5.0 LAKE OKEECHOBEE MODULE ASSESSMENT

5.1 Lake Okeechobee-Description and Background

LO is a large (1,730 km^2) freshwater lake located at the center of the interconnected south Florida aquatic ecosystem (Figure 5-1). The lake is shallow (average depth <3 m), originated about 6,000 years ago during oceanic recession, and under pre-settlement conditions probably was slightly eutrophic with vast marshes to the west and south. The southern marsh was historically contiguous with the Florida Everglades, which received water as a broad sheet flow from the lake during periods of high rainfall (Gleason 1984). Modern-day LO differs in size, range of water depths, and connections with other parts of the regional ecosystem (Steinman et al. 2002). Construction of the Herbert Hoover Dike (HHD) in the early to mid-1900s reduced the size of the lake's open-water zone by nearly 30 percent resulted in a considerable reduction in average water levels, and produced a new littoral zone within the dike that is only a fraction of size of the natural one. LO also has been impacted in recent decades by excessive inputs of nutrients from agricultural activities in the watershed (Flaig and Havens 1995, Havens et al. 1996). These nutrients have exerted the most dramatic impacts on the open-water region, where large algal blooms have occurred, along with accumulation of soft organic mud bottom sediments, which cause the lake water to become highly turbid when they are resuspended during windy periods (Maceina and Soballe 1991). Despite these human impacts, and a consensus that LO’s overall health has been greatly degraded by human actions, LO continues to be a vital aquatic resource of south Florida, with irreplaceable natural and societal values

Ecosystem conceptual models were developed for LO restoration planning purposes. These models indicate, *via* box-and-arrow diagrams, how key communities within the ecosystem are affected by water level and nutrient management activities. The models for LO are complex because the lake is comprised of three distinct components that have dramatically different structure and function: a littoral marsh, a near-shore region, and an open water (pelagic) region. The lake conceptual models were developed in the context of this heterogeneity. The models also reflect LO's present spatial extent, rather than the larger historical boundaries.

