Modeling a Seagrass Restoration Target for an Urbanized Florida Estuary

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Abstract

Loss of seagrasses has been documented worldwide and has been correlated with anthropogenic eutrophication and alteration of habitats. Developing a seagrass restoration target or numeric goal based on available understanding of the history and physical characteristics of an estuary sets up guidelines for ongoing and future habitat restoration projects. Palm Beach County (Florida) Department of Environmental Resources Management has developed a methodology to model a seagrass restoration target in Lake Worth Lagoon. Potential sea grass habitat is modeled using a bathymetric survey to develop a digital elevation model, seagrass mapping from aerial photography to determine seagrass distribution by depth, and estuarine substrate characteristics. A user can determine where seagrass restoration or recruitment is likely to occur and can assist in setting a restoration target based on these factors. Additionally, the information developed provides an effective management tool to determine where restorative and protection efforts should be focused.

Summary

The objectives of this paper are to: (1) discuss existing information used for the development of a seagrass restoration target for the Lake Worth Lagoon (LWL), (2) discuss the methodology to model a seagrass restoration target in LWL; and (3) discuss potential seagrass restoration targets for the three segments of the lagoon.

LWL has realized significant losses of seagrass over time due to water quality impacts, dredging, and urbanization. Seagrass loss and their retreat to shallow water have been attributed to a reduction of available light which is confirmatory of the poor water quality in the lagoon. Mandate for the protection of seagrass comes from several sources including the 1998 LWL Management Plan, Palm Beach County Comprehensive Plan – Coastal Management Element, Florida Statute 376.121 - Liability for Damage to Natural Resources, and the Federal Endangered Species Act protecting listed species of seagrass. Historical seagrass surveys from 1940, 1975, 1990 and 2001, and predictive modeling are presented in this report to provide a benchmark for the development of the seagrass restoration model.

Seagrass restoration target depths for each lagoon segment at which adequate depth, light, and substrate conditions to ensure seagrass growth and future recruitment were identified. Based on the GIS modeling conducted, a possible LWL seagrass restoration target is 2,092[1] acres based on best available information and understanding of the estuarine system. The possible target is based on 2001 seagrass distribution data and modeling of potential seagrass habitat which includes adequate depth and substrate. This target may be achieved over a 20 year period through the management of nutrient and sediment loadings, removal of muck sediments in the lagoon, and diversion of freshwater

[1] 2,092 acres = 1,646 acres existing + 466 acres of recruited seagrass

discharges. Developing a seagrass restoration target or numeric goal based on available understanding of the history and physical characteristics of an estuary sets up guidelines for ongoing and future habitat restoration projects.

LWL is located on the eastern shore of South Florida in Palm Beach County (Figure 1) and is approximately 20 miles in length, ½ mile wide with average depth of 6 feet. It is estimated that current seagrass coverage is 1,626 acres based on an aerial assessment of 2001 conditions. The LWL is divided into three segments (north, central, and south) based on hydrological factors including water quality, circulation, and physical characteristics

