Island had significantly greater numbers of species and greater densities of transients than the other marshes was a result of its geographic location with respect to this tidal transport phenomenon.

Cluster analysis further suggested that sites most similar in fish guild composition were also most similar in salinity regime and proximity to the open waters of the Bay (Figure 5). Sites were clustered according to similarity in their densities of resident, transient, and nursery fish species. Mangrove Bay and Archie Creek appeared to be the most similar (had shortest Euclidean distances), had nearly identical mean salinities (mesohaline), and were both relatively protected marsh systems located several hundred meters from the open waters of Tampa Bay. Picnic Island and E. G. Simmons Park had consistently higher mean salinities with little to no freshwater influence entering either marsh system. McKay Bay had a relatively low mean salinity value and fell between these two distinct pairs (clusters) of sites.

Despite an apparent clustering of sites with similar salinity regimes, only a weak, positive trend was observed between total fish abundance and salinity. No significant trends were observed between total fish abundance and temperature. The lack of significant correlations with either salinity or temperature suggests that many species within the fish community may be more influenced by seasonal emigration and immigration patterns than by physicochemical factors. Examples of this phenomenon occurred with snook, red drum, seatrout, and mullet whose abundances were either unrelated or only weakly correlated with trends in temperature or salinity. Earlier observations by Subrahmanyam and Coultas (1980) in north Florida marshes suggest that breeding patterns, recruitment, and seasonal succession of dominant species have a more profound influence on seasonal changes in fish community structure than do physical factors. Similar findings were described by Potter et al. (1986) in an estuarine fish assemblage in the United Kingdom.

Economically important species such as juvenile snook are colonizing and

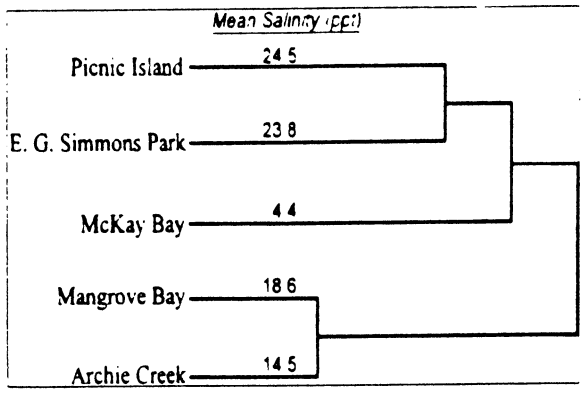

Figure 5. Cluster diagram and mean salinities of five marsh sites in Tampa Bay.

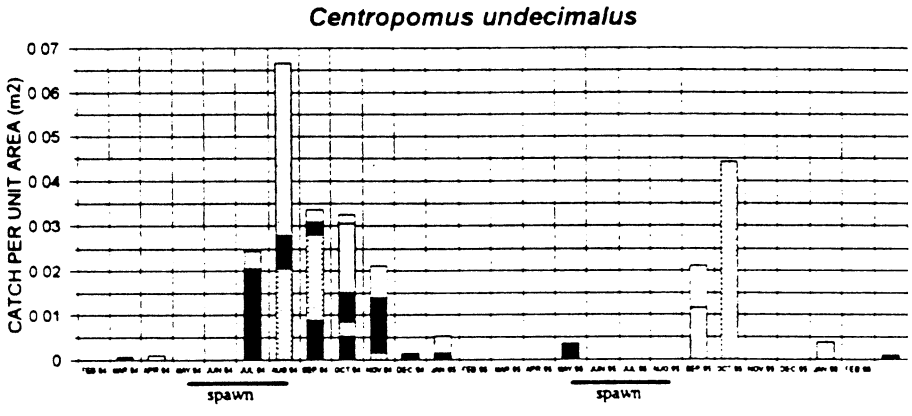

Figure 6. Mean monthly snook densities at the five study marshes in Tampa Bay.

residing in both restored and natural marshes during periods following peak spawning activity (Figure 6). Snook appear to reside in the marshes we studied for a duration of approximately 2-7 months. Similar observations were made by Gilmore et al. (1983), who found juvenile snook ranging in size between 10-174 mm with residence times ranging from 2-5 months in salt marsh habitat on the east coast of Florida. Peak snook densities in both restored and natural marshes at our study sites occurred between July and November following reported peak spawning periods between May and August. Based on age estimates developed by McMichael et al. (1989) for snook in Tampa Bay, snook entering the restored marshes in this study appear to range in age from approximately 27 days to 8 months. The average age of snook for the five marshes we sampled would be approximately 6 months based on an average measured length of 99.3 mm.

Juvenile red drum densities were greatest in December and January and followed reported spawning periods which typically occur between August and November (Peters and McMichael, 1987). These authors found high percentages of juvenile red drum in backwater areas (compared to seagrass beds); habitats which were similar to the tidal creeks created at many of the restored marshes in our study. Peters and McMichael (1987) also reported that peak abundances of juvenile red drum in backwater areas occurred at sizes between 30 to 60 mm. We observed similar peaks in abundance for red drum ranging in length from 20 to 70 mm. Spotted seatrout densities peaked between May and November following a spawning period that typically occurs between May and July.

Other comparisons of restored (or mitigated) and natural marshes have not always been favorable. A study by Chamberlain and Barnhart (1993) found that fish use of a mitigation salt marsh in Humboldt Bay, California was not similar to a nearby reference marsh. Moy and Levin (1991) found fewer Fundulus abundances, lower organic content, and lower Spartina stem densities in man-made marshes than in natural marshes. Even though the average age of the four restored marshes we sampled was less than 3 years old, we found significantly greater numbers of fish species at two of the four restored marshes than at the natural marsh and no significant differences in fish density between restored and natural marshes. Our observations of greater numbers of species at restored marshes suggest that these created habitats are serving as a functional resource

to the local fish community. Several authors (LaSalle et al. 1991; Rulifson 1991; Whitman and Gilmore 1994) have reported similar findings.

We believe that the rapid and consistent presence of resident, nursery, and transient fish species at these four restoration sites provides strong evidence that salt (and oligohaline) marshes are a limited and critical habitat in the Tampa Bay ecosystem. The colonization of created marshes by a wide variety of juvenile fish also suggests that these sites are capable of attracting and supporting early life history stages of economically important species. Continued efforts to create, restore, and enhance coastal marsh habitats should have a measurable' positive effect on stressed fisheries' species in the Tampa Bay ecosystem.

ACKNOWLEDGMENTS

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PROTECTING SEAGRASSES IN TAMPA BAY

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** Editors Note **
Figures 1 - 4 can be found in the Appendix on pages 238 – 242.

ABSTRACT

Seagrass prop scarring was monitored at Cockroach Bay and Fort Desoto Aquatic preserve. Protected areas were set up at both sites to warn boaters of the presence of shallow seagrass beds. Sites were also set up to restrict boaters from seagrass beds. The marking of seagrass beds does reduce the number of prop scars. Damage to seagrasses has declined, especially after the net fishing ban and after members of the community have had time to educate boaters on the necessity of protecting seagrasses. Areas that previously had seagrasses, but lost them due to boat damage, can recover if boat traffic is kept out of the area. The process of marking seagrasses so that boaters are aware of the shallow conditions lessens the amount of damage to seagrasses over time.

INTRODUCTION

The governments of Hillsborough County and Pinellas County, both on the West coast of Florida, established protective measures for seagrasses in 1992 and 1993 respectively. Both governments established rules and regulations for the protection of seagrasses that arose from community discussions, workshops, government agency input, fishermen, scientific task forces, and other concerned

community members. Some of the discussions for the protection of the seagrasses began as early as 1991. The primary concern was the apparent destruction of seagrasses by boats as their propellers cut swaths through the seagrasses. Prop scar damage was apparent from aerial photographs and from ground observations of the seagrass beds. Concern was raised that if the destruction continued, would it reach a point in which the seagrasses would no longer be able to recover and would be lost forever?

The mission for both government agencies was to establish a means to protect the seagrasses, a method to enforce protection, and an instrument to verify whether or not the protective measures worked. Although both governments took different approaches, the results were similar and the lessons learned can be applied to other seagrass beds.

HILLSBOROUGH COUNTY

The seagrass beds of concern in Hillsborough County are located in Cockroach Bay, a pristine bay located in the southeastern portion of Tampa Bay, and connected to Tampa Bay. Cockroach Bay has seagrass beds primarily of *Thalassia testudinum* and *Halodule wrightii*, surrounded by a maze of small mangrove islands.

In 1992 rules were established by the Environmental Protection Commission of Hillsborough County which set up protective measures for the seagrasses of Tampa Bay, especially those of Cockroach Bay. In Cockroach Bay four recovery areas were designated to be protected from boat propeller damage by limiting boat movement into the seagrass beds. The four recovery areas were:

Area 1: located at the north west exit from Cockroach Bay along the channel to Tampa Bay, this small approximately 1.2 ha(3 acre) site was designated as a zone where no boats were allowed.

Area 2: the largest of the zones that borders on Tampa bay with three entrances to Tampa Bay and two entrances to the channel. This zone was designated as an area that boats could enter during medium to high tides, but not at lower tides. Special markers were placed showing the boater the tide levels.

Areas 3 and 4: these zones were located on both sides of "Hole-in-the-wall" pass, a channel which allowed boats to pass from the western portion of Cockroach Bay to the main body of Cockroach Bay. These were denoted as zones where no boats were allowed.

The county EPC and the county commission set up a program to evaluate the effectiveness of the seagrass protection measures. Using pollution recovery funds, the county funded a police patrol of the area to educate boaters on the protection zones and to issue citations for those who damage seagrasses. The county also funded two other projects: a four year study of aerial photography to evaluate seagrass loss or gain, and research into the methods of recovering seagrass loss. Later a full-time park manager was funded to patrol the area and to educate boaters.

PROCEDURE

Seagrass damage to Cockroach Bay was evaluated by using a series of aerial photographs. Two types of aerial images were used:

1. High altitude imaging on a 1 to 2,400 scale, taken twice a year.

2. Low altitude (detailed imaging) using 1 to 600 scale, taken four times a year.

All images were vertical and taken at low tide with a low sun angle to prevent glare on the water surface. The images were digitized and analyzed via computer for analysis of the aerial extent of seagrass beds, the length and number of prop scars in each of the recovery areas, and changes evident over time.

Measurements were made in the water on a monthly basis to compare photographic detail with actual in-field measurements. The ground truthing verified the accuracy of the aerial photographic techniques.

RESULTS 1993 to 1995

Seagrasses were measured in Cockroach Bay for the four recovery areas from January 1993 to January 1995. Measurements were made of the square footage of seagrasses and the linear feet of prop scars, comparing data from 1993 to 1995. Area #2 was divided into the main body of seagrasses and the entrances to the area as entrances A, B, C, D, and E. The results are as follows:

	Sq. Ft seagrasses in 1993	Sq. Ft of seagrasses in 1995
Recovery Area #1	4,780	4,780
Recovery Area #3	241,288	241,253
Recovery Area #4	371,709	362,260
Area #2: Entrance A	106,722	106,722
Area #2: Entrance B	226,805	226,805
Area #2: Entrance C	392,280	391,726
Area #2: Entrance D	129,117	129,117
Area #2: Entrance E	88,184	88,184
Area #2: Middle	5,542,953	5,400,599
Totals:	7,103,838	6,951,446

The total square feet of seagrasses lost to propeller scarring during the two year period was 152,392 square feet.

The amount of scarring in each area during the two year period was:

	Linear feet scarring (1993)	Linear feet scarring (1995)
Recovery area #1	0	0
Recovery Area #3	2,447	2,482
Recovery Area #4	4,297	13,746
Area #2: Entrance A	476	476
Area #2: Entrance B	60	60
Area #2: Entrance C	1,086	1,640
Area #2: Entrance D	1,303	29,553
Area #2: Entrance E	237	68,152
Area #2: Middle	1,460	143,814
Totals:	11,366	259,923

Analysis: Areas 2 and 4 were the most heavily scarred during the two year period. Entrances D and E, coming directly from Tampa bay into Cockroach bay, were the most heavily damaged entrances. Inside entrance E, the seagrass destruction was complete. All of the seagrasses were destroyed.

RESULTS 1995 to 1996

From January 1995 to September 1996 continued evaluation of prop scar damage was conducted. The same techniques were used as before, i.e., high altitude aerial photography and detailed (low altitude) photography. In addition to the images of Cockroach Bay, additional images were obtained and analyzed for Little Cockroach Bay and the seagrasses in Tampa Bay in front of Cockroach Bay and Little Cockroach Bay. The results of the analysis for this

period are as follows:

1. In all of the restricted zones only 6 feet of new prop scars were noted.

2. Most of the new scars were in Tampa Bay in front of Little Cockroach Bay.

3. In area #1, a boat restricted zone, 1.37ha(3.4 acres) of new seagrasses grew in 1996 where very few were growing before. The new grasses were *Halodule wrightii.*

4. Mangroves and seagrasses were outlined on the computer images in order to produce a computer map. The following data were computed for the entire area:

Area	Square feet	Acreage
Seagrasses	35,700,000	819.56
Mangroves	57,800,000	1,326.91

ANALYSIS

A detailed analysis of prop scar damage at Cockroach Bay, Little Cockroach Bay and Tampa Bay was conducted during the time period of this project. Very little new prop scar damage was noted during this time period. During the first three years of observations in Cockroach Bay, prop scar damage had occurred on a regular basis, declining somewhat in 1994 from pervious years. However, in the time period of July 1995 to August of 1996 very little scarring was observed. The following data were compiled from aerial photographs and ground truthing:

Location	Linear feet of old scars	Linear feet of new scars
Cockroach Bay	48,747	6

Little Cockroach Bay Plus Tampa Bay	21,682	2,000
Tampa Bay in front of Cockroach Bay.	4,029	700

The total linear feet of prop scars in the aquatic preserve is 77,164 linear feet or about 0.73ha(1.8 acres).

The data clearly indicate that the rate of prop scar damage has dramatically declined, especially in Cockroach Bay where most of the signs are posted to warn boaters of the presence of seagrasses. The decline in prop scar damage to the seagrasses may be attributed to:

1. The Cockroach Bay Users Group (CBUG): This group has been very active in posting signs and educating boaters of the need to protect seagrasses. Apparently their educational efforts have been paying off.

2. The commercial fishing net ban, effective in 1994, may have reduced the number of fishing boats using the bay. In prior years, it had been noted in several aerial photographs that there was circular prop scar damage in the shallows of Cockroach Bay. This damage was most likely done by commercial net fishermen as they encircled a school of fish. No damage of this type has been seen since the net ban went into place.

CONCLUSIONS FOR COCKROACH BAY

Four years of seagrass studies and analysis at Cockroach Bay lead to several conclusions:

1. Marking of seagrass beds does reduce the number of prop scars.

2. Damage to seagrasses has declined, especially after the net fishing ban and after members of the community have had time to educate boaters on the necessity of protecting seagrasses.

3. Areas once containing seagrasses, but lost them due to boat damage, can recover if boat traffic is kept out of the area.

FORT DESOTO AQUATIC PRESERVE

Pinellas County has designated an aquatic zone at the southern tip of the county as the "Fort Desoto Wetlands and Aquatic Habitat Management Area." The aquatic zone has abundant meadows of seagrasses and is used extensively by recreational boaters and fishermen. Due to the number of boats using the area there has been considerable damage done to the seagrasses by boat propellers. Damage to seagrasses by propellers can be widespread in aquatic habitats and it may take up to five years for damaged seagrasses to recover once a prop scar has occurred.

Taking an active approach to protect the seagrasses, Pinellas County developed the "Fort Desoto Park Wetlands and Aquatic Management Ordinance." The ordinance established the Fort Desoto Park Wetlands and Aquatic Management Area to provide for the preservation, recovery and expansion of marine habitats. The intent of the ordinance was to minimize the extent of damage to seagrasses by propellers by restricting boats from areas where seagrass damage is likely, by requiring:

1. "slow down/minimum wake zones".

2. posting and monitoring the management area.

3. providing a public education forum about the value of seagrasses.

The monitoring program has been established for a five year period beginning in March, 1993.

The specific objectives of the monitoring program were as follows:

1. Establish and post "Boating Restriction Zones" and "Seagrass Caution Zones". Boating Restriction Zones will restrict operation of internal combustion engines to specifically marked "Navigation Channels" where slow

speeds and minimum wake will be required.

2. Internal combustion engine use will be allowed in Seagrass Caution Zones but shall be utilized to avoid damage to seagrasses. Penalties of up to $500.00 and 60 days in jail may be levied for violation of this ordinance. In addition, restoration may be required.

3. A monitoring period will be established for a minimum of a 5 year period to determine the success or failure of the adopted restrictions. During this period aerial photography will be performed on a quarterly basis (later changed to once a year) for purpose of seagrass mapping. Digitization and photo interpretation of the aerials will be performed to determine revegetation rates, additional damage or variations in seagrass communities.

4. The county will establish a public education program to provide for the distribution of information to citizens about the value of seagrasses and the restrictions placed upon boats in the Fort Desoto Area.

5. The management area will be buoyed, posted or marked by the County in accordance with Chapter 16N-23, Florida Administrative Code.

The purpose of this project relates to objective #3 from above. Aerial photographs were taken for the County by commercial aerial photography companies. The film was analyzed by Hillsborough Community College. Computer images were made from the photographs and ground truthing was used to compare the images with the prop scars in the water in the aquatic management area.

Five sets of aerial photographs were used for this analysis. The first set was taken in March 1993, and was used as the baseline because the boat restriction signs were placed in the field at that time. The second set of photographs was taken in the fall of 1993. A third set was taken in the summer of 1992 and has also been used for correlations with the other sets. A fourth set of photographs was taken in the fall of 1994. The final set of photographs were taken in October/November of 1995.

When comparing the photographs from March 1993 to the photographs of the

fall of 1993 it was noted that the rate of scarring was lower in seagrass zones that were designated for boat restrictions and for boat cautions than in unmarked zones. The increase in scarring was computed as a 15.3% increase in scars for the boater restricted zones and an 18.7% increase in scars for boater caution zones. The non-restricted zone had an increase in scarring of 84.7%. The data shows that the presence of signs in the water, whether caution or restrictive, has the effect of reducing prop scar damage. In the photographs from the fall of 1994 we again noted that there was scarring in the zones, but that the rate and percentage of damage had declined.

PROCEDURE

Hillsborough Community College was contracted to analyze three sets of aerial photographs taken over the Fort Desoto Aquatic Management Area for prop scar damage to the seagrasses in 1993. Three sets of photographs were ordered by the department with flight times in July 1992, March 1993 and November 1993. The photographs were taken on nine by nine inch positive transparency film by two separate aerial photographic companies. A fourth set of photographs was taken in the fall of 1994 and in 1995 using the same type of film but was taken under more optimal conditions. The requisite conditions for aerial photographs are as follows:

1. Low tide to reduce the amount of water in the column above the seagrasses for better visualization.

2. Low sun angle preferably between 8:00 am and 10:30 am to reduce sun glare on the film.

3. A consistent altitude and focal length so that all of the images are close to 1 to 2,400 scale.

The following procedures were used for the mapping and computer documentation of seagrasses and prop scars in the Fort Desoto Management area:

1. The Department of Environmental Management photos were assembled into a mosaic and used to create paper overlays with markings for each identifiable type of grass. Each subunit was digitized for accurate mapping of the seagras ses and the prop scars. The subunits were assembled to create a computer map of the entire management area at Fort Desoto.

2. The computerized information is in an AutoCAD format.

3. Seagrass scars were identified individually on computer images. The images were set in layers, with one layer as a base map, another layer showing the seagrasses andanother layer showing the prop scars. Each year a new layer was added for new scars for that year. In the seagrass areas, the "bare" areas were distinguished fromthe grass areas, and every effort was made to differentiate different species of grass beds from one another (where possible). The grass beds were computed in squarefoot units. The prop scars were calculated in linear feet.

4. Aerial photographic information was rectified to the base map to correct any parallax deficiencies. This was verified by "ground truthing" the images for accuracy of scale and orientation.

5. The seagrass scars and the bare areas in the grass beds were also measured in the field to ascertain the accuracy of the photographs.

Ground truthing was conducted each year to assure that the images and measurements from the film were accurate. The ground truthing method allows for sufficient data to account for:

A. Regrowth of seagrasses into prop scars.
B. A biological review of the scars to see what, if anything, is growing in the scars.
C. Sand movement within the scars.
D. The ability to note new scars as they appear in time from the baseline study.

6. The Departmental of Environmental Management has provided three sets of photographs (Summer 1992, Spring 1993 and Fall 1993), a fourth in the

spring of 1995 that was taken in the fall 1994, and a fifth taken in the fall 1995.

DELINEATION ZONES

The Department of Environmental Protection established three types of zones in the aquatic preserve. The establishment of the zones was designed to study the effects of different aspects of boat traffic on the number of scars that would be produced. The zones were as follows:

1. Boat Restricted: boats are allowed in this zone, but they cannot be under power by an internal combustion engine. Drifting, poling, sailing or electric motors can be used to move boats in this area. Signs are posted on piles and buoys to delineate the area.

2. Seagrass Caution: boats may enter this area under power but must be operated in a manner that does not damage seagrasses. Signs warn of "shallow water" and to "use caution".

3. Non-restricted Zone: in this zone no restrictions are placed upon boaters.

The three types of zones allowed for a comparison of boat activity, i.e. scars, from one type of zone to another.

DELINEATION OF AREAS

The aquatic preserve area was divided into six aquatic areas by the Department of Environmental Protection. Each aquatic area was designated as a boat restricted zone, a caution zone, or a non-restricted zone. The areas are as follows:

1. Area I: this area surrounds Indian Key, a National Wildlife Refuge.This area is designated as a boat restricted zone.

2. Area II: this area is bordered by the "Main Channel" to the north; to the

east by the channel in front of the Skyway approach; to the west by Cabbage Key and Isla Del Sol; and to the south by a line drawn from Pardee Key to the east. This is a non-restricted zone.

3. Area III: this area is south of area II and is bordered to the south by Bunces Pass channel; to the west by Cabbage Key; and to the east by drawn just to the west of Tarpon Key. This is a caution zone.

4. Area IV: this area surrounds Tarpon Key and is a boat restricted zone.

5. Area V: this area is in Mullet Key Bayou and is a boat restricted zone.

6. Area VI: this area surrounds Bonne Fortune Key and extends up to the channel at Conception Key. This is a boat caution zone.

7. Another zone was added to the study area in 1994. This site is located northwest of Bunces Pass and is controlled by the State of Florida

SEAGRASS SQUARE FOOTAGE

We measured the square footage of the seagrasses at each of the areas listed above. The available square footage of seagrasses was based on the aerial photographs taken in the spring of numbers are as follows:

Location	Square Feet	Acres
Area I	548,812	12.6
Area II	2,702,098	62.2
Area III	4,637,528	106.4
Area IV	1,801,377	41.4
Area V	3,341,351	76.7

Area VI	4,844,994	111.2
Total	17,884,160	420.5

The special area northwest of Bunces Pass has 2,781,667.4 square feet of seagrasses. This is about 25.86(63.9 acres). This data is not included in the above because this site is not under the control of Pinellas County.

PROP SCAR DAMAGE PROCEDURE

The main focus of this study was to determine the damage caused by boats to the seagrass beds around the Fort Desoto Aquatic Preserve and to compare damage from one zone to another. The extent of prop scar damage was determined in several different ways. The first method was to measure the scars directly from the aerial photographs. First we divided the maps of the preserve into polygons for ease of measurement. After determining the scale of the photographs, each scar was measured along its length and placed in a data base for computational purposes.

The second method was to draw each of the scars on a computer generated map of the preserve. This was accomplished by tracing each scar onto the computer screen and then measuring the length of the scars from the computer (AutoCAD) files. Both methods proved to be compatible and to be accurate in comparing one method to the other (see the section below on inaccuracies). This method provided us with a cross check of the data.

ANALYSIS OF PROP SCAR DAMAGE

Figure #1 compares each area of the preserve from sets of photographs taken in the spring of 1993, the fall of 1993, the fall of 1994 and the fall of 1995 to the number of scars and the linear feet of scars. Figure #2 compares the damage

done to seagrasses in restricted zones, caution zones and non-restricted zones from the four sets of photos.

Most of the data are fairly consistent with the concept that as time passes more and more scars should appear at each area as boat traffic increases and the rate of healing is very slow. The studies at Cockroach Bay have found that prop scars may take from three to five years to heal, therefore, we would expect prop scar damage to be cumulative. This turns out to be true as we analyzed the photographs. Virtually all of the scars noted on the 1993 photographs were also present on the 1994 photographs. However, the photographs from 1995 show that some scars have begun to heal and do not show up on the images. The following data depict scars that have healed over:

Area I: one scar at 122 linear feet

Area II: two scars for 810 linear feet

Area III: none

Area IV: none

Area V: two scars for 1,634 linear feet

Area VI: three scars for 4,080 linear feet

Special area: none

In 1993 and 1994 the following was noted: when the data from one type of zone was compared to another it was found that the use of signs to warn boaters about seagrasses and boat restrictions worked. Apparently boaters are noticing the signs and heeding the warnings, despite a lack of enforcement in the area. In other words, the amount of new scarring in the restricted and caution zones is much less than that in the non-restricted zones. Since the signs were placed in the field in March 1993, the data in figure 3 compares the seagrasses lost to scarring for the three sties from 1993 to 1994 and again from 1994 to 1995.

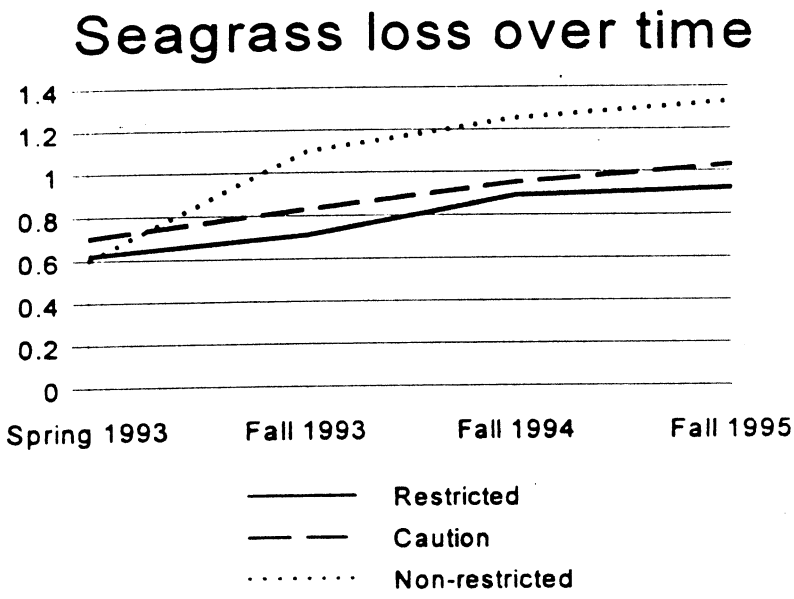
The data indicate the square feet of scarring in all areas dropped from one year to the next. The most dramatic decrease in scarring was for the non-restricted zone, which has continued to drop for several years. This area received considerable scarring in 1993, but the rate dropped off to less than the rate of scarring in the other zones. In fact, the rate of scarring appears to be dropping off for all three types of zones. This would tend to indicate that boaters are being careful in all seagrass zones whether they are marked or not. In addition, seagrass damage may be less due to the commercial net ban. The circular pattern of scarring that was seen in previous images is no longer seen. Circular patterned scarring was determined to be the result of fishermen setting their nets to trap schools of fish.

As in 1993 we were able to measure a number of the scars in the field in the spring, the summer of 1995, and the summer of 1996. When the field measurements were compared to the measurements on the photos, they were shown to be very accurate. In other words, ground truthing confirmed the accuracy of our other measurements.

It is often useful to compare the amount of scarring in an area as a percentage of seagrasses lost. This shows actual footage of seagrasses that have been lost to boats (the average width of a scar at Fort Desoto was computed in the field to be 12 inches). We can compare the data for the spring and fall of 1993, the fall of 1994 and the fall of 1995 photos as follows:

Per cent of seagrasses lost per zone as a per cent of the total seagrasses in each area at the time of measurement (from Figure #4)

Zone loss	1993 Loss	Fall 1993 Loss	1994 Loss	1995
Restricted	0.62%	0.71%	0.89%	0.92%
Caution	0.70%	0.83%	0.95%	1.03%
Non-restricted	0.60%	1.10%	1.25%	1.33%



The data in the chart and the graph show the rate of scarring was more rapid in the early years of the study, but has begun to level off as time has passed. This may mean that boaters are becoming accustomed to the markers and are being more careful. The same events are occurring in Cockroach bay. The more educated the boater, the less damage there is to the seagrasses over time.

The loss of seagrasses as a percentage of the whole shows that the rate of loss was greatest in the non-restricted zone in comparison to the others. The total cumulative loss for all of the zones is 185,431 square feet of seagrasses, or about 1.73ha(4.28 acres). The amount lost from 1994 to 1995 was 17,921 square feet, or about 0.22ha(0.54 acre), a clear reduction in the rate of scarring from earlier years of the study.

The seagrasses in the special area northwest of Bunces Pass did not show any new prop scars on the 1995 photographs.

CONCLUSIONS FOR FORT DESOTO

The establishment of caution and restricted zones for the seagrasses at Cockroach Bay and at Fort Desoto appears to have been successful in reducing

scarring. The rate of scarring in both sites was less in 1995 than in previous years. The process of marking seagrasses so that boaters are aware of the shallow conditions lessens the amount of damage to seagrasses over time.

AGROECOLOGY RESEARCH FOR SUSTAINING SUBTROPICAL PRAIRIE ECOSYSTEMS ON BEEF CATTLE RANCHES OF FLORIDA

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ABSTRACT

Florida has experienced rapid growth and development in both agricultural and urban sectors in recent decades. This growth has resulted in significant modifications of landscape and land use patterns. For example, much of what was once native subtropical prairie system is now managed for cattle production. The University of Florida, Archbold Biological Station, and South Florida Water Management District, are conducting a multi-disciplinary research program to understand prairie ecosystems, and to develop environmentally and economically sustainable cattle production practices. The initial phase concentrated on developing an understanding of how cattle ranching affects a native prairie ecosystem. The field study site is the Buck Island Ranch, an operating cattle ranch located on a 4,000 ha wet prairie. Florida cattle ranches provide habitat for a diverse array of avian species, including wetland-dependent and migrating birds. In 1996, more than 36 species of wetland dependent birds were recorded at the ranch. Avian surveys have identified 46 bird species in summer pastures and 54 in winter pastures at Buck Island Ranch. Additional research from a four-year study indicated that 50% and 30% of nematode populations in pasture land were herbivores and bacterivores, respectively. Vegetative cover in representative summer pasture was dominated (82%) by bahia grass (*Paspalum notatum*), followed by carpet grass (*Axonupus affinis*), bluestem (*Andropogon glomeratus*), and bermuda grass (*Cynodon dactylon*). Mean concentration of total P in runoff from a wetland, a native prairie, a semi-improved, and an improved pasture ranged from 0.24 to 0.82

mg/L. Runoff from improved pasture had the highest total P concentration and runoff from the wetland had the lowest. Organic N and soluble reactive P were the predominant forms of N and P in runoff.

INTRODUCTION

More than 5 million hectare(ha) of range and pasture land are used for beef cattle production in Florida(Campbell and Fraisse, 1997). Florida ranks tenth among all states, and second among states east of the Mississippi River, in beef production (Graetz and Nair, 1996). In 1995, Florida maintained 1.15 million beef cows, and total cash receipts from cattle and calves were $290 million (FDACS, 1996). Florida has experienced rapid growth and development in both agricultural and urban sectors. For example, currently 750 people move into Florida per day. This unprecedented growth has resulted in dramatic modifications of landscape and land use patterns. Two important consequences are (1)conversion of native land to urban and agricultural land, and (2)increase in land use intensity in areas already utilized by urban and agricultural sectors. In the agricultural sector, development and expansion of citrus, vegetable, and sugar industries combined, with a favorable environment for cattle production, resulted in intensification of land use by the cattle industry and its expansion into subtropical prairie ecosystems of south and central Florida.

Competition for natural resources by urban and agricultural sectors creates the need for developing cattle production practices that are economically and environmentally sustainable. In addition to their economic importance, Florida cattle ranches are a buffer zone between the high environmental impact urban/residential ecosystem areas and the native ecosystem areas. In a concerted effort to develop sustainable cattle production practices, the University of Florida, South Florida Water Management District, and Archbold Biological Station are conducting multi-disciplinary research at MacArthur Agro-ecology Research Center(MAERC). This goal is being pursued through a multi-phase research and education effort. The initial phase concentrated on developing an understanding how cattle ranching affects a native prairie ecosystem. This paper highlights the following aspects of MAERC research: 1) the value of cattle ranches as wildlife habitat, 2) nematode community structure in a cattle ranch ecosystem and its comparison to conventional

cropping, 3) vegetation species composition and production in cattle ranch, and 4) the impact of various pasture types on offsite water quality.

STUDY SITE

The field studies site is MacArthur Agro-ecology Research Center (MAERC) located at Buck Island Ranch near the town of Lake Placid in south central Florida. Related research is conducted at the University of Florida (UF) main campus in Gainesville and its participating Research and Education Centers in Immokalee and Ona. Buck Island Ranch is a working 4,000 ha wet-prairie cattle operation managed by Archbold Biological Station under a 30-year lease grant from the John T. And Catherine D. MacArthur Foundation.

Research is conducted in three field laboratories and selected sites throughout MAERC (Figure 1). Field laboratory 1 is composed of a 110 ha bahia grass (*Paspalum notatum*) pasture and an adjacent 63 ha citrus orchard. Field laboratory 2 is composed of a 197 ha summer pasture and a 275 ha winter pasture. These pastures are typical of ranch lands utilized by Florida cattle ranchers during the summer (rainy months) and winter (dry months), respectively. Field laboratory 3 is representative of a cross-section of four types of native ecosystems that has been converted into cattle ranch.

MATERIAL AND METHODS

Value of Cattle Ranch Agro-ecosystem as a Wildlife Refuge

1. Abundance and diversity of avian populations on various ranch habitats:

The abundance and distribution of birds on various ranch habitats was determined with a series of fixed radius point counts (Ralph et al., 1995). Two hundred eighty-nine census points were established in three major habitat types: grasslands, forests, and wetlands. Grasslands were divided into improved pastures and native range. Each point was recorded twice during the winter and twice during the spring. In winter 1997, each point was recorded twice between 1 January and 15 February. Breeding season censuses were conducted between

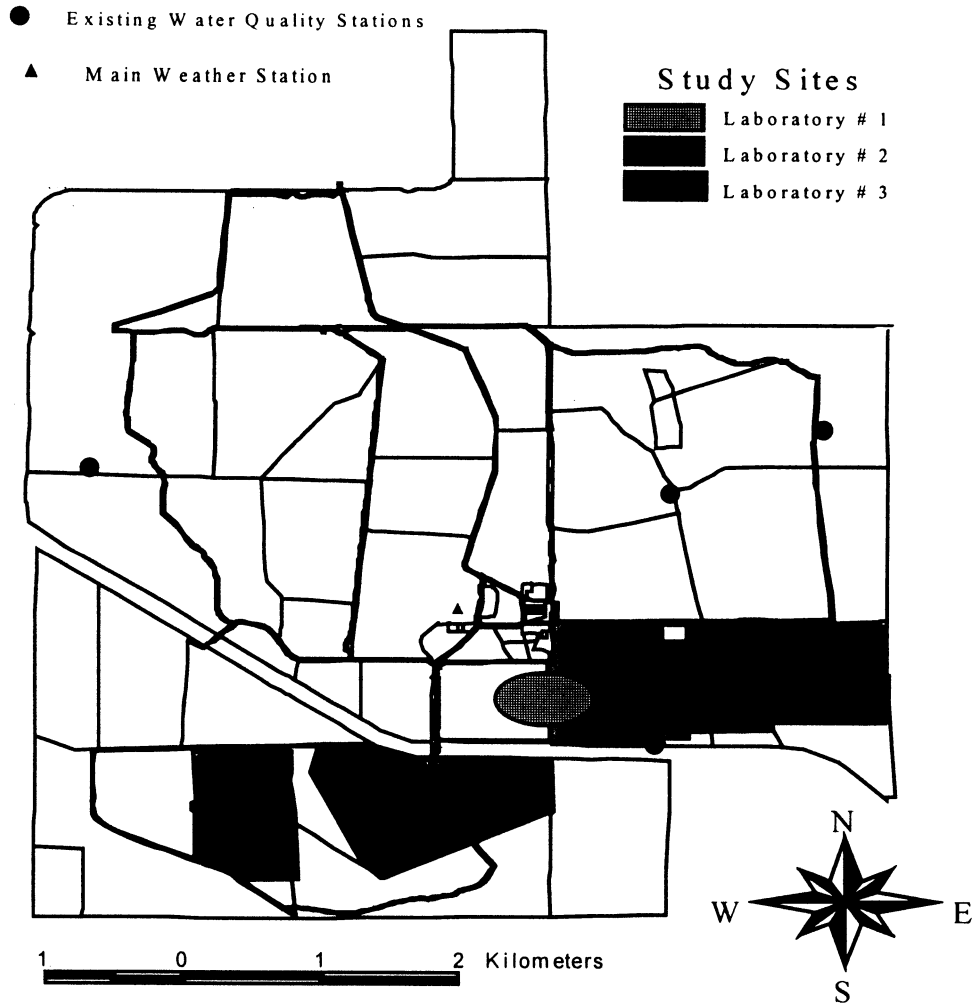


Figure 1. Location of the three field laboratory sites at Buck Island Ranch

15 April and 1 June of each year, which covered the height of the breeding season for species that can be recorded with this technique.

2. Value of cattle ranch as winter habitat for migrating birds:

To evaluate whether the cattle ranches are important wintering areas for migrating birds that breed farther north, comprehensive surveys of the winter abundance and distribution of Eastern Phoebes (*Sayornis phoebe*) and American Kestrels (*Falco sparverius*)in Buck Island Ranch are conducted

annually. These two bird species use central Florida as their winter territories and are currently experiencing declines in their breeding range in northeastern United States.

3. Significance of cattle ranches as habitat for wetland dependent birds:

Drainage ditch systems form a network of linear wetlands across the agricultural landscape of central Florida. For wading bird species that often move over vast areas of Florida in the course of their annual cycle these linear wetlands may be extremely important for their continued survival in Florida.

A 25-km transect was established adjacent to a series of "main" ditches on the Buck Island Ranch. The transect covered all major ditch habitats across the ranch and passed through a diversity of other habitats. During 1996, the transect was recorded four times on consecutive days in the middle of each month. The transect was covered by driving slowly on an all-terrain vehicle, counting all wading birds and other large birds seen in the ditch or within 100 m of the ditch. Relative water depths in the ditches were recorded at 13 staff gauges dispersed along the survey route.

Nematode Community Structure in Two Agro-ecosystems (Cattle Ranch and Citrus Grove)

Nematodes play a significant role in nutrient recycling within the agro-ecosystems. A 4-year study was conducted at field laboratory 1 to investigate the community structure and temporal distribution of nematodes in soils under pasture and citrus agro-ecosystems. The nematode sampling began in December 1991, and continued for 4 years on a bimonthly basis. Five permanent sites for sampling were established in a citrus grove and adjacent pasture located in field laboratory 1 (Figure 1). Each sample consisted of six soil cores (2.5 cm diameter x 20 cm deep) from a 3 m x 3 m pasture plot or around a single citrus tree. Nematodes were extracted and counted from 100 cm^3 soil sub-samples, using a standard sieving and centrifugation procedure (McSorley, 1997).

Forage Species Composition and Biomass Production in a Typical Florida Cattle Ranch

Forage species composition and biomass production in two typical pasture types utilized as Florida cattle ranch was investigated at field laboratory 2 (Tanner and Christman, 1996). This field laboratory consisted of a 275 ha winter pasture and a 175 ha summer pasture. The winter pasture is located on soils with poor internal drainage. The vegetation on this site is composed of a mixture of native grasses along with some bahia grass. This type of pasture is usually used for winter and spring (dry season) grazing by cows immediately after calving and during breeding. The summer pasture is located on well drained soils, is planted to bahia grass, and is used for summertime (wet season) grazing of cattle. These two sites will be used during the next phase of development of sustainable cattle production practices for a replicated experiment that will evaluate the effect of cattle stocking rates on ecological indicators such as forage composition and biomass production. Eight experimental plots have been established on each one of the summer and winter pastures.

Nine 4 m X 4 m exclosure cages were installed along a transect at 100 m intervals in the center of each of the 16 experimental plots. Dominant plant species within each exclosure were measured from a 0.5 m^2 plot. At the time of the exclosure cage installation, two additional 0.5 m^2 plots with vegetation similar to those inside the cage were designated. All vegetation in one of the exterior plots was clipped and weighed. The difference between the biomass in the outside plot at a later date and that of the plot in the exclosure were assumed to represent the forage production. The second plot outside the exclosure was clipped during the next sampling period. Forage use and production within each of the plots were calculated. Initial sampling in both summer and winter pastures was conducted during the last week of July 1995. Additional samples were collected in October-November 1995, January 1996, and March 1996 in both pastures.