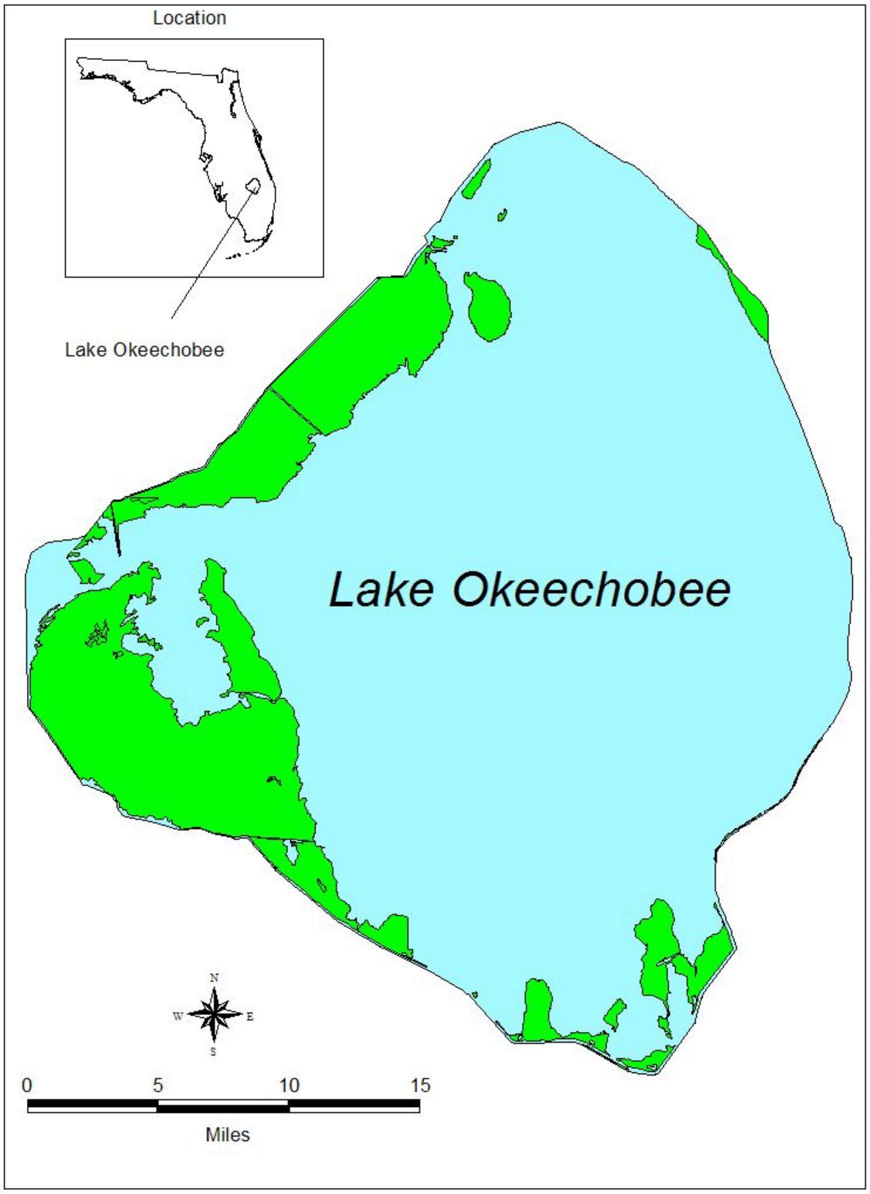

Figure 5-1: Lake Okeechobee.

5.1.1 Relationship of Comprehensive Everglades Restoration Plan Implementation to the Lake Okeechobee Module

CERP will eventually provide alternative water treatment, storage, and disposal facilities that are expected to reduce the range of water level variation in LO as well as reducing nutrient inputs to the lake from the surrounding watershed. These changes are expected to have a positive effect on the distribution and abundance of submerged plant communities. SAV is a keystone component of the lake ecosystem since it provides habitat for fish and wildlife and directly affects water quality by nutrient uptake, sediment stabilization, and a variety of other processes. The ability to quantify and predict how changes in water and nutrient management strategies will affect both water quality and the SAV community is therefore critical to CERP and the state's Lake Okeechobee Protection Program (LOPP)

A number of CERP projects are expected to influence LO. Some of these projects will have direct effects, while others will have indirect effects. Projects expected to affect LO include the following:

- Regional ASR, which is expected to directly affect lake water level variation and lake water quality
- Deep well injection, or related water disposal projects
- Lake Okeechobee Watershed Project (LOWP), which is expected to directly affect lake water levels and water quality, and in particular P loading rates
- EAA Reservoir and Treatment Wetlands, which are expected to directly affect lake water levels and water quality, and in particular P loads
- Lake Istokpoga Regulation Schedule, which is expected to indirectly affect lake water levels and water quality by altering the discharge regime from this lake to its downstream structures that pass water to LO.
- C-44, C-43, Caloosahatchee Storage Reservoirs and/or ASRs, which are expected to indirectly affect lake water levels by altering the capacity of downstream systems to store water that might presently be held in or delivered back to LO
- Canal and structure modifications in EAA and WCAs, which are expected to indirectly affect lake water levels by increasing the capacity to convey water to the south

5.2 Description and Discussion of the Lake Okeechobee Hypothesis Cluster: Submerged Aquatic Vegetation

5.2.1 Background and Description

The spatial extent, density and species composition of SAV has been clearly linked to the success and quality of other trophic guilds including periphyton, phytoplankton, zooplankton, macroinvertebrates and fish. As such, a solid understanding of SAV dynamics is a key to successful management of shallow lakes; thus there has been considerable focus on SAV in shallow lake research, predictive modeling, and long-term ecosystem management. Research has been done to identify SAV responses to sediment type, water depth, transparency, and other attributes. Given this background, it seemed logical to pick the SAV hypothesis cluster for this assessment exercise.

In addition, most of the other hypotheses clusters in the Lake Okeechobee Conceptual Ecological Model (LOCEM) are either in the early stages of baseline data collection (macroinvertebrates and fish) or have extremely large and complex data sets which will require very significant amounts of time and effort to analyze (phytoplankton). SAV had the dual advantage of having both a relatively substantial and actively managed data set which made it an ideal assessment candidate.