Figure 1. Location of Lake Worth Lagoon, Palm Beach County, Florida

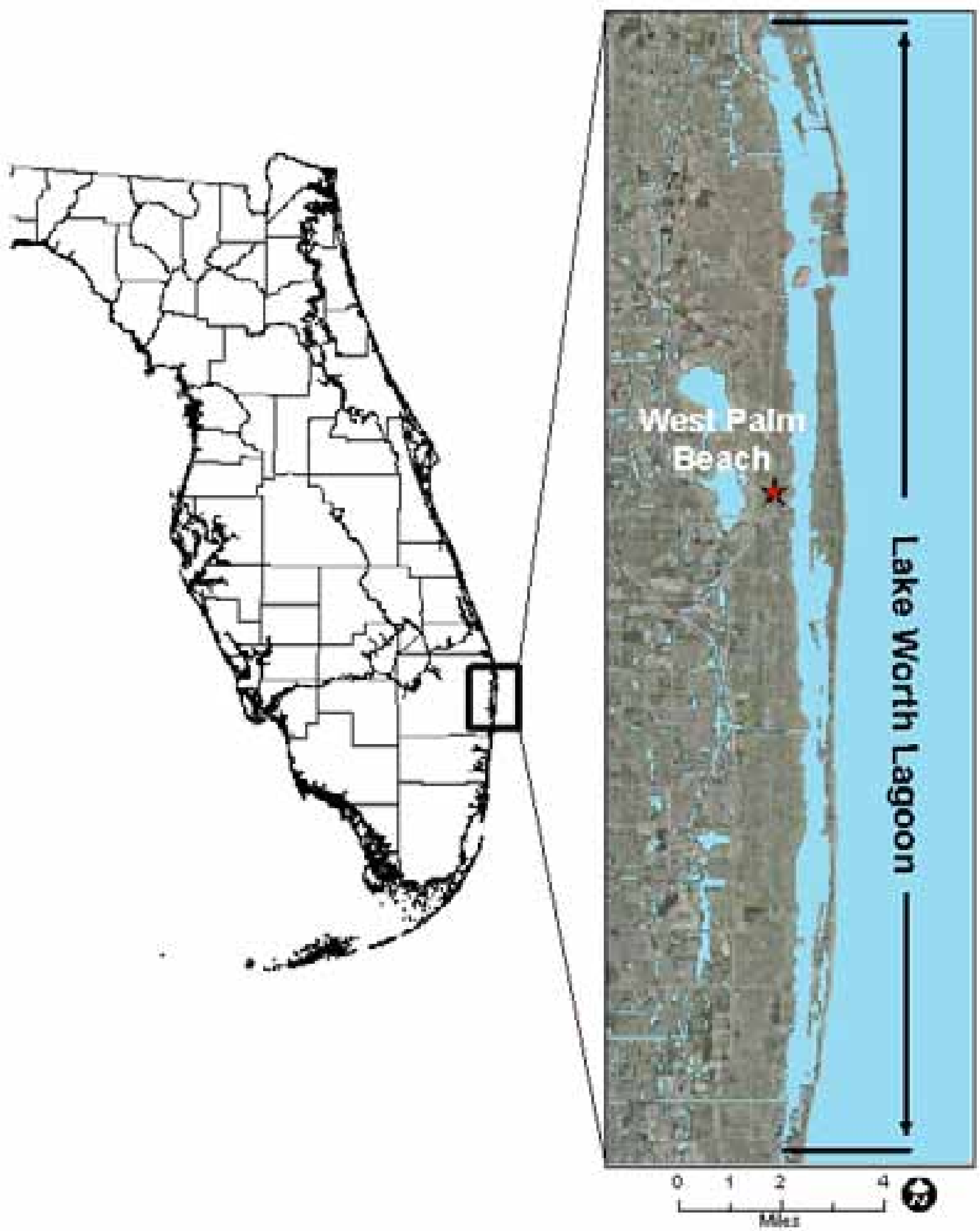


Table 1 presents the current distribution of seagrass in LWL by segment.

Table 1. Current Seagrass in Lake Worth Lagoon

LWL Segment	2001 Seagrass (Acres)	Segment Area (Acres)	% Seagrass Cover
North	1,134	3,386	33.5%
Central	192	2,102	9%
South	300	1,747	17%
Totals	1,626	7,235	22%

Seagrass Background and Current Status

Seagrass beds are highly productive and ecologically important habitats within South Florida's estuaries and coastal lagoons. The combination of plentiful shelter and food results in seagrass beds being perhaps the richest nursery and feeding grounds in South Florida's coastal waters. Seagrass beds are nursery grounds for the juveniles of a variety of finfish and shellfish of commercial and recreational fishing value. The roots and rhizomes stabilize the sediments, promote sedimentation of particles, inhibit resuspension of sediments, and maintain an active environment for nutrient recycling. The seagrass blades provide a substrate on which epiphytes can attach, providing a more valuable food source to most consumers. Seagrasses probably are more important to the food web as detritus than as a source for direct herbivory. Detritus is an important food source for deposit feeders, providing polychaetes, amphipods, isopods, ophiuroids, some gastropods, and mullet with much of their nutrition. Seagrasses are also important because they are the primary food source for the Florida manatee (Palm Beach County Environmental Resources Management (ERM) & FDEP 1998).

Losses of seagrasses have been documented worldwide and have been correlated with anthropogenic eutrophication and alteration of shorelines and habitats. Declines, as seagrass beds typically retreat to shallow depth, have been correlated with a reduction in available light due to an increase in phytoplankton, epiphytic or macroalgal growth (Bortone 2000). The LWL Management Plan recognizes the importance of this resource and the factors responsible for the decline of seagrass and has addressed it through the goal of attaining and maintaining water quality and sediment quality of sufficient quality to sustain a healthy estuarine ecosystem.

The most recent assessment of seagrass coverage was conducted in 2001. Results of the 2001 seagrass mapping project using aerial imagery demonstrate that seagrass beds cover at least 1,626 acres or approximately 22% of the lagoon (Baymont 2001). Additional seagrass was present; however, the lack of water clarity prevented mapping of all seagrass beds. The coverage varies throughout the three segments of the lagoon. Specifically, 69.7% of the seagrass in LWL are in the northern segment of the lagoon, 11.8% of the seagrass are in the central segment of the lagoon, and 18.5% of the seagrass are in the southern segment of the lagoon. The overall seagrass coverage within each of the segments is 33.5% in the north, 9% in the central, and 17% in the south segment of the lagoon.