Impact of Pasture Type on Runoff Water Quality

Research at field laboratory 3 focused on runoff water quality from four types of pasture ecosystems used for cattle production in Florida. These

ecosystems are a wetland, a native prairie, a semi-improved, and an improved pasture. The wetland pasture is composed of a mosaic of wetland communities, including saw grass and broad-leaf marsh species. The native prairie pasture is dominated by native grassland species. The semi-improved pasture has been planted extensively in bahia grasses, but contains substantial wetland areas. The improved pasture is dominated by bahia grass(Campbell and Graetz, 1997). Trapezoidal flumes were installed at each one of the above four sites for collection of surface water runoff. Each flume was equipped with automatic water samplers, where programmable data loggers triggered the samplers based upon flow volume and hydrograph geometry. Weather information was collected by automated meteorological stations. Runoff samples were analyzed for total Kjeldahl nitrogen (TKN), Ammonia (NH_4-N), Nitrate (NO_3-N), soluble reactive phosphorus (SRP), and total phosphorus (TP).

RESULTS AND DISCUSSIONS

Value of Cattle Ranch Agro-ecosystem as a Wildlife Refuge

1. Abundance and biodiversity of avian population on various ranch habitats:

Preliminary results were collected during the winter of 1997. The number of bird species per census point averaged 4.1, 4.6, and 3.8 in forests, wetlands, and grasslands, respectively. The number of individuals per point averaged 4.8, 4.9, and 4.6 in the three land types respectively.

Species composition between the three habitats differed substantially. Palm Warblers (*Dendroica palmarum*), Yellow-rumped Warblers (*D. coronata*), Blue-gray Gnatcatchers (*Polioptila caerulea*), Red-winged Blackbirds (*Agelaius phoeniceus*) and Cardinals (*Cardinalis cardinalis*) were frequently seen in the forest. Common Yellowthroats (*Geothlypis trichas*), Savannah Sparrows, Swamp Sparrows (*Melospiza georgiana*), Sedge Wrens and Red-winged Blackbirds were typical birds of the wetlands. Eastern Meadowlarks (*Sturnella magna*) and Savannah Sparrows were the most common birds in grasslands. Sedge Wrens, Palm Warblers, and Red-winged Blackbirds were also relatively

common in grasslands. These data allow some tentative exploration of the possible consequences of various land management decisions. Native range pastures (4.4 species, 5.8 individuals) averaged significantly more species and individuals per point than bahia grass pastures (3.4 species, 3.8 individuals). This primarily resulted from the higher density of Savannah Sparrows (1.8 vs 0.7 per point) and Sedge Wrens (0.7 vs 0.25 per point) per point in native range pastures than in bahia grass pastures. The density of Eastern Meadowlarks was quite similar between native range (1.1 per point) and bahia grass pastures (1.2 per point).

Table 1. Mean number of individuals observed at census points in native range pastures and bahia grass pastures.

Species	Native Range	Bahia Pasture
	(# per point)	
Savannah Sparrow	1.8	0.7
Sedge Wren	0.7	0.2
Eastern Meadowlark	1.1	1.2
TOTAL INDIVIDUALS	5.8	3.8
TOTAL SPECIES	4.4	3.4

2. Value of cattle ranch as winter habitat for migrating birds:

In 1997, 139 Eastern Phoebes were found across the Buck Island Ranch. They tended to be located near wetlands and permanently wet drainage ditches. In addition, 32 American Kestrels were found across the ranch. Kestrels tended to be found in more open areas but often where there were suitable perches from which to forage.

The high number of Eastern Phoebes and American Kestrels found on Buck Island Ranch suggest that cattle ranches in central Florida are important wintering areas for these species. An important implication of this finding is

that several million hectares of ranch land in Florida can support a large proportion of the northeastern population of these species. If these lands are converted to other land-uses, there may be significant ramifications regarding the status of these species in eastern United States.

3. Significance of cattle ranches as habitat for wetland dependent birds:

In 1996, 36 species of wetland-dependent birds were recorded, with seven species accounting for 66% of the observations. Great Egrets (21%) were the most abundant species recorded. The endangered Wood Stork, threatened White Ibis, Little Blue Heron and Great Blue Heron each accounted for 7 to 8% of the birds. Comparisons of mean number seen between months were significant for the above five species. All species were most common during two wet periods for that year, one in January and another in July-August.

Wading bird use of Buck Island Ranch was highly variable among months. Wading birds moved onto Buck Island Ranch when it was wet, but their numbers decreased as the area dried. It appears that when central Florida ranches are wet, many of the wetlands in southern Florida have water levels too deep for many wading birds to feed, so they move into central Florida and onto ranches such as Buck Island Ranch. The network of ditches and isolated wetlands on central Florida ranches represent important refuge for wading birds during high-water times. The continued maintenance of healthy wading birds populations in Florida may in part depend on maintaining feeding opportunities on ranches during high water periods in the more natural areas.

Nematode Community Structure in two Agro-ecosystems (Cattle Ranch and Citrus Grove)

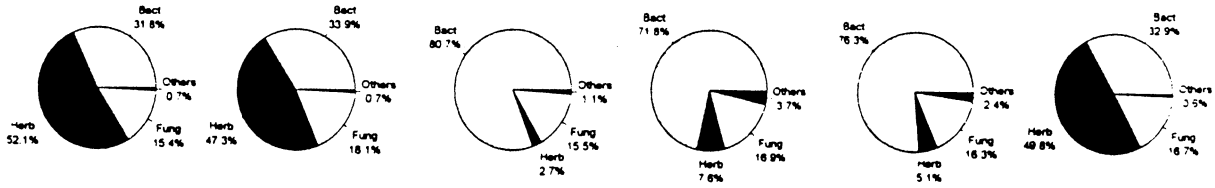
Data collected during 1991-1995 at field laboratory 1 indicated that in the citrus grove 76.3% and 5.1% of the nematodes were bacterivores and herbivores, respectively (Figure 2.a)(McSorley, 1997). In the pasture 49.8% and 32.9% of the nematodes were herbivores and bacterivores respectively. Predominance of bacterivores in the citrus grove and herbivores in the pasture establishes a linkage between the predominant nematode group and the type of agro-ecosystem. Fungivore nematodes comprised 16.3% and 16.7% of soil nematode community in the citrus grove and pasture respectively, indicating a lack of habitat preference by this group of nematodes. In the pasture 15.4% and 18.1%

of nematodes were fungivore in May and December, respectively (Figure 2b). In the citrus grove 2.7% and 7.6% of the nematodes were herbivores in May and December, respectively (Figure 2.c)(McSorley, 1997).

Figure 2.a
Citrus ans Pasture Ecosytem, 1991-1995.

Figure 2.b
Pasture samples, 1991-1995.

Figure 2.c
Citrus samples, 1991-1995.



Citrus Pasture May December May December

Figure 2. Nematode community structure in a citrus grove and a pasture.

Forage Species Composition and Biomass Production in a Typical Florida Cattle Ranch

Vegetation composition in the winter pasture was dominated by bahia grass (*Paspalum notatum*) at 42%, followed by carpet grass (*Axonupus affinis*) at 16%, and bermuda grass (*Cynodon dactylon*) at 14%, with field Paspalum (*Paspalum Laeve*) and various sedges comprising the remainder. Somewhat similar patterns were observed in the summer pasture, which was dominated by bahia grass (*Paspalum notatum*)at 82%, followed by carpet grass (*Axonupus affinis*) at 10%, and minor proportions of bluestem (*Andropogon glomeratus*), bermuda grass (*Cynodon dactylon*) and vasey grass(*Paspalum urvillei*)(Tanner and Christman, 1996). Mean forage standing crop in the summer pasture was 6000 kg ha^{-1} in July, but decreased regularly to 2240 kg ha^{-1} in March, because forage production failed to keep up with forage use during this period. Mean standing crop in the winter pasture increased from 3900 kg ha^{-1} in July to 4800 kg ha^{-1} in March, because very few cows were kept in the winter pasture plots from July to March. Consequently forage production exceeded forage consumption during this period.

Impact of Pasture Type on Runoff Water Quality

In 1995, mean concentrations of Total P (TP) in runoff from four pasture types ranged from 0.24 to 0.82 mg/L (Campbell and Graetz, 1997). Runoff from improved pasture had the highest TP concentration (0.82 mg/L) and that from the wetland had the lowest (0.24 mg/L). In 1995, mean concentrations of total Kjeldahl Nitrogen (TKN) ranged from 3.67 to 5.33 mg/L. Runoff from wetland had the highest TKN (5.33 mg/L) and that from the wet prairie had the lowest (3.67 mg/L). Total phosphorus was more sensitive to land use than TKN. Soluble NO_3-N and NH_4-N were a small fraction (6% to 23%) of TKN, indicating that organic forms of N were the predominant N fraction in the runoff from the four pasture types. In contrast, a large fraction of TP (33% to 78%) was soluble reactive phosphorus. Evaluation of the temporal distribution of nutrient concentrations indicated that N species were relatively uniform in the runoff from the wet prairie, semi improved and improved pasture. However, runoff from wetland (Marsh)showed a flush for TKN, NH_4-N and TP during the spring and remained constant during the rest of the year (Campbell and Graetz, 1997). The flush was perhaps due to export of dried decomposing vegetation from the wetland following the dry winter. These data, soon to be published in complete form, will be useful in quantifying the effect of manipulating cattle management practices on water quality.

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INTERAGENCY COORDINATION AND DESIGN PLANNING OF A PINE FLATWOODS AND ISOLATED WETLANDS RESTORATION PROJECT: THE MARION I SUSTAINABLE MITIGATION PROJECT

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ABSTRACT

The Marion I Sustainable mitigation project was a cooperative venture between the Florida Department of Transportation District(FDOT) 5 and the Southwest Florida Water Management District(SWFWMD) to provide mitigation for wetland impacts associated with the widening of State Road 44. A conceptual design was developed that met criteria of both the District's Regulatory Department and the Land Resources Department. The proposed mitigation entailed restoration of 183.2 ha (458 acres) of depressional wetlands and pine flatwoods on two sites. Site I was a 86 ha (215-acre) tract of bahia pasture containing approximately 33.2 ha (83 acres) of high quality freshwater marsh. Development of the mitigation design evolved around the restoration of natural processes to the site, specifically a return to historic fire patterns. Therefore, plant species and planting configurations were developed based on desired fire patterns and intensity, presence of fire shadows, and optimal wind patterns and smoke management requirements. Site II was a 97.2 ha (243-acre) bahia pasture that was interspersed with a system of freshwater marshes. The mitigation involved backfilling a network of ditches that were draining the site and the removal of several culverts that were allowing unnatural surface water discharges to the Withlacoochee River. These actions returned natural surface water retention, thereby restoring the marshes to pre-alteration hydroperiods. In order to successfully perform the Marion I mitigation project, FDOT had to coordinate with the SWFWMD's Regulatory Department and Land Resources Department.

INTRODUCTION

The Marion I Sustainable Mitigation Project is a cooperative venture between the Florida Department of Transportation District 5 and the Southwest Florida Water Management District to provide mitigation for approximately 5.08 ha (12.7 acres) of forested and herbaceous wetland impacts associated with the widening of S.R. 44 from C.R. 229 in Citrus County to the Sumter/Lake County Line. Additionally, it is anticipated that the project will provide compensatory mitigation for 16-20 ha (40-50 acres) of FDOT wetland impacts in the Withlacoochee River Basin over the next 10 years. The project was conceived during the early permitting process, when Department and District staff were attempting to identify a single large mitigation project that could provide suitable compensatory wetland mitigation. Mitigation conducted on public lands is desirable for many reasons, some of which include the following: the cost of mitigation is reduced, restoration of altered sites is accomplished, long-term management and protection is assured, and the general public gains aesthetically improved property on which to recreate.

The District owns in excess of 108,000 ha (250,000 acres) of land dedicated to conservation and protection of natural resources. Many of these properties have been disturbed to some degree by various land use activities, including drainage, conversion to pasture, forest clearing, silvicultural practices, and agriculture. Although Save Our Rivers/P2000 legislation directs the District to restore altered lands and processes if practicable, available funds to perform restoration are often severely limited.

With the assistance of the Land Resources Department, a number of District properties within the Withlacoochee River Basin were evaluated by FDOT and their consultants to determine their capability of providing the required mitigation. Marion I was determined to be the most suitable property on which to accommodate the mitigation, and a conceptual mitigation plan was developed and submitted to the District for approval. At the staff level, the proposal was reviewed by individuals in the Regulatory Department to ensure that the plan met compensatory requirements and sustainable mitigation guidelines. The proposal was also reviewed by the Land Resources Department to ensure that

it was consistent with natural systems management goals and District Procedure 61-10 Natural Systems Restoration. Once the plan was approved at the staff level, it was presented to the District's Withlacoochee River Basin Board and the Governing Board for approval. Management & Storage of Surface Water Permit #4012339.04 authorizing construction of the Marion I Sustainable Mitigation project was issued on December 1, 1995, and a modification (#4012339.07)was issued July 1996. The permit contained regulatory requirements typical of similar projects, but also incorporated Landowner Terms and Conditions as stipulated by the Land Resources Department, which has jurisdiction over all resource management on District lands. The proposed mitigation was also approved by the U.S. Army Corps of Engineers, which had jurisdiction.

STUDY SITE

The Marion I property is located approximately 2 miles east of the city of Dunnellon in southwest Marion County, Florida in Sections 1,2,3,10,12 Township 17S Range 19E. State Road 484 extends east/west just north of the property boundary, and its southern boundary includes approximately 6.4 km (4 miles) of frontage on the Withlacoochee River. The property is approximately 3,200 ha (8,000 acres) in size, and the dominant land cover classifications include flatwoods, sandhill, scrub, marsh, cypress swamp, improved pasture, and pine plantation (Southwest Florida Water Management District,1992). A project location map is shown in Figure 1.

The project consists of 2 mitigation sites comprising approximately 176 ha (440 acres). Both are located in a matrix of improved pasture which abuts State Road 484. Area 1 is 86 ha (215 acres) and Area 2 is 97.2 ha (243 acres). A site location map is shown in Figure 2.

MATERIALS AND METHODS

In addition to revegetation, one of the primary objectives of the project was to restore ecosystem dynamics and function, specifically to restore historic fire regimes to the upland communities in Area 1 and to restore historic

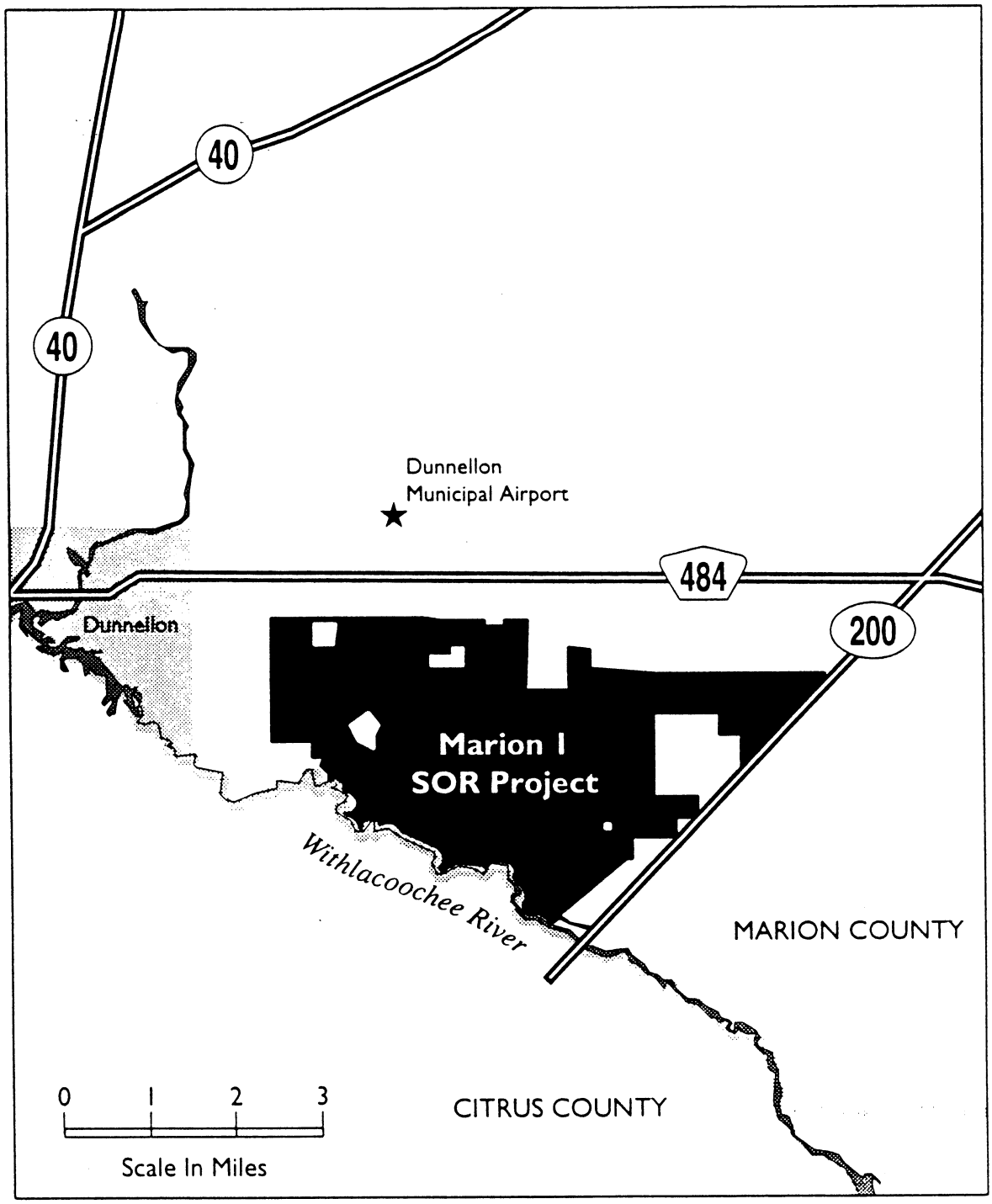

Figure 1. Project location map.

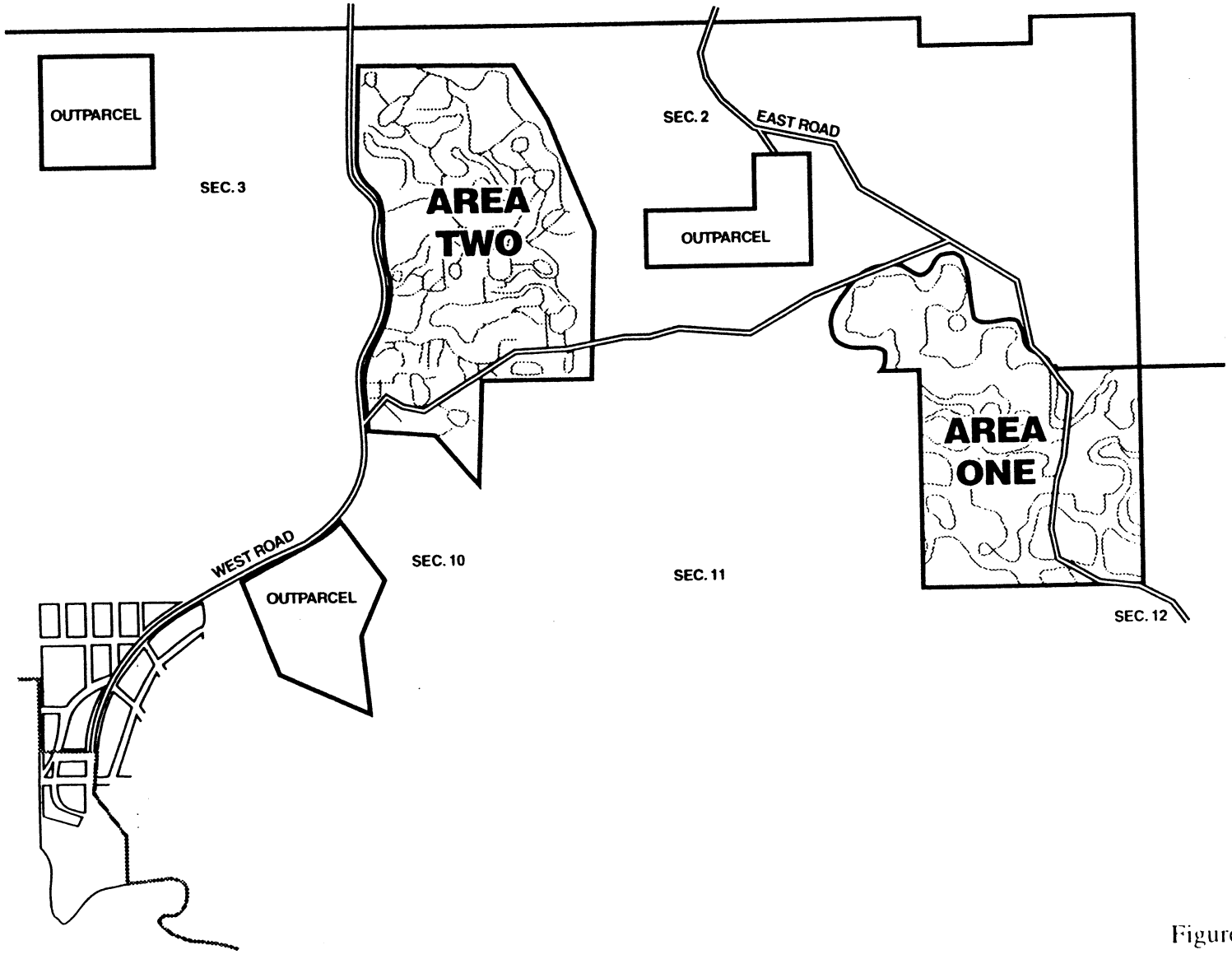

Figure 2. Site location map

hydroperiods and hydrological conditions to wetlands impacted by drainage and ditching in Area 2.

Mitigation on Area 1 will consist of planting four vegetation zones to enhance the existing wetlands and to restore the upland communities. The planting zones can be classified as forested wetlands, transitional buffer, upland buffer, and oak hammock. Each zone is discussed in detail below, and the configuration of each is shown in Figure 3. The detailed plan is contained in the document *Sustainable Mitigation Project for FDOT Impacts Within the Withlacoochee River Basin* (FDOT, 1995). Size specifications for the plant material will be as follows: herbaceous materials will be liner-sized, all of the shrubs, and all of the trees designated for planting in the fire shadows will be 1-gallon size, and all trees to be planted in the oak hammocks and the forested wetlands will be 3-gallon size.

The planting sequence will entail planting the groundcover, shrub, and tree species simultaneously, with the exception of slash pine (*Pinus elliottii*), which will be planted after groundcover is sufficiently established to tolerate a period of no burning.

The transitional buffer zone, which is approximately 31.7 ha (79.2 acres) in size, will be located around existing wetlands. Historically, these areas had characteristics of both wet prairies and low pine flatwoods. Aerials reveal that this area was lightly forested prior to pasture conversion. A diverse groundcover is already present, and restoration will consist primarily of installing tree species. Slash pine and pond pine (*Pinus serotina*) will be planted in low densities on approximately 12 m (40-foot) centers throughout. Due to the presence of an extensive pine plantation to the south, high density plantings will be avoided. Four hectares (10 acres) of wiregrass (*Aristida stricta*) and 4 ha (10 acres) of muhly grass (*Muhlenbergia capillaris*) and eastern gamma grass (*Tripsacum dactyloides*), both present on adjacent lands, will be installed on approximately 1 m (3 foot) centers and will function as flashy fuels to carry fire through the system. Wiregrass will be installed in the higher areas and muhly grass at lower elevations. These concentrated clusters of wiregrass and muhly grass will be located along the perimeter of the transitional area and next to the upland buffers in order to facilitate the spread of fire into the restored uplands. Several native blueberry species (*Vaccinium* spp.) occur onsite and will also be

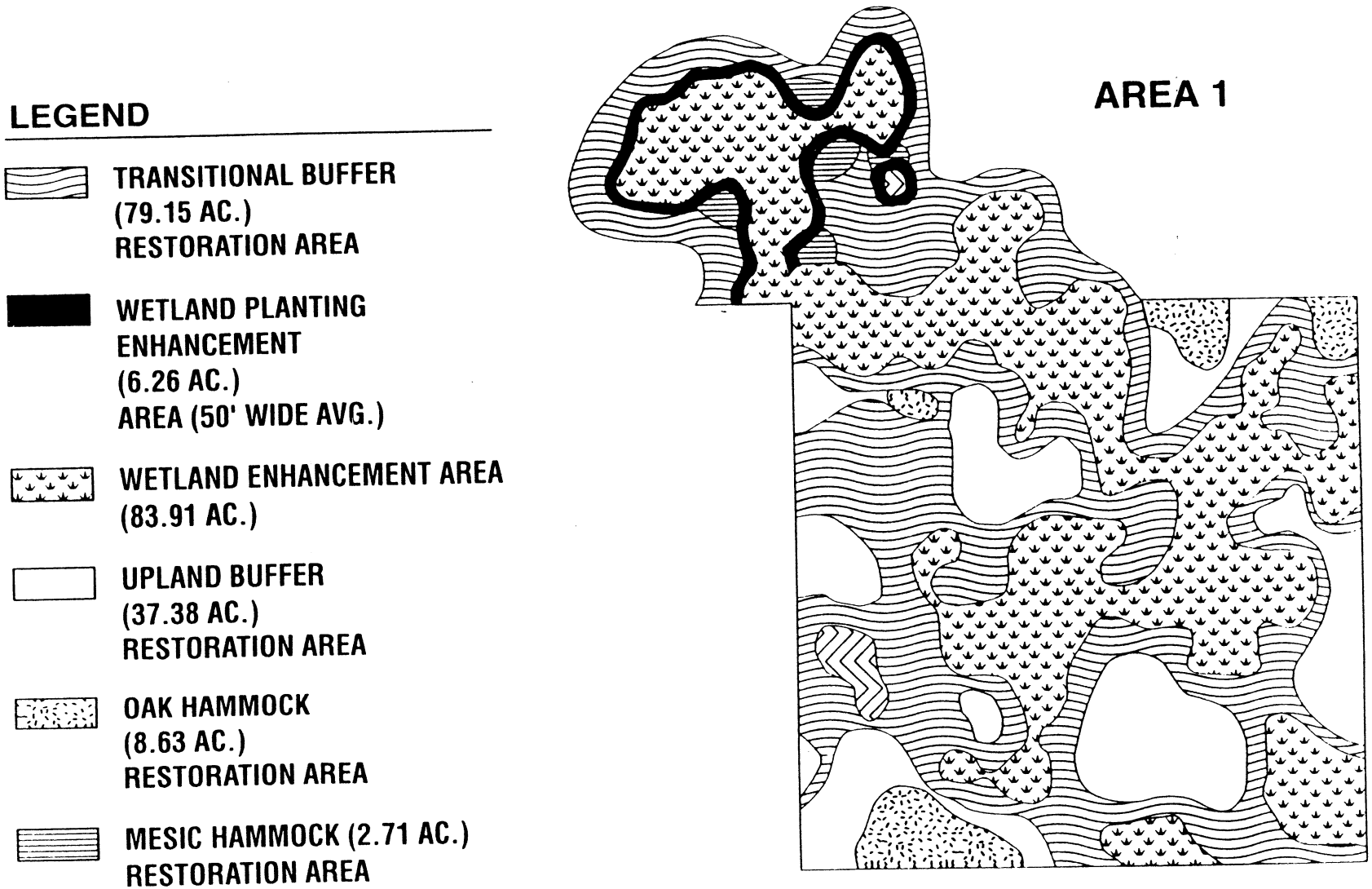

Figure 3. Area 1. Figure showing plant zonations.

planted at a rate of 8 per hectare (20/acre) to encourage wildlife utilization.

Conversion of pine flatwoods to improved pasture often results in changes in mychorrhizae populations and composition. Mychorrhizal fungi aids in nutrient uptake, reduces water stress, and helps plant establishment. An absence of specific mychorrizae in the soil can impede the success of the restoration and adversely affect survival rates of certain species. All of the ericaceous shrubs will be innoculated with mychorrhizae under nursery conditions. To date, root cuttings of *Vaccinium darrowii* and *Vaccinium myrsinites* incorporated existing mychorrhizae. *Vaccinium arborium* mychorrhizae innoculation was conducted by Urban Forestry Services utilizing stock currently growing at the nursery. Inoculation of *Befaria racemosa* and *Lyonia ferruginea* will utilize collection of mychorrhizae from the Lochlosa Wildlife Management Area.

Clusters of sweetgum (*Liquidamber styraciflua*) and water oak (*Quercus nigra*) will be planted in natural fire shadows, again to add structural and species diversity. By installing these species initially, the natural progression of the vegetation matrix can be accelerated. Fire shadows were determined based on the most desirable wind direction for smoke management. Smoke sensitive areas included Dunellon Airport and CR 484 to the north, and CR 200 to the east. Therefore, the most favorable wind for prescribed fire application was a north to north-east wind. Based on wetland configurations and a north-northeast wind, those zones that appear to be protected from fire will be planted with less-fire tolerant hardwoods.

The uplands are currently dominated by bahia grass (*Paspalum notatum*), and consequently, more effort will be expended on planting groundcover species that may effectively compete with the bahia grass. Longleaf pine (*Pinus palustrus*) will be the only tree species planted. This species was selected because it is an essential component of the upland communities in the area and has significant wildlife value. Saw palmetto (*Serenoa repens*), rusty lyonia (*Lyonia ferruginia*), lyonia (*Lyonia lucida*) and tarflower (*Befaria racemosa*) will be established due to their low rate of recruitment in disturbed communities, especially as compared to wax myrtle (*Myrica cerifera*) and gallberry (*Ilex glabra*).

The critical component of restoring the upland buffers is the grouping of the

vegetation associations. Total acreage proposed for restoration is approximately 5 ha (37.4 acres). The saw palmetto, rusty lyonia and tarflower will be planted in groupings comprising approximately 1/3 [5 ha(12.5 acres)]of this planting zone amongst a matrix of wiregrass and other herbaceous species. Wiregrass and its associates will be located on 1 m (3 foot) centers along the perimeter of the site so as to facilitate fire movement from the transitional buffers into the uplands. The wiregrass/herb zone will comprise another 1/3 [5 ha(12.5 acres)] of the total area of this zone. Finally, the interior 1/3 [5 ha(12.5 acres)] of the zonation, where fire spread is less critical, clusters of wiregrass and lop-sided indiangrass (*Sorghastrum secundum*) will be planted. Although the exact configuration may be variable, approximately 12 clusters will be planted, and each cluster will consist of 200 wiregrass, 50 pennyroyal (*Piloblephis rigida*), and 50 paint brush (*Carphephorus corymbosus*) individuals.

Oak hammocks are late successional communities and are not typically addressed in restoration efforts. These communities will be concentrated on isolated knolls amidst the wetlands where fire intensity will be limited, and therefore a pine community would not be maintained. Also, existing large oaks are already present on some of these knolls, and it is the District's desire to retain these large, aesthetically pleasing trees within a community context. Finally, hardwoods are an essential element within the community matrix, and are especially important in the Marion I landscape due to the presence of large expanses of pine plantations. The prevalent hardwoods currently on the site are primarily wetland species. Tree species installed will include laurel oak (*Quercus hemisphaerica*), live oak (*Quercus virginiana*), magnolia (*Magnolia grandiflora*), and pignut hickory (*Carya glabra*). These species are significant mast producers, have aesthetic value, and are adapted to the current and anticipated (low fire intensity) physical conditions. Additionally, berry-producing shrubs will be installed that will attract birds and insects to the community. These include beauty berry (*Callicarpa americana*) installed at low densities and sparkleberry (*Vaccinium stamineum*)and yaupon holly (*Ilex vomitoria*) installed at higher densities.

Most of the wetlands on the site already supported a large assortment of native herbaceous species. Therefore an intensive effort to reestablish vegetation is not needed. A few areas that were determined to support forested hardwood species in the 1940's, but have since been logged, were chosen to receive cypress

(*Taxodium distichum*), blackgum (*Nyssa sylvatica*), and red maple (*Acer rubrum*) trees. Cypress will be installed in the waterward portion of these existing marshes. Red maple and blackgum, which were chosen due to their aesthetic and forage value, will be installed on the landward edges. These species are both present in areas adjacent to the project site. No herbaceous plants will be installed, since this strata already supports a diverse flora.

Area 1 was burned by District staff in January 1996 in order to reduce vegetation growth (dog fennel (*Eupatorium* spp.), blackberry (*Rubus* sp.), and bahia grass), oxidize excess nutrients, and to prepare the site for planting. In June, the FDOT mowed the site to further reduce vegetation which had regrown since the prescribed fire was conducted. Water and Air Research, Inc. performed construction monitoring on the site, and prior to planting, verified soil types and flagged planting zones. Planting of 4,070 longleaf pine liners and 117,000 wiregrass plugs commenced during the first week of September 1996. An automatic tree-planting machine, which automatically scalps a linear segment of soil and plants liner material, was utilized for planting. The remainder of the plants will be installed in Summer 1997.

Area 2 is approximately 97 ha (243 acres), and consists of several depressional wetlands and wet prairies interspersed in bahia grass. The entire pasture had been heavily ditched and drained, decreasing the size and hydroperiod of the marshes to maximize cattle production. Restoration consisted of backfilling the ditch network and removing 3 culverts which connected the wetlands to the Withlacoochee River. Figure 4 depicts the on-site wetlands, the created borrow area, the ditch network, and the culvert locations.

District staff burned Area 2 in February 1996. The FDOT contractor conducted earthmoving activities in May and June, 1996. Prior to earthmoving, the contractor installed protective silt barriers at the ditch/wetland junction. The ditches were then filled to match existing grade and the bare soils were seeded with a temporary fast-growing millet mix. Due to erosion, sufficient backfill was not available to completely fill the ditches. The two alternatives available to compensate for this shortage was either to obtain fill material from offsite or to get fill from on site by creating a shallow wetland. The second alternative was chosen, and the proposed 2 ha (5-acre) borrow area was located so as to remove some of the ditches, reducing the fill material needed. This wetland was

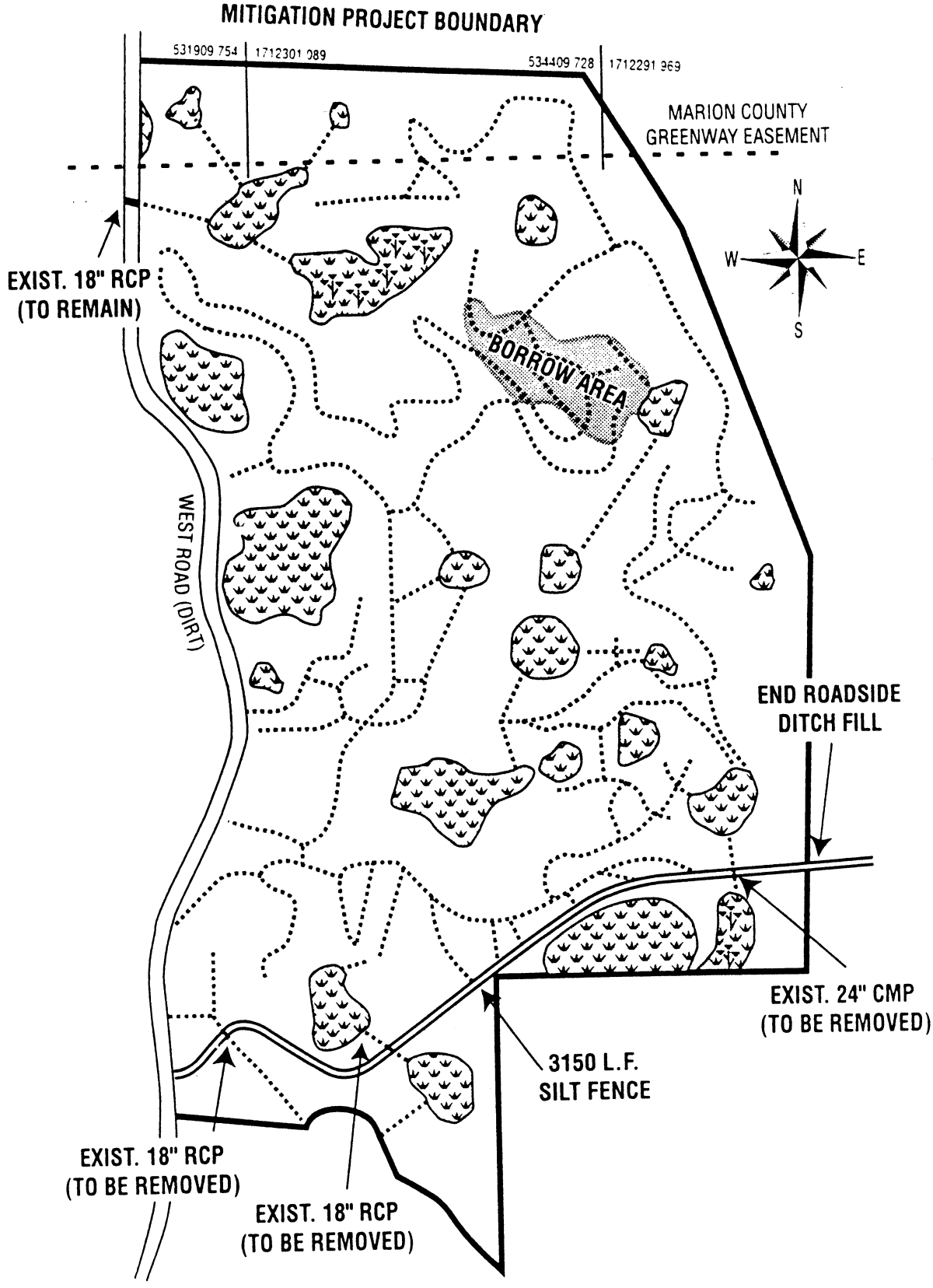

Figure 4. Area 2. Depicting wetlands. borrow area ditches to be filled and culverts to be removed.

densely planted with rapidly proliferating species including arrowhead, pickerelweed, soft rush. and cordgrass immediately following excavation. District personnel treated an approximately ½ acre patch of cogongrass with 1 application of Roundup, and additional treatments will be conducted as needed. FDOT personnel treated dense cattail populations that were present in many of the wetlands, and will continue to monitor and maintain both Area 1 and Area 2 for exotics.

For the most part, the required success criteria was consistent with projects of similar size and complexity, and included conditions for plant survival, canopy cover, and nuisance vegetation control. Since re-establishment of low density pines and a complimentary shrub and ground strata was the desired outcome, canopy coverage requirements were set at 25% with an 80% survival rate of planted trees. Requirements for survival of wiregrass and other upland herbaceous components were more lenient since upland restoration technology is a relatively new one and so little is known about how to best achieve high survival rates. In addition, groundcover establishment was primarily a landowner concern and not a regulatory one. However, nuisance and exotic plant maintenance requirements were stringent, and included provisions that coverage by nuisance plants could not exceed 10% of the mitigation area, all exotic plant species would be maintained below 1%, and any exotic plant that appeared to radiate from the zone of planting would be completely eradicated. For success to be achieved, at least one year must elapse within which no treatment is required. Bahia grass, which was already established on the property, was exempt from this condition.

Maintenance and monitoring of both restoration areas will be the responsibility of FDOT until success is achieved. Maintenance will consist of replacing dead plant material, exotic vegetation control, and prescribed fire application. The District will review and approve all burn plans, and whenever possible, burns will be conducted as a subunit within a larger District burn, thus allowing District staff to assist with burns and equipment. Once the District's Regulatory Department releases the project from further monitoring, management responsibilities will revert back to the District's Land Resources Department.

RESULTS

We will provide updates of our research at the next ecosystems conference, and look forward to sharing our findings on pine flatwoods restoration from improved pasture.

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DEVELOPMENT OF AN ASSESSMENT FRAMEWORK FOR RESTORED FORESTED WETLANDS

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ABSTRACT

Development of an assessment framework and associated indicators that can be used to evaluate the effectiveness of a wetland restoration is critical to demonstrating the sustainability of restored sites. An interdisciplinary approach was developed to assess how succession is proceeding on a restored bottomland site in South Carolina relative to an undisturbed reference and a naturally agrading site. Comparisons of populations and processes across successional gradients and treatments allows the effect of disturbance and restoration activities to be evaluated. Studies involving vegetation communities, organic matter and nutrient dynamics, seedling establishment and competition, and avian, herpetofauna, fish and macroinvertebrate communities have been implemented. Seedling establishment and competition studies suggest nonchemical and minimal mechanical site preparation techniques, tree shelters and root pruning should be considered as alternatives depending on restoration objectives and site conditions. The restored site contains many of the functional capabilities of a wetland with respect to fauna, however certain species tend to dominate populations in Pen Branch when compared to late successional wetlands. Fish populations show higher population densities in the restored site as compared to the reference site. A conceptual framework for integrating biotic and abiotic processes into a restoration response model will be used to synthesize ecosystem response and to identify indicators for restoration assessments.