Submerged Aquatic Vegetation Hypotheses

The model below summarizes environmental interactions that are known to affect SAV areal distribution and density in LO (Figure 5-2). Many of these parameters are currently being monitored and will be used in the development of evaluation tools based on the hypotheses listed below.

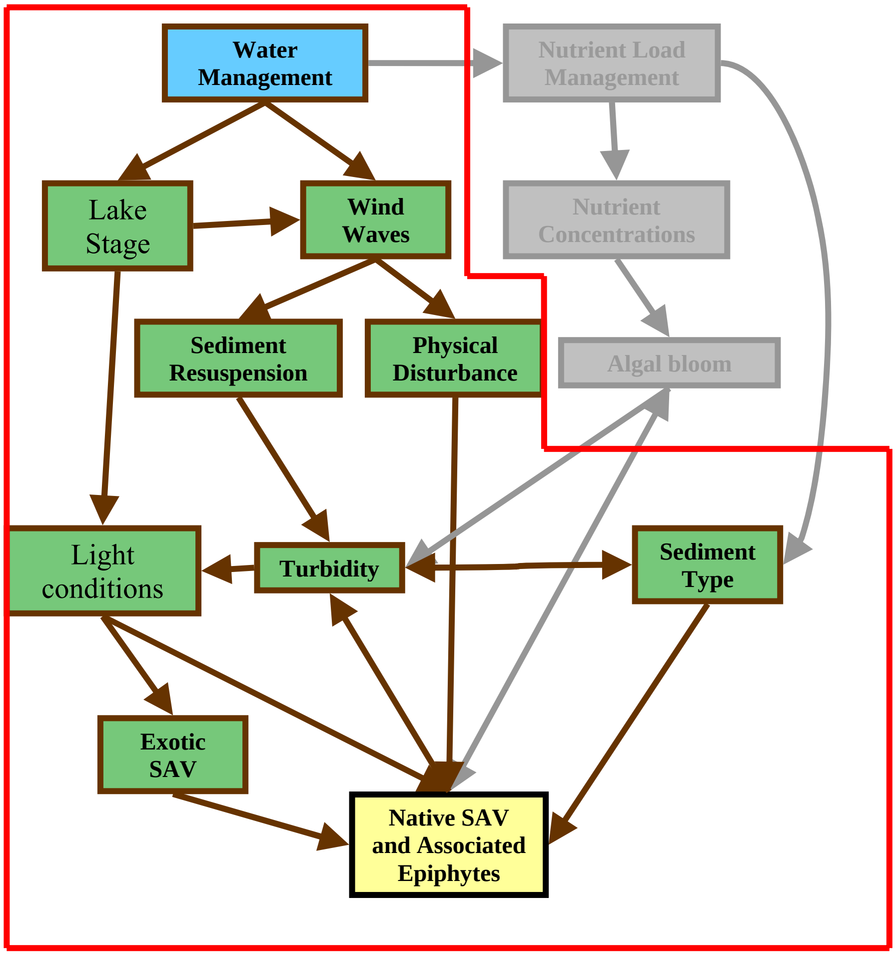

Figure 5-2: Conceptual model of stressors and/or factors that affect SAV areal distribution and density in LO. The hypotheses associated with the parameters within the large box will be addressed in this assessment.

Overall Goal

CERP RECOVER targets currently specify an annual standing stock of 49,420 acres (200 km^2) of total SAV, with at least 50 percent due to vascular taxa. Under existing circumstances, the spatial extent of SAV varies widely from year-to-year. During prolonged periods of high stage, spatial extent of native vascular submerged plants, in particular *Vallisneria*, *Potamogeton*, and *Najas*, is reduced to near zero and conditions may favor the exotic species *Hydrilla*. During years of moderate to low lake stage, spatial extent of vascular and non-vascular SAV combined can reach >50,000 acres. In years of recovery from high water stress, much of the SAV community may be comprised of pioneer species, such as the non-vascular macro-algae *Chara,* which may provide limited habitat or water quality benefits as compared to the vascular species.