Methodology for Developing a Model

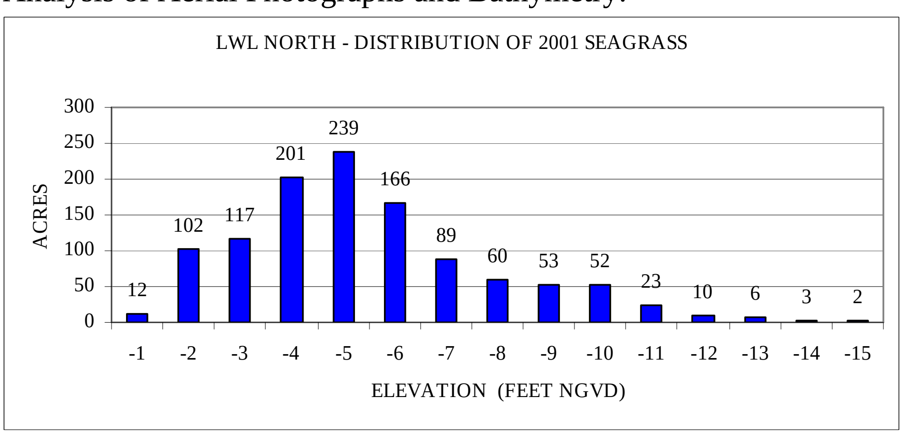
Step 1: Assembling Data Sets and Base Analysis

The first step in developing the model is to assemble existing data sets and determine the distribution of seagrass by depth using seagrass coverage and bathymetry data. Figure 2 presents the intersection of bathymetry point data and seagrass data in a selected area of LWL.

Figure 2. Intersection of Bathymetry Transect Data and Seagrass Data for Determination of Seagrass Distribution by Depth.

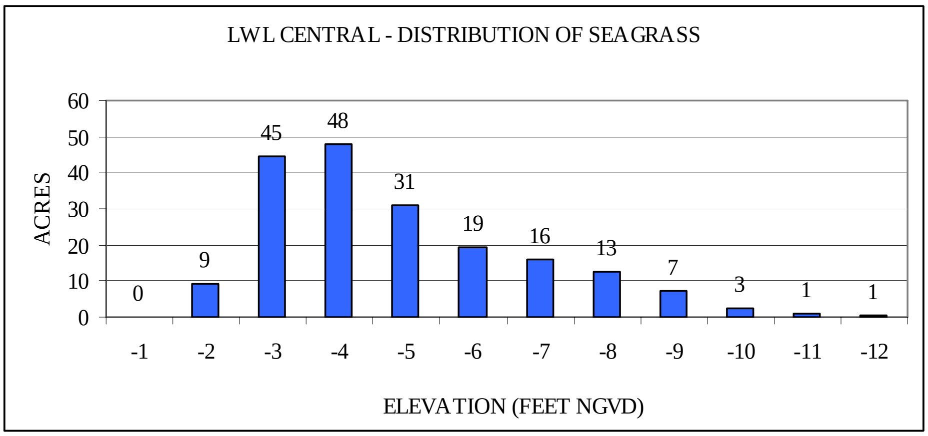
Approximately 92% of the seagrass in the north segment is present at depths of -2.0 to -6.0 feet NGVD. The average depth of seagrass in the north segment is -5.0 feet NGVD. Figure 3 presents the distribution of existing seagrass by depth.

Figure 3. Distribution of Existing Seagrass by Depth in Lake Worth Lagoon North Based on Analysis of Aerial Photographs and Bathymetry.



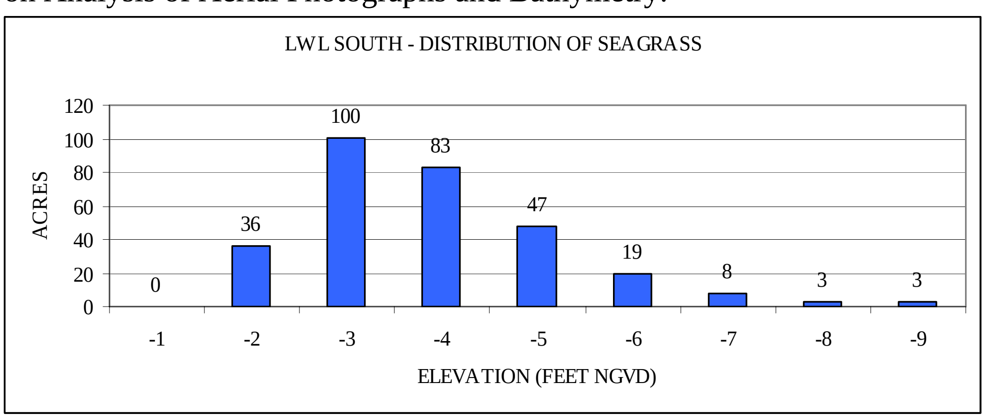
The central segment of LWL is the most severely impacted segment of the lagoon with respect to water quality and the presence of muck. The central segment is currently listed on the FDEP Verified List of Impaired Waters. As water quality and light attenuation decrease, seagrasses have been known to retreat to shallow depths (Bortone 2000). The central segment of the Lagoon typifies this phenomenon. In a striking contrast to the north segment, there are only 192 acres (9% coverage) of seagrass in the central segment. The majority of seagrass is only found at depths between -3.0 to -5.0 feet NGVD. The average depth of seagrass in the central segment is -4.4 feet NGVD. Figure 4 presents the distribution of existing seagrass in the central segment.