INTRODUCTION

Wetland restoration involves re-establishment of wetland conditions and

processes on a site in such way as to provide the basis for a self-sustaining vegetation community (D'Avanzo 1990; Niering 1990). Typically this is accomplished by characterizing the hydrology and soil conditions on the site and prescribing appropriate plant species (Davis 1994). Determining whether the project is a success with respect to the restoration goal is difficult to determine when the assessment period is short (e.g. 1-3 years) and indicators of desired wetland conditions or processes for recently established sites have not been developed (Clewell and Lea 1990) . The common success criteria for restoration projects is survival of plant species. However, early survival measurements do not necessarily reflect future composition of the vegetation community on the site (Clewell and Lea 1990), nor are they a predictive indicator of the efficacy of the restoration project with respect to restoration goals involving other desired wetland conditions, like wetland plant community composition, hydrologic regime, or water quality enhancement (Erwin 1990; Niering 1990; Bartoldus 1994).

The approach that we propose is a comparison of important ecological parameters and processes on a restored site to norms established in mature and agrading wetlands. The approach measures conditions over time (stage of development) and is used to assess the effectiveness of attaining the desired wetland conditions (e.g. restoration objective). Our objective is to evaluate if the restored system is on the planned trajectory toward a recovering forested wetland. Accordingly, we are assessing whether the rehabilitated wetland has conditions that one would expect from a naturally agrading forested wetland. To accomplish this objective we compare sensitive indicators of wetland conditions in the restored, agrading, and mature forests. Those indicators are: (a) the relationship between hydrologic regime and vegetation community composition, structure and productivity; (b) stream morphology, aquatic community composition, and riparian zone water quality; (c)organic matter decomposition and nutrient dynamics; (d) faunal community comparisons. This study is ongoing and here we present, in most cases, preliminary results.

STUDY SITE

For over thirty years the bottomland hardwood system of the Pen Branch corridor and delta was used for the discharge of coolant water from a nuclear

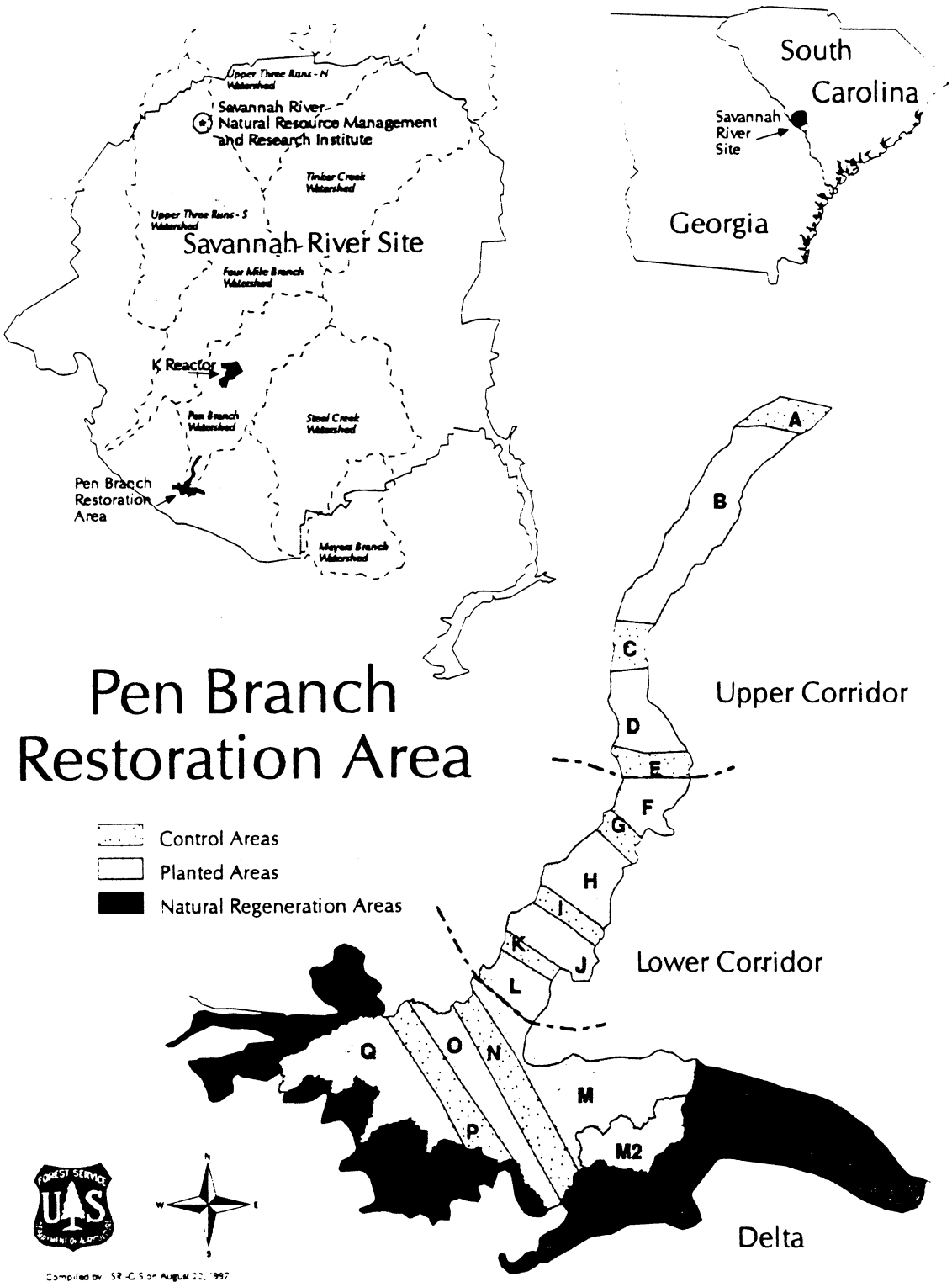

Figure 1. Location and treatment areas of Pen Branch Creek and other bottomland systems involved in wetland restoration studies on the Savannah River Site.

reactor at the Savannah River Site (Figure 1) . Prior to reactor placement, flow in Pen Branch was typically 0.28-0.57 $m^3 s^{-1}$ (10-20 cfs) . Reactor operations increased the flow to as much as 11.3 $m^3 s^{-1}$ (400 cfs) with secondary coolant water temperatures ranging from 40-65 'C (100-150 'F) (Nelson 1996) . When the reactor was retired in 1989, this high-temperature, elevated flow effluent had removed virtually all vegetation and eliminated the seed bank and root stock from the previous bottomland hardwood wetland (Figures 2 and 3) . Once the thermal discharges ceased, a narrow range of early successional species including black willow *(Salix nigra),* smooth alder *(Alnus surrulata),* wax myrtle *(Myrica cerifera)* and buttonbush *(Cephalanthus occidentalis)* took advantage of the exposed mineral soil conditions and colonized the area aggressively. Dispersed by wind and water, these light-seeded species quickly became established, and dominated the floodplain corridor and delta.

In total, thermal discharges affected 236 ha (583 acres), including 88 ha (218 acres) in the riverine floodplain and 148 ha (365 acres) in the delta. Assessment of natural regeneration found approximately 99 ha (245 acres) in the lower delta fringe and 48 ha (118 acres) in the uppermost part of the watershed to be sufficiently stocked with desirable bottomland species. The Forest Service monitored the remaining 49 ha (120 acres) in the delta and the 40 ha (100 acres) in the riverine floodplain for three years. Virtually no natural regeneration of desirable bottomland tree species occurred.

Results from investigations in Pen Branch are compared, in most studies, to agrading and/or mature bottomland communities. Two agrading communities are found on the Savannah River Site, both had thermal impacts from the operation of a nuclear reactor similar to that of Pen Branch. Fourmile Creek has been in natural recovery since 1985 while Steel Creek has been in recovery since 1968. Three mature bottomland forests have been considered in studies. These three bottomland systems, Meyers Branch, Upper Three Runs and Tinker Creek, have never received thermal effluents.

MATERIALS AND METHODS

In this paper we are summarizing the results of 13 studies. Materials and methods will be briefly summarized, when appropriate, for individual studies

Figure 2. Aerial photo of Pen Branch prior to thermal disturbance (1943). Note the mature bottomland hardwood community in the floodplain corridor. (Photo courtesy of the Savannah River Archaeological Research Program).

Figure 3. Aerial photo of Pen Branch showing the damage of thermal effluents. (Photo by Westinghouse Savannah River Company).

in the results section. More in depth materials and methods for individual studies can be found in the references cited (Kolka and Trettin 1997). Here, we will summarize those methods used to artificially regenerate Pen Branch.

Artificial regeneration efforts began in 1992 and were concentrated on the 89 ha (220 acres) that were most severely affected by the thermal discharges. The goal was to plant seedlings in sufficient numbers and diversity to allow the development of a mature bottomland hardwood forest in the stream corridor and a cypress-tupelo forest in the delta.

To assess the effect of active intervention, only 75% of the entire area was planted. The remaining 25% of the area was left as unmanipulated and unplanted control strips, located between planted areas (Figure 1) . Desirable bottomland species were planted using various site preparation techniques depending on site conditions (no site preparation, herbicides, herbicides+burning) . Although some valuable information came from using the various site preparation techniques, they were not considered as treatments, only as the most appropriate technique for the establishment of seedlings. Seedling species for planting were selected based on soil type and expected hydrology in the floodplain corridor and delta. Following each planting, surveys were conducted to monitor survival and growth (Dulohery et al. 1995); areas understocked were replanted in the winter 1995-1996. The 1992-1996 plantings included green ash *(Fraxinus pennsylvanica),* sycamore *(Platanus occidentalis),* cherrybark oak *(Quercus falcata var. pagodifolia),* swamp chestnut oak *(Q. michauxii),* water oak *(Q. nigra),* shumard oak *(Q. shumardii),* water tupelo *(Nyssa aquatica),* swam tupelo *(N. sylvatica var. biflora),* persimmon *(Diospyros virginiana),* water hickory *(Carya aquatica),* pignut hickory *(C. glabra)* and bald cypress *(Taxodium distichum).* In total, the upper Pen Branch corridor received approximately 1825 seedlings ha-', the lower corridor 1296 seedlings ha-' and the delta 1078 seedlings ha-' (Dulohery et al. 1996).

RESULTS

Vegetation Establishment

Results of a seedling survey conducted in 1996 indicated good survivalship of planted seedlings. The upper Pen Branch corridor averaged 716 $\pm$ 158 stems

ha-' (290 ± 64 stems ac^{-1}, mean ± standard error), the lower corridor 555 ± 109 stems ha^{-1}(225 ± 44 stems ac^{-1}) and the delta 1358 ± 198 stems ha-' (550 80 stems ac^{-1}) of desirable species (Kolka and Trettin 1997). Approximately 12% of the desirable stems counted were species that had not been planted, most notably red maple and sweetgum *(Liquidambar styraciflua)* . These stocking levels compared favorably to a nearby mature bottomland hardwood community (Upper Three Runs) with 593 stems ha-' (240 stems ac^{-1})(Keeland and Sharitz 1995).

Herbaceous competition can effect seedling survival and growth (McKevlin and Dulohery 1997). Initial results from studies addressing the effect of herbaceous competition on growth and survival of seedlings indicated that the four overstory competition control treatments (no control; intermediate control, stems left in place; complete control, stems left in place; and complete control, clear-cut) resulted in significant differences in 1) diurnal fluctuations in depth to the water table, 2) light environment of the seedlings both in terms of quantity and quality, and 3) biomass of herbaceous competition. Larger diurnal fluctuations in the water table were found in treatments where the willow canopy was undisturbed. As expected, light transmittance is directly related to the level of canopy manipulation in the treatments. Greater light transmittance in the clear-cut plots has led to greater herbaceous competition in these plots. Analysis of seedling height, growth, and survival is currently being conducted. Initial results suggest differences in both height growth and survivalship among species and among treatments. It appears that a sparse to moderate willow canopy can ameliorate the stresses of growth limiting hydrology, herbaceous competition, and be beneficial to the establishment, growth. and survival of tolerant bottomland hardwood species. Future reforestation efforts in bottomland hardwood wetlands should consider alternative site preparation techniques that minimally alter the early successional vegetation.

In the Pen Branch delta the feasibility of planting wetland species was examined (Conner et al., 1996). Species chosen for planting were bald cypress, water tupelo, swamp tupelo and green ash. On four sites seedling roots were pruned to compare responses to non-pruned roots. Additionally, tree shelters were placed on a portion of the seedlings to evaluate effects on seedling response.

Differences between root pruned and non-root pruned seedlings were variable

depending on the species and area in which they were planted. Highest survival was found for bald cypress and water tupelo. Root pruning does not seem to significantly affect growth of these species, and in some cases may stimulate root growth. With enough sunlight, root pruned seedlings could be used to revegetate disturbed swamp areas where natural regeneration has not occurred.

Tree shelters significantly improved survival and height growth of all four species. Although tree shelters may be cost prohibitive on a large scale project such as the Pen Branch reforestation, they may be cost effective in areas where seedling establishment is deemed critical. If stream stabilization and stream community recovery are primary restoration objectives, assuring seedling survival adjacent to streams with tubes may be a viable alternative. In a relatively short period of time, these seedlings will stabilize the banks and provide the light conditions necessary for stream biota recovery.

To assess physiological and morphological responses of seedlings to flooding, bald cypress, water tupelo, swamp tupelo and green ash seedlings were planted in the Pen Branch delta (Rozelle and Hook 1996). Seedlings were removed from plots at periodic intervals and roots were tested for viability with tetrazolium dye and activity with alcohol dehydrogenase (ADH) . Staining by tetrazolium dyes suggested that a smaller percentage of green ash roots were alive than the other three species. Activity of bald cypress roots averaged about 0.035 units per mg dry weight; whereas the other three species averaged less than 0.01 units per mg dry weight. All four species showed a strong seasonal response for ADH activity with the rate being highest in the spring and rapidly decreasing to near zero during late summer. Bald cypress, water tupelo, and swamp tupelo showed either recovery of ADH activity in the fall or maintained a low level of activity whereas green ash ADH activity fell to zero in August and did not recover. The combined results suggest that green ash is more susceptible to prolonged flooding than are bald cypress, water tupelo and swamp tupelo. Prolonged soil saturation and inundation are typical conditions in the Pen Branch delta and other stream deltas in the area. Future reforestation in deltas or other areas that experience prolonged floods should choose species that are consistent with these findings.

New studies are currently being initiated to compare vegetation community structure and production among planted and control areas in Pen Branch, Fourmile Creek and Meyers Branch.

Stream Communities

The availability of fast decomposing biomass that is currently in the Pen Branch corridor and stream is leading to high rates of instream faunal activity. Preliminary analysis indicates that removal of the low willow/shrub canopy has greatly increased aquatic macrophytes and fish abundance in the Pen Branch planted areas (Fletcher et al. 1997).

The effects of past effluent release on current fish communities are being addressed using Fourmile Creek and Pen Branch as replicate impacted sites, and Upper Three Runs and Meyers Branch as replicate un-impacted control sites (Fletcher et al. 1997). Preliminary analysis indicated that the impacted steams had at least as many species of fish as control streams, and two to five times the densities of individuals. Even though species richness was similar, distribution of individuals among the species differs greatly. Impacted streams are heavily dominated by a few taxa of fishes, including suckers, mosquitofish, minnows, and sunfishes, which are characteristics of disturbed areas. Un-impacted streams have a more even distribution of individuals among species, which is characteristic of a more natural sites. Community compositions also differed, indicating a possible change in the functional organization of these communities. Past disturbances appear to be having long-term effects on the community structures in these streams (Fletcher et al. 1997).

In coordinated with the fish community studies there is an ongoing study addressing stream autotroph and macroinvertebrate populations (Lakly and McArthur 1996). Preliminary results indicated that insect densities in Pen Branch were significantly higher than in late successional systems and those populations were dominated by early successional species (Lakly, personal communication).

Studies are concluding comparing stream structure and morphology among Pen Branch, Fourmile Creek, Meyers Branch and Upper Three Runs (Reichert and Dean 1997).

Terrestrial Vertebrate Communities

The assessment of avian communities included Pen Branch, Steel Creek and Tinker Creek. Results indicated that there were few differences in the avian community among treatments (Miller and Chapman 1997). However, plots in Pen Branch that were herbicide treated, burned, and planted tended to have greater richness in 1994 and abundance in 1995 ($P < 0.05$). Bird species composition differed slightly among treatments. Abundance of individuals was lower in the Steel Creek bottomland compared to Pen Branch and did not differ between Pen Branch and Tinker Creek. Species richness differed among all sites (lowest in Pen Branch, highest in Tinker Creek). Bird species diversity was greater in the Tinker Creek bottomland compared to Pen Branch. Short-distance migrants and species associated with forest edge/scrub habitats were more common in the early successional bottomland (Pen Branch) compared to the other sites. Neo-tropical migrants and interior species were most common in the late successional habitat (Tinker Creek).

A small mammal sampling program was conducted in the Pen Branch restoration area during the summer of 1996 (Wike et al. 1997). Trapped animals were identified, sexed, weighed, and ear tagged. One hundred and ninety two traps operating for 18 nights provided 3,456 trap-nights of effort. Four hundred and eight captures occurred for a success rate of 11.8%. Species captured included cotton rats *(Sigmodon hispidus,* 151), rice rats *(Oryzomys palustris,* 117), cotton *mice (Peromyscus gossypinus,* 107), Southeastern short-tailed shrew *(Blarina carolinensis,* 8), and single captures of Golden mouse *(Ochrotomys nuttalli)* , Wood rat *(Neotoma floridana)* , and Star-nosed mole *(Condylura cristata)* Cotton rats, rice rats, and cotton mice are considered species that are associated with early successional systems (Wike, personnel communication) . These species represented 92% of the captures. Currently, trapping is also being conducted in Meyers Branch to develop data sets for control systems.

A study of recolonization by reptiles and amphibians in Pen Branch was initiated in 1995 (Hanlin and Guynn 1997). A total of 11,802 individual reptiles and amphibians representing 70 species were captured in 221,126 trap nights between January 1, 1995, and June 30, 1996. Total captures equaled 13,834 of which 12% were recaptures and 3% escaped. The most frequently captured species was the eastern narrowmouthed toad *(Gastrophryne carolinensis;* 3601

individuals captured) making up 30.5% of the total captures. The other top four species captured were: southern toad *(Bufo terrestris;* 19.1%), southern leopard frog *(Rana utricularia;* 16.7%), marbled salamander *(Ambystoms opacum;* 6.7%), and slimy salamander *(Plethodon glutinosus;* 6.02%). These five species represented about 79% of the total captures. Of the 70 species captured, snakes were represented by 24 species (524 individuals) , anurans by 16 species (8281 individuals) , salamanders by 13 species (1818 individuals) , turtles by 9 species (459 individuals), lizards by 8 species (718 individuals) , and crocodilians by 1 species (2 individual American alligators). Eastern narrow-mouthed toad, southern toad, and southern leopard frog are species that inhabit early' successional systems. Like small mammals, these species dominated the herpetofauna representing 66% of the captures. Currently, discussions are ongoing to develop data sets for a mature bottomland hardwood system.

Results from terrestrial vertebrate studies indicate the avifauna, small mammal, and herpetofauna communities are well established in Pen Branch. For some faunal communities, it appears that Pen Branch is providing greater opportunity for establishment and survival than in late successional systems. Although species abundance and in some cases diversity are higher in Pen Branch than in mature control systems, the community structure is very different. The initial results suggest that certain species dominate populations in Pen Branch and the distribution of species is very different than in late successional systems.

Organic Carbon and Nutrient Dynamics

Studies have begun investigating organic carbon and nutrient cycles in Pen Branch, Fourmile Creek and Meyers Branch. Soil organic matter (SOM) is a critical interface for the exchange of nutrients between vegetation and soil, and is directly linked to patterns of forest productivity. Studies have been initiated to examine SOM development by assessing forest floor processes along the successional gradient (Lockaby and Wigginton 1997). Forest floor organic matter mass was found to increase rapidly during early succession, reaching a maximum of 657 g m-' in Pen Branch (early succession) and decreasing to 338 g M in the late successional system of Meyers Branch. The herbaceous fraction steadily declined through succession from 74% in the earliest stage to less than 1% in the latest stage of succession. Conversely, the amount of woody foliage increased from 6.7% in the earliest stages of succession to over 70% in late succession. Carbon and nitrogen estimates reflect patterns of increasing

concentration during early succession, reaching an equilibrium during the later stages of succession.

Carbon and nitrogen ratios were relatively constant throughout all stages of succession, ranging from 41 to 48. Measures of the rate of transformation of litter to soil organic matter using the lignocellulose index were not significantly different between stages of succession. Higher ratios of lignin to lignin+cellulose are predicted in later stages of succession due to the expected increase in a refractory lignin component over time. The hydrologic dynamics of floodplains, in conjuction with the warm climates of the southeastern U.S., may prevent the application of this procedure to studies of succession in floodplain forests.

Studies have begun investigating carbon and nutrient dynamics along the successional gradient of Pen Branch, Fourmile Creek and Meyers Branch (Kolka and Trettin 1997). To perform this study we have separated two main components; 1) carbon and nutrient fluxes and, 2) carbon and nutrient pools. In studies investigating carbon and nutrient fluxes, we are combining hydrologic monitoring with soil water, precipitation, throughfall, and stream water chemistry to determine if carbon and nutrient transport processes vary by successional state.

In a closely related study investigating carbon and nutrient pools, we are assessing both insitu pools and the turnover of these pools along the identical successional gradient (Augst and Giese 1997). Within the scope of this study are individual studies addressing net primary productivity, standing biomass, vegetation community structure, soil and forest floor carbon and nutrient content, litterfall production and decomposition, lateral litter transport, instream biomass, and instream litter transport.

The two studies will be integrated to develop a holistic approach to investigate the dynamic processes that affect carbon and nutrient allocation and transport in bottomland hardwood wetlands. Differences in carbon and nutrient allocation and transport processes among and within systems will be used as one set indicators to establish a framework for wetland restoration effectiveness.

DISCUSSION

For restoration to be considered effective, wetland functions need to be restored or at least on a trajectory where restoration of those functions is probable (Figure 4). The problem arises when predicting the effectiveness of restoration efforts in forested systems because of their longevity. Methodologies need to be developed to predict the effectiveness of restoration efforts within the first few years after restoration. Through the use of naturally agrading systems and un-impacted control systems we expect to develop wetland function response curves such as those shown in Figure 4.

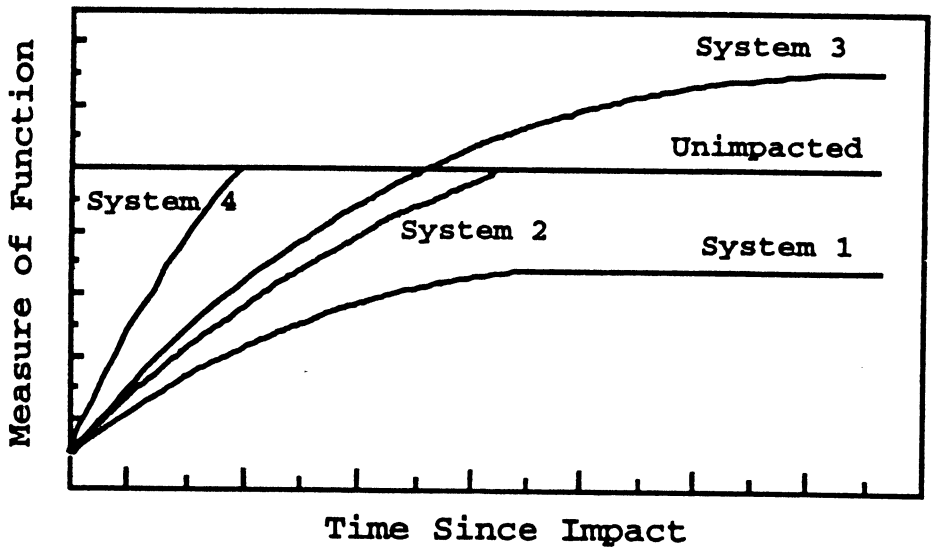

Figure 4. Theoretical response curves of wetland functions after an impact.

Response curves of specific parameters can be variable depending the parameter and the magnitude of the impact (Figure 4). Un-impacted systems have relatively constant rates of providing specific functions over time. If an inherent property of the ecosystem is not restored to its previous state, such as hydrology, we might expect to find some functions to never fully recover (System I in Fig. 4). Alternatively, other inherent ecosystem properties may be restored to higher state than in the original ecosystem and may provide more or greater functions after the impact (System 3 in Fig. 1) Although there are a multitude of response surfaces that different functions can exhibit over time, theoretically we expect

functions to agrade over time and, at some point, approach that of the previous un-impacted system (Systems 2 and 4 in Fig 4). By using active intervention strategies such as planting, we expect to accelerate the recovery of wetland functions (System 4 in Fig. 4) when compared to a naturally agrading system (System 2 in Fig. 4).

As shown by the breadth of research being conducted in association with the Pen Branch wetland restoration, the focus is on the assessment of ecosystem level processes that are occurring as succession proceeds. Comparisons of populations and processes across successional gradients and treatments allows the effect of disturbance and restoration activities to be evaluated. Knowledge gained from the above studies will enable future restoration efforts to be more efficiently and effectively performed and evaluated. Once all the results of past, ongoing and planned research are integrated, we will have a holistic view of the biotic and abiotic parameters that have the most promise as wetland function indicators.

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A FRAMEWORK FOR WATERFRONT AND WETLAND SITE ECOSYSTEM MANAGEMENT
Phase I

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INTRODUCTION

Restoration and creation of wetlands sites on public and regulated private properties is often the result of a mediation effort required to meet a permit or regulatory condition. It is not the same as a public restoration project such as replacement of seagrasses at an aquatic preserve. These private type restoration actions must therefore be considered in the context of other organizational activities in order to avoid becoming islands of cost without contributing to operational productivity.

This paper suggests a site ecosystem restoration effort will be more effective and economical when integrated into the overall organization environmental management system (EMS) rather than being conducted as an independent restoration project that is high on media hype and low on operational cost effectiveness.

An environmental management framework, based on the ISO 14004 guidelines, is proposed as a useful model for developing restoration management projects.

For purposes of clarity, the functional environmental programs considered by this analysis are: conservation, prevention of pollution, regulatory compliance, and environmental remediation. Also, it should be noted that the use of the term environmental applies to all activities related to natural resources, not just clean up of hazardous waste as is the popular current concept.

Planned future research will focus on case studies of locations where restoration projects have been conducted in Central Florida, particularly in the Tampa Bay Estuary area.

ENVIRONMENTAL AND ECOSYSTEM MANAGEMENT

Management of natural resources and related ecosystems at the organization level has a different approach than what may be considered appropriate by organizations committed solely to natural or biological resource conservation and preservation. In Central Florida typical organization goals are to raise cattle, mine phosphate, produce citrus, construct housing subdivisions, conduct military flight operations, and provide marina services to boaters. Environmental management activities are, therefore, a sub-system ot the larger operational management system.

The definition for this type of an environmental management system (EMS) is:

> *The part of the overall management system which includes organizational structure, planning activities, responsibilities, practices, procedures, processes and resources for developing, implementing, achieving, reviewing and maintaining the environmental policy.*

As an example of a different terminology is the one used by the Florida Department of Environmental Protection (DEP) which terms the process "ecosystem management" and defines it as

> *"an integrated, flexible approach to management of Florida's biological and physical environments- conducted through the use of tools such as planning, land acquisition, environmental education, regulation, economic incentives, and pollution prevention, designed to maintain, protect, and improve the state's natural, managed and human communities."*

Achieving an absolute universal definition is not the most important issue. Agreement by all parties, owners, regulatory agencies, environmentalists, etc. prior to development or resolution of an environmental issue is the critical issue. Secondly, there must be an understanding and agreement as to the structure or framework that will be utilized to determine the final agreement. Those who

have been through a NEPA EIS scoping exercise will understand this well. This framework should be considered a best management practice rather than a bureaucratic dictated command and control devise. It should clearly stipulate the components, sub-elements, phases of the EMS, and sequence of the environmental program. In this way, real improvements can be made to physical systems which take advantage of technological and cultural changes. This does not, however, imply elimination of environmental laws and standards. Unfortunately, human nature requires a mechanism to address the problem of the irresponsible polluter.

FRAMEWORK FOR MANAGEMENT ANALYSIS

In establishing a framework for analysis of the environmental management of site ecosystems the following objectives are suggested:

- Focus on the facility manager's need to be productive and a good steward.
- Apply approaches that incorporate recognized system engineering procedures. A model similar to the ISO 14000 Standards is suggested, particularly use of the ISO 14004 general guidelines and ISO 14010 environmental audit standards.
- Integrate environmental costs AND benefits into capital and operational budgets.
- Work within existing programs and applications.
- Standardize information documentation on a spatial database. (Current applications of CADD & GIS techniques are already in place in many organizations).

The framework for management analysis is depicted in the matrix below. The column on the left identifies the major components within an environmental management system. The column on the right identifies the sub-components or elements. The majority of restoration activity effort will normally be conducted under the implementation and operations component. It should be recognized, however, that it is appropriate to consider it under all of the other components. In this way the manager has a grasp of all activities that impact on the operations of the facility.

Model for Environmental Management Analysis

COMPONENT	Elements
A. COMMITMENT AND POLICY	1. Executive commitment and leadership 2. Initial Environmental Review 3. Environmental policy
A. PLANNING	1. Environmental Aspects and impacts 2. Legal & Other Requirements 3. Internal Performance criteria 4. Environmental Objectives and Targets 5. Environmental Management Programs
A. IMPLEMENTATION & OPERATIONS	1. Resources human, physical and financial 2. EMS Alignment and integration 3. Accountability and responsibility 4. Environmental awareness and motivation 5. Knowledge, skills and training 6. Communication and reporting 7. EMS Documentation 8. Operational Control 9. Emergency Preparedness Response
A. MEASURING AND EVALUATION	1. Measuring and monitoring 2. Corrective and preventive action 3. EMS records and information management 4. Audit of the EMS
A. REVIEW AND IMPROVEMENT	1. Review of the EMS 2. Continual improvement

APPLICATIONS AND FOLLOW ON RESEARCH

It is concluded that the use of the environmental management analysis matrix is a useful organizational tool for integrating retention and restoration of sensitive areas such as wetlands and waterfront areas into the overall management plan.

The next phase of this effort is to apply the concept in reviewing environmental management systems at selected public and private facilities in the Central Florida region and document these in an "Atlas of Environmental Management Systems".

THE USE OF PHYTOLITH ANALYSIS IN PALEOENVIRONMENTAL RECONSTRUCTION AND ENVIRONMENTAL MANAGEMENT; A CASE STUDY ON MARTHA'S VINEYARD, MA.

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ABSTRACT

Phytoliths are opaline silica bodies precipitated inside plant cells. They are produced by a wide variety of plants and exhibit a high degree of morphological variation. Although they are not species specific like pollen, they do have some use as taxonomic indicators.

The composition of phytoliths is nearly pure silica which makes them resistant to erosion and allows them to persist in the soil after the decay of the plant tissues containing them. Phytoliths thus incorporated into soils can be extracted and used as indicators of past environments. In this paper the use of a new method of phytolith analysis is discussed in relation to environmental management issues.

In this method, phytoliths are first extracted from humus layers of soils with current plant communities in order to establish phytolith profiles for each community. Phytoliths can then be extracted from soil cores and compared to the previously established profiles. The ecological history of a site can be reconstructed in this manner. Such reconstructions can be very useful in designing environmental management strategies.

INTRODUCTION

Phytoliths are bodies of opaline silica produced primarily in the epithelial leaf cells of many plants (Mulholland and Rapp, 1992; Brown, 1984). Their principle function within the plant is uncertain and many possibilities have been suggested. Recent evidence seems to indicate that one of the primary functions of phytoliths is to deter insect predation (Hochuli, 1993; Vicari and Bazely, 1993). Phytoliths are produced by a wide variety of plants and come in many highly diverse morphologies (Mulholland and Rapp, 1992; Pearsall and Dinan, 1992) as can be seen in Figure 1.

Many researchers use phytoliths as taxonomic characters for different plants (Kaplan, et al., Lewis, 1978; Mulholland, 1989, 1986, 1990;1992; Piperno, 1988). These efforts have met with only limited success, because identical phytoliths may be produced by different species and that many species of plants produce multiple types of phytoliths (Blackman, 1971; Brown, 1984). This combined with the high number of species that have not been examined for phytoliths, make it impossible to make specific identifications based solely on phytoliths (Starna and Kane, 1983).

Recent work by Krauss (1997) has developed a new way to get useful information from phytoliths found in soils.. By examining the suites of phytoliths produced, not by particular taxa of plants, but rather by discreet plant communities, it is possible to identify past plant communities from phytolith assemblages extracted from soil cores. Although this technique has some drawbacks it can be a very powerful tool to gain highly local information about specific site histories (Krauss, 1997). It will be the purpose of this paper to discuss the usefulness of this technique for environmental management applications using the island of Martha's Vineyard, MA. as an example.

STUDY SITE

Martha's Vineyard is located off the southern coast of Massachusetts at approximately 41^0 23' north latitude, 70^0 41' west longitude. The Island was formed as a conjunction of two terminal moraines and an outwash plain during the last glaciation (Oldlae, 1992). It is easily accessible by ferry and

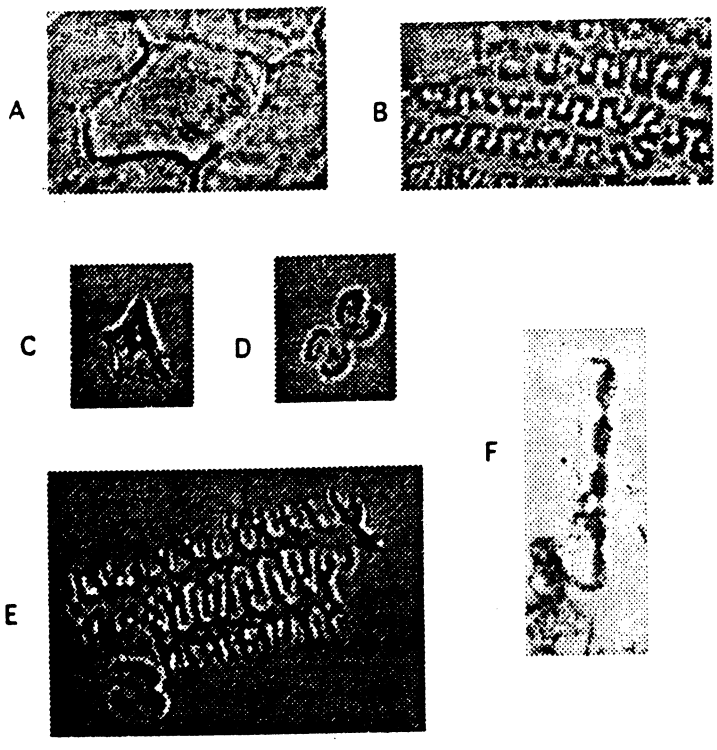

Figure 1. Some examples showing the morphological range of phytoliths. A is a simple quadrilateral from Rosa sp., B, E, F are more ornate quadrilaterals from various grasses, C is a saddle and D is a dumbbell also from grasses.

has an extensive network of roads which allow easy access to all parts of the island by car and bicycle. The island is dominated by four principle plant communities; sand-plain grassland, heath, oak woods and pine woods. Although there is some overlap between these communities (mostly in the form of transition zones) they form distinct patches over most of the island. Fifty-six separate sites on the island were sampled in this study.

MATERIALS AND METHODS

The methods used in this analysis were developed by Krauss (1997) as part of a paleo-environmental study of Martha's Vineyard and are based on those of Kaplan, et al. (1992). The first critical step in using phytoliths to study past environments is to develop a phytolith profile for each plant community. Once established these profiles will then serve as search images for the analysis of phytolith assemblages extracted from soil cores. The ideal method for

producing these profiles is to collect several leaf litter samples from each of several patches of the plant communities in question. Phytoliths are extracted directly from the leaf litter by ashing the leaf litter in an oven at 450^0 C for 12 hours. When the resulting ash is viewed under the microscope, phytoliths are easily observed and quantified. Multi-variate analysis is performed on the data to establish distinctions between the phytolith profiles of the different plant communities in question. A variety of multi-variate methods may be used, although principle component analysis and cluster analysis are generally the most useful. The proportion of each type of phytolith encountered in the survey present in each sample should be used as variables.

If it is established that the different plant communities produce quantifiably different phytolith profiles, then the extraction of phytoliths from soil samples can produce valuable information about environmental change at various localities. Any appropriate soil coring methodology can be used to obtain soil samples. In our study of Martha's Vineyard we found that 1 ½ inch PVC tubing cut to three foot lengths and hammered into the ground produced ideal soil cores. The outer portion of each core should be discarded to avoid contamination of lower levels by upper levels due to the coring process. Phytoliths are then extracted from various levels of the soil core through heavy liquid floatation. Any heavy liquid may be used provided that it does not dissolve silica and that it can be diluted to a specific gravity between 2.4 and 2.5. At this density phytoliths will float and can easily be separated from other mineral components of the soil. Prior to heavy liquid separation the soil sample may be swirled in water and left to stand for twenty four hours in order to separate out organic components of the soil and fine particles that will also float in the heavy liquid.

The procedures outlined above are described in detail in Krauss (1997). In order to identify the phytolith assemblages extracted from the soil samples, each one is compared to the samples obtained from the leaf litter samples. Each phytolith assemblage from a soil sample is included in the multi-variate analysis performed on the leaf litter assemblages and compared through grouping with known plant communities. This procedure is simple to do with most modern statistics programs. The soil sample would then be identified as coming from a specific plant community based on cluster analysis. Performing this analysis for multiple levels within a soil core, a site history of environmental change can

be constructed. By comparing many cores, a picture of environmental change across a region can be developed.

Establishing a time scale to correlate with the environmental changes observed is problematical. Phytoliths can be dated radiometrically, but this procedure is expensive and unreliable for recent samples. Where historical records for a site exist, it is often possible to correlate depth in the soil core with known environmental changes. The time scale thus established can be extrapolated to other cores provided that soil conditions are similar. on Martha's Vineyard this method was used and yielded an approximate time scale for phytolith analysis on the island. Most of the variability seen was due to local variations in soil composition.

Phytolith assemblages can be dated by association with the soil layers in which they are found in. Extreme caution must be taken when using this method, however, as phytoliths do percolate downwards through the soil. This is especially a problem in sandy, highly permeable soils, and in areas where freeze - thaw activity is significant. The fact that phytoliths percolate through the soil does not negate the usefulness of phytolith analysis. As long as the soil composition is fairly consistent with depth and does not have any impermeable layers (such as clay or permafrost) or any extremely permeable layers (like beach sand), it is probably safe to assume that the percolation rate is constant. Since the vast majority of phytoliths fall into the 10 - 100 micron size fraction the percolation rate of different types is not likely to vary greatly. It is therefore probably safe to assume that within a study area a given depth at a particular set of soil conditions will yield contemporaneous phytolith assemblages. Of course Lyell's Law of Superposition can be applied to phytolith samples in order to infer that the deeper the sample comes from the older it is.

RESULTS

This study yielded a variety of interesting and useful results for environmental management programs on Martha's Vineyard. The four principle plant communities (hardwood forest, pine forest, heath and sand-plain grassland) on the island were clearly distinguishable based on the ground cover of different floral types. Figure 2 shows the clustering pattern of the different ecosystems based on a Ward's clustering method. The percent cover of conifers,

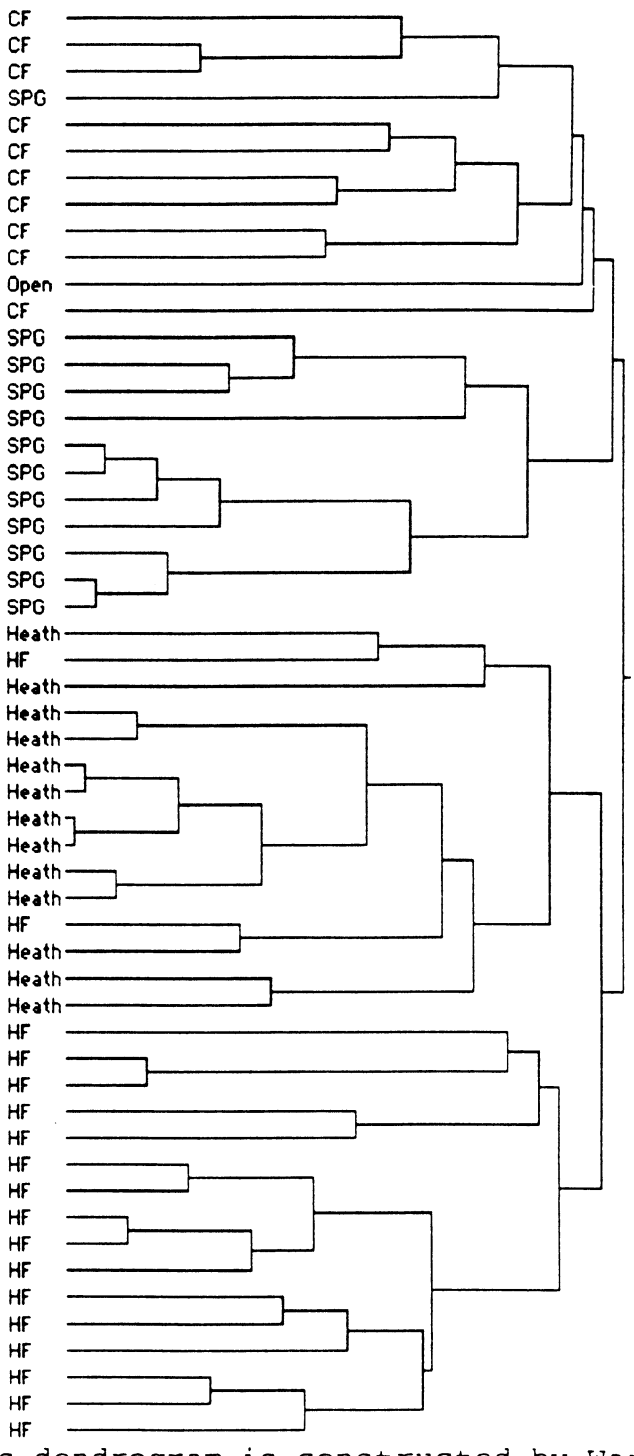

Figure 2. This dendrogram is constructed by Ward's clustering method. The proportion of different vegetative cover types are used as variables.

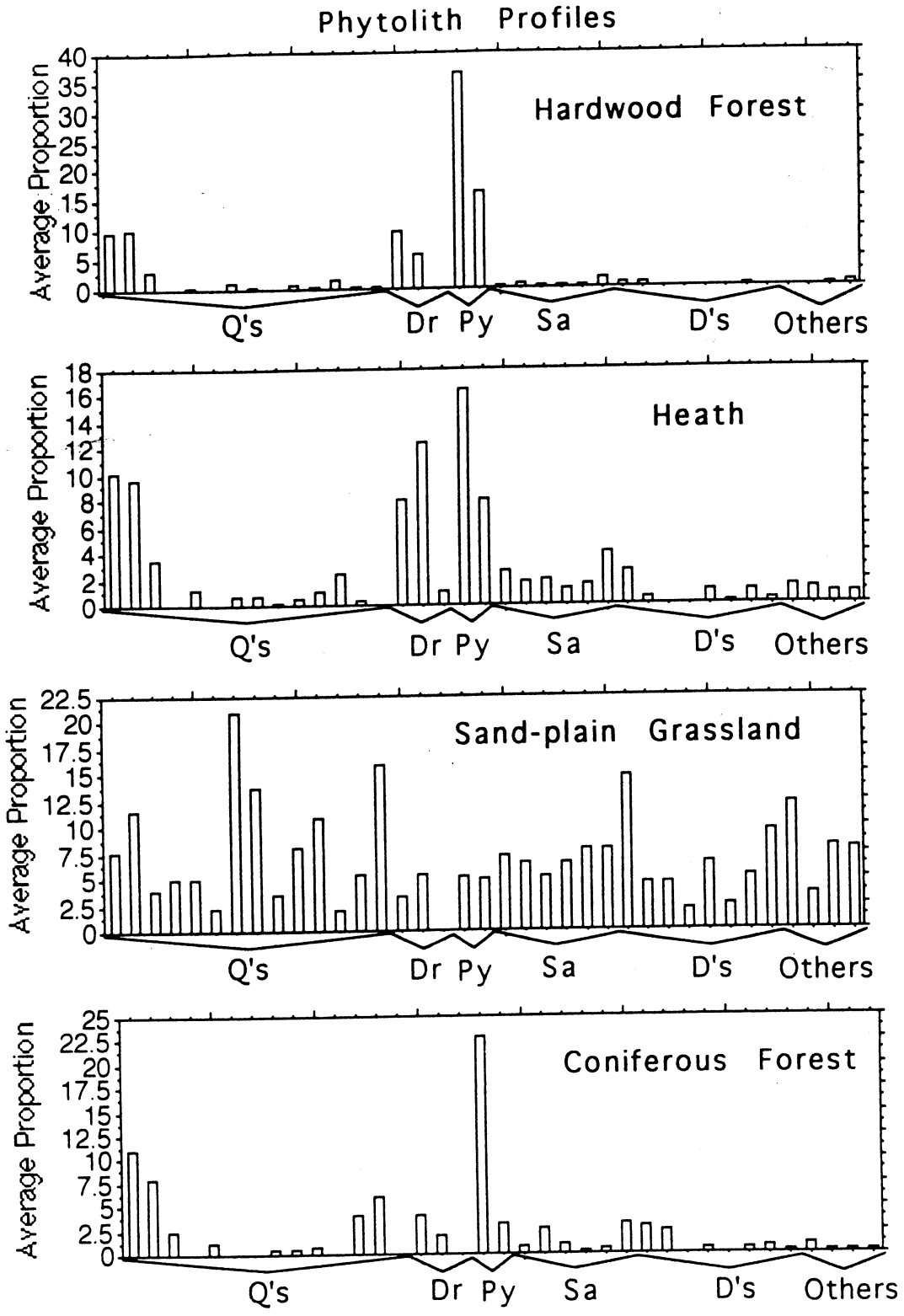

Figure 3. These histograms illustrate the phytolith profiles of the four major plant communities on Martha's Vineyard. The x-axis is a standardized array of the 39 phytolith types found in this study.

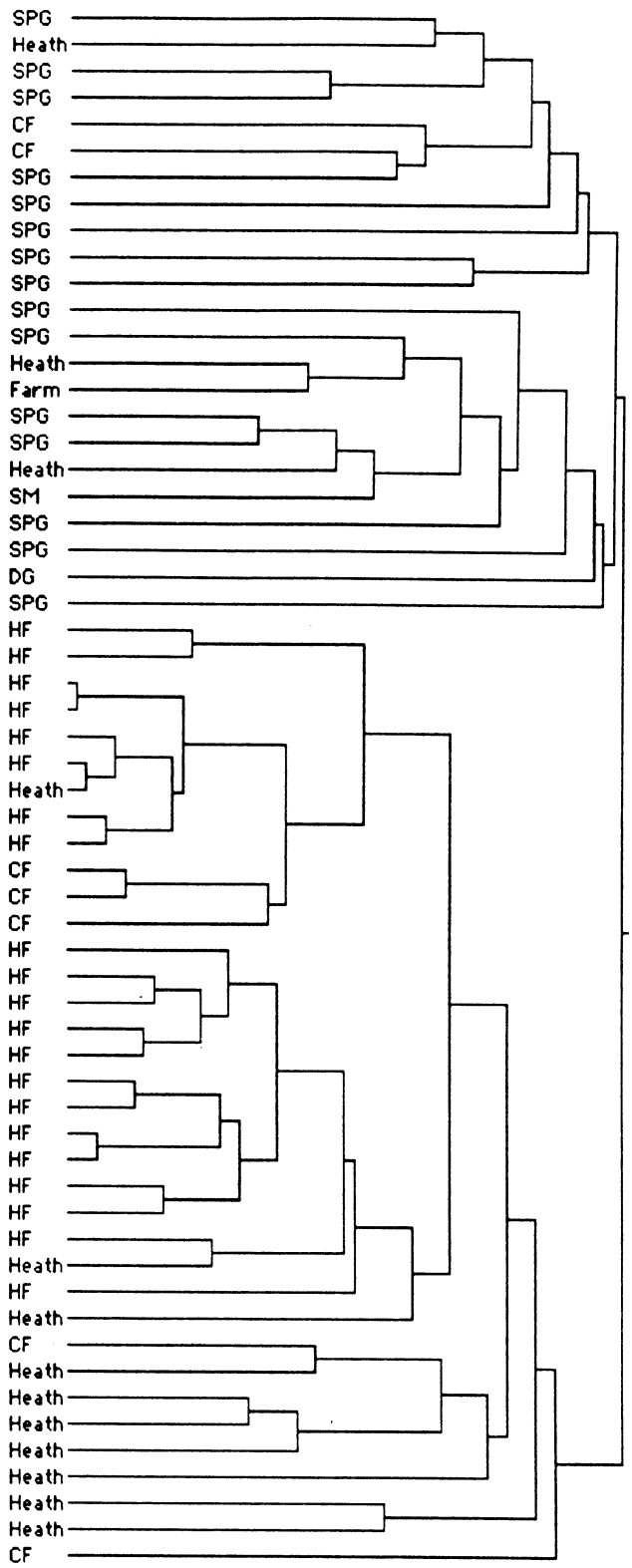

Figure 4. This dendrogram illustrates the clustering pattern of the different plant communities on Martha's Vineyard based on the phytolith assemblages extracted from their leaf litter humus layers. Coniferous forests are scattered through the other communities based on their understory composition.

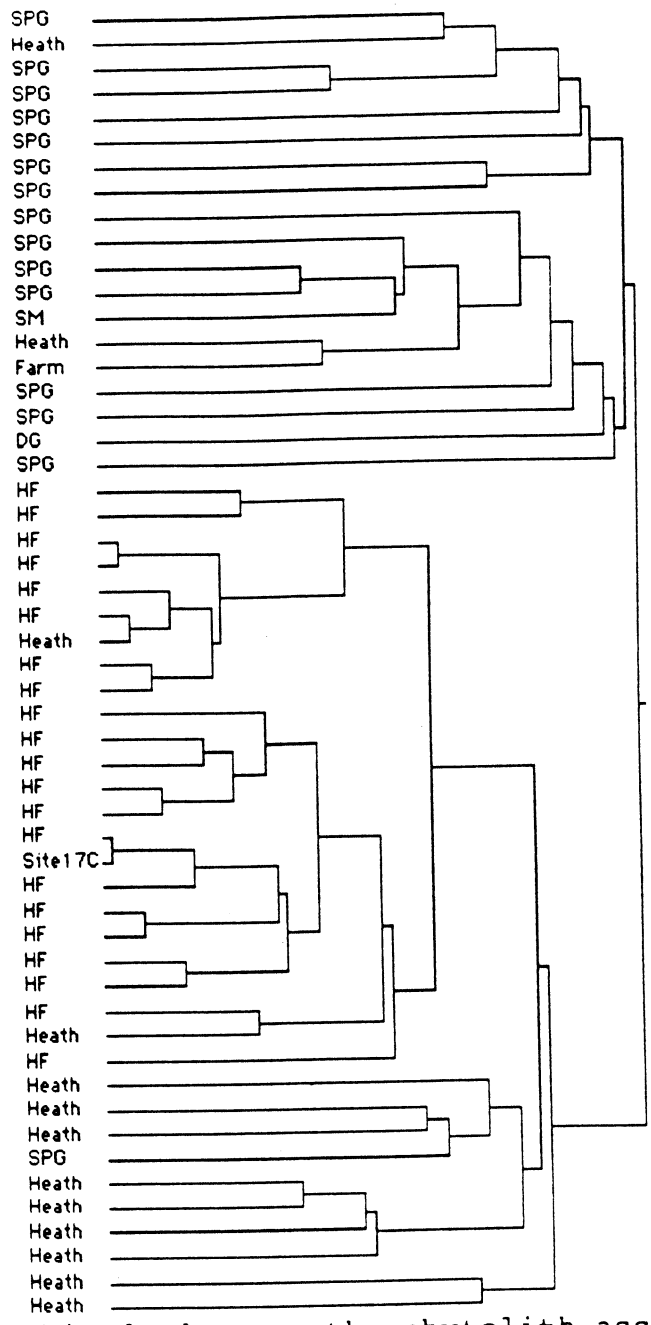

Figure 5. In this dendrogram the phytolith assemblage from Site 17, Level C of the core is included with the humus layer data. As it clusters with the hardwood forests this assemblage is considered to represent a hardwood forest. The Coniferous forest data is excluded for the sake of clarity.

hardwoods, woody shrubs, grasses, forbs and open space in three meter diameter sample plots are used as variables.

Based on this finding, it was then possible to group the phytolith profiles extracted from the humus layers of the different communities. The conifers present on Martha's Vineyard, primarily Pitch Pine *(Pinus* rigida), were not found to produce any identifiable phytoliths, although many species of conifers in other parts of the world are known phytolith producers. The lack of coniferous phytoliths meant that it was impossible to identify the presence or absence of coniferous forest in the soil record of Martha's Vineyard. The other three plant communities did produce distinctive phytolith arrays (Figure 3) and therefore could be identified in soil cores. The clustering pattern of the different plant communities is shown in Figure 4, coniferous forests are found scattered throughout the dendrogram based on the phytoliths present in the understory plants associated with the conifers.

Using this basis for analysis, soil cores from each of 56 sites on the island were divided into six segments and the phytoliths extracted from each segment were compared to the humus layer phytoliths. Identifiable phytoliths were extremely rare below a soil depth of 24 cm. Each sample was identified as having come from either sandplain grassland, heath or hardwood forest. An example of such an analysis is provided in Figure 5. Using this technique, a detailed history was constructed for each site. Although space constraints prohibit a full accounting of this information here, it is available in Krauss, 1997. Correlation of the data obtained in this analysis with historical records yielded an estimate of approximately 200 years for the phytolith record on Martha's Vineyard.

Aside from particular site histories, a number of different ecological patterns were observed on Martha's Vineyard. For instance, it was found that the number of occurrences of sand-plain grassland in a core was highly correlated ($p=.0001$ in a linear regression analysis) with the number of plant community changes in the core (Figure 6). A chi square analysis also showed that sand plain grassland is significantly ($p = .0001$) more common within one mile of the coastline than it is farther inland through time (Figure 7). It was also shown that the proportion of the island occupied by sand-plain grassland did not change significantly through time (Figure 8). These island wide patterns have significant implications for conservation efforts aimed at preserving sand-plain

The Relationship Between Sand-plain Grassland Occurrence and Plant Community Turnover

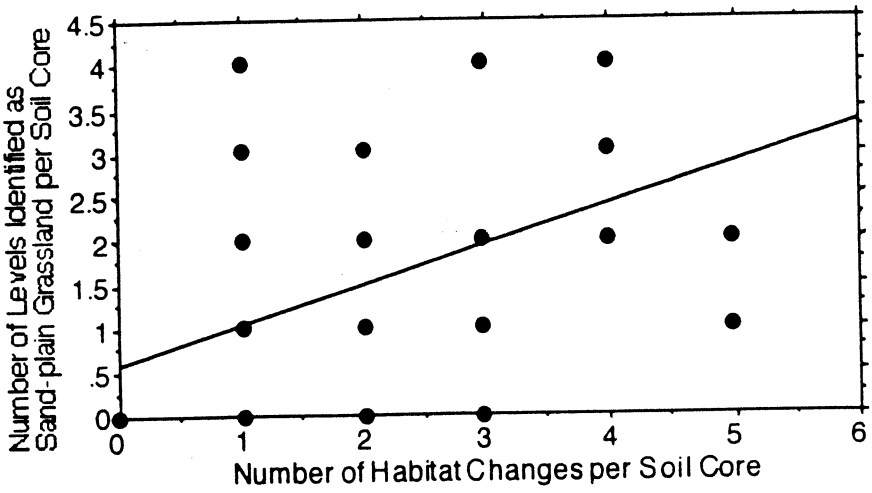

Figure 6. Linear regression analysis reveals that sand-plain grassland is significantly more likely to occur on sites that experience frequent plant community turnover (p=.0001). The regression line and 95% confidence intervals are illustrated in this graph.

The Relative Occurrence of Sand-plain Grassland Near the Coast and Inland

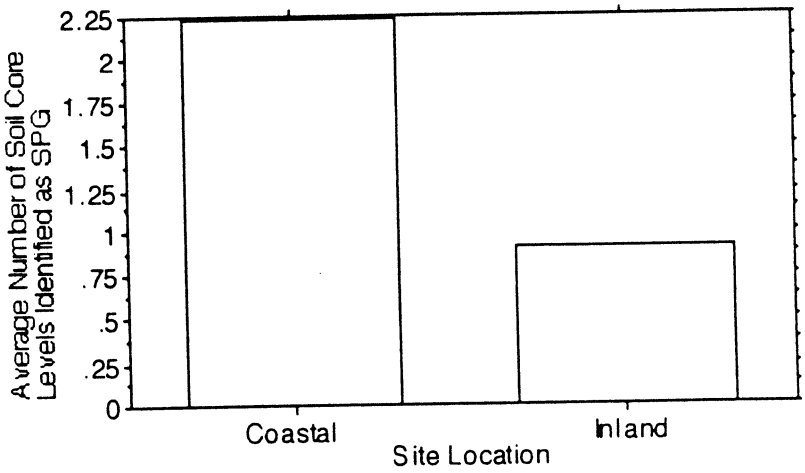

Figure 7. Sand-plain grassland is significantly more likely to be present within 1 mile of the coast than farther inland (p<.0001 by chi square analysis). On average sand-plain grassland is present in 2.2 soil core levels near the coast and only .9 levels inland.

grasslands, both on Martha's Vineyard and elsewhere.

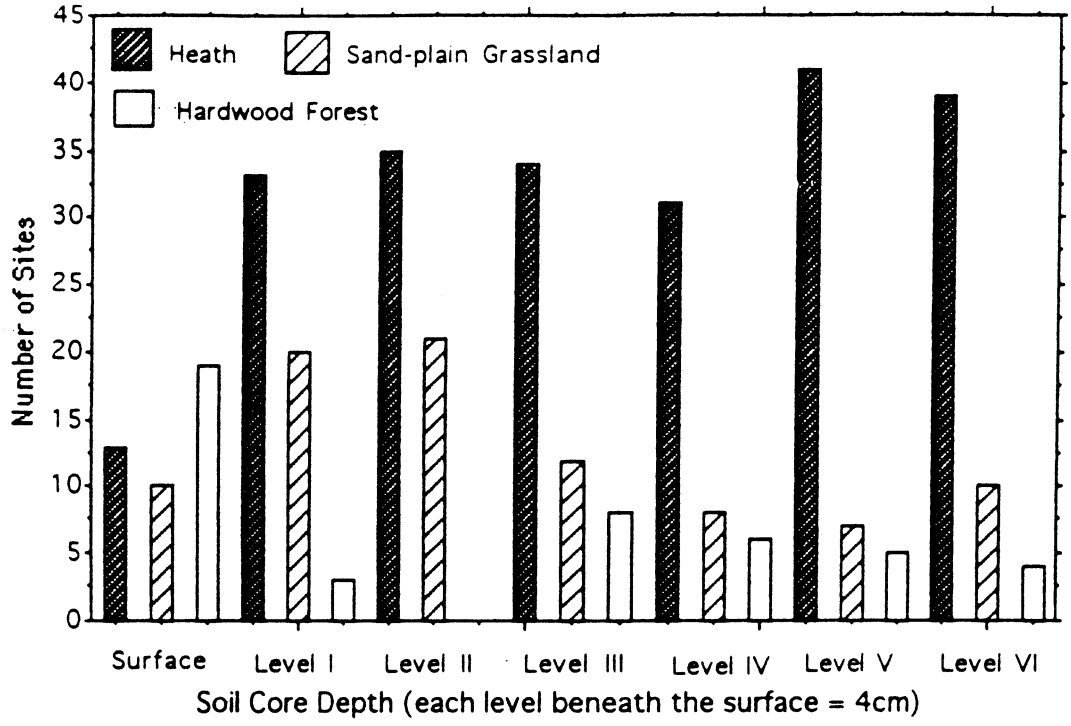

Figure 8. Histogram showing the number of sites that are recorded for each plant community at each level of the cores taken on Martha's Vineyard. The surface level is the community currently present on the site. There are fewer total sites at the surface level due to the exclusion of coniferous forests which were found only at this level.

DISCUSSION

The method described above for the use of phytolith analysis to identify the occurrence of past plant communities has proven useful within certain limitations on Martha's Vineyard. The most significant limitation of this method was the inability to identify the presence or absence of coniferous forests due to their lack of phytoliths. [Conifers elsewhere have been shown to produce identifiable phytoliths (Klein and Geiss, 1978).] Because the island's conifers do not produce phytoliths, communities dominated by pine would have been identified by the less common species present in their understory. In the open pine forests of Martha's Vineyard, heath species such as Huckleberry *(Gallysacchia baccata)* and festucoid and agrostid grasses are often scattered sparsely through the understory. It is the authors, belief that this situation may contribute to an over representation of heath in the soil core analyses.

It was often tempting to identify samples with extremely low concentrations of phytoliths as having come from coniferous forests. Other researchers have used the quantity of phytoliths in the soil to distinguish between certain plant communities (e.g. Jones and Beavers, 1964; Wilding and Drees, 1968; Witty and Knox, 1964). However this study was not designed to measure the quantity of phytoliths, only the types of phytoliths present. The impression that some samples had a higher phytolith content than others was purely subjective and was based on the use of identical processing procedures for all samples and the effort required to find 100 phytolith in each microscopy slide. Although the observer's impressions might have yielded accurate results, they were not quantifiable and hence could not be considered valid data.

There is also strong evidence that phytoliths can percolate downwards through the soil (Krauss, 1997). Such movement within the soil may cause the phytoliths themselves to erode through abrasion by other soil particles. Phytoliths with more ornate morphologies or thinner cross-sections may be more susceptible to this type of abrasion than others. If one type of plant community is characterized by phytoliths that are highly prone to abrasion and the soil structure is such that percolation can occur, then that community may be under-represented in the phytolith record. on Martha's Vineyard, the phytoliths typical of the heath community are particularly resistant to erosion and it is possible that this resistance has contributed to an over representation of heath in the lower portions of the cores.

In spite of these limitations, phytolith analysis yielded some valid and instructive results on Martha's Vineyard. It was possible to reconstruct specific histories of plant community transition (within the limits discussed above) for each site in this study. The real power of phytolith analysis is seen in this context. Because phytoliths are incorporated into the soil through the decay of leaf litter, it provides very specific local information. Pollen analysis can provide a much more accurate time scale but is only useful on a regional level. Phytoliths were found to give an accurate account of varying environmental conditions within a few yards. Such high precision can be extremely useful in determining former environmental boundaries or the locations of previous communities.

Sand-plain grassland is considered to be an endangered ecosystem in New

England and increasing our understanding of how it functions was one of the primary goals of this project. Sand-plain grassland was clearly identifiable by its phytolith profile at all levels in the soil core. It was therefore possible to compare the past and current distributions of this community across the island. The data derived from this study provided some new insights into the nature of the sand-plain grassland community.

It has almost become dogma amongst local conservationists that sand-plain grassland is a fixed community that is shrinking from its former range in New England. This impression is probably due to the fact that it is sparsely distributed and contains many locally rare species. Also, agricultural practices that have become unprofitable within the last 50 years tended to maintain the presence of sand-plain grassland. With the reduction in farming, many open fields have succeeded to heath and forest communities. The finding that the amount of sand-plain grassland in natural areas (all but two of the study sites are unfarmed) has not changed significantly suggests that the area of sand-plain grassland that the island of Martha's Vineyard formerly supported was artificially high.

The evidence that sand-plain grassland is an ephemeral community is also significant for environmental management on the island. The correlation between the number of core segments identified as sand-plain grassland and the number of community turnovers in the core indicates that sand-plain grassland is a community of frequently disturbed environments. The relative abundance of sand-plain grassland within one mile of the coastline also tends to support this assessment as this coastal region is more highly prone to severe disturbances. This information may prove highly useful to conservationists in designing management strategies for sand-plain grasslands on Martha's Vineyard and elsewhere.

Martha's Vineyard has been used as a testing ground for the method of phytolith analysis described above. This method was shown to have some significant limitations but still yielded some significant data with some highly useful interpretations. With some basic, inexpensive preliminary work, this method could be used at virtually any study site where information about past plant communities would be useful. Site restorations, replications, management

strategies, purchasing decisions, and pure academic research are just a few examples of the use of phytolith analysis.

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CREATION OF A LARGE, DIVERSE, FORESTED WETLAND ECOSYSTEM IN NEW HAMPSHIRE

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ABSTRACT

A condition of the Army Corps 404 permit for a major highway improvement in southern New Hampshire required the creation of 43 ha of wetlands at the Pine Road Gravel Pit site. During the summer of 1994, about 332,000 m^3 was excavated to create a diverse groundwater-fed depressional wetland basin within a 16-ha portion of the site. Between 1996 and 1997 an additional 612,000 m^3 was excavated from an adjacent 36-ha area to create several wetland basins. Most of the excavated material was used for the highway construction. A mound-and-pool microtopography was constructed over the forest/shrub wetland zone, similar to the relief which occurs naturally in forested wetlands from the combined effects of rootmounds raised up by windthrown trees and the tendency for plant roots to seek an oxygenated environment in saturated soils. This elevational diversity is an important microsite condition for plant establishment and growth given the water table fluctuations both seasonally and year to year. Observations and published reports of the relationship of hydrology and microtopography in red maple swamps were used to develop the construction guidelines, which called for an average 60-cm elevation difference between the tops of the mounds and the low areas of the pools. The mounds were spaced an average of 6 m apart. The slope of the forested wetland was gradual, about 20 to 1. A good understanding of the site's water table fluctuation was necessary to determine grading elevations because water levels could not be artificially controlled in these isolated groundwater basins. The mound-and-pool microtopography offered a range of microsite conditions for plant establishment. After the first growing season, 141 plant species were identified in the permanent monitoring plots, resulting mostly from seed present in the salvaged soil or blown onto the site.

INTRODUCTION

Mined out gravel pits are preferred locations for wetland construction because these disturbed "low habitat value" landscapes can often be restored or reclaimed efficiently as mitigation for unavoidable wetland impacts of a nearby development project. If establishment of a suitable wetland hydrology seems possible, gravel pits often fit environmental agencies' expectations for a suitable mitigation site. High land values in the densely populated Northeast may make mined-out gravel pits easier to obtain than alternative properties. In many instances, the excess material excavated from the mitigation site can be used on the development project, offsetting construction costs. There is a considerable favorable history of the use of these sites in the personal experience of wetland scientists, reported in the literature and in numerous wetland monitoring reports filed with the U.S. Army Corps of Engineers (USACE) (Garlo 1992, Branch 1985; Svedarsky and Crawford 1982).

The technique for creating an open water/emergent wetland seems to be well accepted in the Northeast. Briefly, the excavation intersects the groundwater table to the desired depth of the open- water zone and slopes of the emergent zone are kept as gradual as possible, about a 1-to-10 slope or more gentle. Islands and a sinuous shoreline are typically incorporated into the design to increase habitat interspersion and diversity. Because sandy subsoil is a poor plant growth medium, topsoil, preferably salvaged from the impacted wetland, is spread 15-30 cm deep on the emergent zone. The wetland may be planted; however, robust vegetation usually develops from natural seed present in the topsoil or blown onto the site (Garlo 1992, Padgett and Crow 1995).

Attempts to create forested wetlands by duplicating the distinctive hummock-and-hollow or mound-and-pool microtopography found in northeastern forested wetlands are relatively recent. This microtopography is thought to originate naturally from the combined effects of rootmounds raised up by windthrown trees and the tendency for plant roots to seek an oxygenated environment in saturated soils. The degree of microtopographic relief is directly related to the magnitude of the seasonal fluctuation of the water table elevations observed in red maple forested wetlands (Golet et al. 1993, Allen et al. 1989). This range of microsite conditions increases the margin of tolerance for plants in saturated and periodically flooded conditions of a seasonally fluctuating water table.

Crispin and Randall (1990) document the attempt to create 66 ha of forested wetland on a heavy silt-clay soil with a hydrology supplied by precipitation.

SITE DESCRIPTION

A condition of the USACE Section 404 permit issued in 1992 for the New Hampshire Route 101 highway improvement project required the New Hampshire Department of Transportation (NHDOT) to create 43 hectares of wetland to offset unavoidable wetland impacts. The Pine Road Gravel Pit site lies adjacent to the highway project in the Town of Brentwood in southeastern New Hampshire (Figure 1). Most of the site is underlain by a large stratified-drift aquifer. Groundwater well monitoring, initiated in 1991, revealed a sloping groundwater table that generally ranged between 2 and 3 m below the surface with a seasonal fluctuation in most areas of about 1 m. Based on groundwater topographic contours developed from the monitoring well data, the wetland was designed with several (11) isolated basins at various elevations to account for the sloping groundwater table. Hydrology is provided via groundwater discharge. As there is no inlet or outlet to the basins, there is no possibility of water elevation control. Therefore, establishing the correct elevations of the finish grade relative to the seasonal fluctuation of the groundwater table is crucial to the success of the wetland.

The first phase, referred to as the "southern pit" of the wetland creation effort, which is the subject of this paper, was excavated in 1994 and reported on by Garlo et al. (1995). Details of the microtopography construction and hydrology were discussed by Barry et al. (1996) and Arcieri (1996), respectively. This paper focusses on construction of the remainder of the project and observations on vegetation development of the southern pit since planting in 1995.

Construction of Phase 2, Northern and Eastern Pits

Construction of the second phase of the project encompassing an adjacent 36-ha area began during the summer of 1996 and was completed by the fall of 1997. About 612,000 m^3 of material was excavated, most of it used for the road bed of the adjacent Route 101 highway improvement. The mound-and-pool

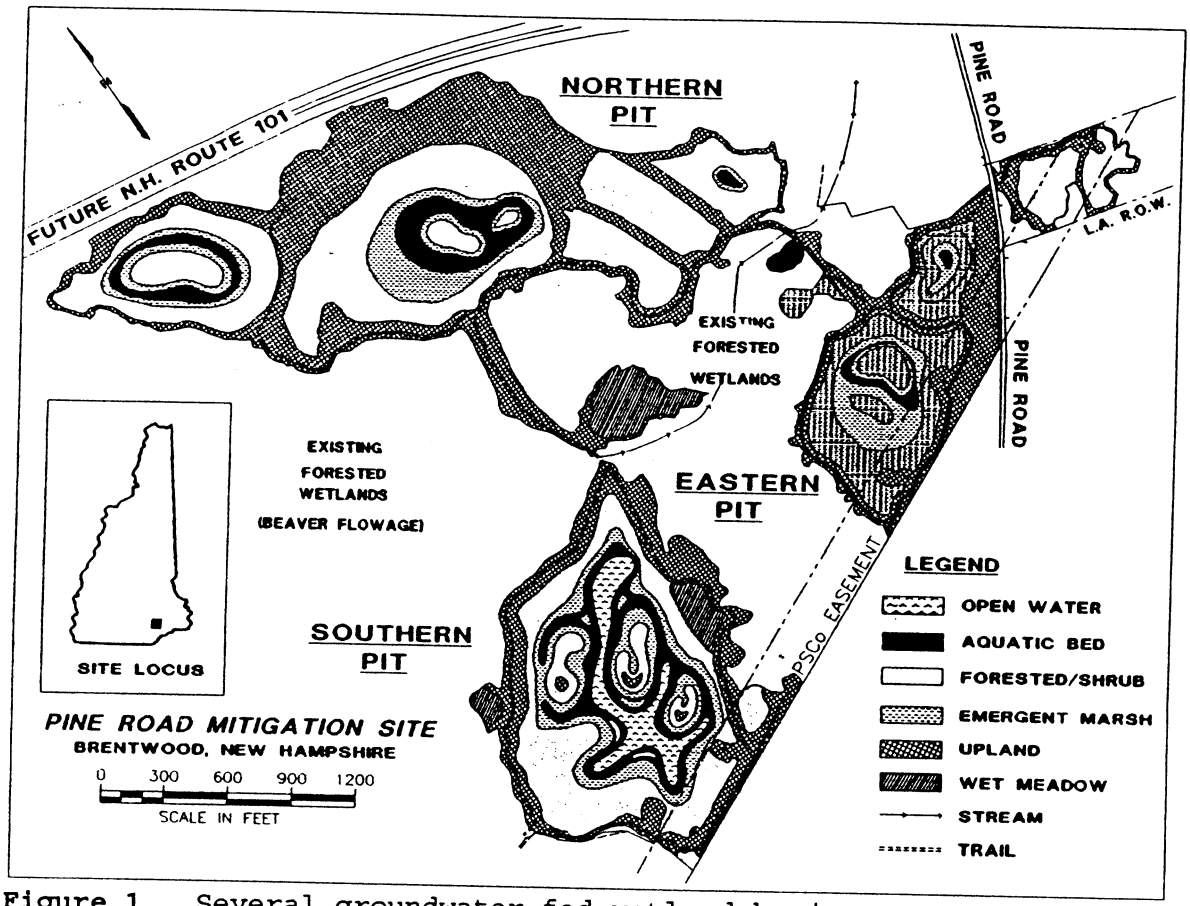

Figure 1. Several groundwater-fed wetland basins were constructed as mitigation for wetland impacts of the New Hampshire Highway 101 improvement.

microtopography was constructed in the subsoil for support, before placement of 30 cm of the wetland topsoil salvaged from wetlands impacted by the highway. The geometry of the finished landscape is on average a 60-cm elevational difference between the tops of the mounds and the bottom of the pools, with the mounds spaced about 6 m apart. Some variation in dimensions is desirable to produce a more natural appearance. Depending on the preference of the contractor, microtopography can be constructed either by bulldozer or backhoe (with seemingly equal efficiency). A moving bulldozer, by lowering and raising its blade, leaves deep gouges which alternate with subsequent passes. This rough landscape is tracked over with a widetrack dozer, topsoil is then spread and the surface is tracked again. If a backhoe is used, it first shapes the subsoil, then places the topsoil as it backs its way out.

Construction of the microtopography can only be accomplished during low

water while this zone is in a relatively dry condition; if free water is present the unconsolidated soils lead to poor results. Grading elevations are based on the expected groundwater elevations developed from analysis of the monitoring well data. The slope of the forested wetland is 20 to 1 or more gradual. During the spring, the seasonal high water should ideally be near the top of the mounds (Photo 1). It is our observation that excavating such a large area had the effect of lowering the groundwater elevation. The original design groundwater elevations were lowered by 30 to 60 cm during construction on all except one basin. The hydrologic theory of a groundwater table similarly lowered by a proposed created wetland is developed by Winston (1997).

Photo 1. Mound-and-pool microtopography constructed during the "dry season" of late summer 1996 (shown the following spring at high water).

Modification of a wetland design based on observations made during construction is often necessary and usually difficult to accomplish. In this case, however, the USACE permit placed the responsibility for developing this mitigation with an interdisciplinary team comprising knowledgeable representatives of the regulatory and scientific community and the NHDOT. Therefore, a management structure was in place to efficiently modify the plan based on field conditions.

Vegetation Establishment of Phase 1, Planted 1995.

The planting plan of the forest/shrub wetland zone called for the more expensive container-grown trees and shrubs to be placed on the top of the mounds where there would be less mortality caused by flooding or prolonged saturation, at a density of 500 per hectare. Around these mounds and in the lower elevation of the pools bare-root and cutting stock were planted at a density of about 2500 per hectare. Species included most of the shrub species commonly found in wetlands in New Hampshire, and two wetland tree species, red maple (*Acer rubrum*) and swamp white oak (*Quercus bicolor*). The uplands were planted primarily with bare-root white pine (*Pinus strobus*), oaks (*Quercus rubra* and *Q. alba*), and several species of upland shrubs at about the same overall density as the forested wetland. The goal was to establish a diversity of shrub species within the forest/shrub wetland zone with the expectation that tree species, mostly gray birch (*Betula populifolia*), pin cherry (*Prunus pennsylvanica*), and red maple would eventually establish from seed present in the topsoil or blown onto the site from adjacent forested areas.

A wetland seed mix made up of marsh milkweed (*Asclepias incarnata*), fox sedge (*Carex vulpinoidea*), and blue vervain (*Verbena hastata*) was broadcast over the forested wetland zone. The seed mix for upland areas consisted of a non-competitive grass, sheep fescue (*Festuca ovina*), and the following species of native or naturalized wildflowers: daisy (*Chrysantheum leucanthemum)*, chicory (*Cichorium intybus*), coreopsis (*Coreopsis lanceolata*), evening primrose (*Oenothera lamarchiana)*, Indian blanket (*Gaillardia pulchella)*, dame's rocket (*Hesperis matronalis*), and black-eyed Susan (*Rudbeckia hirta*). An objective of the seeding was to avoid competition with the seed naturally present in the soil or blown onto the site. For this reason, aggressive species usually found in erosion-control or conservation mixes were not used. The hydroseeding and a dormant planting of the following marsh species were done during fall 1994: burreed (*Sparganium americanum*), pickerelweed (*Pontederia cordata*), duck potato (*Sagittaria latifolia*), iris (*Iris versicolor*) tussock sedge (*Carex stricta*) and water lily (*Nymphaea odorata*).

Given the sandy subsoil and the disturbance of the surface after topsoiling, a poor water-holding capacity was expected and an irrigation system was considered necessary for survival of the plantings. The irrigation system was

invaluable during the region-wide drought of 1995, the first growing season. It was used only infrequently during the second season and then removed.

Vegetation Monitoring

Permanent one-meter-square plots were established to monitor herbaceous vegetation randomly at the end of the first growing season (1995) along transects which bisect the various vegetation zones. The plots were marked by a numbered grade stake (a one-inch-square hardwood stake four feet tall) in the northeast corner of each plot. Data (species and percent cover) collected at the end of the first growing season included the identification of 141 species (Table 1). At the end of the second growing season (1996) a small subset of these plots was sampled. The change in the herbaceous vegetation since the first growing season is mostly in the increased ground cover of the tufts and rosettes of perennials and resultant decrease in bare ground. Tree seedlings, mostly gray birch, pin cherry, red maple and willows, have established themselves also, as expected, apparently aided by the variable microtopography. There was a great reduction in the annuals that colonize disturbed ground, including several weedy species, such as ragweed (*Ambrosia artemisiifolia*) and witch grass (*Panicum capillare*). There was very little germination of nuisance plant species because the areas of salvage of the wetland topsoil were carefully selected. However, those areas with purple loosestrife (*Lythrum salicaria*) germination were hand-weeded early, to establish a dense competitive herbaceous groundcover.

Due to the seed mixes, the natural seed bank in the topsoil, seed blown onto the site, tree and shrub plantings, and irrigation, very good vegetation cover occurred by the end of the first growing season. The few container-grown plants that died were replaced per the landscaper's guarantee during 1996. However, by the end of the third growing season (1997) noticeable stress and some mortality was evident on some of the mounds which were too wet. This is especially evident with alders, which were planted as bare-root stock and in general, grew exceptionally well; most were about 3.7 m tall at the end of the third growing season. The effect of the water stress can be easily seen by comparing adjacent alders on slightly wetter locations where the plants have survived but are barely 1 m tall, as they were at the time of planting. As expected, this created wetland is proving to be a stressful environment for growth of most woody plantings (Perry et al. 1997).

TABLE 1. PLANT SPECIES IDENTIFIED WITHIN 123, ONE-METER SQUARE PERMANENT SAMPLE PLOTS, SEPTEMBER 1995.

Scientific Name		Common Name	Frequency
Acer	rubrum	Red maple	13
Agrostis	alba	Redtop grass	17
Agrostis	hyemalis	Tickle grass	9
Alisma	plantago-aquatica	Water-plantain	8
Alnus	rugosa p.*	Speckled alder	5
Ambrosia	artemisiifolia	Common ragweed	33
Anaphalis	margaritacea	Pearly everlasting	3
Aralia	hispida	Bristly sarsaparilla	9
Aristida	sp.	Triple-awned grass	3
Aronia	melanocarpa p.	Black chokeberry	3
Asclepias	incarnata s.	Swamp milkweed	63
Aster	simplex	Lowland white aster	2
Aster	sp.	Aster	2
Barbarea	vulgaris	Common wintercress	1
Betula	papyrifera	Paper birch	9
Betula	sp.	Birch	9
Bidens	cernua	Nodding sticktight	15
Bidens	connata	Swamp beggar ticks	4
Bidens	frondosa	Beggar-ticks	6
Bulbostylis	capillaris	Bulbostylis	12
Calamagrostis	canadensis	Bluejoint grass	1
Carex	swanii	Swan's sedge	1
Carex	vulpinoidea	Fox sedge	22
Carex	sp.	Sedge	23
Cephalanthus	occidentalis	Buttonbush	1
Cephalanthus	occidentalis p.	Buttonbush	5
Chenopodium	leptophyllum	Lamb's quarters	4
Chrysanthemum	leucanthemum s.**	Common daisy	31
Cichorium	intybus s.	Common chicory	15
Comptonia	peregrina	Sweet-fern	2
Cornus	amomum p.	Silky dogwood	5
Coreopsis	lanceolata s.	Lanceleaf coreopsis	24
Cyperus	strigosus	Umbrella sedge	56
Cyperus	sp.	Umbrella sedge	50
Daucus	carota	Queen Anne's lace	3
Dichanthelium	acuminatum fasciculat	Panic grass	33
Digitaria	ischaemum	Small crabgrass	25
Digitaria	sanguinalis	Hairy crabgrass	11
Digitaria	sp.	Crabgrass	19
Dulichium	arundinaceum	Three-way sedge	2
Echinochloa	crusgalli	Barnyard grass	9
Eleocharis	obtusa	Blunt spikesedge	44
Eleocharis	ovata	Ovate spikerush	15
Eleocharis	tenuis	Spikerush	49
Eleocharis	sp.	Spikerush	1
Erechtites	hieracifolia	Pilewort	7

(continued)

TABLE 1. PLANT SPECIES IDENTIFIED WITHIN 123, ONE-METER SQUARE PERMANENT SAMPLE PLOTS, SEPTEMBER 1995.