Figure 4. Distribution of Existing Seagrass by Depth in Lake Worth Lagoon Central Based on Analysis of Aerial Photographs and Bathymetry.



The south segment of LWL is also stressed due to poor water quality and is typified by the retreat of seagrass to shallow depths where light requirements can be met. Presently, there are only 300 acres (17% coverage) of seagrass in this segment. The majority of seagrass is only found at depths between -3.0 to -4.0 feet NGVD. The average depth of seagrass in the south segment is only -3.4 feet NGVD. Figure 5 presents the distribution of existing seagrass in the south segment.

Figure 5. Distribution of Existing Seagrass by Depth in Lake Worth Lagoon South Based on Analysis of Aerial Photographs and Bathymetry.



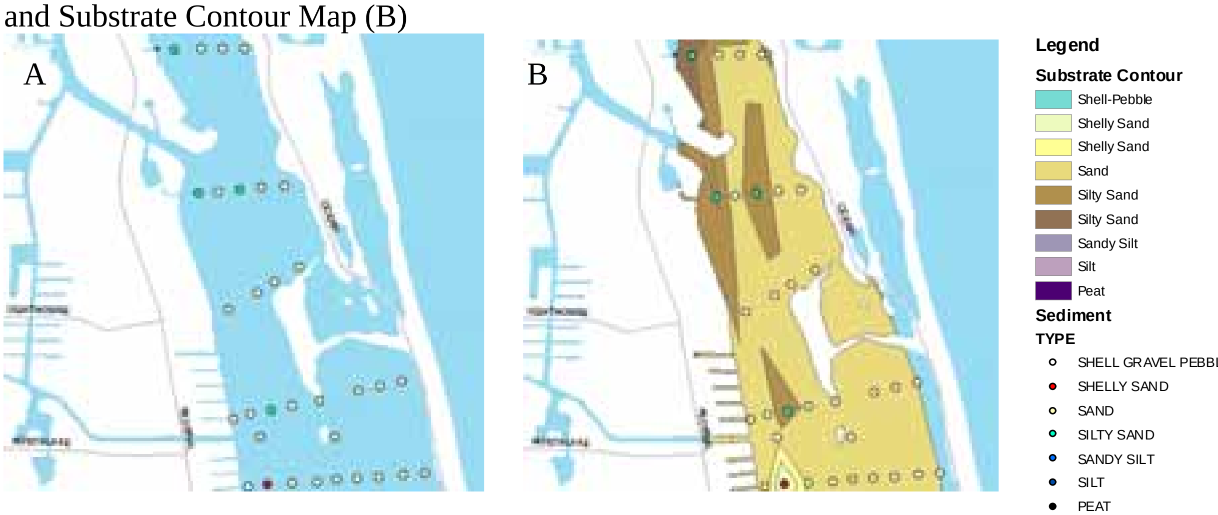
Step 2: Digital Elevation Model

The second step is to generate bathymetry for the entire LWL based on a bathymetry transects performed in 2003 (Morgan & Eklund). Using 3D Analyst, the bathymetry data is interpolated to a raster data set using the inverse distance weighted (IDW) interpolation technique. This technique is used to determine cell values using a linearly weighted combination of a set of sample points. The rasterized data set is reclassified as necessary for ease of analysis of other factors. Now that a digital elevation model for the LWL has been created, analysis based on depth can be achieved for a variety of factors. For example, different seagrass recruitment scenarios may be set up based on depths at which seagrass is likely or targeted to recruit. Other ecosystem component models may be developed for other benthic organisms using this approach (e.g., American oyster).

Step 3: Modeling Substrate

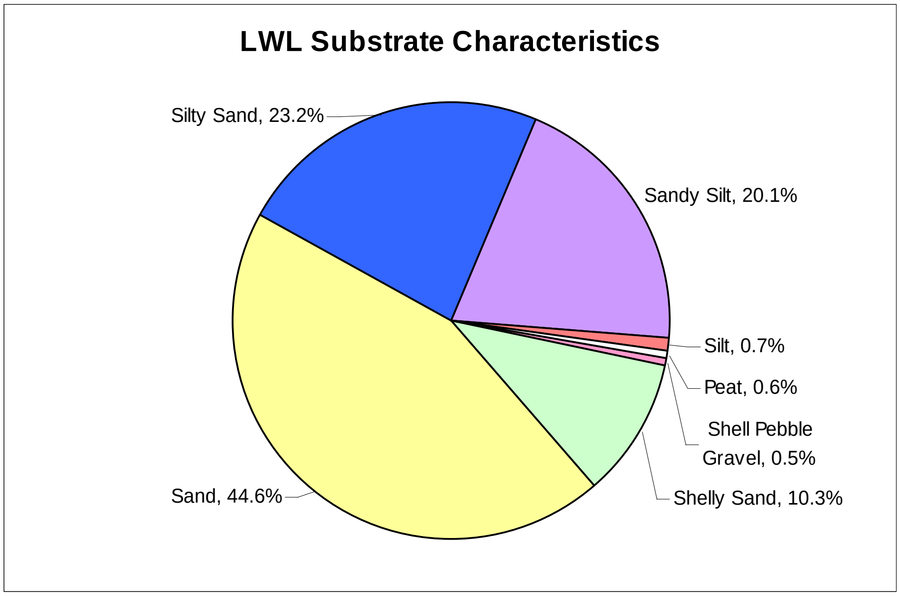
While seagrass recruitment is dependent upon a complex set of factors and dynamics, there are basic building blocks which are important to the colonization of seagrass. One of the building blocks is suitable substrate. For this exercise, substrate characteristics were modeled for LWL because a substrate map had not been previously developed. Historical data from the late 1960's collected by the U.S. Environmental Protection Agency was digitized and combined with a muck survey performed during the 2003 bathymetric data collection event. In this case, muck deposits greater than 1 foot were mapped principally in the central and southern segments of LWL using a dual frequency fathometer. These data sets were integrated into a single shapefile. Once integrated, a Triangulated Irregular Network (TIN) was created to interpolate unmapped areas of the LWL. The TIN was then converted to raster and reclassified. Figure 6 presents the raw data and reclassified substrate map.

Figure 6. Digitized Substrate Characteristics from Sediment Cores and Muck Survey (A) and Substrate Contour Map (B)



In the same manner that seagrass distribution by depth is analyzed, seagrass distribution by substrate is developed. Figure 7 presents seagrass distribution within LWL by substrate.

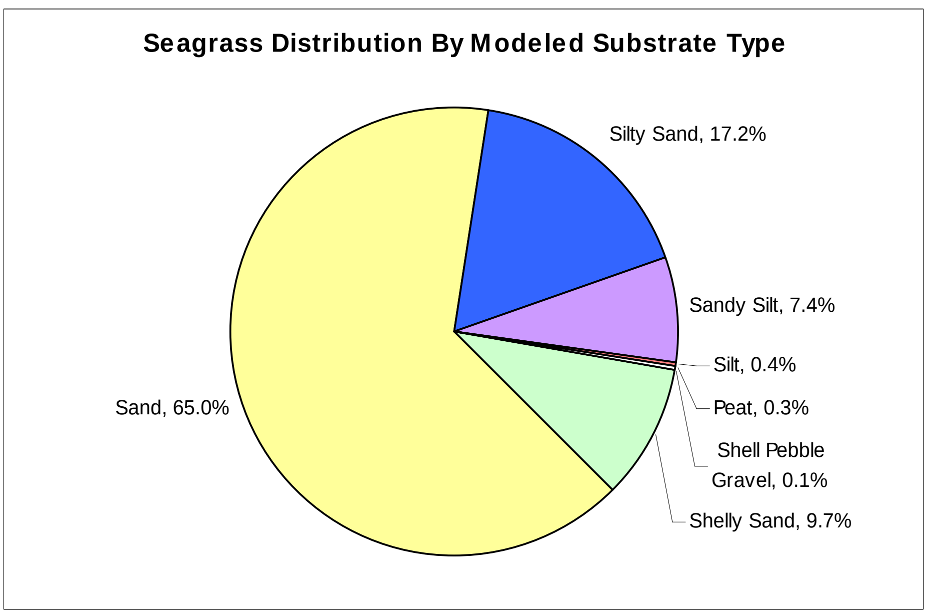
Figure 7. Lake Worth Lagoon Modeled Substrate Characteristics Distribution



Note: LWL Substrate Characteristics based on 1990 Lake Worth Lagoon Natural Resource Inventory and Morgan & Eklund 2003 Bathymetry/Muck Survey.

Figure 8 presents LWL 2001 seagrass data distribution by modeled substrate characteristics. An analysis of the results indicate that seagrass is predominantly found in sandy environments and does not colonize well in silty environments. However, further analysis of the results demonstrates that seagrass is colonizing silty environments within the central and southern segments of LWL. These seagrass beds, found in impacted areas of LWL are not typical of healthy beds. Although seagrass may be found in these environments, seagrass is not expected to successfully recruit in areas with high silt content.