Scientific Name		Common Name	Frequency
Eupatorium	maculatum	Spotted joe pye weed	1
Eupatorium	perfoliatum	Boneset	3
Eupatorium	sp.	Thoroughwort	1
Euthamnia	graminifolia	Grass-leaved Goldenrod	20
Festuca	ovina	Sheep's fescue	24
Forbs	Unidentified	Broad leaf seedling	38
Fragaria	vesca	Wood strawberry	1
Fragaria	virginiana	Wild strawberry	10
Gaillardia	pulchella s.	Indian blanket	10
Galium	triflorum tinctorium	Fragrant bedstraw	13
Galium	triflorum trifidum	Fragrant bedstraw	5
Galium	sp.	Bedstraw	24
Gerardia	paupercula	Small flowered gerardia	8
Gerardia	purpurea	Purple gerardia	2
Geum	sp.	Avens	1
Gnaphalium	obtusifolium	Sweet everlasting	2
Gnaphalium	uliginosum	Low cudweed	31
Hieracium	florentinum	King devil	1
Hypericum	boreale	Northern St. Johnswort	9
Hypericum	canadense	Canada St. Johnswort	25
Hypericum	gentianoides	Pineweed	50
Hypericum	mutilum	Dwarf St. Johnswort	30
Hypericum	perforatum	Common St. Johnswort	1
Hypericum	virginicum	Marsh St. Johnswort	1
Hypericum	sp.	St. Johnswort	2
Impatiens	capensis	Jewelweed	1
Iris	versicolor	Blue flag	1
Juncus	acuminatus	Rush	9
Juncus	articulatus	Jointed rush	3
Juncus	brevicaudatus	Short tailed rush	58
Juncus	brifonius	Toad rush	18
Juncus	canadensis	Canada rush	39
Juncus	effusus	Soft rush	81
Juncus	marginatus	Shore rush	42
Juncus	tenuis	Path rush	54
Juncus	sp.	Rush	8
Leersia	oryzoides	Rice cut-grass	21
Linaria	canadensis	Old-field toadflax	22
Lindernia	dubia	False pimpernel	5
Linaria	vulgaris	Butter-and-eggs	7
Lotus	corniculatus	Bird's foot trefoil	15
Ludwigia	palustris	Water-purslane	15
Lycopus	americanus	Cut-leaf water horehound	2
Lycopus	uniflorus	Water horehound	1
Lycopus	sp.	Water horehound	4
Lysimachia	terrestris	Swamp candles	5
Lythrum	salicaria	Purple loosestrife	2

(continued)

TABLE 1. PLANT SPECIES IDENTIFIED WITHIN 123, ONE-METER SQUARE PERMANENT SAMPLE PLOTS, SEPTEMBER 1995.

Scientific Name		Common Name	Frequency
Mikania	scandens	Climbing hempweed	1
Muhlenbergia	uniflora	Muhly grass	12
Oenothera	lamarkiana p.	Evening primrose	16
Osmunda	cinnamomea	Cinnamon fern	1
Oxalis	europaea	Common sorrel	21
Panicum	capillare	Old-witch grass	41
Panicum	clandestinum	Corn grass	10
Panicum	dichotomiflorum	Fall panicum	23
Panicum	lanuginosum	Panic grass	25
Penthorum	sedoides	Ditch-stonecrop	4
Phalaris	arundinacea	Reed canary grass	2
Phleum	pratense	Timothy	2
Pinus	strobus	White pine	2
Plantago	lanceolata	English plantain	2
Plantago	major	Common plantain	2
Poaceae		Grasses	30
Polygonella	articulata	Jointweed	2
Polygonum	careyi	Carey's knotweed	5
Polygonum	lapathifolium	Pale smartweed	13
Polygonum	pensylvanicum	Pink smartweed	8
Polygonum	persicaria	Lady's thumb	14
Polygonum	prolifum	Smartweed	2
Polygonum	saggitatum	Arrow-leaved tearthumb	13
Polytrichum	sp.	Hair-cap moss	1
Pontederia	cordata	Pickerel weed	4
Portulaca	oleracea	Common purselane	1
Potentilla	canadensis	Dwarf cinquefoil	8
Potentilla	simplex	Old-field cinquefoil	27
Potemogeton	spirillus	Spiral pondweed	3
Prunus	pensylvanica	Bird cherry	1
Quercus	rubra	Northern red oak	2
Rhynchospora	capitellata	Beak-rush	2
Riccia	sp.	Aquatic liver wort	1
Rorippa	islandica	Marsh yellow cress	5
Rubus	allegheniensis	Blackberry	1
Rubus	allegheniensis p.	Blackberry	1
Rubus	flagellaris	Whip bramble	1
Rubus	hispidus	Trailing bramble	4
Rudbeckia	hirta s.	Black-eyed Susan	25
Rumex	acetosella	Sheep sorrel	9
Rumex	crispus	Curled dock	2
Sagittaria	latifolia	Arrowhead	3
Salix	sp.	Willow	8
Salix	purpurea p.	Purple ossier willow	5
Scirpus	validus	Great bulrush	8
Setaria	glauca	Foxtail grass	3
Septaria	sp.	Foxtail grass	1

(continued)

TABLE 1. PLANT SPECIES IDENTIFIED WITHIN 123, ONE-METER SQUARE PERMANENT SAMPLE PLOTS, SEPTEMBER 1995.

Scientific Name		Common Name	Frequency
Silene	cucubalus	Bladder campion	1
Sisyrinchium	sp.	Blue-eyed-grass	4
Solanum	nigrum	Black nightshade	2
Sparganium	americanum	Burreed	9
Sparganium	sp.	Burreed	2
Spiraea	latifolia	Meadowsweet	19
Spiraea	tomentosa	Steeplebush	2
Tanacetum	vulgare	Common tansy	1
Trifolium	arvense	Rabbit-foot clover	28
Trichostema	dichotomum	Bluecurls	11
Trifolium	hybridum	Alsike clover	47
Trifolium	pratense	Red clover	11
Trifolium	repens	White clover	42
Typha	latifolia	Cattail	36
Typha	sp.	Cattail	17
Umbelliferae		Parsley family	1
Vaccinium	corymbogum p.	Highbush blueberry	6
Verbena	hastata s.	Blue vervain	90
Verbascum	sp.	Mullein	5
Viburnum	cassinoides	Northern wild raisin	3
Viburnum	cassinoides p.	Northern wild raisin	1
Viburnum	recognitum p.	Northern arrowwood	4
Viburnum	trilobum p.	Highbush cranberry	5
Vicia	cracca	Cow vetch	6
Viola	lanceolata	Lanceleaved violet	65

* p. indicates from planting
** s. indicates from seed mix

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CHANNEL STABILIZATION AND FISH COMMUNITY STRUCTURE OF A SOUTHEASTERN UPLAND STREAM

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ABSTRACT

Weirs were installed in the upper reach of Twentymile Creek, an unstable tributary of the Tombigbee River (Mississippi-Alabama) to reduce erosion. A survey of fish in the stabilized, upper reach and in the unstabilized, lower reach was used to infer effects of channel stabilization on fish community structure. Of 49 fish species, 38 occurred in the stabilized reach, 42 in the unstabilized reach. Two measures of diversity were calculated for individual collections, number of species(S) and Shannon heterogeneity (H'), were not appreciably different between the stabilized and unstabilized reaches. Ubiquity and abundance of six minnows, and rarity of most species, impaired discriminant ability of diversity measures based on individual collections. Rarefaction curves, however, constructed from pooled collections, indicated substantially higher diversity in the stabilized reach (35 species/2000 fish) than in the unstabilized portion of the stream (27 species/2000 fish). Higher diversity in stabilized reach is attributable to greater habitat permanence and variation providing benign, preferred microhabitats for comparatively uncommon, specialized species.

INTRODUCTION

Diversity of stream fishes is positively correlated with stability and complexity of physical habitat (Harrel *et al.*, 1967; Sheldon, 1968; Gorman and Karr, 1978; Evans and Noble, 1979; Foltz, 1982; Williams *et al.*, 1996). Consequently, man-made structures that reduce erosion and increase variation in substrate and hydraulic conditions should also promote diversity in fish assemblages. Weirs are often used to reduce erosion in streams, and complex fish assemblages may occur in their vicinity (Cooper and Knight, 1987; Shields and Hoover, 1991). Herein we evaluate benefits of stream stabilization for fish communities by quantifying the number of species likely to occur in a reach after stabilization.

Twentymile Creek, in northeastern Mississippi, has experienced over a century of erosion and channel modification (Shields and Hoover, 1991). Originally it was a sinuous stream in a landscape of forested hills. Intensive agriculture resulted in erosion, aggradation, and flooding during the early 1900's. Local agencies ditched and channelized the stream between 1904 and 1938, and in 1966 the United States Army Corps of Engineers enlarged the channel, cleared banks, and removed snags. This was followed by a period of stream degradation and bank failures. In 1982, the Corps of Engineers stabilized the channel upstream of river kilometer (RK) 18.7 with bank armor (rip rap), anchors (concrete jacks), plantings (willows), and by constructing "grade control structures" or weirs.

Previous fish collections document 24 species in Twentymile Creek, but 119 species are known from the entire upper Tombigbee River system (Boschung, 1989), only a few of which are characteristic of big rivers and are unlikely to occur in smaller waterways (Swift *et al.*, 1986). Consequently, potential diversity of the ichthyofauna is high, particularly in areas with favorable habitat. We infer effects of stabilization by comparing fish communities in the stabilized, upper reach of the stream with those from the unstabilized, lower reach.

STUDY SITE

Twentymile Creek is a principal tributary in the extreme northern portion of the Tombigbee River drainage and is part of the Mobile Bay basin (Fig. 1) It occurs in the Black Belt Prairie region, is 46 km long and drains 450 sq km. Landscape is cultivated floodplain and low steep hills. Floodplain is Recent and Quaternary alluvium and soils are of the Selma Group (Vestal 1947; Parks, 1960). These include: Catalpa silty clay loams, Demopolis chalks, and Coffee sands.

The stream is shallow, with moderate water velocity, and high, steep banks. Predominant substrate is sand with chalky clay in the upper sections. Most stations consist of shallow runs, but riffle-pool sequences occur in some sections of the stream. Backwaters are uncommon and poorly developed. Summer water temperatures are high (27-34 C) and conductivity moderate (133-267 umhos).

MATERIALS AND METHODS

Spring and summer fish assemblages were collected at sixteen stations (Fig. 1). Three stations (#1-3), in the upper, stabilized reach, were sampled in May and July 1989. Twelve stations (#4-15) in the lower, unstabilized reach were sampled in July 1995. The lowermost station (#16) was sampled once in July 1989. Stations sampled twice were characterized by cumulative numbers of species in both samples and by abundance data from the collection with the greater number of fish.

Small, shallow-water fishes were collected using seines of 6.4 mm mesh and lengths of 1.3, 3.1, and 9.2 m. Experimental gillnets 30 X 2 m with 19 - 89 mm mesh were set overnight to sample large, demersal fishes from pools > 2 m depth at stations # 2, 6, and 15. Large fishes were identified in the field and released. Small fishes were preserved in 10% formalin. In the laboratory, these fishes were washed, identified and counted, and preserved in 50% isopropanol. Taxonomy is consistent with that of Douglas (1974), Boschung (1989), and Suttkus and Boschung (1990). Nomenclature follows Mayden *et al.* (1992). Specimens were deposited at the Museum of Zoology, Northeast Louisiana

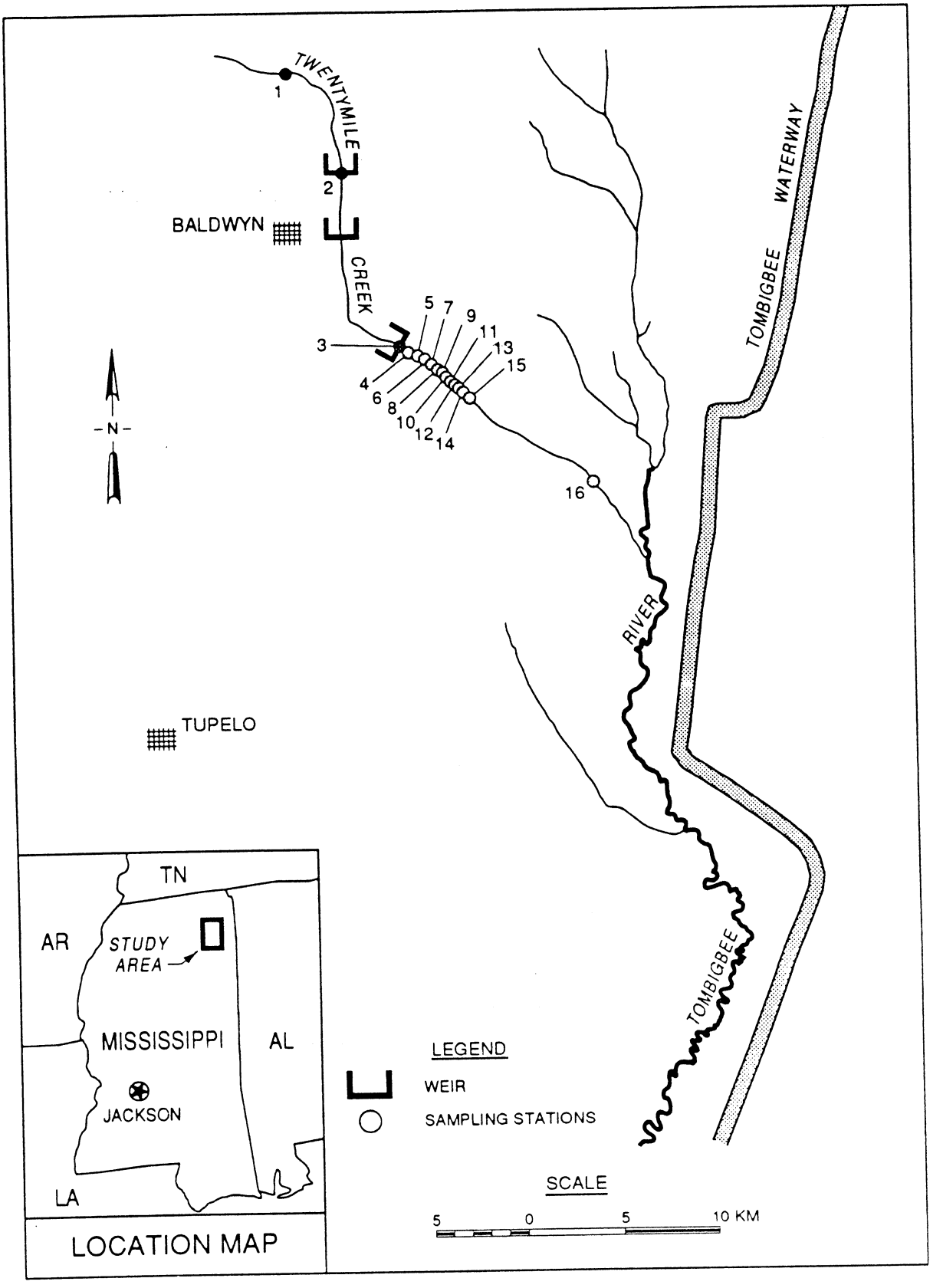

Fig. 1. Stations sampled on Twentymile Creek, MS.

University and in the Environmental Laboratory, Waterways Experiment Station. Diversity of individual fish collections is quantified using two indices widely used by community ecologists: species richness and Shannon heterogeneity (Magurran, 1988). Species richness, S, is the total number of species observed. When sampling effort, population densities and species-abundance relationships are comparable among collections, S provides a direct measure of differences in complexity of a community. Values can range from 1 to S* (total number of species in community). Values for S of fish communities in small southern streams sampled using our methodology typically range from 3-40.

Shannon heterogeneity, H', is a logarithmic function based on information theory and developed for communication research (Shannon, 1948). It expresses the "uncertainty" of correctly predicting the identity (species) of a single observation (fish) in a group of observations (collection). Values for H' are high when: 1) there are many species; and 2) abundances diminish gradually from most to least abundant. High values indicate greater complexity and, possibly, stability (Lloyd *et al.*, 1968). H' is responsive to variation in both components of species diversity: species richness (number of species) and species evenness (equitability of abundances among species). Values can range from 0.00 (community consisting of a single species) to lnS (all species in a community present in equal abundance). Values for H' of fish communities in small southern streams sampled using our methodology typically range from 0.50 to 2.50.

Diversity of collections pooled within reach is described using rarefaction (Hurlbert, 1971). This technique quantifies the number of species expected, Es, from a random subsample of stated size, N. Rarefaction allows direct comparisons of species richness among data sets of unequal size by standardizing subsample size (Magurran, 1988). We constructed rarefaction curves; x-axis is subsample size, y-axis is expected number species (Ludwig and Reynolds, 1988). Shape of curve provides information on equitability of species abundances, sampling effort required to detect differences in diversity, and effort required to detect progressively rarer species.

Table 1. Fishes of Twentymile Creek, Mississippi. Stations correspond to Figure 1.

	Station, Longitudinal Position															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gars, Lepisosteidae																
Spotted gar, *Lepisosteus oculatus*			x		x											
Longnose gar, *L. osseus*			x												x	
Bowfins, Amiidae																
Bowfin, *Amia calva*															x	
Herrings, Clupeidae																
Gizzard shad, *Dorosoma cepedianum*		x	x			x									x	
Threadfin shad, *D. petenense*				x	x	x			x		x				x	
Juvenile shad, *D.* sp.													x	x		
Minnows, Cyprinidae																
Largescale stoneroller, *Campostoma oligolepis*						x										
Blacktail shiner, *Cyprinella venusta*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Common carp, *Cyprinus carpio*		x	x													
Cypress minnow, *Hybognathus hayi*			x													
Pretty shiner, *Lythrurus bellus*	x	x	x	x	x	x		x	x	x	x		x	x	x	x
Golden shiner, *Notemigonus crysoleucas*			x													x
Orangefin shiner, *Notropis ammophilus*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Silverstripe shiner, *N. stilbius*		x	x	x	x		x	x	x	x	x	x	x	x	x	x
Weed shiner, *N. texanus*			x													x
Mimic shiner, *N. volucellus*			x													
Pugnose minnow, *Opsopoeodus emiliae*			x													
Bluntnose minnow, *Pimephales notatus*	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Table 1. (cont.)

	Station, Longitudinal Position															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Minnows, Cyprinidae (cont.)																
Fathead minnow, *P. promelas*					x											
Bullhead minnow, *P. vigilax*		x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Creek chub, *Semotilus atromaculatus*	x							x								
Suckers, Catostomidae																
River carpsucker, *Carpiodes carpio*						x										
Highfin sucker, *C. velifer*		x	x			x				x					x	
Juvenile carpsucker, *C.* sp.				x				x	x		x	x	x		x	
Smallmouth buffalo, *Ictiobus bubalus*						x										
Black buffalo, *I. niger*		x				x									x	
Juvenile buffalo, *I.* sp.				x	x			x	x			x			x	
Spotted sucker, *Minytrema melanops*														x		
Blacktail redhorse, *Moxostoma poecilurum*		x			x						x					
Catfishes, Ictaluridae																
Yellow bullhead, *Ameiurus natalis*		x														
Channel catfish, *Ictalurus punctatus*		x	x			x		x	x	x			x	x	x	x
Killifishes, Cyprinodontidae																
Blackspotted topminnow, *Fundulus olivaceus*	x	x	x			x		x		x		x	x	x	x	
Livebearers, Poeciliidae																
Eastern mosquitofish, *Gambusia holbrooki*	x	x	x	x			x	x	x	x	x	x	x	x	x	x

Table 1. (cont.)

	Station, Longitudinal Position															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Silversides, Atherinidae																
Brook silverside, *Labidesthes sicculus*				x	x	x	x	x	x	x	x	x	x	x	x	
Inland silverside, *Menidia beryllina*																x
Sunfishes, Centrarchidae																
Green sunfish, *Lepomis cyanellus*	x	x	x	x	x		x	x	x			x	x			x
Bluegill, *L. macrochirus*		x	x	x	x		x	x	x	x	x		x	x	x	x
Longear sunfish, *L. megalotis*	x	x	x	x	x		x		x	x	x	x	x	x	x	x
Redear sunfish, *L. microlophus*		x	x													
Spotted bass, *Micropterus punctulatus*			x	x	x					x	x		x		x	x
Largemouth bass, *M. salmoides*		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
White Crappie, *Pomoxis annularis*		x	x						x							
Black crappie, *P. nigromaculatus*			x													
Perches, Percidae																
Eastern sand darter, *Ammocrypta meridiana*			x			x	x	x	x	x	x	x	x	x		x
Bluntnose darter, *Etheostoma chlorosomum*		x	x							x	x	x	x	x		x
Tesselated darter, *E. nigrum*		x														
Rock darter, *E. rupestre*			x	x		x		x								
Stippled darter, *E. stigmaeum*			x		x											
Redfin darter, *E. whipplei*	x	x	x							x						x
Blackside darter, *Percina maculata*							x			x	x		x	x	x	
Dusky darter, *P. sciera*			x	x	x	x	x	x	x	x	x	x	x	x	x	
Drums, Sciaenidae																
Freshwater drum, *Aplodinotus grunniens*						x									x	

RESULTS

Forty-nine species were collected in Twentymile Creek (Table 1). These were dominated taxonomically by minnows (15 species) and, to a lesser extent, darters (8 species) and sunfishes (8 species). Six minnows were ubiquitous, occurring at 14-16 stations: blacktail shiner, pretty shiner, orangefin shiner, silverstripe shiner, bluntnose minnow, and bullhead minnow. Over 25 species occurred at fewer than half the stations sampled and most of these occurred at only 1-4 stations. Progressive longitudinal (downstream) addition of species was not observed. Silversides, however, were collected only from the lower reach, and eastern sand darter and rock darters were more common in the lower reach. Thirty-eight species were recorded from the stabilized reach, 42 from the unstabilized reach.

The six ubiquitous minnows were abundant, together accounting for more than 60% of all fish collected in each reach (Fig. 2). Four of these species were more abundant in the stabilized reach. Two species, bluntnose minnow and orangefin shiner, were more abundant in the unstabilized reach. Blacktail shiner were numerically dominant in both reaches. Brook silverside were comparable in abundance to several minnows in the lower reach.

Diversity indices for individual collections were not appreciably different in the stabilized and unstabilized reach (Fig. 3). Species richness ranged from 8-33 in the stabilized reach, 14-26 in the unstabilized reach. Heterogeneity ranged from 1.75-2.06 in the stabilized reach, 1.69-2.31 in the unstabilized reach. Numbers of fishes collected in each reach, however, were disparate. Sample size at two of the stations in the stabilized reach were substantially higher ($n > 1000$) than at any of the stations in the unstabilized reach ($n = 138$-885).

Rarefaction curves for pooled stations within reaches indicated that substantial differences in diversity existed, but were detectable only at relatively large sample size (Fig. 4). For sample sizes greater than 1000, there were 7-9 more species expected from the stabilized reach than the unstabilized reach. For sample sizes < 200, differences in species richness were not detectable. Steepness of the left side of curves indicated high equitability of numbers among abundant and moderately abundant species in both communities. Right side of curves shows new species would be detected with additional sampling

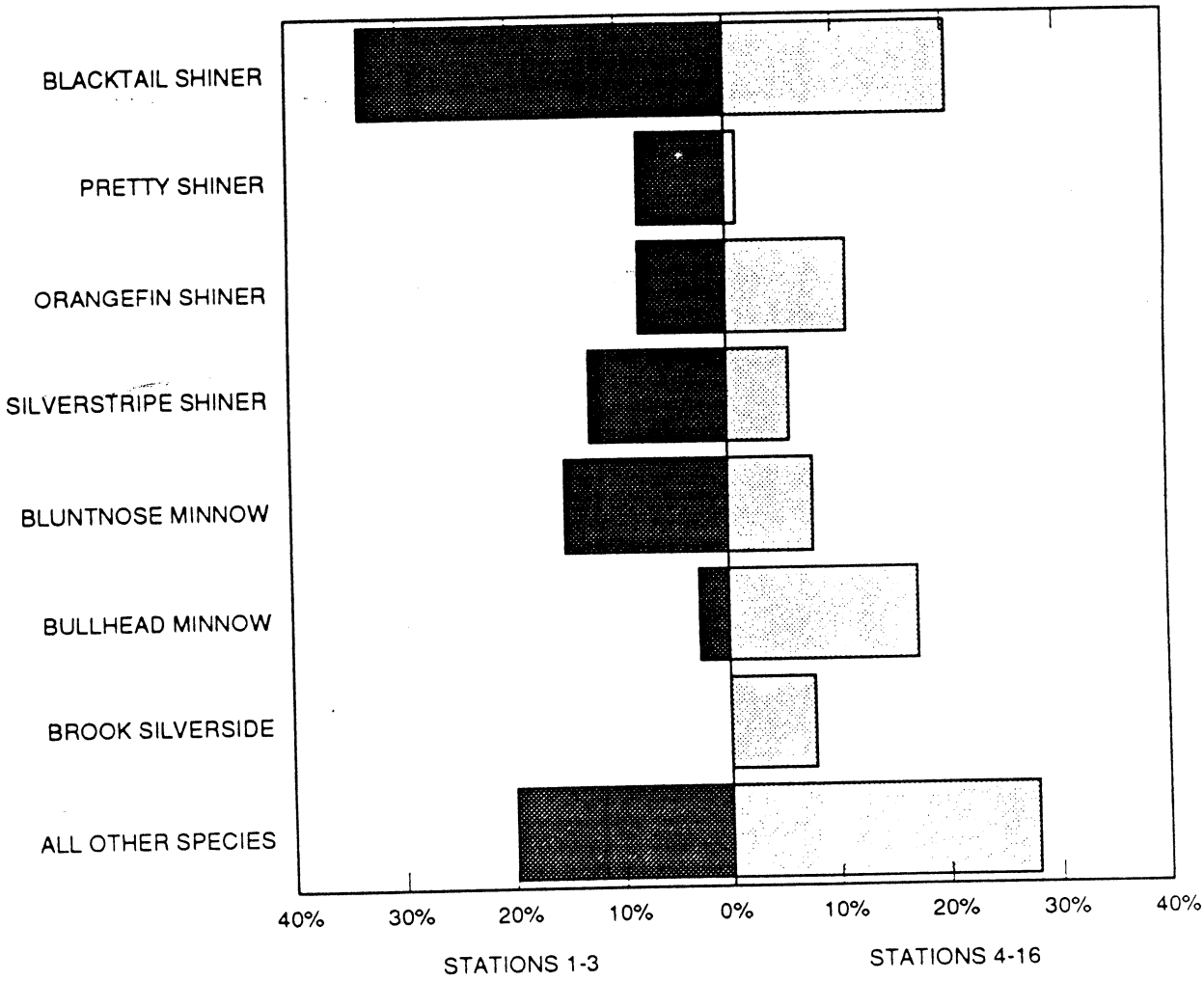

Fig. 2. Relative abundance (percentage by number) of fishes in the stabilized (#1-3) and unstabilized (#4-16) reaches of Twentymile Creek, MS.

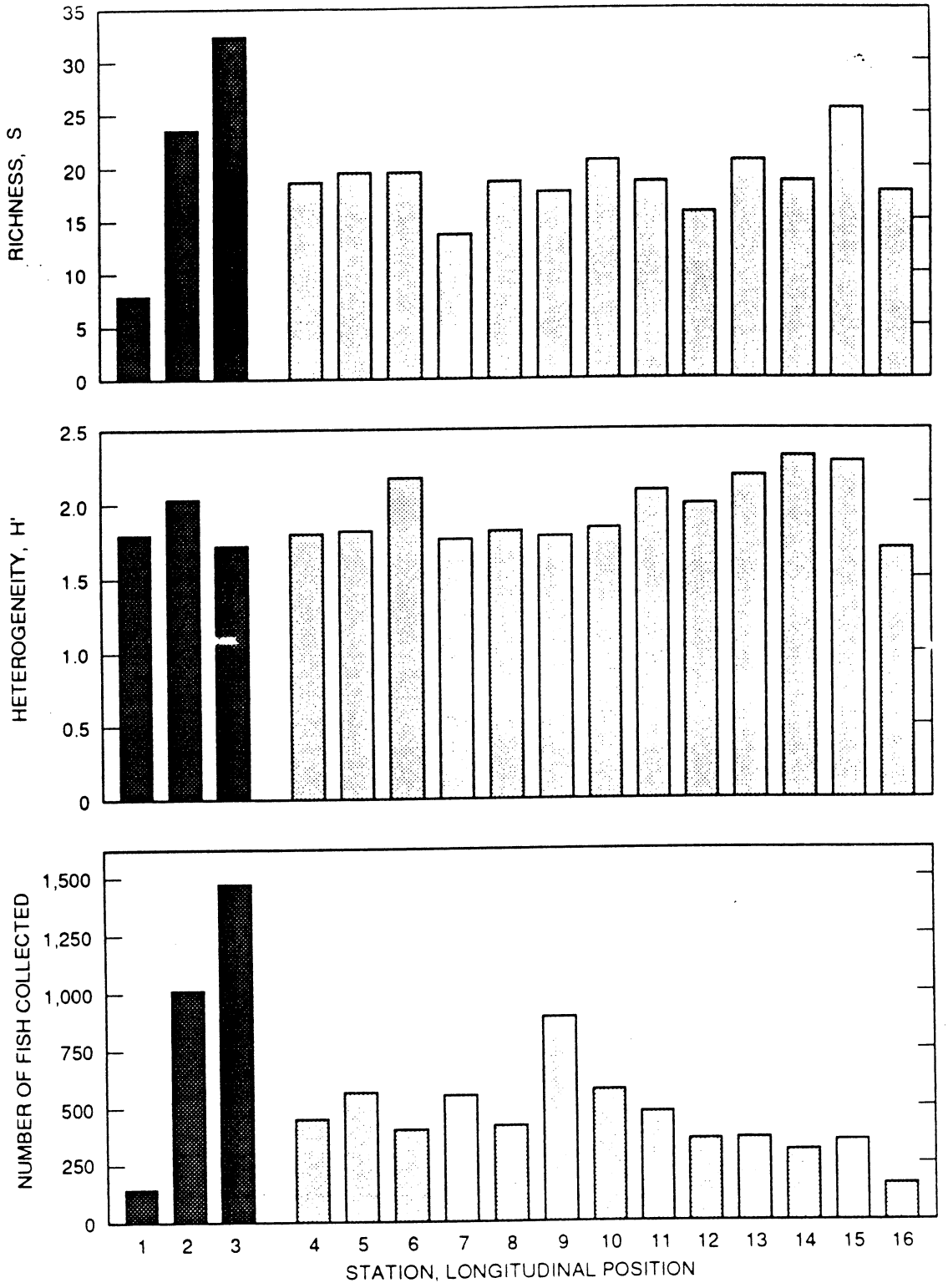

Fig. 3. Community metrics for fish collections from Twentymile Creek. A) number of species observed; B) Shannon heterogeneity function; C) number of fish collected.

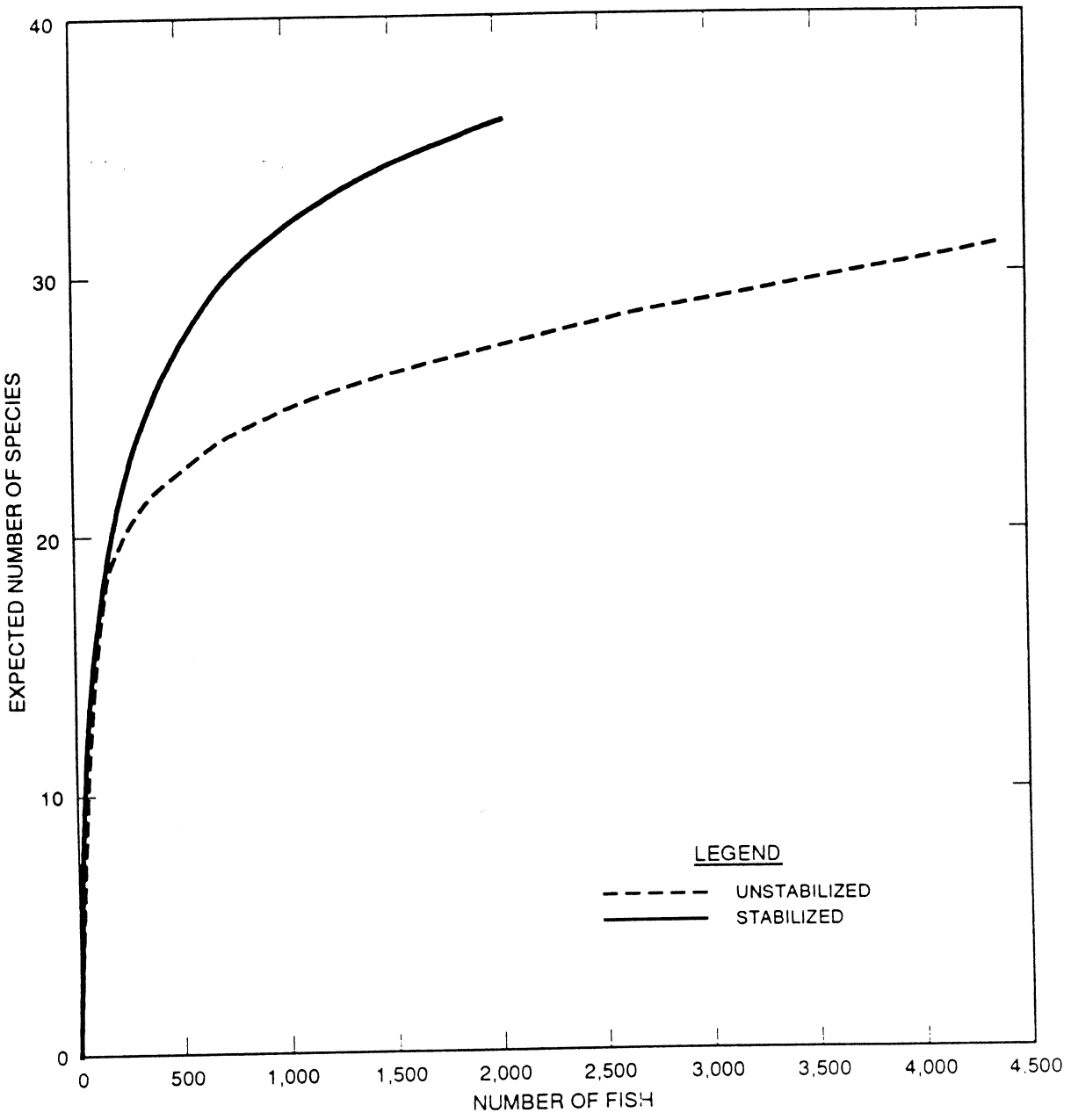

Fig. 4. Rarefaction curves for fish communities in stabilized and unstabilized reaches of Twentymile Creek, MS.

but scale of x-axis indicates that total sample size would have to multiplied several-fold to detect each additional species. Expected number of species for subsamples of 2000 individuals was 35 species in the stabilized reach, 27 species in the unstabilized reach.

DISCUSSION

Species composition of Twentymile Creek is comparable to that of small upland streams in this drainage (Swift *et al.*, 1986; Boschung, 1989), but longitudinal zonation is not apparent (Table 1, Fig. 3). Typically fish assemblages in small, southern streams become more speciose and heterogeneous downstream, even over short distances. Downstream habitats are more persistent, benign, and complex. They support greater numbers of species and more equitable abundances among species (Harrel *et al.*, 1967; Whiteside and McNatt, 1972; Evans and Noble, 1979, Williams *et al.*, 1996). These patterns, however, may be obscured in physically degraded streams (Harrel and Dorris, 1968; Tramer and Rogers, 1973). In Twentymile Creek, agricultural runoff and stream bed degradation reduce occurrences of "intolerant" species (sensu Jester *et al.*, 1992) and fishes characteristic of larger, temporally "mature" habitats (sensu Shelford, 1911).

Higher diversity in the upper reach (Fig.4) underscores effect of stabilization on fish community. Physical habitat in the vicinity of weirs is complex. Variation in water depth, velocity, and substrate are high due to impounded water, overflow riffles, and scour pools. Desiccation and intermittent flow, factors associated within lower diversity of stream faunas, are reduced (Harrel *et al.*, 1967; Harrel and Dorris, 1968).

Failure of diversity indices to reflect differences among reaches may be an artifact of sampling and fish abundance(Fig. 3). Values for such indices are positively correlated with sample size; they increase rapidly with progressively higher numbers of individuals, asymptote, and level off at some critical number of individuals when all but extremely rare species are detected (Margalef, 1957; Magurran, 1988). Our rarefaction curves indicate that sample sizes greater than 250 were required to detect any difference among reaches, but that samples greater than 1000 were required to determine maximum differences in diversity (Fig.4). Majority of samples consisted of < 500 individuals. S and H' values for

such samples, then, may underestimate diversity since rare and sporadically occurring species are unlikely to be collected. This study emphasizes the need for large collections or large numbers of collections to characterize diversity of stream fish communities in disturbed ecosystems.

ACKNOWLEDGMENTS

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WILDLIFE RESPONSE TO HYDROPATTERN RESTORATION IN THE NORTHERN EVERGLADES

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ABSTRACT

The Holey Land Wildlife Management Area, a 14,306 ha marsh in the northern Everglades, historically consisted of sawgrass (*Cladium jamaicense*) interspersed with sloughs and tree islands. Extensive drainage, beginning in the early 1900s, caused a shift from sawgrass to shrub communities. Restoration began in 1974 when 54 artificial islands were built and continued with the construction of a levee system, culverts, and pumps in the late 1980s. After hydropattern restoration in 1991, populations of alligators (*Alligator mississippiensis*) and foraging use by some wading birds increased but deer (*Odocoileus virginiana*) populations decreased due to higher water levels. There was a positive correlation between marsh water depth and use of boundary levees by deer and raccoons (*Procyon lotor*). A gradual increase in peak yearly water depths may ease the transition into natural hydropatterns for plant and animal communities affected by Everglades restoration projects.

INTRODUCTION

The Everglades once covered nearly 1.2 million ha in southern Florida, but only 618,000 ha remains, most of which has suffered damage caused by the extensive system of canals and levees built for flood control associated with farming and urbanization along the Atlantic Coast. Most of the research on the effects of water management in South Florida has focused on the southern Everglades, although most of the damage has taken place in the northern Everglades, where 75% of the sawgrass plains have been lost (Davis et al. 1994).

This paper evaluates an ongoing restoration project in the remaining sawgrass plains. The first large-scale attempt to restore Everglades habitat, and one of the

largest wetlands restoration projects in the United States, was focused on the Holey Land Wildlife Management Area (WMA). An examination of this project will aid in restoring the remainder of the Everglades.

STUDY SITE

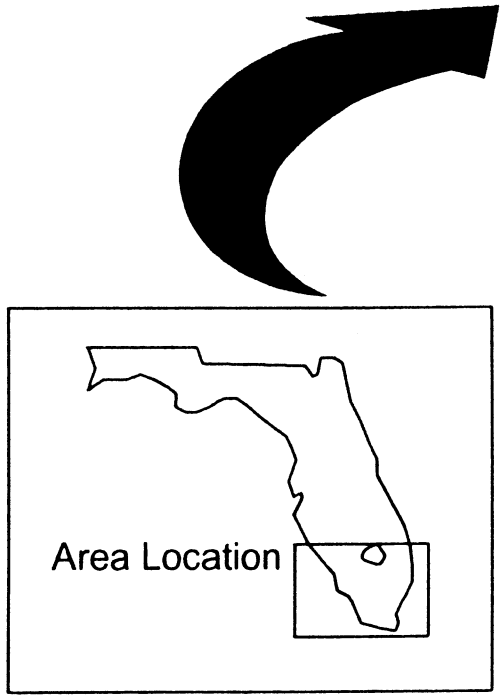
The Holey Land WMA is a 14,306 ha wetland situated in the southwest corner of Palm Beach County, Florida (Figure 1). The area was originally a marsh of sparse to dense sawgrass with scattered shrubs and sloughs (Davis 1943). Alteration of the area's hydropattern began when the Miami Canal was excavated (1907-1917) along the western border of the area. This process continued with the construction of the L-5 levee (1954-1959), blocking sheetflow to the south (Light and Dineen 1994). By the late 1960s, these changes, in combination with conversion of marsh to farmland to the north and east, had altered the area's hydropattern and caused a significant change in plant communities (Cornwell and Hutchinson 1974).

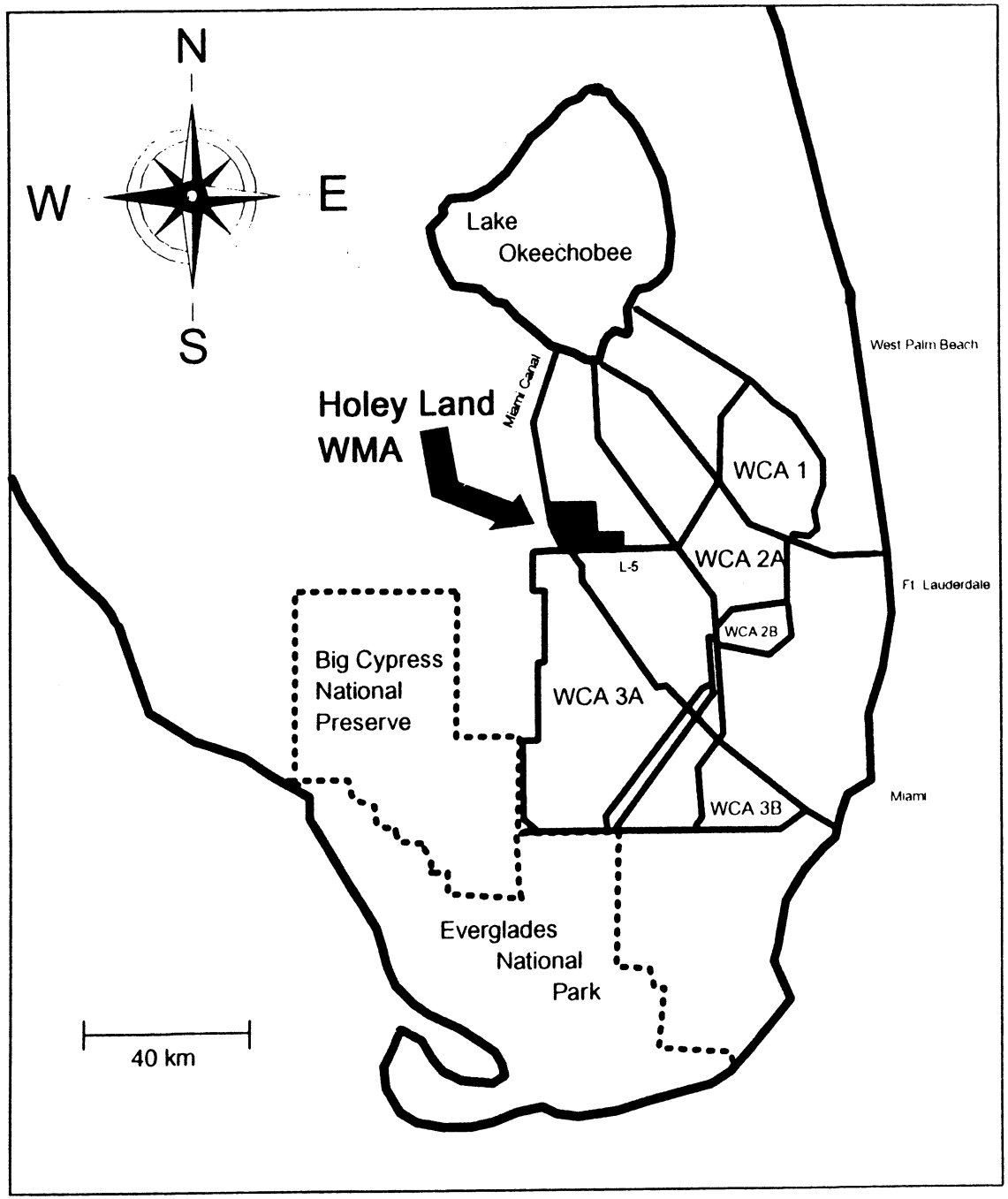
Wildlife species composition changed in conjunction with the lowered water levels. Aquatic species such as alligators (*Alligator mississippiensis*), snail kites (*Rostrhamus sociabilis*), and frogs decreased in numbers. The distribution and use by migratory waterfowl and foraging wading birds became sporadic due to undependable habitat conditions. Correspondingly, terrestrial species such as white-tailed deer (*Odocoileus virginiana*), marsh rabbits (*Sylvilagus palustris*), and raccoons (*Procyon lotor*) increased as the area dried out (Brady 1975).

In 1968 the area was leased to the Florida Game and Fresh Water Fish Commission (GFC) for fish and wildlife management purposes. Pursuant to that objective, restoration was initiated, first (1974-1975) with the construction of 54 artificial islands 0.3 to 0.5 ha in size, created by dredging muck from the marsh, leaving behind a small pond adjacent to each island. This was part of an Everglades-wide program, initiated by sportsman Francis "Franny" Taylor to mitigate for the loss of tree island habitat caused by muck fires (Schortemyer 1980).

Then, a 1983 interagency agreement between the GFC, the South Florida Water Management District, and the Florida Department of Environmental Regulation

Figure 1. Holey Land Wildlife Management Area vicinity map.





Division of Wildlife
Everglades Region

identified hydropattern improvement as the method for restoring the Holey Land WMA. Subsequently, in the late 1980s a system of levees, canals, and pumps was built that allowed managers to pump water from the Miami Canal into the area to achieve desired water levels.

This system was fully functional by 1990 and the initial water schedule, which called for water levels varying from 11.5-13.5 feet above mean sea level (ft. MSL), was achieved in June 1991. A topographic survey performed in 1992 revealed that the average elevation was 11.1 ft. MSL--lower than the previous estimate of 11.5 ft. MSL. The water regulation schedule was accordingly lowered to 11.0-13.0 ft. MSL in July 1993. In early 1995, the schedule was again dropped to 10.5-12.0 ft. MSL in an attempt to slow the proliferation of cattails.

METHODS

Systematic reconnaissance flight (SRF) surveys modified from Norton-Griffiths (1978) were used to monitor wading birds (1986-1996) and deer populations (1985-1996). The SRF flights were conducted in Cessna 172, 182, or 182RG aircraft equipped with a LORAN C navigational receiver or Trimble GPS system. The survey consisted of a series of east-west transects 2 km apart, flown at an altitude of 61 m, and at a ground speed of 80 nautical miles per hour. All animals detected in strips 100 m wide along both sides of the flight path were recorded. Monthly wading bird surveys covered 10% of the area. The distance between transects was reduced to 1 km for the June deer survey, resulting in 20% coverage.

Aerial deer recruitment surveys (number of fawns observed/total deer observed) were conducted each April. Beginning at sunrise, a series of transects spaced approximately 0.5 km apart were flown by a Bell Jet Ranger at an altitude of 8-61 m. When a deer was located, the helicopter left the transect to approach the animal so that biologists could verify its age.

Nighttime spotlight surveys were conducted from July 7, 1992 through January 11, 1993. The vehicular survey along the southern and western levees measured use of this elevated habitat by wildlife at varying marsh water depths in response

to a flood situation. Two 1 million-candlepower spotlights were used to locate deer and raccoons on these 26 km surveys.

A spotlight survey of nighttime alligator activity was conducted each May (1990-1997) from an airboat traveling in the interior canals along the northern and eastern boundaries. The airboat was operated fast enough to keep on a plane, but slow enough to observe alligators. Each animal was approached and its size estimated (Wood et al. 1985, Woodward and Marion 1978). Length of surveys varied somewhat from year to year as the canal system was completed and due to accessibility problems in 1993. Survey lengths were 10.8 km (1990-1991), 23 km (1992), 18.2 km (1993), and 23 km (1994-1997).

Three survey methods were used to monitor alligator nesting trends each July. Active nests were distinguishable as intact domes approximately 1.5 m in diameter and 0.5 to 1.0 m in height. False nests were smaller, often incomplete and in most instances in close association with larger true nests. One method was a search of each of the 54 artificial islands (1993-1997) using a helicopter. Another method utilized SRF flights (10% coverage) to locate alligator nests (1988-1994).

Plot surveys were also flown to locate alligator nests (1988-1995). Three fixed-plots of approximately 5 square kilometers each were delineated within open marsh habitat, resulting in a total surveyed area of 3,108 ha (22% of the area). A helicopter was used to conduct a thorough search of each plot, made at an altitude of 30-46 m. Within each plot, parallel transects approximately 100 m apart were surveyed.

SYSTAT for Windows, Version 5 (Wilkinson 1992) was used for statistical analyses of data. Comparisons of pre- and post-restoration mean monthly wading bird observations (1986-1996) were made using the t-test. Observations through June 1991 were placed into the pre-restoration category, the remainder classified as post-restoration. Wading bird presence was calculated for each species by using the percentage of months it was observed each year, and then grouping them into pre- and post-restoration categories before analysis with the t-test. The percentage of months observed was utilized rather than number of months observed because not all months were surveyed each year prior to restoration. Comparisons of pre- and post-restoration deer population and

recruitment were also made with the t-test. A general linear model regression was made on levee spotlight counts of deer and raccoon. No statistical analysis was performed on alligator data due to small sample sizes.

RESULTS

Overall, wading bird observations on SRF flights did not change after hydropattern restoration, although great blue heron (*Ardea herodias*) observations/month increased from 0.4 to 3.6 ($P<0.001$), and for little blue herons (*Egretta caerulea*) the decrease was from 6.6 to 1.3 ($P=0.019$)(Table 1). The percentage of months/year great blue herons, great egrets (*Casmerodius albus*), and little blue herons were observed increased after restoration (Table 2).

The deer herd decreased significantly after restoration in 1991. The annual SRF population index fell from its 1985-1990 average of 314 (SD=85) to 98 (SD=86) during 1991-1996 ($P=0.001$). Deer harvest rose sharply in the 1991 and 1992 seasons after restoration began (Figure 2). Deer recruitment, which averaged 24.2% (SD=6.9) from 1982-1990, fell to 13.7% (SD=7.7) from 1991-1996 ($P=0.016$).

Levee spotlight surveys showed positive correlations between water depths and counts of deer and raccoons. Deer use was highest when water depths were greater than 0.46 m (Figure 3). This threshold was exceeded an average of 114 days/year (SD=11.4) from 1991-1994, 160 days in 1995, and 0 days in 1996.

Spotlight counts of alligator density increased, from 1.9-2.8 alligators/km in 1990-1991 to as high as 10.3 alligators/km in 1993 (Table 3). Low counts in the alligator SRF (range=0-2 nests) and fixed plot (range=0-6 nests) surveys prevented statistical measurement of trends in alligator nesting. Between 22 and 31% of Holey Land's artificial islands were used as nest sites in 1993-1995, and 1997, but none was occupied in 1996 (Table 3).

Table 1. Comparison of pre- and post-restoration mean monthly wading bird observations in the Holey Land Wildlife Management Area, Palm Beach County, Florida, 1986-1996.

SPECIES	OBSERVATIONS/MONTH (#)				
	Pre-restoration		Post-restoration		*P*-
	Mean	(SD)	Mean	(SD)	VALUE
Cattle egret[1]	24	(80)	13	(33)	0.286
Great blue heron	0.4	(2)	4	(4)	<0.001
Great egret	23	(49)	28	(72)	0.642
Little blue heron	7	(18)	1	(2)	0.019
Snowy egret[2]	6	(21)	3	(5)	0.218
White ibis[3]	40	(72)	33	(117)	0.709
Total	102	(199)	82	(164)	0.554

[1] *Bubulcus ibis*

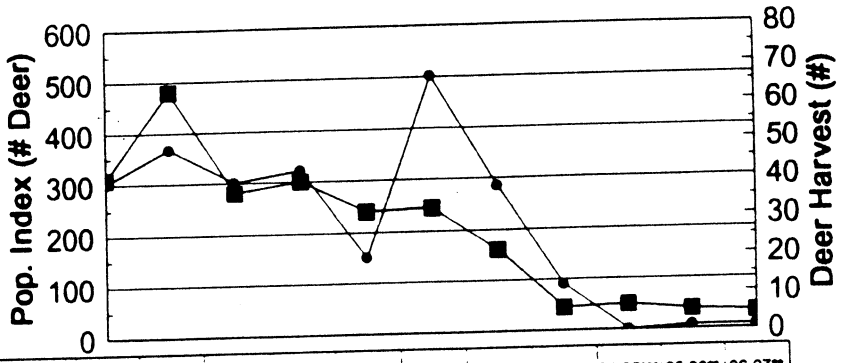
[2] *Egretta thula*

[3] *Eudorcimus albus*

Table 2. Percentage of months/year selected wading birds were present in the Holey Land Wildlife Management Area, Palm Beach County, Florida, 1986-1996.

SPECIES	MONTHS/YEAR PRESENT				
	Pre-restoration		Post-restoration		*P*-
	Mean (%)	(SD)	Mean (%)	(SD)	VALUE
Cattle egret	42	27	53	25	0.505
Great blue heron	28	40	89	07	0.004
Great egret	59	30	97	04	0.012
Little blue heron	32	15	53	11	0.021
Snowy egret	26	20	46	22	0.124
White ibis	53	29	32	22	0.187

Figure 2. Deer population index and harvest in the Holey Land WMA, 1985 - 1996.



YEAR	85-86	86-87	87-88	88-89	90-91	91-92*	92-93	93-94**	94-95***	95-96**	96-97**
POPULATION INDEX ■	310	480	280	300	240	245	160	45	50	40	35
HARVEST ◆	40	49	40	43	20	67	38	12	0	1	1

* Archery and Gun-Vehicle hunts only
** Archery, Muzzleloading, and Gun-Walk hunts only
*** Archery hunt only

Figure 3. Levee spotlight surveys in the Holey Land WMA, 1992-1993.

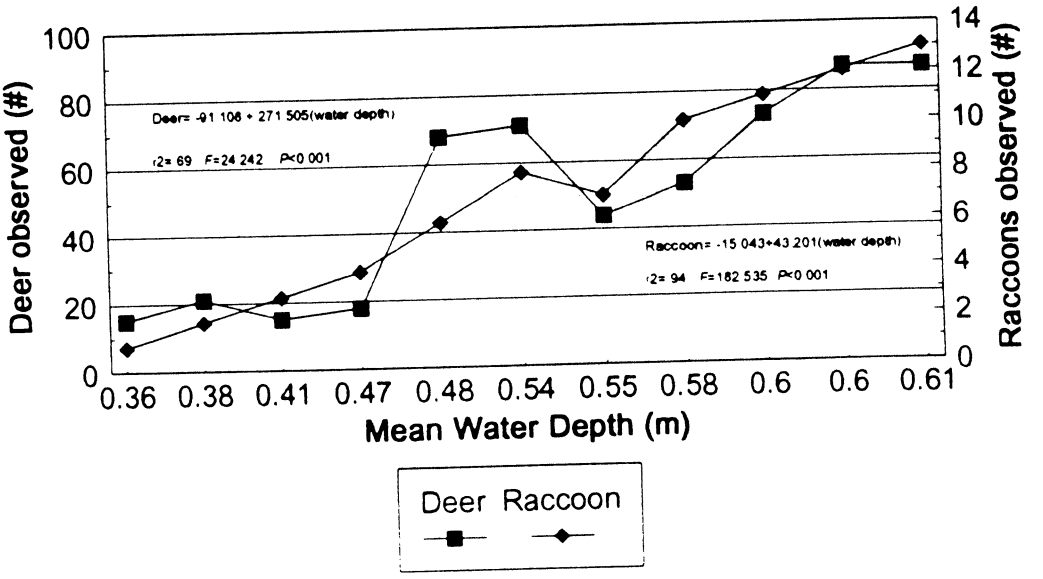


Table 3. American alligator monitoring results in the Holey Land Wildlife Management Area, Palm Beach County, Florida, 1988-1997.

	NESTING (# Nests observed)			SPOTLIGHT SURVEYS
Year	SRF	Fixed Plot	Artificial Islands	Alligators/km
1988	0	0	N/A	N/A
1989	0	0	N/A	N/A
1990	0	0	N/A	2.8
1991	0	1	N/A	1.9
1992	0	3	N/A	7.5
1993	1	1	12	10.3
1994	2	6	13	5.6
1995	N/A	0	15	7.9
1996	N/A	N/A	0	4.7
1997	N/A	N/A	17	6.5

N/A= Not available (No survey was performed)

DISCUSSION

Hydropattern restoration had little effect on mean wading bird observations in the Holey Land WMA. Only two species demonstrated significant changes; great blue heron observations increased while little blue heron observations decreased. Half of the most common wading bird species were observed on a significantly larger percentage of post-restoration surveys. This suggests that resident populations of great egrets and great blue herons, recorded on nearly all post-restoration surveys, were established in the Holey Land WMA. Restoration had little impact on numbers of short-legged wading birds, such as white ibis and cattle egrets. However, population trends for species which tend to move in large flocks are difficult to discern as foraging patterns are dependent on vegetation, current and past water levels, fire history, and the availability of other foraging sites in surrounding areas (Hoffman et al. 1994).

Changes in the habitat of the sloughs in the northeastern corner of Holey Land may have contributed to the lack of a positive response to restoration by some

wading birds. Most of the open water habitat created immediately after restoration converted to cattails; coverage increased from 41 ha in 1990 to 2622 ha in 1995, with some of the thickest stands in former open-water sloughs (GFC, unpublished data). Current management practices are aimed at using prescribed fire in concert with rapid water level increases to reduce cattail densities in these areas. Herbicides may be used to kill cattail before burning should funding become available.

While the effects of restoration on wading bird foraging were mixed, other research has shown that nesting use increased for a short time following restoration. Incidental observations of nesting by large colonies of great egrets, anhingas, cattle egrets, tricolored herons, and other wading birds were made in flooded willows in the northeastern part of the area. However, with the high water levels following restoration, the brush used for nesting died and colonies were not formed (GFC, unpublished data).

Few snail kites were seen prior to 1993, but when water was restored, it provided foraging areas in the large areas of open water in the northeast corner and they also used the flooded brush in that area as nesting substrate. Five snail kite nests were found in 1992, and there were at least 25 in 1993 (Bennetts et al. 1992, Bennetts and Kitchens 1993). As with the wading birds, nesting attempts stopped after the loss of the brush and snail kites were also affected when their foraging areas closed in with cattails.

Hydrology is one of the most important factors in the health of white-tailed deer in the Everglades. High water depths force deer to concentrate on tree islands and levees, where forage is rapidly depleted and starvation or diseases can occur (Loveless 1959, Fleming et al. 1994). Small mammals also are affected by high water events in the Everglades (Anderson 1997). Early Holey Land WMA water regulation schedules had results similar to that of natural flooding events on terrestrial wildlife, deer populations and recruitment rates declined. Increased water depths concentrated deer and raccoons on Holey Land levees, which made deer more vulnerable to hunter harvest.

Improved topographical information and concerns about water quality prompted a revision in the water regulation schedule in 1995 to one with lower peaks. Deer recruitment has returned to pre-restoration rates, but herd population

numbers will probably stabilize at low levels in balance with the quality of presently available habitat.

Alligators rapidly populated the new canals constructed for the restoration project as demonstrated by the rise in spotlight count observations. However, it is hard to determine if hydropattern restoration increased alligator use of the marsh. Fixed-plot and SRF surveys showed small increases in nesting following restoration, but the number of nests observed was too low to provide a reliable estimate of their use of this habitat.

Although artificial islands were originally built to mitigate for the loss of deer habitat in the Everglades, alligators have also benefited from this program. Alligator nesting on an artificial island in the Everglades was noted by Fogarty (1974), but this study presents the results of the first systematic survey of alligator use of these islands. The juxtaposition of ponds and high ground seem to represent good nesting habitat, although reproductive success at these sites is unknown.

Overall, the restoration project has been partially successful in returning Everglades wildlife to the Holey Land WMA. The change in habitat resulting from hydropattern restoration has allowed for increases in alligator populations and foraging use by some wading birds but limited habitat available for terrestrial wildlife. The lack of good topographical information led to high water regulation schedules which kept small wading birds from fully utilizing the area and was associated with expansion of cattail coverage. Future Everglades hydropattern restoration plans should gradually increase peak water depths over a period of several years to ease the transition to a more natural hydropattern for both animal and plant communities.

ACKNOWLEDGMENTS

Spanning over a decade, the research and monitoring program initiated to study the Holey Land restoration project has benefited from the knowledge and expertise of many GFC biologists and wildlife officers. Early lead investigators were Tim Breault, Jim Ruhl, and Dwane Carbonneau. Among the biologists who assisted in data collection were Jeff King, Bert Trammell, and Jeff O'Dell.

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THE USE OF WETLANDS BANKING IN SITING A RADAR FACILITY: THE MIAMI TERMINAL DOPPLER WEATHER RADAR

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ABSTRACT

The Federal Aviation Administration (FAA) developed a wetlands banking strategy to use as a tool in mitigating unavoidable impacts resulting from constructing aviation facilities in wetlands. The FAA realized that the traditional mitigation scheme of creating, restoring, or enhancing wetlands on airports or on small, isolated tracts was not as desirable as environmental scientists originally envisioned. We searched for a more cost-effective mitigation that, where applicable, would enable the more timely installation of facilities needed to enhance aviation safety and capacity. Wetlands banking is an excellent alternative that will serve facility siting needs and promote aviation safety, while benefiting the environment.

The FAA negotiated with the Florida Department of Environmental Protection (FLDEP) to purchase wetlands banking credits to mitigate wetlands losses resulting from locating the Miami terminal Doppler weather radar (TDWR) in wetlands. This is the first time the FAA has purchased banking credits to compensate for construction rather than carrying out frustrating on-site mitigation. The FAA purchased the credits from the Everglades National Park Hole-in-the-Donut Restoration Mitigation Bank.

Wetlands banking benefits FAA and the aviation community in a number of ways. Wetlands banking streamlines the construction permit process. Banking eliminated the amount of time the FAA had to otherwise allot to develop project-specific, complex, time-consuming wetlands plans. These time savings helped the FAA to better achieve the projected construction schedule. Last, the FAA was able to better use limited public funds in a successful wetlands mitigation strategy, wetlands banking.

INTRODUCTION

The FAA and airport authorities, responsible for building aviation facilities, provide radars, runways, other facilities, and equipment necessary for safe, efficient air travel. Due to air traffic requirements, sometimes the facilities and equipment must be constructed in wetlands to meet operational criteria. This criteria may include orientation to the runway, aircraft flight paths, weather fronts, and performance specifications.

The FAA developed a wetlands banking strategy to use as a tool in mitigating unavoidable impacts resulting from constructing aviation facilities in wetlands. The FAA realized that the traditional mitigation scheme of creating, restoring, or enhancing wetlands on airports or on small, isolated tracts was not as desirable as environmental scientists originally envisioned. We searched for a more cost-effective mitigation that, where applicable, would enable the more timely installation of facilities needed to enhance aviation safety and capacity. Wetlands banking is an excellent alternative that will serve facility siting needs and promote aviation safety, while benefiting the environment.

TDWR provides air traffic controllers with detection of dangerous low-altitude windshear and gust fronts, and movement of hazardous thunderstorms. Specifications require the TDWR to be located 13 to 20 nautical kilometers (8 to 12 nautical miles) from the end of the airport runway that is designated for use in bad weather. For best performance, the FAA must locate the radar at no more than a 30-degree aspect angle from the centerline of that runway.

The TDWR to serve Miami International Airport is located on .304 hectares (.75 acres) of land, adjacent to the Krome Detention Center, 19 nautical kilometers (11.2 nautical miles) west of the airport. The facility consists of a standard TDWR tower, radome, equipment shelter, and propane fuel tank. The TDWR tower consists of a 30 meter (98.4 foot) tall steel lattice structure with a 5 meter by 5 meter (16.7 foot by 16.7 foot) base that supports a 10 meter (33.1 foot) tall spherical radome. The total structure height, including the lightning rods, is 42.5 meters (139.5 feet) AGL.

MITIGATION SEQUENCING

To progress to considering wetlands banking, the FAA had to follow the mitigation sequencing requirements of the National Environmental Policy Act of 1969, the Clean Water Act regulations, and FAA procedures in environmental assessment. First, in avoiding harm to the wetlands, the FAA identified the jurisdictional bounds of the wetlands. Section 404(b)(1) of the Clean Water Act required the FAA to verify that the selected wetlands location is the only practicable alternative that would enable the facility or equipment to provide its intended purpose. (DOT Order 5660.1A, 1978)

Next, the FAA considered minimizing harm. Wetlands loss or degradation was unavoidable because of design specifications and limited availability of sites. The means to avoid harm through careful siting and design was considered, i.e., minimizing the footprint. Adjustments of the facility location and design were made to minimize the footprint. Commitments were made to minimize harm, especially during construction, using best construction management practices.

Since harm could not be sufficiently mitigated by avoidance or minimization, then FAA had to compensate for the loss by restoring, enhancing, or creating wetlands. Succinctly, wetlands banking was a compensation method to mitigate unavoidable wetlands impacts without the FAA going into the wetlands construction business.

DESCRIPTION OF SITE ENVIRONMENT

The TDWR site is characterized by freshwater swamp with a number of wetlands species present. Melaleuca and pine forests predominate as the natural vegetation surrounding the site. The TDWR facility was built on a fill pad. The site is on the margin of the Everglades. The site location is considered within the Transitional Northeast Everglades and is classified as wetlands by both county and state regulatory agencies.

THE ORIGINAL FLDEP WETLANDS CONSTRUCTION PERMIT

In 1996, the FAA applied for a permit modification to replace the on-site mitigation requirement with a wetlands banking purchase. The FLDEP wetlands construction permit would have required on-site mitigation by construction of wetlands. This construction project would have consisted of:

- Grading down an adjacent spoil bank;
- Construction and planting of 0.854 hectares (2.11 acres) of wetlands including tree islands interspersed;
- Clearing pervasive, invasive nuisance species predominantly consisting of melaleuca (Melaleuca quinquenervia) and Australian pine (Casuarina equiseifolia);
- Ultimately involving the FAA in a five-year construction and monitoring commitment to achieve success criteria.

THE PERMIT MODIFICATION FOR WETLANDS BANKING

Metro-Dade County had acquired the rest of the land adjacent to the Krome Detention Center on the northwest, north and northeast for correctional facilities. The county is constructing a prison complex on that property in several phases. While the TDWR was under construction, the county commenced construction of phase-1 facilities, with 1,200 beds. An additional 1,900 beds facility continues under construction. At build-out, in about 25 years, the county prison complex will have 6,000 to 10,000 beds. All other adjacent properties are owned by a variety of government agencies also planned for prison facilities.

The TDWR site was already considered within stressed wetlands by state and county regulatory authorities, even before this development. It became clear to the FAA that based on soil, vegetation and hydrologic conditions that the surrounding area was a stressed environment that would not successfully support the wetlands that the agency was required to construct.

Therefore, in lieu of this requirement, the FAA negotiated with FLDEP to purchase wetlands banking credits. The wetlands loss amounted to 0.304 hectares (0.75 acres) of sawgrass wetlands and temporary filling of 0.05 hectares (0.12 acres). Because of the commencement of construction of the

extensive prison complex, the FAA convinced the FLDEP that the original on-site wetlands project was unreasonable. The area simply would no longer support the project because of the lack or degradation of suitable soil and hydrology in the vicinity.

FAA applied for a permit modification. The banking credits would compensate for the radar construction rather than carrying out frustrating on-site mitigation. Further, FAA negotiated with FLDEP to choose the Everglades National Park Hole-in-the-Donut Restoration Mitigation Bank for purchase of credits. Instead of performing the requirement for creation of 0.745 hectares (1.84 acres) of wetlands at a mitigation ratio of 2.45 to 1, the FAA purchased credits. The cost of a credit at that time was $28,840.00 per 0.405 hectare (1 acre)-credit. Therefore, 0.745 hectares (1.84 acres)-credits required a payment of $52,404.00.

The modified permit changed the specific condition to allow payment to the bank, administered by Dade County Department of Environmental Resources Management (DERM), instead of constructing wetlands on-site. Dade County DERM sent a receipt to FLDEP and the FAA to show evidence of completing the mitigation obligation. This was the first time that wetlands banking was used to site an FAA facility.

The Hole-in-the-Donut Bank is pre-approved by the FLDEP for wetlands mitigation purposes. In this circumstance, the bank, located in Everglades National Park but administered by Dade County DERM, is known as a "third party bank". This is because Dade County DERM, the "third party banker", may sell credits to the FAA, a FLDEP permittee, to mitigate wetlands impacts from the construction of the TDWR, the permittee's action. This "third party banking" was favorable because the FAA purchase from a reputable banker provides one significant benefit--- it absolved the FAA of the responsibility for undertaking and monitoring a complex and difficult wetlands mitigation plan that had little chance of success.

Two major considerations are apparent from this wetlands banking experience--- the availability of the wetlands banking option and negotiation of credits.

AVAILABILITY OF THE WETLANDS BANKING OPTION

Wetlands banking should be used in away that promotes aviation safety, ecology and economic responsibility. For geographic consideration, the FAA first had to consider using a bank that was in the same watershed as the TDWR. Fortunately, just as the FAA was considering wetlands banking for the Miami TDWR, FLDEP policy allowed use of a wetlands bank that was in an adjacent watershed (and County). This applied since the TDWR facility was in less than one acre of wetlands. Another consideration was that the FAA not support a wetlands bank that would encourage bird strikes on aircraft. Therefore, the bank could not be found closer than 5,000 feet from an airport runway used by propeller aircraft or 10,000 feet from a runway used by jet aircraft (FAA Advisory Circular).

Institutional considerations included dealing with a wetlands regulatory agency that would allow a permittee to utilize wetlands banking to satisfy mitigation requirements. Additionally, the regulatory agency had an association with the wetlands bank. This took care of the FAA strategy criteria that banks be U.S. Army Corps of Engineers approved and meet Federal wetlands banking guidelines (U.S. Army Corps of Engineers, 1995; Melisky et al, 1996).

As in all facets of FAA program management, the usefulness of wetlands banking was ultimately based on considerations of cost, schedule and performance. In considering cost, the FAA comparatively "shopped" to ensure that the Federal government did not overpay, also that the credit offset was reasonable. For schedule, it was clear that we could quickly conclude negotiations with FLDEP for use of wetlands banking. As far as performance, the wetlands banking met all FAA "ground rules" as a quality bank and was preferable to wetlands construction.

NEGOTIATE CREDITS

Once it was determined that wetlands banking could be used, another consideration was negotiating the required compensatory credits to satisfy the FLDEP concerns. Again, in considering cost, schedule and performance, it was found that banking was desirable. The banking credits purchase in the amount

of $52,404.00 resulted in over a $200,000.00 savings compared to wetlands construction.

Negotiations between the FAA and FLDEP went very quickly. FLDEP and Dade County DERM streamlined the purchase process allowing FAA to meet the TDWR construction schedule. Therefore, time, cost and uncertainty associated with the permit process was reduced by all three agencies.

CONCLUSION

Through developing a consistent agency-wide strategy and the Miami TDWR siting experience, the FAA realizes that wetlands banking benefits both aviation safety and wetlands permitting by:

Substantially reducing the development of individual, complex, time consuming, expensive and uncertain mitigation projects;

Leaving the management, monitoring and maintenance of complex, dynamic wetlands to wetlands specialists associate with "third party" banks;

Strongly discouraging on-site or on-airport wetlands mitigation, minimizing waterfowl interference with aircraft operations and radar coverage for enhanced aviation safety; and

Allowing the FAA to use funds for a wetlands mitigation strategy with a greater success rate than traditional mitigation efforts at less cost, i.e., the Miami TDWR banking strategy resulted in saving $200,000.00.

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COMPREHENSIVE WETLAND MITIGATION PLAN FOR MARYLAND ROUTE 100 DEVELOPED WITH AGENCY COORDINATION AND INNOVATION

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ABSTRACT

This paper will discuss the importance of maintaining frequent coordination with the applicable regulatory agencies throughout the design development process for mitigation projects, and specifically for the MD Route 100 project. This coordination led to the development of a comprehensive and ecologically beneficial design by reducing the proposed wetland creation ratio to 1:1 at the University of Maryland Horse Farm. In addition, adjacent existing wetlands, floodplain, and uplands were proposed to be preserved at a minimum of 10:1 ratio. This combined strategy generated a preservation and creation area encompassing 10.7 hectares (26.5 acres) of land positioned between an existing and a proposed highway alignment across the entire width of the Horse Farm. The agreed-upon plans also included reforestation in the upland preservation areas that are currently in pasture. Tree plantings were proposed to transform the pasture into a more natural forested area, providing a forested buffer to the proposed creation area. This comprehensive mitigation approach resulted in the protection of the entire eastern portion of the stream valley across the Horse Farm site. Frequent coordination with the regulatory agencies is stressed throughout the paper, including during the site search and selection phase, the evaluation of site constraints, and the development of plans, specifications, and cost estimates.

INTRODUCTION

The MD Route 100 project from U.S. Route 29 to I-95, in Howard County, Maryland, is the last major portion of an important suburb-to-suburb limited access highway from Columbia to Glen Burnie, Maryland, west of Baltimore (Figure 1). This roadway is a long-awaited east-west connection for Marylanders and will provide access to the major north-south corridors of central Maryland including U.S. Route 29, I-95, U.S. Route 1, the Baltimore-Washington Parkway, I-97, and Maryland Route 2. Although extensive measures were taken to avoid and minimize impacts to wetlands during the highway planning and design process, 1.6 hectares (4.0 acres) of unavoidable nontidal wetlands impacts occurred as a result of the project.

Initial wetland permit requirements stipulated that Maryland State Highway Administration (SHA) would be required to create 3.3 hectares (8.2 acres) of nontidal wetlands as compensatory mitigation. This mitigation would be at a 2:1 creation acreage ratio for forested wetlands and 1:1 creation acreage ratio for emergent wetlands.

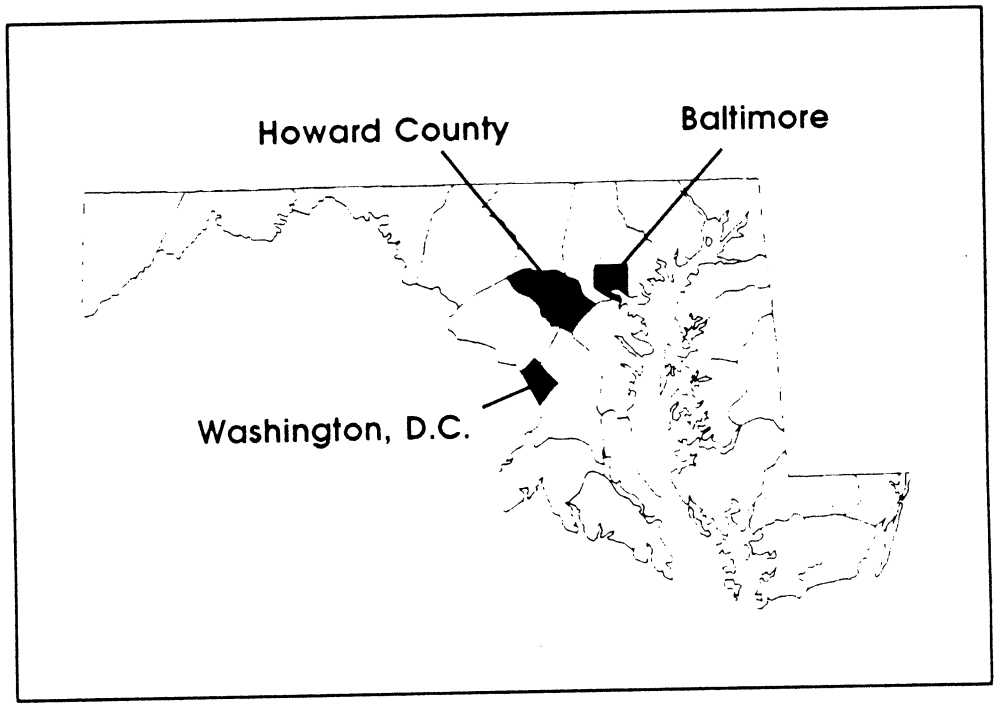

Figure 1: Site location in Maryland

Although stream restoration is not the focus of this paper, 1,032 meters (3,385 linear feet) of stream channel impacts were proposed by the project, resulting in the restoration of 367 meters (1,204 linear feet) of stream channel and a $50,000 donation for the construction of a fish ladder project.

We found that coordination with the regulatory agencies throughout the design development process to be critical throughout the development of the MD Route 100 project, including during the site search and selection, the evaluation of site constraints, and the development of plans, specifications, and cost estimates. Innovation and flexibility in the interpretation of the State and Federal mitigation policies can generate a more ecologically beneficial design. This includes substituting different mitigation techniques as opposed to strictly following acreage replacement ratios.

Site Selection and Early Considerations

During the preparation of an Environmental Impact Statement for the project, a site selection study was undertaken to determine appropriate sites to conduct the wetland mitigation (Federal Highway Administration and SHA, 1994). Site characteristics that were desirable included areas that were non-forested, within the same watershed as the impact area, and nearby a hydrologic source. Other characteristics included good access for construction and maintenance equipment from public roads, minimal utility conflicts, and agreeable landowners.

In July 1993, a list of twenty-six potential sites was reduced to two sites considered to have good potential for success by the regulatory agencies. The two remaining sites were known as the Zeltman Farm and the University of Maryland Horse Farm. Initially, the Zeltman Farm site exhibited good potential for mitigation because construction of a wetland would eliminate the grazing and watering of livestock in the existing stream. The potential for utilizing surface and groundwater hydrology appeared promising, and the site could provide sediment removal, flood storage, nutrient uptake, wildlife habitat, and groundwater discharge functions. Additionally, a wetland creation area would provide stream shading, and a buffer to future development.

However, the Horse Farm site was selected due primarily to economic reasons. Although the State of Maryland owns the Horse Farm, SHA needed to pay fair market value for the site. However, because land for an old MD Route 100 alignment was purchased in the early '80's across the eastern portion of the Horse Farm by SHA, and a new alignment was proposed in the western portion of the Horse Farm, the land between the two alignments was able to be devalued and purchased at a lower than market value price. This equated to a cost to the SHA of $3,500 per acre for the Horse Farm compared to $ 37,500 per acre for the Zeltman Farm.

At this early stage, although deep excavation of the site was anticipated, it was envisioned that all of the required palustrine, forested mitigation would fit at the Horse Farm Site. However, the agencies cautioned us about trying to maximize the creation area at the site. Thus, mitigation for palustrine, emergent wetland impacts would be accomplished at another site.

In addition to the economic feasibility of the site, the site had good access to a public road, was an open pasture, was partly within a 100-year floodplain of Deep Run and was adjacent to existing nontidal wetlands (Figure 2). Proximity to existing wetlands was an important feature in creating a larger wetland system with the addition of the proposed mitigation area. Also, deep excavation was not a concern from an expense viewpoint because the fill dirt was needed for the adjacent highway construction. One drawback of the site was that multiflora rose (*Rosa multiflora*), a common invasive shrub species in Maryland, was beginning to invade the site. Another drawback was that the existing topography was relatively steep (Figure 3).

In September 1994, it was determined that some impact areas were erroneously classified as emergent wetlands, but were actually forested wetlands. This increased the mitigation required for forested wetland impacts from 2.4 hectares (6.0 acres) to 3.2 hectares (7.9 acres). Although this additional acreage would induce further excavation into the slopes of the site, it was determined that the Horse Farm site was still feasible. This approach was agreed upon by the agencies in a Final Supplemental Environmental Impact Statement for the project.

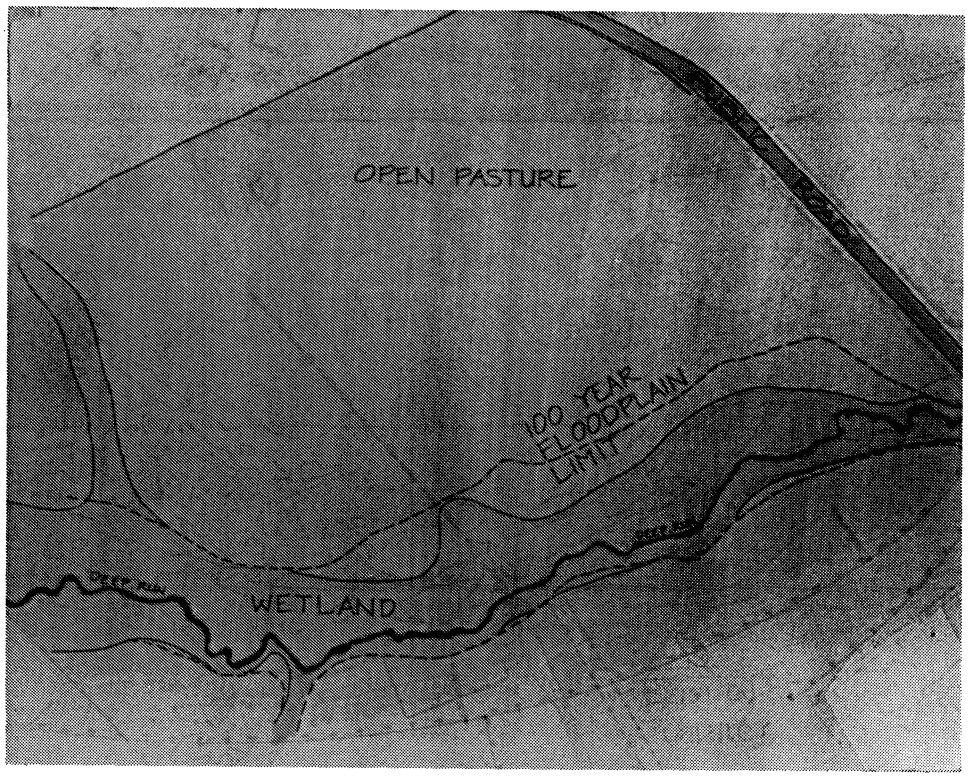

Figure 2: Existing site conditions

Functions and goals of the creation area were the establishment of an enhanced wildlife corridor, and water quality functions through sediment trapping and nutrient uptake and retention. Although the site was adjacent to an existing stream (Figure 4), it was not anticipated that the stream would provide adequate hydrology to sustain the site.

Therefore, groundwater monitoring wells were installed at the site in spring 1994. Additional wells and soil borings to obtain additional subsurface data were installed in spring, 1995. Groundwater elevations were recorded bi-weekly during the growing season and monthly during the remainder of the year (Figure 5). Results of the groundwater monitoring showed consistent and predictable fluctuations in groundwater levels, and the water level in all of the wells appeared to rise and fall correspondingly with each other.