Figure 8. Lake Worth Lagoon Seagrass Distribution by Modeled Substrate Characteristics



Step 4: Developing the Target

Several factors were analyzed to determine a possible target for seagrass restoration. These involve using a historical seagrass model, earlier seagrass mapping studies, and the use of current seagrass distribution, and substrate characteristics to predict future recruitment.

The earliest seagrass survey for LWL was performed in 1940 (Palm Beach County ERM & Florida DEP 1998) and found that 4,271 acres of seagrass were present. An analysis performed for this study using current seagrass distribution data confirmed the results of the 1940 study. The comparison was developed based on the premise that given pristine water quality conditions in the lagoon and ideal depth at which light penetration allows for the growth of seagrass, a prediction can be made as to the total distribution of seagrass in an arbitrary year (e.g., 1940). Assuming that seagrass would be present at -9.0 feet NGVD, the total amount of seagrass is predicted at 4,440 acres. The prediction is within 4% of that surveyed in 1940. It should be noted that areas of the lagoon have been deepened since 1940 and this has not been accounted for in the current study.

In 1975, a resource inventory was performed and found that only 161 acres of seagrass remained in LWL, representing a substantial loss of seagrass from 1940. The loss of seagrass was hypothesized to be linked to sewage disposal outfalls that directly discharged to LWL as well as degraded water quality. This was inevitable due to the rapidly expanding population surrounding the estuary and the technology associated with wastewater treatment plants. During the 1950s, an estimated ten million gallons per day (MGD) of raw sewage was discharged to LWL resulting in extensive bacterial and nutrient pollution. By 1970, seven major waste water treatment plants had been constructed, discharging 18.49 MGD of secondarily treated sewage effluent. The volume was reduced to 2.98 MGD by 1984, largely as a result of the NPDES program administered by the USEPA (Palm Beach County ERM & Florida DEP 1998). Today there are only two small "package" wastewater treatment plants discharging into LWL.

In 1990, a natural resource inventory was performed on LWL (Dames & Moore) and included detailed in-water surveys which provided the most complete information to date. The survey indicated that there were 2,110 acres of seagrass; approximately half of the amount of seagrass in 1940. However, there was an increase of 1,945 acres when compared to results of the 1975 survey. It should be noted that the surveys used markedly different methodologies and the preceding discussion is designed to illustrate magnitude of change.

In 2001, true color aerial photographs were interpreted to determine the seagrass coverage in LWL. While this did not include extensive in-water ground truthing, the goal was to develop a method to be used for a baseline for future studies. The north segment was determined to have the majority of seagrass, 1,134 acres followed by the south segment with 300 acres; and the central segment with 192 acres of seagrass. The total coverage was determined to be 1,626 acres of seagrass. Although the methods of analysis were markedly different for the 1990 and 2001 surveys, there appears to be a loss of seagrass coverage over an 11-year period. One possible explanation for the loss during the 1990's is that development increased rapidly in the watershed causing upland disturbance and increased stormwater discharge. This development led to increased eutrophication and release of sediments into the lagoon which supported by water quality data for the time period. Table 2 presents a summary of seagrass coverage in LWL from 1940 through 2001.

Table 2. Historical Seagrass Coverage in Lake Worth Lagoon

Year	Seagrass (Acres)	% Change[3]
1940	4,271	-
1940 Model[1]	4,440[2]	-
1975	161	(96%)
1990	2,110	1,210%
2001	1,626	23%

[1]Arbitrary date reflects conditions prior to intense urbanization; conditions allow for maximum coverage of seagrass.
[2]4,440 acres is the maximum of seagrass given pre-WWII conditions under these model assumptions.
[3]Due to gross differences in survey methods, these values should only be used to indicate an order of magnitude change.

Target Development

To establish a seagrass restoration target for LWL, a benchmark time period is needed. Although the 1940 seagrass beds were modeled, there have been significant changes in shoreline and many areas that have been dredged and filled since the 1940's. Overlaying the 1990 or 2001 seagrass maps over the 1940 coverage to determine restorable areas has limitations given the above changes to the system. Likewise, overlaying the 2001 maps over the 1990 map is also problematic due to the difference with which the surveys were conducted. Therefore, it is recommended that the 2001 seagrass survey be used as the benchmark time period supplemented by predictive modeling.

One goal of the management plan is to halt the loss of current seagrass beds in LWL. A second goal is to restore seagrass to an historic and achievable level given the effects of a highly urbanized estuary and the effects of rapid population growth in Palm Beach County. A compromise needs to be achieved between the 1940 coverage of 4,271 acres and the 2001 coverage of 1,626 acres of seagrass. A third goal not explored in this paper is to preserve existing seagrass beds with a focus on preserving high-density beds.