In May 1995, a Phase One Nontidal Wetlands and Waterways and Department of the Army Permit was issued for the project, authorizing the SHA to proceed with the development of construction documents for the Horse Farm site. A

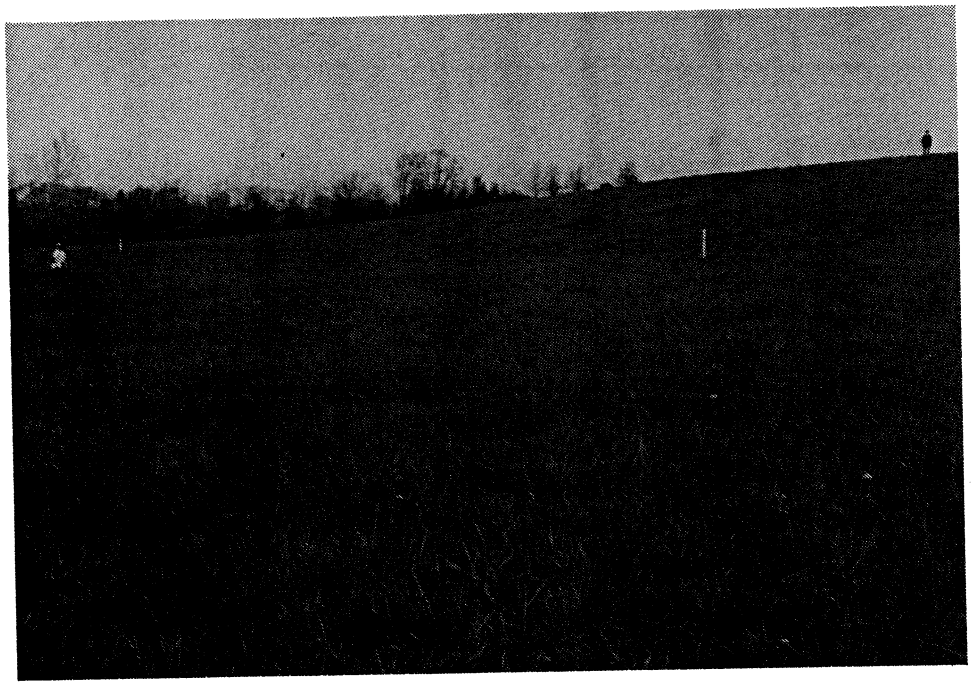

Figure 3: Existing site steepness

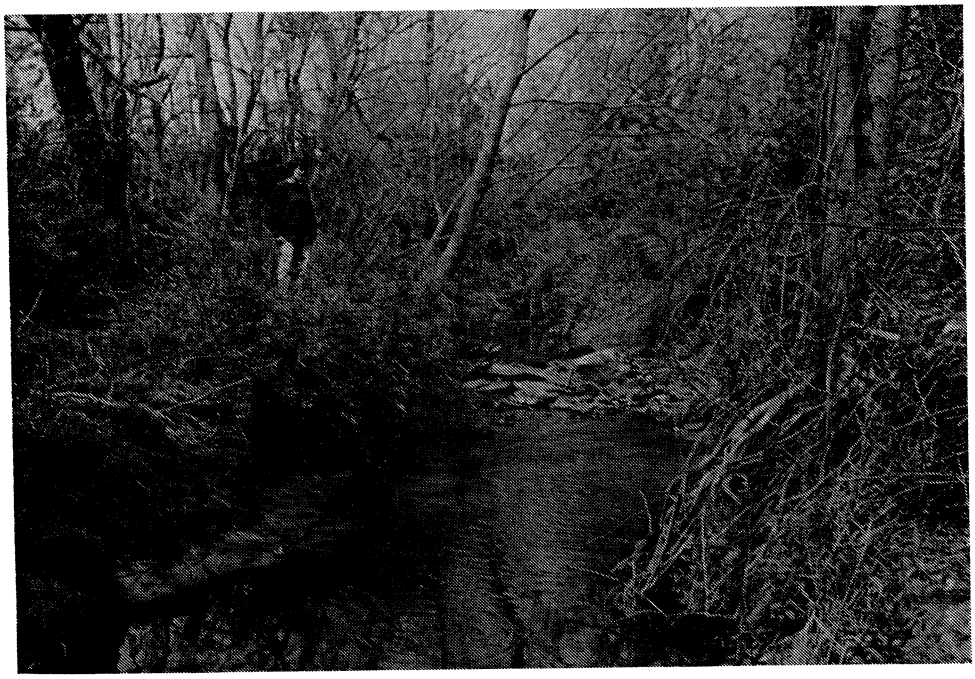

Figure 4: Adjacent stream to site

Figure 5: Groundwater monitoring

total of 3.2 hectares (7.9 acres) of wetland mitigation was approved to be constructed at the site.

Design Development

In May 1995, development of the construction documents was initiated. For SHA projects, design submittals are made at various stages of the design development. These stages include Preliminary Investigation (30% Design), Semi-Final Review (60% Design), Final Review (90% Design), Plans, Specifications, and Estimate (PS&E, 95% Design), and Advertisement Documents (100% Design - Figure 6). Although the contract documents for this project were included in the design submittals for the entire highway project, SHA requested that we make separate submittals for the Horse Farm site. These separate submittals enabled us to present the design to the SHA, and enabled the SHA to distribute copies of the documents to the regulatory agencies in an expeditious manner at every design stage. Duplication of submittals allowed the SHA's Environmental Programs Division the opportunity to review plans independently from the Highway Design Division for compliance with the State and Federal wetlands regulations.

Design Stages

- Preliminary Investigation (30%)
- ⇩
- Semi-Final Review (60%)
- ⇩
- Final Review (90%)
- ⇩
- Plans, Specifications and Estimate (95%)
- ⇩
- Advertisement Documents (100%)

Figure 6: SHA submittals

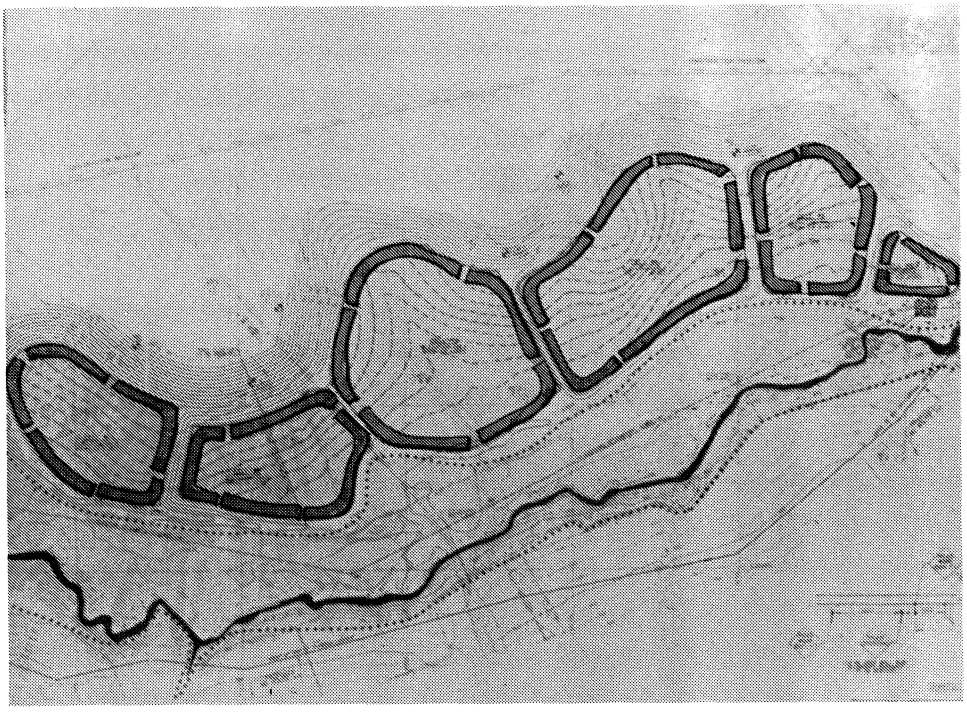

Figure 7: Preliminary site design

The Preliminary Investigation Design began in May 1995 and encompassed the design of six excavated cells, approximately 0.4 hectare (1 acre) each in size, arranged in a cascading fashion parallel to the stream valley (Figure 7). The individual cells were designed flat with no slope. Between each cell, a rock berm was proposed as a control structure with a top elevation 10.2 centimeters (4 inches) higher than the floors of the cells. This elevation was selected because it was decided that the maximum desirable inundation, if it occurred, would be 10.2 centimeters (4 inches) for deciduous wetland trees. The main source of hydrology would be groundwater, and the average excavation was approximately 3 meters (10 feet) below the existing ground surface. As much as 7.6 meters (25 feet) of cut was required to meet the proposed grade. Sideslopes were designed at a maximum grade of 3:1, and 15.2 centimeters (6 inches) of topsoil would be placed in the floors of the cells and the sideslopes to provide a suitable planting medium.

The Preliminary Investigation Plans were completed in June 1995 and a field meeting was held with the resource agencies to review the site and the plans in the field. At that time, SHA asked the resource agencies if preservation credits could be obtained by placing existing wetlands under restrictive covenants. Also at that time, it was understood by all that deep excavation would be required, but that the site would still be feasible. Following the Preliminary Field Investigation meeting, development of the Semi-Final Plans commenced.

Semi-Final Plans, including 60% stage plans for grading, erosion and sediment control, planting, and maintenance of traffic, were prepared and submitted to SHA in August 1995. At that time, the resource agencies were sent copies of the plans and requested to comment on them. Unfortunately, the agencies did not respond to the request until after the Final Plans were submitted in late September 1995.

In October 1995, the Corps replied to the August request for comment. In the response, the Corps recommended that the SHA eliminate grading in areas requiring more than 1.2 meters (4 feet) of excavation. The Corps was concerned with the unpredictability of the final groundwater elevation following deep excavation of the site, and stated that the probability of success for the wetland creation area as designed was low. Since eliminating some grading at the site

would greatly limit the available area for 2:1 mitigation, the Corps was agreeable to an innovative approach to the mitigation at the site.

It was decided that to avoid deep excavation, and to provide a more comprehensive mitigation design, wetland creation at a 1:1 ratio would be provided at the site. In addition, adjacent existing wetlands, floodplain, and uplands would be preserved at a minimum of 10:1 ratio. When this strategy was combined, a total of 10.7 hectares (26.5 acres) of preservation and creation area sandwiched between the old and the new alignment across the entire width of the Horse Farm was proposed (Figure 8). The agreed-upon plan also included reforestation in the upland preservation areas that are currently in pasture. These tree plantings were proposed to transform the pasture into a more natural forested area, providing a buffer adjacent to the proposed creation area. The reforestation was also utilized as reforestation mitigation for forest clearing in conformance with the Maryland Forest Conservation Law. This integrated ecological restoration will accomplish the preservation/restoration of the entire eastern portion of the stream valley of Deep Run across the University of Maryland Horse Farm parcel.

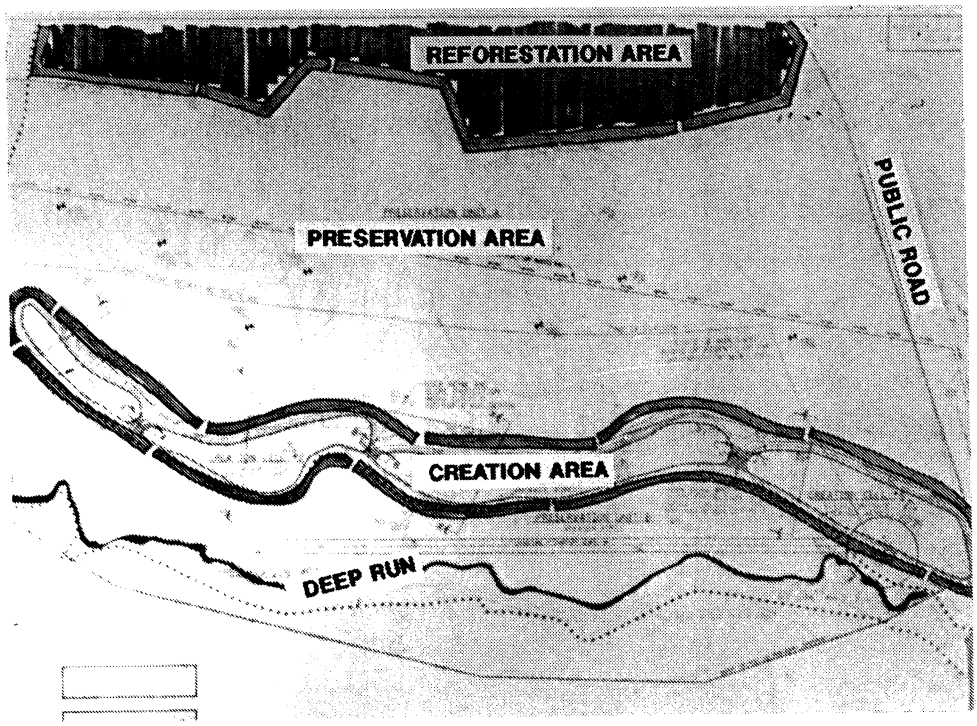

Figure 8: Comprehensive Design

DISCUSSION

We discovered through the selection and design of the Horse Farm site that although the strict application of replacement ratios has been relied upon in the past, this may not be appropriate if forced on a particular site (Figure 9). Also, it is important to work closely with regulatory agencies to explore other mitigation options to reduce replacement ratios. These options include stream restoration, reforestation of buffers, preservation of existing wetlands, and restoration of degraded habitats. We found it important to seek frequent consensus with the agencies during the design process so that you are not surprised with an agency's request at the last minute. We also found it very important to step back and investigate mitigation options that make good overall ecological sense, as opposed to becoming too focused on replacement ratios and how you can force a site to work with the ratios.

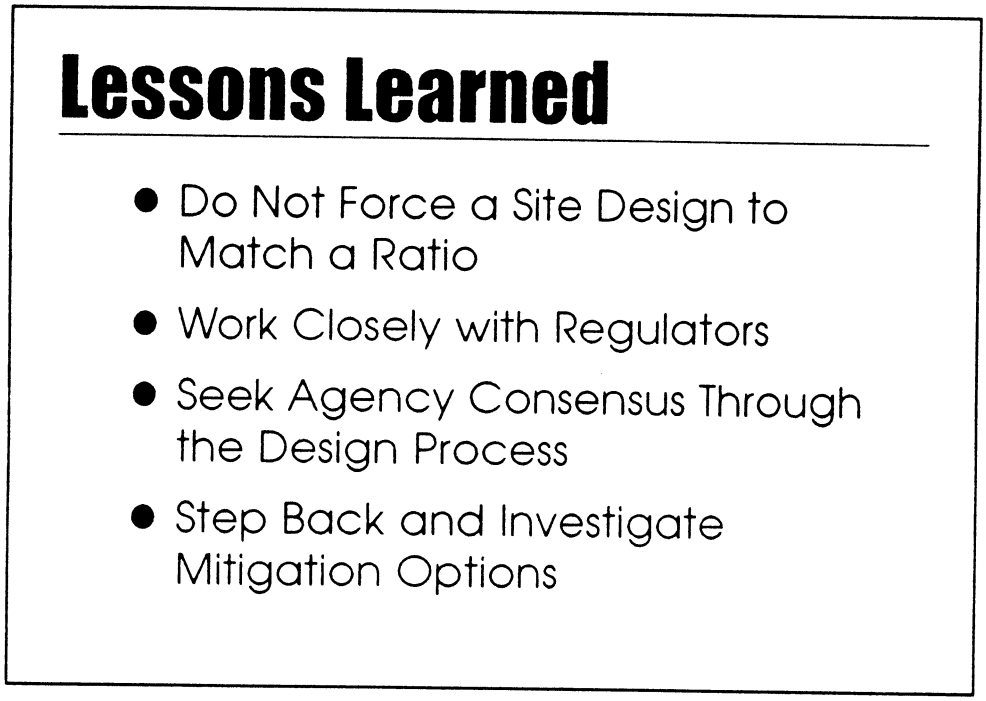

Figure 9: Lessons learned

The construction contract for the highway development was awarded for $21,700,700 to Haverhill Contracting Company on July 25, 1996. The wetland mitigation estimate was $300,000, and the contractor began work in June 1997.

ACKNOWLEDGMENTS

We thank John Delp and David Rathert of URS Greiner, Inc. for their assistance with photography and graphics.

LITERATURE CITED

U.S. Department of Transportation, Federal Highway Administration, State Highway Administration. 1994. MD 100 From West of MD 104 to I-95, Howard County, Maryland, Final Supplemental

COST EFFECTIVE MEASURES APPLIED TO ACHIEVE PERMIT COMPLIANCE AND HABITAT DIVERSITY AT A COUNTY OWNED MITIGATION SITE

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ABSTRACT

Due to contract disputes, a Pinellas County mitigation site received virtually no maintenance for approximately two years. During that time the site had become infested with invasive species and the desirable vegetation was not thriving. The Southwest Florida Water Management District (SWFWMD) issued a letter of non-compliance for this site and the Pinellas County Department of Environmental Management was contacted by the Public Works/Engineering Design Section to assist in site remediation.

The site was assessed for hydroperiod, desirable and invasive species, herbaceous cover, and tree survival. Several options were discussed and the County decided to design an in house multi-directional, non-destructive approach that was able to gain the support of SWFWMD to try this most cost effective option first. The County modified the hydroperiod and recontoured areas at the site. Post construction monitoring revealed that the trees experienced a tremendous growth spurt as a result of the more favorable hydroperiod and many species of wildlife previously not observed recruited into the area. Invasive species declined markedly with no herbicide use.

Coordination with the Pinellas County Jail enabled inmate volunteers to plant over 500 trees as well as herbaceous species such as pickerelweed, spatterdock and 6900 maidencane plants with no cost for labor. The site is functioning extremely well at this time and the Department will continue monitoring the site to ensure success.

INTRODUCTION

Studies conducted by contractors on behalf of Pinellas County resulted in the design of a flood control strategy for the Spanish Oaks and Spanish Pines subdivisions located in northern Pinellas (Figure 1). In late 1985, construction was started on the Curlew Pond #3 flood storage facility to help alleviate flooding in these areas. Storm events such as hurricane Elena may have helped speed the project along.

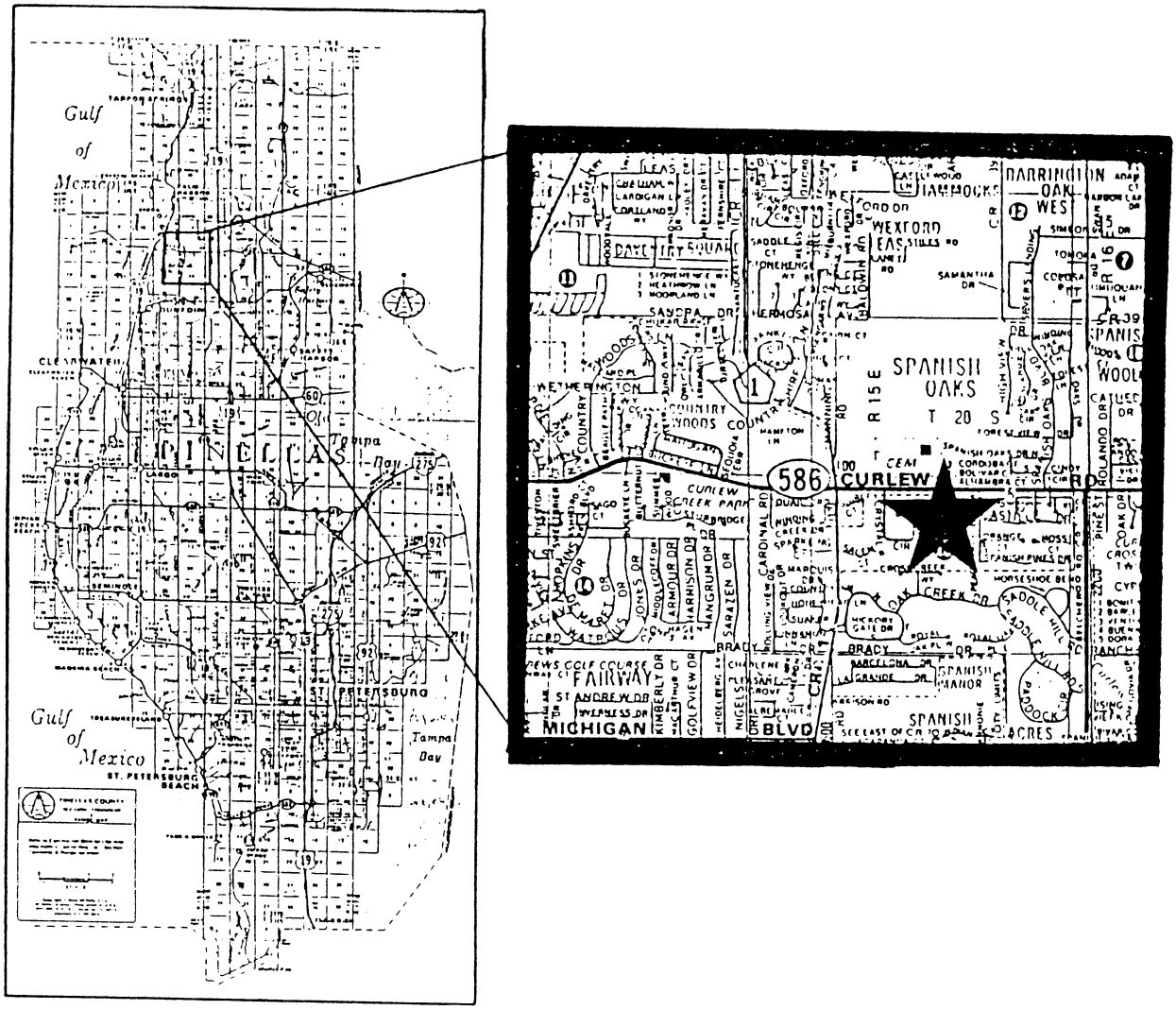
Curlew Pond #3 receives water from Curlew Pond #1, Curlew Pond #2 and from the Spanish Pines subdivision. Water eventually outfalls into Curlew Creek. The drainage basin covers approximately 223 hectares. Curlew Pond #3 required extensive excavation to match grades with the two existing ponds. Nearly 400,000 cubic meters of material were excavated to construct the site. Much of the site was situated over green marine clays which resulted in some of the unique hydrological characteristics of the site.

In 1987, after the flood control project was completed, a 1.52 hectare forested mitigation site was required for 0.6 hectares of maple hardwood impact associated with construction of the Jerry Lake Weir. Mitigation was also required for minor impacts associated with a sidewalk for C.R. 1. The permitting agencies agreed that Pond #3 was a suitable site for the mitigation. A total of 3.0 hectares were planted - somewhat more than what was required.

The overall pond site encompasses 5.4 hectares of land. The mitigation site is in the northern 3.0 hectares of the pond. The flood attenuation, storage, and the underdrain system is located in the southern 2.4 hectares.

The original flood design was performed by a contractor, but due to irreconcilable differences, the contract was terminated and the Design Division of the Pinellas County Engineering Department was asked to design the project. The pond was eventually designed by the Engineering Dept.'s Planning & Programming Division.

The pond is located in an area that had an average elevation of 12 meters NGVD. The area was vegetated with a sand hill community that included sand



STUDY SITE

Figure 1. The study site is located in northern Pinellas County. The area is adjacent to a sand ridge aligned north to south and underlain by green marine clays.

Curlew Pond #3 receives water from Curlew Pond #1, Curlew Pond #2 and from the Spanish Pines subdivision. Water eventually outfalls into Curlew Creek. The drainage basin covers

pine, sand live oak and slash pine and was fairly open under the canopy. The Parks Department spaded about 400 sand live oaks which were transported to Howard Park in Tarpon Springs and about 400 sand pines, which were relocated to Sand Key Park in Clearwater.

The pond was excavated about 6 meters into the soil to match drainage pipe inverts from Pond #2. In many areas, the bottom 4 meters was composed of green gumbo marine clay. An underdrain system was then installed in the southern portion of the site.

The pond was designed with a characteristic horseshoe shape to save a stand of mature Live Oaks with 0.5m+ DBH'S. The oak stand is used by a variety of wildlife including hawks, owls, and small mammals.

The original pond design did not specify an elevated berm through the center of the site separating the mitigation area from the underdrain, but there was a concern that the underdrain system would draw down the water table in the mitigation area and cause it to dry out. The berm was approximately at the same elevation as the outfall structure, 4.14 meters NGVD. There was concern that water would stage up behind the berm and cause problems in the mitigation area. Thus an equalizer pipe was installed in the center of the berm. The permitting agencies were worried that the mitigation area would be drawn down, and ordered the pipe removed.

During planting of the mitigation area, the planting consultant warned that the water appeared too deep and that the plants and trees would not likely thrive at the site, but no action was taken at that time due to the previously stated agency concerns.

Anywhere from 10cm to 20cm of muck was placed in the mitigation area as a growing substrate. Approximately 5000 trees were planted at the site on 3. 1 meter centers and consisted of a mixture of cypress, maple, tupelo, laurel oak, and sweet bay. Trees were planted in groupings of like species. No herbaceous mitigation was required by the permit, but pickerelweed, arrowhead, bulrush, juncus, and blue flag iris were planted, although unfortunately also on 3.1 meter centers.

Due to the large amount of unvegetated area and the shallow water conditions, invasive species began to proliferate. The general contractor had hired an environmental contractor to maintain the pond and provide monitoring reports. When the funds allocated by the general contractor were spent on maintenance (after only 6 months) the subcontractor stopped performing maintenance or doing mitigation reports.

No maintenance was performed for approximately two years as the County was trying to find a way to hold the general contractor responsible for maintenance. Unfortunately, there was no legal recourse to make either company responsible to perform the work. Needless to say, the County administers contracts differently now.

The pond's non-compliant conditions were observed by SWFWMD in the late summer of 1991, and the Engineering Department received a letter of non-compliance shortly thereafter, The Engineering Design Section contacted the Environmental Support Services Section and requested assistance in assessing the pond and determining the best and most cost effective option.

MATERIALS AND METHODS

A general site assessment was performed in September of 1991 at the request of the Engineering Design Section. The mitigation area was staged up to the berm with water and the team could only look around the edge of the pond. The trees looked very stressed and had few leaves. Invasive species proliferated and coverage approached 90%. Water levels seemed to be slightly lower in the south side of the pond, but supported a near monoculture of cattails only three small clumps of willow were present.

The Environmental Support Services Section coordinated with Engineering Design and the Construction Division to devise a better way to assess the pond. It was decided that the best option would be to drain as much water as possible out of the mitigation area by tapping into the main underdrain pipe. This would afford the opportunity to better assess the vegetation within the pond and examine the muck depth for uniformity. At this time the Environmental Support

Section authored a 26 point memo outlining Pinellas County's options on pond planting and hydrologic modifications.

SWFWMD staff met with County representatives at the site and agreed to let the County drain the pond as part of the plan for bringing the pond into compliance. In November, the underdrain main pipe was accessed and rim ditch construction started along the western side of the pond to facilitate drainage of the standing water.

It took about 45 days for the pond to drain and dry sufficiently to where one could walk around with rubber boots without going waist deep into the muck holes. In early January of 1992, members of the-Environmental Support Services Section, Engineering Design, Construction and Planning and Programming returned to the site to perform another assessment.

Once among the vegetation, it was noted that many of the trees had died, probably from excessive inundation. A surprising amount of trees had survived, though, and they seemed to be producing new growth. Almost all the trees were stunted and had grown adventitious roots. Some of the trees were easily uprooted because the muck had not solidified and the trees had not anchored themselves. Cypress seemed to have fared better than the other species.

Most of the cypress looked like baseball bats; they were short, but very thick at the base. The trees were probably trying to either stabilize or maximize gas exchange by maximizing basal growth and lenticil surface area. It was at this time that the site appeared to have much more potential for long term success than previously thought.

Several options were discussed at this time to develop a plan to get the mitigation site back into compliance:

1. Raze the whole pond and start over. This would be extremely expensive and would lose decent existing habitat. Also, there was no guarantee that the cattails would not again re-establish.

2. Raze the south cattail pond, bury the cattails in a hole on site, bring in new muck, move viable trees, and herbaceous vegetation from the north

pond to the south pond, and plant heavily with new herbaceous species to suppress invasive. Then replant the north side and nurture for banking. Again, this would be very expensive and time consuming.

3. Use a combination of hand labor and machinery to clear out the invasive from between the trees in the north mitigation site. Selectively herbicide remaining invasive. Recontour the site for better invasive suppression and better habitat value, lower the weir elevation to keep water levels lower, and implement a stringent maintenance program. Construction stated that past hand labor activities proved fruitless on other projects and heavy machinery could not operate in this type of environment. There were also doubts about the ensuring a stringent maintenance program if was to be contracted out.

None of these option ns appeared satisfactory and discussion continued about the basic facts of the site.

1. It appeared that no matter how far the outflow weir elevation was reduced, the pond would not totally dry out because of the natural clay lining and the constant groundwater seep from the side slopes into the pond.

2. The permit had no requirement for success of herbaceous species, so as long as the trees could out compete the invasive, it was assumed they would eventually shade them and kill them off.

3. Almost twice the required amount of mitigation area was planted than was required for the Jerry Lake Weir Project.

4. There was a sizable wildlife population utilizing the pond.

5. Stormwater treatment was still being accomplished.

SWFWMD was invited back to the site to meet with the original evaluation team and view the pond in it's drawn down condition.

By this time the trees had started to f lush out and the cattails seemed to be

somewhat suppressed by the drier conditions. It was also interesting to note the growth rings formed from the widely spaced herbaceous plantings.

The current habitat value of the site was also pointed out and it was agreed that it would not be environmentally sound to lose the habitat and trees if they were to raze the site.

It was decided to allow the site to grow out over the summer to ascertain if the trees would actually gain height and canopy cover or remain stunted. This was done in order to help determine whether over inundation or the clay substrate was causing the stress response. Although the growth spurt looked promising, SWFWMD wanted to make sure that the trees were not permanently stunted. SWFWMD requested a long term plan based on tree growth success, such that if the trees started to increase in height, SWFWMD would consider allowing the County a greater than 10% invasive species coverage on a temporary basis. The County would also have to replant trees that had died. To document tree growth Environmental Support Services tagged and measured selected trees for monitoring of height and DBH.

The underdrain access would have to be sealed again to ensure long term tree growth and survival. It was known that the weir height needed to be reduced, but it was not known by how much. The assessment team returned in April 1992 to do some survey work to determine if there were large elevation changes in the pond or if the surface was relatively flat.

The elevation of the weir was also measured to see if it was installed correctly, and the berm was surveyed to determine if it was in fact hindering water flow. The height of adventitious roots on the trees in both the mitigation area and the water treatment area were surveyed to determine standing water depth in each of the areas.

Surprisingly, the pond bottom was fairly level. The elevation of the adventitious roots on the trees were very consistent and measurements were within several centimeters of each other. Even more surprising, the treatment pond's trees had adventitious roots at the same elevation as the mitigation site, indicating that the underdrain system was not drawing down the system as was thought when the pond was first built.

The survey indicated that the weir was constructed at the design elevation and the berm had a similar elevation as the weir.

It was decided that the weir elevation should be reduced by about 15 centimeters to maintain a summer stage-up of water with a bleed down orifice 16 to 18 inches below that to maintain a winter drawdown to stimulate growth and suppress invasive. A debris skimmer would be added to the outfall structure.

It was also agreed that a winding deep channel should be cut through the middle of the mitigation area to get more open water habitat for waterfowl and wading birds. In addition, sediment sumps were designed into the project. The spoil would be used to construct slightly elevated areas to plant the replacement trees.

Construction on the rim ditch and meandering channel began in June of 1992 and took approximately eight weeks to complete. The topsoil (muck) was scraped off the construction area and placed in the planting area and smoothed into a shallow dished shape to help hold water to give the replants a healthy start.
The clay underlayer was hauled off site. once the site stabilized, a plug was installed in the underdrain pipe and a temporary riser was constructed to stage the water up to an elevation approximately 15 centimeters lower than the original weir elevation. A permanent gate valve was installed on the underdrain to facilitate easier draining of the site for future maintenance. A catwalk and staff gauge was also installed.

RESULTS AND DISCUSSION

The water reached the design elevation within a few days and the channel filled to the top of bank. Vegetation started recruiting immediately along the shore banks but no cattails appeared to be invading the area. Within a short period of time, a varied fish population developed including some larger species. Many reptiles thrived in the new habitat and a river otter had taken up residence at the site and was observed in the channel each time the site was visited. Many species of small mammals took advantage of the superior site conditions and extended their range throughout the site. Wading birds and waterfowl were also observed frequenting the newly created habitat.

A baseline assessment of the trees was performed, and the site was allowed to remain in the staged up condition through the fall of 1992. Several monitoring events for tree growth were performed in the succeeding months and tree growth was phenomenal. Trees were exhibiting 20 - 30 % growth in height and DBH after only 6 months of monitoring. Relative biomass of the trees appeared to have more than doubled. The trees appeared much healthier and had branched significantly with a tremendous rate of leaf growth. In an interesting side note, the trees within the cattails were as tall or taller than those in the more open areas. This coincides with research performed at other sites with similar conditions. More research needs to be performed to determine if invasive species competition is as much of a problem for tree growth as previously assumed.

A planting plan was designed that would replace the trees that had died as well as fill in some of the areas that had not been planted previously. In addition, some herbaceous plants were specified to vegetate the banks and middle of the channel. Over 500 trees were specified with species centered on red maple but included cypress, tupelo, pop ash, laurel oak and sweet bay. Herbaceous plants centered on pickerelweed, which seemed to be doing well in other areas of the site.

The assessment group decided to perform replanting of trees in November of 1992. To attempt to save replanting labor costs, the Environmental Support Section contacted the Pinellas County Jail to determine if Jail trustees could perform the planting. The Jail agreed to supply trustees, a corrections officer and a landscape instructor to oversee the work crew. surprisingly, when the planned date arrived there were not enough trustees to form a work crew.

The replanting project was delayed until January of 1993, At this time the Jail was able to supply a work crew and the plant material was ready for delivery. As a bonus, 8000 maidencane plants and a variety of native ferns were available that the County had payed f or but could not use on another mitigation site

The Highway Division excavated holes for tree planting with a mini backhoe to save manual labor effort for actual planting. The weekend prior to the planting date, a heavy thunderstorm inundated the work area and planting was delayed another week.

Finally, all parties were able to coordinate and perform the planting. The site conditions were still poor from the rain but progress was swift. The trustee work crew was split in half with one crew planting maidencane and the other carrying trees into the planting site and installing them. Under the direction of the Environmental Support Section, the trees were planted according to their hydrological requirements as well as in an aesthetically pleasing random manner. Maidencane and ferns were planted in a "floodplain" type area near the outfall structure as well as in the voids between the trees. The work was completed within one week.

Follow-up observations in March of 1993 revealed that all the newly planted trees had sprouted new growth. Over the past 3 years, the Environmental Support Services Section has continued to monitor to site and the phenomenal tree growth has not only maintained its rate but increased.(Figure 2) The trees have matured and have had several seasons of seed set. Invasive species competition has been minimal but some minor exotic species control has been implemented to ensure that the establishment of Brazilian Pepper and Chinese Tallow does not occur. Pinellas County was notified in September 1996 that the site has been deemed a success by the permitting agencies.

CONCLUSION

Success of a mitigation project cannot be simply measured and judged using numerical indices or limited variables. A site can be in compliance with permit conditions but not be an environmental success. Conversely, a site can be out of compliance but in fact be an environmental success. Success of the mitigation site lies with the establishment of a functioning wetland community including a wide variety of floral and faunal species. Designers must learn to look beyond permit conditions when creating wetlands and create systems made up of a variety of habitats that complement each other.

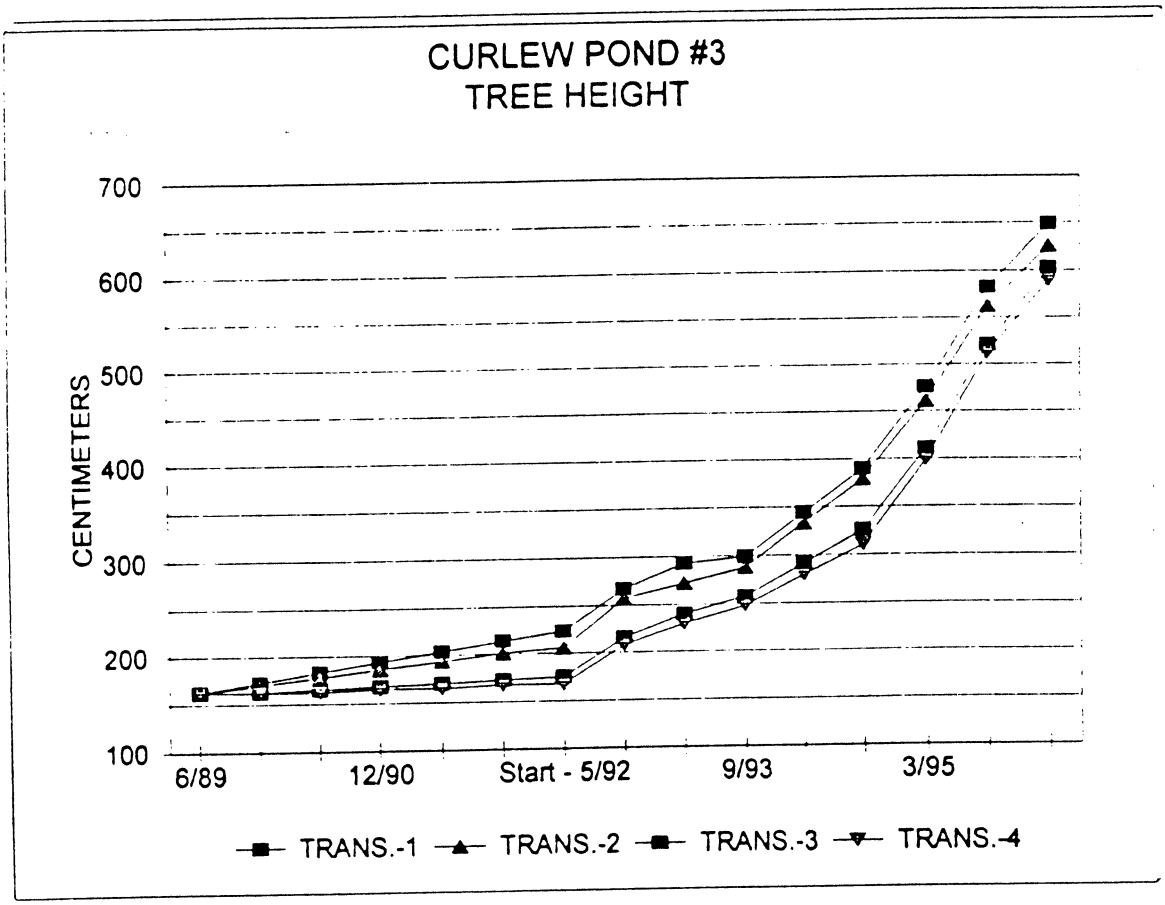


Figure 2.

ACKNOWLEDGMENTS

Appreciation is given to Jim Meyer and Steve Robinson of the Pinellas County Environmental Support Services Section and to Kevin Murren, Rudy Garcia and James Richter of the Pinellas County Public Works Department, and to Karen Gruenhagen of SWFWMD for their hard work and dedication to make this project a success.

SELF-ORGANIZATION AND PLANTING STRATEGIES AT A WETLAND MITIGATION SITE IN CENTRAL MARYLAND

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ABSTRACT

The establishment of a desired, vegetative community at a wetland mitigation site through intentional plantings can contribute a significant proportion of the total cost of a project. The conventional approach is to select and plant a small subset of native species from the local wetland flora that are characteristic of the hydrology expected to occur at the mitigation site. However, this approach is often not successful because hydrology is difficult to predict and the selected species may not be competitively superior.

In this study alternative planting strategies were tested at a wetland mitigation site in central Maryland. The strategies were tested in an effort to assess their effectiveness in terms of resulting plant community structure and economic cost. The site was divided into four cells ranging in area from 0.2 ha to 0.5 ha. A conventional planting approach was used in two cells which received relatively heavy seeding of 11 plant species. Another cell received only colonization from natural seed dispersal. The final cell was seeded with a high diversity of 132 species, in an attempt to remove seed source as a limiting factor to plant community development. Vegetation was monitored for the first two years of the project (1994-1995) and hydrology was monitored for the second year (1995). The cells quickly diverged through self-organization, with different hydrographs and plant community structures developing in each cell. Success of the intentional plantings is described along with species diversities and regulatory wetland status of the communities. The results indicate tradeoffs between alternative planting strategies which may be important in decision-making about effective mitigation techniques.