Rather than choosing an arbitrary date as a restoration target which may be unachievable in the long run, it may be reasonable to expect incremental improvements in water quality which in turn will allow more light to penetrate the water column. This small improvement in light attenuation will provide the environment for the restoration of seagrass throughout LWL.

Utilizing historical data is not without problems due to changes in technology and survey method differences. Therefore, using current seagrass distribution to predict future seagrass distribution along with examining historical trends should result in setting a suitable target for seagrass restoration. As presented earlier, analyzing 2001 seagrass distribution in concert with 2003 bathymetric data for LWL results in establishing seagrass distribution by depth (See figures 2-4). The average seagrass depth for each LWL segment was computed using seagrass distribution and bathymetric data. Setting a target depth assumes that there should be at least a small improvement in water quality that would allow for increased light attenuation through the water column. Using a very conservative approach of increasing the average seagrass depth by one foot in the north segment and 0.6 feet in the central and south segments, respectively, leads to the target depths as presented in Table 3.

Table 3. Average Seagrass Depth and Potential Target Depth by Segment in Lake Worth Lagoon

Zone	**Average* Seagrass Depth Feet in NGVD**	**Target Depth**
North	-5.0	-6.0
Central	-4.4	-5.0
South	-3.4	-4.0

*Weighted average

Predicting where seagrass is likely to recruit based on depth and suitable substrate provides a more realistic target. Figure 9 presents a snapshot of where seagrass is predicted to recruit in conjunction with suitable sediment characteristics within 5 feet of the surface.

Figure 9. Snapshot of Suitable Depth and Substrate for Seagrass Recruitment

In summary, it is recommended to use seagrass depth distribution data and substrate data to develop segment specific seagrass target depths, expressed as NGVD. Potential target depths are: -6.0 feet for the north segment, -5.0 feet for the central segment, and -4.0 feet for the south segment. These targets will allow for the protection of the existing 1,626 acres and the restoration of 466 acres of seagrass. Table 4 presents the current distribution of seagrass in LWL as well as the restoration target for seagrass in each of the three segments. The potential seagrass recruitment target is the sum of existing seagrass plus potential seagrass recruitment as predicted by both depth and substrate.

Table 4. 2001 Seagrass Acreage and Potential Seagrass in Lake Worth Lagoon

LWL Segment	**2001 Seagrass (Acres)**	**Potential Seagrass by Depth (Acres)**	**Potential Seagrass by Depth and Substrate**	**Potential Seagrass Target (Acres)**	**Increase**
North	1,134	321	**197**	**1,331**	17%
Central	192	537	**204**	**396**	106%
South	300	236	**65**	**365**	22%
Totals	1,626	1,094	**466**	**2,092**	29%

It is evident from Table 4 that the greatest potential for seagrass recruitment is in the Central segment of LWL. There are extensive, relatively shallow areas that currently are not colonized by seagrass. Therefore, it would appear that efforts should be directed toward water quality and sediment management in this portion of the lagoon. A map of LWL with the target developed for this model is presented in the Appendix.