INTRODUCTION

Wetland mitigation continues to be used as an option to compensate for wetland impacts associated with development and some agricultural activities. Although the science is still in its infancy, it has become a multi-million dollar industry for engineering firms, environmental consultants, lawyers, wetland plant nurseries, and mitigation bankers in response to the challenge of balancing development and conservation (Beck 1994). It is also an exciting new exercise in the interdisciplinary field of ecological engineering. The very nature of

mitigation, however, is a dangerous issue: it involves a trading of one habitat for another (Race and Fonesca 1996). A permit is issued allowing a developer to destroy a natural wetland and, as part of the permit conditions, the developer must create a wetland somewhere else in the landscape as compensation. There are many questions about whether or not it is possible to create wetlands that have sufficient ecological value to substitute for natural wetlands. Research is being undertaken on all aspects of created wetlands (Kusler and Kentula 1990, Mitsch 1995, Zedler 1996).

The purpose of this paper is to test several strategies for creating a wetland plant community at a mitigation site. The establishment of a desired vegetative community at a wetland mitigation site through intentional plantings can contribute a significant proportion of the total cost of the project. The conventional approach is to select and plant a small subset of native species from the local wetland flora that are characteristic of the hydrology expected to occur at the mitigation site. However, this approach is often not successful because hydrology is difficult to predict and the selected species may not be competitively superior. In this study, alternative planting strategies were tested in an effort to assess their effectiveness in terms of resulting plant community structure and economic cost. The overall design was to compare two forms of self-organization, natural seed rain and "multiple seeding" or high diversity seeding, with the conventional approach of seeding a small subset of selected species to test for the most effective strategy of developing a wetland plant community.

In the context of wetland creation and vegetative establishment, self-organization is an alternative to the usual detailed planting plans that landscape architects prepare for most mitigation projects. Self-organization is the concept of allowing natural forces to design the plant community. This can be done through natural colonization or by introducing as much genetic material (i.e., species) as possible and allowing nature to select the community structure. Another way to view this strategy is thinking of self-organization as a form of ecological engineering in which succession is accelerated and augmented (Odum 1989, Mitsch and Wilson 1996).

SITE DESCRIPTION

The Little Patuxent Mitigation Project is located in the floodplain of the Little Patuxent River in the northern part of Howard County, Maryland, approximately 4.3 kilometers north of Columbia. More specifically, the site is situated a few hundred meters south of Frederick Road on the western bank of the Little Patuxent River between the developments of Rolling Acres on the east and Font Hill Manor on the west. The site lies within Maryland's Piedmont Region with an elevation of approximately 104 meters above Mean Sea Level. The climate in Howard County exhibits an average annual temperature of approximately 13-14 degrees Celsius and an average annual precipitation of 105 cm (Soil

Conservation Service 1968, Tiner and Burke 1995). The site lies within an area of Codorus silt loam, a common floodplain inceptisol in Howard County classified as an Aquic Fluventic Dystrochrept (Soil Conservation Service 1968). Although the soil is well-drained and not considered hydric (Soil Conservation Service 1991), it does have a high probability of experiencing flooding and has flooded numerous times since the project was constructed. Grading and excavation of the project wetlands were completed in 1993 and the primary planting effort took place during the spring of 1994.

The site was divided into four cells ranging in area from 0.2 hectares to 0.5 hectares (Figure 1). A conventional planting approach was used in two cells (1 and 2b) which received relatively heavy seeding of 5 herbaceous species and seedlings of 6 woody species. Another cell (2a) received only colonization from natural seed dispersal or "rain". The final cell (3) was seeded with a high diversity of 132 species, including many different kinds of plants that were chosen based on availability of seed, in an attempt to remove seed source as a limiting factor to plant community development. This represents the multiple seeding approach described by Beyers and Odum (1993) and Adey and Loveland (1991) for establishing microcosms.

METHODS

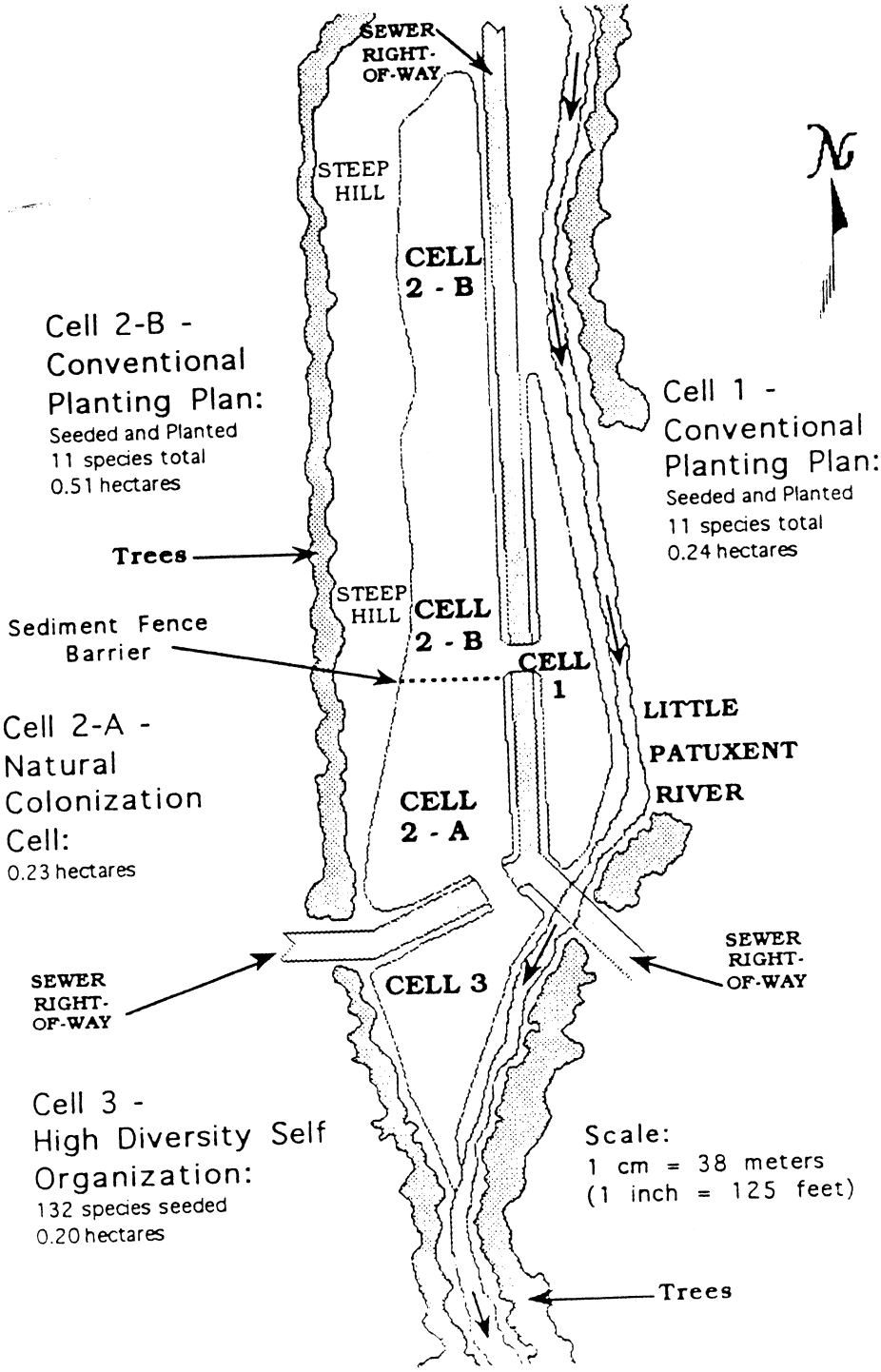
Hydrology

Unlined boreholes with slightly raised edges were used to monitor the water table fluctuations in the site during the second growing season (1995). Three of these hydrology monitoring wells were strategically placed throughout each cell with one exception. The larger size of cell 2b allowed the use of seven monitoring wells. These wells were monitored approximately every two weeks over an annual cycle and the level of the water table above or below the soil surface was measured and recorded.

Vegetation

Eleven permanent plots were randomly placed in each of the four study cells for a total of 44 permanent sample points. These plots were marked by 60 cm metal rebar rods sunk into the ground until only a few centimeters were above the ground. Quarter square-meter circular quadrats were used to sample the vegetation at the permanent plots. Stems were counted in the quadrats during the summers of 1994 and 1995 and these counts were used to calculate relative abundances of species. Sampling procedures generally follow Hayes et al. (1981) with the definition of an individual encompassing clumps of stems for those plants known to grow from rhizomes, tubers and other propagules. In addition to the detailed sampling at the permanent plots, a complete list of all species observed was maintained for each cell. The cells were carefully monitored throughout the growing season and all unidentified plant species were collected and identified according to Brown and Brown (1972, 1984). In this

Figure 1: Mitigation Site Plan For The Little Patuxent Mitigation Project Showing Locations of Each Wetland Study Area.



way a more detailed picture of the plant community was established which could reveal details missed by the 44 permanent sampling plots. Only data from the second growing season (1995) are reported here and further information is given by MacLean (1996).

The botanical data were tallied and then compared to the national list of plant species that occur in wetlands (Reed 1988). This list attributes various wetland plant species to certain categories by a national interagency panel of wetland experts. An obligate (OBL) wetland plant is a plant which occurs in a wetland greater than 99 percent of the time. A facultative wet (FACW) plant occurs in a wetland from 67 to 99 percent of the time. A facultative (FAC) plant occurs in a wetland from 33 to 67 percent of the time; these are the plants which can tolerate the widest range of environmental conditions. Taxa which cannot be given an indicator status are those species which are not on the list, are listed but have no indicator status due to insufficient data, or could only be identified down to the family or generic level.

Economics

The costs involved in the design and implementation of the Little Patuxent project were calculated. These costs were determined by examining the files, proposals and contracts of both the contractor (Environmental Systems Analysis of Annapolis, Maryland) and the Maryland Department of the Environment. By examining paperwork from both offices, a detailed summation of all costs could be calculated and the amounts could be confirmed.

RESULTS

Hydrology

Hydrology, as reflected by data from the shallow groundwater wells, diverged between the cells (Table 1). Although all the cells were at essentially the same average elevation, differences were apparent in the hydrographs. Only wells in cell 1 and 2b behaved similarly in terms of overall hydrology. These cells had annual average water levels that were slightly below the soil surface but which fluctuated above and below the soil surface over the monitoring year. The average annual water level in cell 2a was always above the soil surface and the range of values was relatively small. Conversely, the average annual water level in cell 3 was always below the soil surface and the range of values was relatively large.

Plant Community Structure

The summary data on plant community structures from the cells during the second growing season are shown in Tables 2 and 3. In terms of observed species richness (Table 2), cells 1 and 2b were similar with about 80 species

Table 1. Comparison of overall hydrologic characteristics from shallow groundwater wells at the study sites during 1995.

	Cell 1	Cell 2a	Cell 2b	Cell 3
no. of wells	3	3	7	3
average elevation of wells above MSL, m	102.3	102.0	102.6	102.3
annual average water level relative to the soil surface, cm	- 4.3	+ 16.4	- 2.0	- 36.8
range of average water levels, cm	69.1	14.9	29.5	69.4
percent of observation days above the soil surface	57	100	48	0
percent of observation days below the soil surface	43	0	53	100

Table 2. Comparison of plant communities in the second growing season based on richness of observed species.

	Cell 1 low diversity	Cell 2A natural seeding	Cell 2b low diversity	Cell 3 high diversity
number of introduced species	11	0	11	132
number of introduced species observed	4	0	8	38
total number of species observed	80	43	83	99
percent of the observed community that was FAC, FACW, and OBL	75	86	72	72

Table 3. Comparison of plant communities in the second growing season based on numbers of individuals in samples (11 quarter meter square quadrats in each cell).

	Cell 1 low diversity	Cell 2A natural seeding	Cell 2b low diversity	Cell 3 high diversity
percent of the sampled community that was introduced	0.8	0	4.5	35.6
percent of the sampled community that colonized naturally	99.2	100	95.5	64.4
percent of the sampled community that was FAC, FACW, and OBL	71.9	95.8	75.3	39.0

observed, of which about 75 percent were characteristic of wetlands. Most of these species colonized the site in natural seed rain since only 11 species were intentionally planted at these sites. Cell 2a, which received only natural seed rain, had the lowest species richness (43) but the highest percentage of wetland species (86) of all the sites. Cell 3, which received high diversity seeding of 132 species, had the highest total species richness (99) with 38 species surviving from the intentional seedings. 72 percent of the species observed in cell 3 were characteristic of wetlands.

In terms of densities of species populations sampled at the sites (Table 3), cells 1 and 2b again had similar patterns. Very few of the intentionally seeded species appeared in the samples (0.8 percent for cell 1 and 4.5 percent for cell 2b) and most of the sampled individuals were from species that colonized the cells from natural seed rain (more that 95 percent in both cells). Most of the sampled individuals in these cells were from wetland species (71.9 percent for cell 1 and 75.3 percent for cell 2b). Cell 2a, which had no intentional seeding and thus 100 percent contribution from natural seed rain, had the highest percentage of wetland plants in the samples (95.8). Finally, cell 3 had a mix of individuals that were intentionally seeded (35.6 percent) and that colonized from natural seed rain (64.4 percent), but only 39 percent were characteristic of wetlands.

Success of Intentional Seeding

Five herbaceous species were intentionally seeded into cells 1 and 2b for the low diversity treatment and 132 species of various life forms were intentionally seeded into cell 3 for the high diversity treatment. The total amount of seeds applied to each cell was as follows: cell 1 received 3,538 g, cell 2b received 5,607 g and cell 3 received 27,353 g.

Success of the intentionally seeded species in cells 1 and 2b was low (Table 4). Agrostis alba was found in both cells and Scirpus cyperinus was found in cell 2b during the second growing season, but neither species was dominant in terms of relative abundance in stem density samples. The other three intentionally seeded species, along with the Scirpus cyperinus seeded in cell 1, were not observed in the cells and thus it was assumed that they did not survive through the second growing season.

Thirty eight species (29 percent of the original 132 species) that were intentionally seeded in cell 3 were observed during the second growing season (Table 5). 15 of these species were sampled in the quadrats and they made up 35.6 percent of the total relative abundances of stem density in the samples. Trifolium pratense and Achillea millefolium shared dominance in cell 3 along with Cyperaceae spp. (16.3 percent of the total relative abundance) and Arthraxon hispidus (10.8 percent of the total relative abundance), both of which colonized the cell from natural seed rain.

Table 4. Comparisons of introduced herbaceous species. The first column shows the percent of the total seeding effort and the other columns show relative abundance in the plant communities in the second growing season.

Species	percent of total seeding	relative abundance	
		Cell 1	Cell 2b
Agrostis alba (redtop)	15	0.8	4.4
Aster novi-belgii (New York aster)	4	0	0
Echinochloa crus-galli (barnyard grass)	77	0	0
Elymus riparius (riverbank wild rye)	2	0	0
Scirpus cyperinus (woolgrass)	2	0	0.1

Table 5. Intentionally seeded species in cell 3 that were observed during the second growing season. The first column shows the percent of the total seeding effort and the second column shows the relative abundance for those species found in quadrat sampling.

Species	percent of total seeding	relative abundance
Trifolium pratense	6.6	13.0
Achillea millefolium	2.1	10.0
Leersia oryzoides	0.1	4.9
Juncus effusus	0.1	3.4
Bidens cernua	0.1	1.4
Carex vulpinodea	0.4	1.0
Coreopsis lanceolata	0.6	0.6
Rudbeckia hirta	0.4	0.4
Agrostis alba	1.7	0.2
Asclepias incarnata	0.1	0.2
Helenium atumnale	0.1	0.2
Alisma plantago-aquatica	0.1	0.1
Bidens frondosa	0.2	0.1
Lobelia cardinalis	<.1	0.1
Oenothera biennis	0.1	0.1
Aster novi-angilae	0.7	-----
Aster novi-belgii	0.5	-----
Aster puniceus	<.1	-----
Carex lurida	0.1	-----
Desmodium canadense	0.1	-----
Echinacea purpurea	0.4	-----
Eleocharis obtusa	0.1	-----
Eupatoria-delphus maculatus	0.1	-----
Euparotium perfoliatum	0.1	-----
Euthamia graminifolia	0.1	-----
Fagopyron saggitatum	6.6	-----
Gaillardia aristata	0.4	-----
Heliopsis helianthiodes	0.1	-----
Liatris spicata	2.1	-----
Polygonum pennsylvanicum	0.7	-----
Rudbeckia laciniata	0.1	-----
Scirpus cyperinus	0.2	-----
Scirpus robustus	1.7	-----
Scirpus validus	0.1	-----
Solidago canadensis	0.1	-----
Spartina pectinata	0.2	-----
Verbena hastata	0.2	-----
Vernonia noveboracensis	0.3	-----

Economics

The total cost for the Little Patuxent Project was $74,981. The costs of the project can be broken down into three categories: design, construction, and planting. The design phase of the project consisted of preliminary fieldwork, meetings and project management, engineering work and the actual design of the planting plan. The cost for the design phase was $17,350. The engineering portion of the design phase included the grading, earthwork calculations, cross sections, grading stakeout and an as-built survey. The construction phase of the project included sediment and erosion control measures and excavation and cost $35,292. The implementation of the planting plan cost $19,589 and included materials and installation. The cost does not reflect the additional cost for monitoring of the project over time.

Approximately $4,600 of the costs from the design phase were directly applicable to the design of the planting plan. The total costs for the high diversity self-organization seeding in cell 3 was approximately $2,750. When these costs are added to the costs of the planting phase, the cost for the design and implementation of the planting plan rises to a total of $24,189. The cost of the planting component for the Little Patuxent Mitigation Project was approximately 35 percent of the total costs of the project.

Dividing the costs of the planting component by the area of the project, the cost for the original planting plan in cells 1 and 2b was approximately $20,500 per hectare; these costs reflect the design and planning costs for the cell as well as the cost of the nursery stock and landscape contractor. The cost of the high diversity self-organization experiments in cell 3 was approximately $13,750 per hectare; this included the cost of the seed and the short time period it took to broadcast the seed within the cell. There were no planting costs associated with cell 2a, the cell which was allowed to naturally colonize with vegetation.

DISCUSSION

The divergence of hydrologies in the different cells limits comparisons that can be made between plant communities that developed by the second growing season. Cells 1 and 2b (the low diversity seeding treatment) had similar hydrologies by coincidence, with water levels fluctuating above and below the soil surface, and generally their plant communities were similar. However, in cell 2a the average water table was always below the soil surface and in cell 3 the average water table was always above the soil surface and, in turn, their plant communities differed greatly in terms of species richness and relative abundances of species. All of the cells, except for cell 3, met the Corps of Engineers criteria of wetland status by having greater than 50 percent of the

stem density in wetland species (the last row in Table 3). While the plant community in cell 3 had a high percentage of observed wetland species, only 39 percent of the stem density was made up of wetland species. Presumably, the terrestrial conditions of cell 3 caused the plant community to be dominated by non-wetland species.

Success of intentionally seeded species in the low diversity treatment (cells 1 and 2b) was low and none of these species were dominant during the second growing season. Success of intentionally seeded species in the high diversity treatment (cell 3) was greater. About 36 percent of the total stem density in cell 3 came from intentionally seeded species and 38 of 132 seeded species were observed. In fact, two of the four dominant species in cell 3 were intentionally seeded species, which further indicates the success of this seeding strategy.

Overall, colonization from natural seed rain dominated the plant communities in all of the cells, both in terms of observed species richness (Table 2) and of relative abundance contributions to stem density (Table 3). The majority of plant diversity at the sites colonized naturally. Even in cell 3, where 132 species were intentionally seeded, 62 species and 64 percent of the total stem density came from natural seed rain. This influence of natural seed rain is an example of the role self-organization plays in plant community development. In essence, seed sources from the surrounding landscape contribute species to the sites which mix with intentionally seeded species. Environmental conditions at the sites along with species interactions select the plant community structure.

Self-organization was enhanced in cell 3 by the addition of the high diversity seeding treatment and a unique plant community was created. Although the plant community in cell 3 might not be designated as being characteristic of a wetland, it had high diversity and was not completely dominated by species from natural seed rain, as in the other cells. This plant community is an example of the new systems being created by humans with guided self-organization from nature. However, the results reported here are only for the second growing season and the contribution to the plant community from the high diversity intentional seeding may disappear over time. We look forward to monitoring the plant communities in the future to examine longer term changes.

Policy implications from the study are clear. The strategy of relying on natural colonization to develop a wetland plant community, as seen in the results from cell 2a, was the most effective. The plant community in cell 2a had the highest percent contribution from wetland species (last rows in Tables 2 and 3) compared with the other cells. This result may have been caused by the higher water levels in cell 2a but natural colonization strongly influenced all plant communities in the study and it was the main source of wetland species to them. The natural colonization strategy also was the least costly strategy for developing a wetland plant community. Planting costs in the other treatments which used intentional plantings were high. Since the success of the intentionally planted species was low, especially in cells 1 and 2b, the money

spent on seeding could have been saved to be used for other purposes, such as mid-course corrections to the project site. In the Little Patuxent River Wetland Mitigation Project approximately $24,000 was spent on the planting portion of the project, which was unnecessary and could have been used more profitably for other conservation objectives. Extrapolating this kind of cost across the entire mitigation industry in the State of Maryland could yield hundreds of thousands of dollars that are spent annually without significant effect. Decision makers who regulate the wetland mitigation process need to challenge the idea that intentional plantings of human selected species are necessary to develop a wetland plant community. As long as the surrounding landscape provides a seed source, the most effective planting strategy may be to allow natural colonization to substitute for the human work of choosing and planting species at a wetland mitigation site (Galatowitsch and van der Valk 1995, Shenot and Kangas 1993). This is an example of ecological engineering, where the subsidy of nature is used to achieve human goals through self-organization.

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PLANT INSPECTION - A GUIDE TO THE BASICS

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ABSTRACT

Designers of ecosystem restoration and creation projects routinely specify tens of thousands of nursery plants to hasten plant succession. Plant inspection, before and during site construction, insures that the stock meets specifications, is of good quality and has been properly conditioned. Plants may have a healthy appearance, but if they have not been properly acclimated or their genetic make-up is unsuitable for a specific planting site, the survival rate will decrease. Projects that include large-scale plant installation are particularly deserving of vigorous plant stock, if for no other reason than the economics of mortality and claims. Standards of plant quality are incorporated into the project design and installation, usually by an ecologist, rarely by a native plant grower/horticulturist. Frequently, this inspector is a non-horticulturist. The authors have compiled some general field guidelines for conducting plant inspections.

INTRODUCTION

Usually, the first time an ecologist may encounter plant inspection is during a construction project, such as construction of a mitigation area. Specific grades and standards of plants are required in the construction plans and specifications. Other projects that may require plant inspections include landscaping, xeriscaping, and remedial planting projects.

Why are plant inspections so important? Korbobo (1959) stated that landscaping would be no more successful than the plants being used. Mediocre specimens mean mediocre landscaping. The main reasons for conducting plant inspections are quality control and economics. For example, permit criteria may require that trees planted in a mitigation area must achieve 30% canopy coverage in three years or 80% survival. If the installed trees do not meet minimum standards as detailed in the planting specification, the survival rate may decrease, thus causing an added expense of remedial plantings. Also, the monitoring period may be extended, thus causing an added cost of continued monitoring and maintenance. Furthermore, because there is a fairly substantial increase in cost as the container size gets larger (Table 1), the purchaser wants to make sure that they are getting what they paid for. For example, if a one-gallon (3.8-liter) containerized plant has just been potted into a three-gallon (11.4-liter) container and hasn't had the time to develop into a size that is representative of a three-gallon plant (11.4-liter), then the purchaser is paying extra for that particular size plant.

DISCUSSION

Often plant inspection is not included in the design of a mitigation area or landscape plan. It is assumed that the designer has taken the genetic makeup of a plant, such as its response to different environmental conditions or its growth form and size, into account in the planting design. For example, in a wetland restoration project, selecting plants that are tolerant of, or prefer growing in, areas that are inundated, is critical to the potential success of the plantings.

Planting stock may be supplied from plant nurseries (nursery-grown) or authorized donor sites (wild-harvested). Nurseries may be certified, which means the nursery has met certain specifications, such as supplying plants free from diseases and infestations and conforming to the current American Association of Nurseryman Standards for Nursery Stock. The Florida Department of Environmental Protection through the issuance of a permit regulates the harvesting of plants from authorized donor sites.

Many different sizes of containerized plants can be specified for ecosystem restoration and creation areas. Container-grown trees may range in size from

Table 1
Approximate wholesale cost of plants relative to container size

Trees	**1 gal (3.8 liters)**	**3 gal (11.4 liters)**	**15 gal (56.8 liters)**	**30 gal (113.6 liters)**	**65 gal (246.1 liters)**
Bald Cypress (*Taxodium distichum*)	$1.95	$5.25	$32.50	$75.00	N/A
Red Maple (*Acer rubrum*)	$1.95	$5.50	$35.00	$75.00	$150.00
Shrubs					
Wax Myrtle (*Myrica cerifera*)	$1.95	$5.00	$35.00	$75.00	N/A
Yaupon Holly (*Ilex vomitoria*)	$2.00	$5.50	$35.00	$80.00	$155.00
Herbaceous	**Bare Root**	**2 in (5.2 cm) liner**	**1 gal (3.8 liters)**	**3 gal (11.4 liters)**	**N/A**
Cordgrass (*Spartina bakeri*)	$0.50	$0.55	$1.85	$5.00	N/A
Sawgrass (*Cladium jamaicense*)	N/A	$0.60	N/A	N/A	N/A

less than one-gallon (3.8-liter) in size to over 65-gallon (246.1-liters) in size. Field-grown trees may even be delivered to the planting area as bare-root or balled-and-burlapped stock. Herbaceous plants may be supplied as bare-root stock, or in the nursery containers they were grown in. They may range in size from a tubling to three-gallon (11.4 liters). Bare-root trees are usuallysupplied from a nursery and are not wild-harvested. Bare-root, non-woody plants are either nursery-grown or wild-harvested.

Ecosystem restoration and creation areas may have specific success criteria if restoration and creation have been done as mitigation. Often, larger sizes of herbaceous species are used in order for the site to meet success criteria (such as reaching 80% cover) at a faster rate. However, Turnbull (1991) has observed

that plants purchased small and established early will often catch up and surpass "specimen" plants. Because so many combinations exist for the ecologist to specify in design of restoration and creation areas, the authors have decided to focus on the most common sizes and conditions in which plants are delivered to the project site. The most common container size criteria is based on the authors' personal experience and may vary with each ecologist's own experience.

Because the cost of a plant increases as its container size increases, smaller plants are often specified in ecosystem restoration and creation design plans. Cost is often a limiting factor for plant container size selection. Balled-and-burlapped plants cost more than those dug with bare roots because of the extra labor that is involved in the preparation of the tree (Korbobo, 1959). The most common sizes of woody plants (trees and shrubs) specified in design plans are one and three-gallon (3.8 and 11.4 liter) container sizes. The most common sizes of non-woody plants used in restoration areas are four-inch (10.2-centimeter) diameter liners and one-gallon (3.8-liter) container size.

Pre-Inspection

Before the plants can be delivered to the project site, some preliminary inspection tasks should be conducted.

1) The plant inspector should be familiar with the design plans and specifications. At what elevation and location should each species be planted? Have as-builts of the site been completed to verify that current elevations are the same as the design elevations?

2) The plant inspector should know the source of the planting material. Has a certified nursery been specified in the plans? Is the planting stock coming from an authorized donor site?

Preliminary Inspection at Source of Planting Material

A preliminary plant inspection should be conducted at the source of the planting material. Berger (1990) stated that vast improvements in nursery practices, seedling storage, and the timing of reforestation projects have resulted in great increases in seedling viability since the 1960's. A visit to the plant nursery to see the growing conditions may be required in order to ascertain if the plants

have been conditioned before they are brought to the site. If a plant has not been grown in a hydrologic regime and is specified to be planted in an area that is inundated, the survival rate of the plant may be decreased due to the sudden change in its growing environment.

Inspectors should be observant of the following cultural conditions:

- Have the plants been grown close together, or has space been left between the containers in order to facilitate trunk development (Figure 1)?

Figure 1: Example of properly spaced trees.

- Has the specified plant been grown in a shady environment? Ecosystem restoration areas are usually graded to meet specific planting elevations and no areas of shade exist. A different light regime may affect the viability of the plant.

- Are the plant containers free of nuisance/exotic vegetation that can be transferred to the planting site and become a future maintenance problem? The presence of even non-nuisance weeds may adversely affect nutrient uptake to

the containerized plant.

Preliminary Planting Site Inspection

The plant inspector should visit the project site to verify planting conditions. Are specific planting areas and elevations staked out? Is it clear where the plants are to be planted?

In the case of wetland restoration, are the water levels at the proper elevation? Flooding has a stunting effect on may species. Kozlowski (1984) flooded American elm (*Ulmus americana*) for 39 consecutive days. He found that the growth rate of unflooded plants exceeded those in flooded conditions by three to five times. On the other hand, he found that flooding could increase the growth rate of some flood-tolerant species such as swamp tupelo (*Nyssa aquatica*). The duration of flooding and the age and the species of the tree all have an effect on whether the tree will die from flooding. Kozlowski (1984) found that trees that eventually died from prolonged flooding often exhibited a rapid growth rate when they were first flooded.

Prolonged flooding, as well as prolonged drought, presented numerous challenges to a project ecologist charged with maintaining the Seminole Mitigation Site. Despite harsh conditions, bald cypress (*Taxodium distichum*) and pop ash (*Fraxinus caroliniana*) have flourished (Cryor, 1996).

The plant inspector should establish a plant staging area on site prior to plant delivery. This area should be accessible by a large truck, located in a shady area if there is shade present on or adjacent to the site, should be flat and clear for ease of unloading and counting plants, and in an area where irrigation is accessible. Some permit conditions prohibit plant staging and specify that the plants be installed within 24 hours of arriving on site. If no shade is present and plant installation will be conducted over a long period of time, a shady area should be constructed on site.

Containers for most plants are a dark color. Soil on the sunny side of a container can reach temperatures of 120° F (48.9° C) and remain above 100° F (37.8° C) for up to eight hours. Harris (1983) demonstrated that increased soil temperatures reduced the growth of black locust roots by 75%. If a temporary shady area can not be constructed, place the plants close together to

protect the outside of the containers from the sun. Boards, cardboard, and mulch can be placed up against the outside of the containers to protect the plants from excessive heat. Covering the plants with tarpaulins or other water-proof and air-proof materials can cause the build up of excessive heat that can damage the plants (Korbobo, 1959).

Is there a source of water for irrigation? Turnbull (1991) stated that the nicest thing you can do for your new plants is WATER, WATER, WATER. He recommended that plants be soaked immediately after they are planted and that long and deep watering is more important that frequent watering. Long and deep watering encourages deep root development which is essential to the plant in times of drought.

Plant Inspection

The plants should be unloaded in the designated plant staging area and arranged in blocks of 100's so that they are easy to count. If numerous blocks are established, flagging one plant per block or spray painting one container in a block will help the plant inspector keep track of the plants that have already been counted. The number of each different type of plant, as well as the size of each plant, should be compared to the total number of plants specified for the project. If quantities are large, approximately 10% of the planting stock should be selected at random from all areas of the blocks of plants for inspection. If a large portion of the plants sampled are unacceptable, then a larger percentage should be inspected.

The plant inspector should know what grades and standards for nursery plants were specified in the construction or design plans. Specific grades and standards are determined by the Division of Plant Industry, Florida Department of Agriculture and Consumer Services (FDACS, 1973). There are four designated grades and standards for nursery plants: Florida Fancy, Florida No. 1, Florida No. 2, and Florida No. 3. A Florida Fancy tree is described as an exceptionally healthy and vigorous tree. Florida Fancy is usually specified for formal landscape projects because the plant must be well-shaped and heavily branched with dense foliage. A Florida No. 1 tree is healthy, vigorous, well shaped, branched, and foliated. A Florida No. 2 tree only needs to be fairly well shaped, branched and foliated. A Florida No. 3 tree is a plant that does not meet any of the previous specifications. Grades and standards are also specified for palms,

shrubs, and liners. A lower grade of plant maybe brought to the site. The plant inspector should discuss this topic with the client to determine if lower grade plants will be accepted. For example, if plants are to be installed in a mitigation area where the shape of a tree is not as critical as in a landscape, perhaps a lower grade tree would be just as acceptable.

A new Standard for Wetland Plants is currently being developed by the FDACS. When used for mitigation plantings, specific grades, such as Florida No. 1 (which are currently specified by the Florida Department of Transportation to be used in mitigation areas) will no longer be specified. These new standards are intended to assess the health and vigor of the plant and reduce the emphasis on the plant's overall appearance (Clark, Pers. Comm., 1997).

Inspecting Woody Vegetation

1) Verify the species if similar species are to be planted or if a similar species exists, even though it may not be specified.

2) Start by checking the top growth - Is it vigorous?
Unacceptable plants can be characterized by the following
- a broken leader, often caused by wind or crowding
- The foliage has insect or mechanical damage (<5% of the total foliage for Florida Fancy, <25% of the total foliage for Florida No. 1, and <75% of the total foliage for Florida No. 2) (FDACS, 1973) (Figure 2).
- The foliage exhibits chlorosis (yellowing of the leaves). Chlorosis can be caused by disease, insects, excessive moisture, cold temperatures, air or soil pollutants, or high nutrient levels in the soil (Harris, 1983). No chlorosis should be present in Florida Fancy trees, <10% of total foliage for Florida No. 1, and <25% of the total foliage for Florida No. 2 (FDACS, 1973).

Chlorosis may also be caused by a nutritional deficiency of the plant, such as a nitrogen deficiency, which is the most widespread of all nutritional deficiencies of woody plants (Dickey, 1977). Mineral and organic soils of Florida are frequently deficient in one or more nutrients essential to plant growth. Fertilizer addition may give the plant an additional boost in nutrients to aid in its establishment, especially in areas where poor drainage and aeration may reduce the roots ability to take up nutrients from the soil (Dickey, 1977).

Figure 2: Unacceptable pests.

- The foliage has an unknown fungus or virus (a sample can be taken to the Department of Plant Inspection for identification).

Check the height or diameter at breast height (D.B.H.) if a certain height or D.B.H. is specified.

Harris (1983) stated that the size of a plant's top growth in relation to the size of the root system is an important factor in the failure of container-grown plants in a landscape. He observed that nursery grown plants usually develop proportionately large tops due to frequent fertilization and irrigation while they are at the nursery, especially while their roots are being confined in a container. The result is that the transpiring surface is much larger than the moisture-holding capacity of the roots and may decrease the survival rate of the plant, especially if frequent watering does not occur.

Florida Fancy, Florida No. 1, and Florida No. 2 all have different specifications for trunk and branches. These specifications range from a straight trunk and uniformed branching beginning at a predetermined point with four or more breaks at the crown for Florida Fancy to a single trunk with at least 2 breaks at the crown for Florida No. 2 (FDACS, 1973). These standards for trees will not

be used for mitigation purposes.

3) If the top growth is acceptable, then check the root system. The container should be removed from the root ball. Improper handling of the plant can cause damage. Consult a nursery grower to learn the proper way of removing a plant from a container. If the tree is staked in the container, remove the stake. If the tree bends sharply at the soil line, then the roots are probably kinked or circling. Harris (1983) describes kinked roots as a greater that 90° bend in the main root(s) and less than 20% of the root system originating from above the kink. He describes circling roots as circling at least 80% or more of the root system by 360° (Figure 3). If girdling occurred, this would leave only 20% of the roots free to support the plant. Circling peripheral roots can be corrected at planting and are usually exhibited, to some extent, in container-grown plants with adequate root development.

Figure 3: Kinked roots.

If, after lifting the plant, the top moves an inch before the container and soil move, the root system is either under developed or the roots are circling (Harris, 1983). Circling and girdling roots can eventually cause strangulation or impeded growth (Korbobo, 1959). As a girdling root grows tighter around the trunk or stem, it prevents development of nutrient and water-conduction tissues,

which will kill the plant (Carpenter, 1990). Even if the top of the plant looks healthy, a constricting root system reduces the chances of that plant to be healthy and long lived (Carpenter, 1990).

After removing the plant from the container, the root system should hold at least 90% of the soil mass intact without being rootbound. The root system should also be inspected for dryness and for pests. Damage to the root system by disease or pests may reduce the plants ability to obtain nutrients from the soil (Dickey, 1977).

Unacceptable containerized plants are characterized by the following:

- excessively rootbound and/or roots growing out of the container (Figure 4). The root system should be well distributed throughout the container and 90% of the soil mass should stay intact after the container has been removed.

Figure 4: Unacceptable rootbound condition.

- roots damaged by digging, or exposure to direct sunlight, wind, or changes in temperature.

These unacceptable characteristics can also be applied to bare-root and ball-and-

burlapped woody vegetation. Minimum ball diameters are specified for trees with specific caliper D.B.H. as well as ball depths in relationship to diameters. For bare-root woody vegetation, it is important for the root system to be well supplied with both lateral and feeder roots and the roots be free of damage caused by digging.

Stakes should be removed from the tree as soon as possible after planting. Studies have shown that staking should be used sparingly and may be only necessary for very small saplings so they won't tip over until their roots have developed. The waving of the trunk in the wind induces the plant to grow a thicker trunk (Turnbull, 1991). Trees should be untied from the stakes as soon as possible. Ties left on trees will girdle the tree, which eventually may cause the tree to die above the stake.

Inspecting Non-Woody Vegetation

For liners, standards are set for the minimum and maximum lengths of time that the plant has been in the liner. These lengths of time vary depending on the diameters of the liners.

1) Start by checking the top growth. Is it vigorous? Unacceptable plants can be characterized by the following:

- insufficient top growth;
- wind burn;
- desiccation; and
- chlorosis.

2) If the top growth is sufficient, check the root system. Unacceptable plants can be characterized by the following:

- poorly developed root system;
- desiccation; and
- inadequate biomass to support the leaves.

The root system should be well-distributed so that at least 75% of the soil stays intact after it is removed from the liner. For bare-root herbaceous planting stock, the root system should contain white, actively growing roots.

Plants grown in containers shall have been growing in the containers for a

sufficient amount of time so that there is uniform root development throughout the container but lacking evidence of root confinement.

Plants that are rejected should be removed immediately from the project site.

CONCLUSION

Healthy and vigorous plants do not guarantee a successful restoration or landscape project. Preliminary tasks must also be completed, such as confirming the correct planting elevations are present before the plants are installed. A plant inspection is an important preliminary step in completion of a successful project. Richard Clark, Chief of the Bureau of Plant and Apiary Inspection, stated that he is often asked to perform an inspection after the plants have been installed and subsequently died (Clark, Pers. Comm., January 1997). A plant inspection before installation may reduce or eliminate any mortality.

The inspection of plants for ecosystem and habitat restoration projects, as well as landscape projects, is only the first step in a successful project. Careful planting techniques, proper irrigation, and follow-up maintenance, such as tree staking and removal of nuisance species, are as important as the plant selection and inspection in achieving a successful planting project (Berger, 1990). Carpenter (1990) also stated that correct plant installation is an absolute necessity if plants are to develop to their fullest potential.

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APPENDIX

Figure 1

Comparison of Prop Scar Damage at The Fort Desoto Aquatic Preserve Cumulative Data

	Spring 1993		Fall 1993		Fall 1994		Fall 1995	
	Scars #	Feet Linear	Scars #	Feet Linear	Scars #	Feet Linear	Scars #	Feet Linear
Area I	20	1,606	30	2,302	39	3,982	40	4,154
Area II	66	16,119	123	29,777	139	33,655	150	35,365
Area III	96	36,548	115	42,141	128	44,731	142	48,946
Area IV	86	18,569	91	19,664	109	22,758	120	24,977
Area V	61	16,747	86	20,622	105	23,702	116	23,447
Area VI	120	29,868	147	36,707	178	45,359	201	48,573
Total	449	119,457	592	151,213	698	174,187	769	185,431

The following figures are from Ehringer, J.N., J. Wysong, and C.J. Dawes. 1998. Protecting Seagrass in Tampa Bay. Pp. 52-69.

Figure 2

Comparison of Prop Scar Damage at The Fort Desoto Aquatic Preserve Cumulative Data

Comparison of sites according to protective status

Zone	Spring 1993		Fall 1993		Fall 1994		Fall 1995	
	Scars #	Feet Linear	Scars #	Feet Linear	Scars #	Feet Linear	Scars #	Feet Linear
Boat Restricted	167	36,922	207	42,570	253	50,442	276	52,578
Seagrass Caution	216	66,416	262	78,848	306	90,090	343	97,519
Non-Restricted	66	16,119	123	29,777	139	33,655	152	35,905

Figure 3

Comparison of Prop Scar Damage at The Fort Desoto Aquatic Preserve

Seagrasses loss from the Fall of 1993 to the Fall of 1995

Location	1993 to 1994	1994 to 1995
Boat Restricted	7,872 square feet	3,892 square feet
Seagrass Caution	11,242 square feet	11,509 square feet
Non-restricted	3,878 square feet	2,520 square feet

Figure 4

Per Cent of Seagrass Lost at The Fort Desoto Aquatic Preserve

Per cent of seagrasses lost per zone (total) as a per cent of the total seagrasses in each area at the time of measurement

Zone	Spring 1993 Loss	Fall 1993 Loss	Fall 1994 Loss	Fall 1995 Loss
Restricted	0.62%	0.71%	0.89%	0.92%
Caution	0.70%	0.83%	0.95%	1.03%
Non-restricted	0.60%	1.10%	1.25%	1.33%