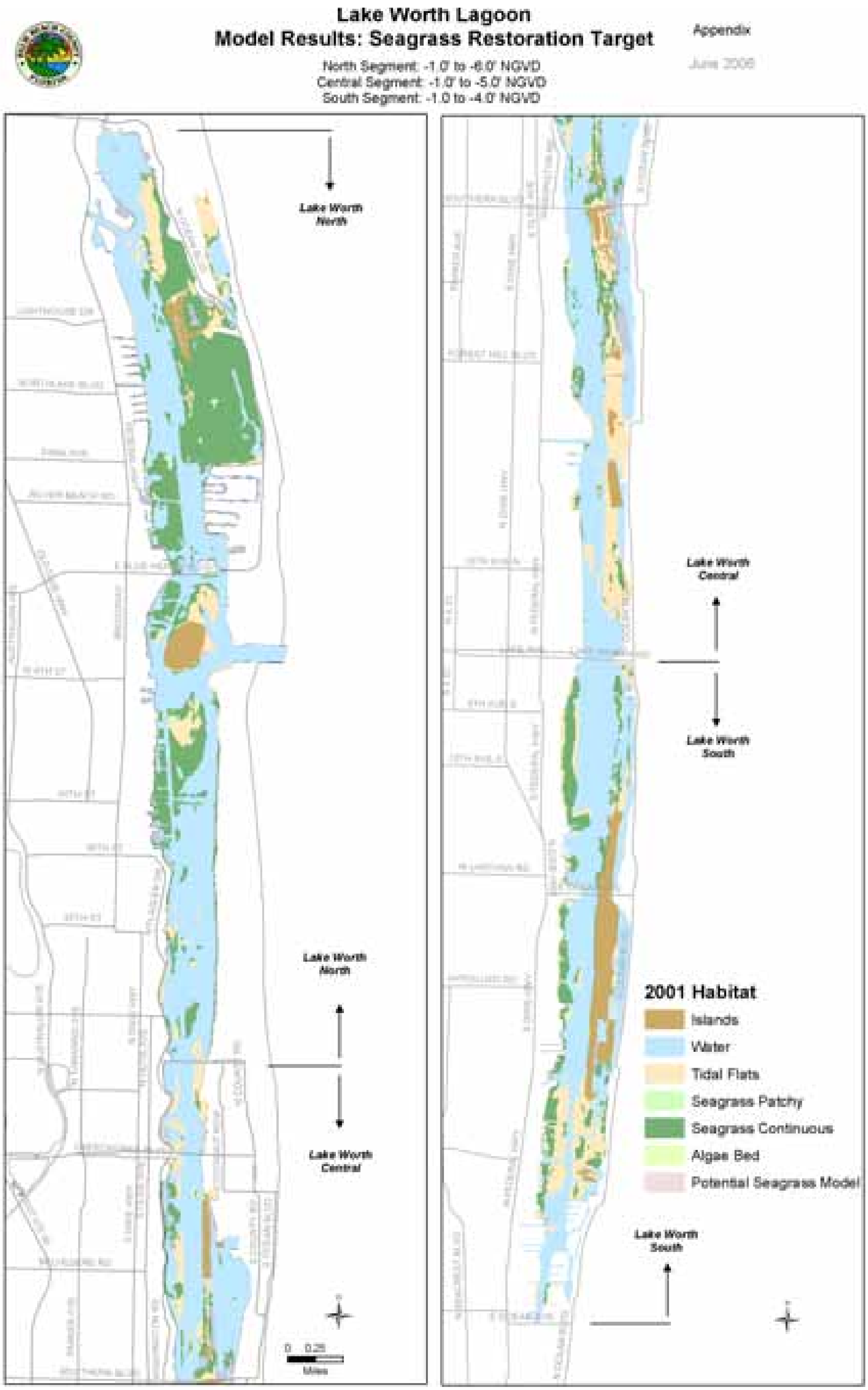
Achieving the Target

The LWL seagrass restoration goal will be accomplished when the deep edges of the seagrass eventually extend to, delineated by high-resolution aerial photography, the target depths and substrate delineation set for each segment. Protection of existing coverage and the restoration of an additional 466 acres (based on model results) of seagrass may be accomplished through management of external nutrient and sediment loadings as well as the removal of muck sediments in the central segment of LWL. A possible timeframe for the proposed restoration target is 20 years. These goals are outlined in the LWL Management Plan and are currently being implemented. For example, the LWL Partnership Grant Program has received $12,800,000 from the Florida State Legislature since 1999. A total of 37 construction projects have been funded as well as baseline monitoring projects. The following projects have been implemented to initiate the restoration of seagrass:

- 17 stormwater projects treating more 1,200 acres of runoff;
- 11 habitat enhancement projects creating new and restored habitat;
- 3 sewage treatment projects; and
- 7 baseline studies assessing the health of LWL

Additionally, PBC ERM has proactively embarked on many restoration and enhancement projects (Munyon Island, Peanut Island, Snook Islands, John's Island, and many mangrove planter projects) to increase habitat in LWL.

The Comprehensive Everglades Restoration Plan (CERP) is addressing water quality, sediments, muck deposits and habitat in LWL through the Northern Estuaries Module. Additionally, the Palm Beach County Comprehensive Plan – Coastal Management Element addresses improving water quality in estuarine environments.


Lake Worth Lagoon
Model Results: Seagrass Restoration Target
Appendix
North Segment: -1.0' to -6.0' NGVD
Central Segment: -1.0' to -5.0' NGVD
South Segment: -1.0 to -4.0' NGVD
Lake Worth North
Lake Worth North
Lake Worth Central
Lake Worth Central
Lake Worth South
Lake Worth South
0 0.25
Miles
2001 Habitat
Islands
Water
Tidal Flats
Seagrass Patchy
Seagrass Continuous
Algae Bed
Potential Seagrass Model

End Notes

There are several limitations and uncertainties associated with the possible restoration target. The target is based on a 2001 aerial interpretation of seagrass which mapped seagrass beds of 0.25 acres or larger. The proposed target assumes that depth, light penetration, and substrate are the major factors affecting seagrass recruitment. Further study is recommended on assessing sediment characteristics of the lagoon and potential seagrass recruitment. Additionally, this study does not take into account annual variations, effects of natural events (e.g., weather events), diversion projects affecting the lagoon (e.g., C-51 canal diversion), or water quality of contributing basins to the LWL watershed. The possible seagrass restoration target discussed in this paper was developed to foster support for improved conditions in LWL. The methodology and target are currently under review and have not been adopted by the LWL Program or PBC ERM.

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