By providing a reduction in the frequency of extreme high and low water levels and an increase in the frequency of spring recessions, as a result of CERP implementation, beneficial water quality and habitat conditions should be created that promote an increase in the spatial extent and density of native vascular submerged plants, in particular *Vallisneria*, *Potamogeton*, and *Najas.*

Hypothesis 1

Lake stage is a major determining factor in the areal extent and density of SAV in the littoral pelagic fringe zone of LO.

Rationale

At higher lake stages, light penetration is reduced and the area capable of supporting dense SAV is consequently smaller. In addition, at higher lake stages the pelagic and littoral fringe zones of LO become hydrologically connected resulting in increased turbidity which further decreases light availability for SAV growth (James and Havens 2005). Conversely, at lower lake stages, larger areas of the lake bottom receive adequate light to support SAV growth and much of the potential SAV growth zone becomes partially hydrologically uncoupled from the pelagic zone, thereby confining the export of additional pelagic zone sediment. This results in a reduction in turbidity and further improvements in the light climate.

Hypothesis 2

Major wind and wave events can result in large scale destruction of SAV by direct physical tearing and uprooting of plants.

Rationale

Following hurricanes Frances and Jeanne in 2004, and Wilma in 2005, observational and monitoring data indicated a rapid and nearly instantaneous decline in SAV density and distribution. Although this phenomenon would occur sporadically and is independent of CERP effects, it has potential major consequences for the ecological health of LO.

Hypothesis 3

Under physical conditions that results in low light levels, the exotic SAV species *Hydrilla* may have a competitive advantage over more desirable native SAV species.

Rationale

Mesocosm experiments conducted under natural light indicate that *Hydrilla* has a lower light requirement than any of the major native SAV species in LO (Grimshaw and Sharfstein, in review).

Hypothesis 4

Changes in the extent of mud sediments in the pelagic-littoral fringe zone of LO, resulting from changes in runoff and nutrient loading, influence the potential area available for colonization by SAV.

Rationale

In LO SAV colonizes peat and sand sediment but grows much less well in mud sediment. Changes in runoff and nutrient loading are expected to reduce the coverage of mud sediments and increase the area potentially available for colonization by SAV.

5.2.2 Rationale for Selecting the Submerged Aquatic Vegetation Hypothesis Cluster as the Pilot of the Assessment Process for Lake Okeechobee

SAV plays a key role in shallow lakes, providing critical habitat for fish, wading birds, and other wildlife, by providing a substrate for epiphyton (algae which grows on plants), which can be an important source of carbon and energy in the lake food web, and by directly affecting water quality. SAV influences the biomass of phytoplankton and the transparency of water through a number of processes. These include stabilization of sediments by roots, reduction of shearing stress to sediment surfaces, uptake of nutrients by periphyton (epiphytes and algae which grows on benthic substrates) attached to SAV, and precipitation of P with calcium when intense photosynthesis results in high water column pH (Murphy et al. 1983, Dennison et al. 1993, Scheffer 1998, Vermaat et al. 2000). Lakes with dense SAV can have clear water and low phytoplankton biomass and then switch to an alternative state, consisting of highly turbid water with algal blooms if the plants are lost (Scheffer 1989, 1998). Some lakes, including LO, have shallow areas with SAV and clear water adjacent to deeper areas with no SAV and turbid water (Scheffer et al. 1994, Phlips et al. 1993, Havens et al. 2004, James and Havens 2005). While the maintenance of alternative steady states is viewed as being a positive feedback loop, lake level and turbidity act as external forcing functions to drive changes from one state to the other; thus, the near-shore zone switches between a SAV/clear water state when water levels and turbidity are low to a phytoplankton/turbid water state when there are periods of prolonged high water levels with accompanying sediment resuspension (Havens et al. 2001, Havens 2003, Havens et al. 2004, James and Havens 2005).

An SAV monitoring program has been in place in LO since the spring of 1999 so the database for this component encompasses over seven years of biological data collected over a wide range of hydrological and environmental conditions. Additionally, historical SAV biomass and distribution data exists from a study conducted in the late 1980s and early 1990s that can be used to compare the current SAV distribution and abundance during comparable historic lake stages.

Also, an empirical model has been developed from recent SAV monitoring data that predicts SAV distribution based on light penetration to the bottom as a function of water transparency, indirectly measured by total suspended solids (TSS) and water depth (lake levels). This model is intended to be used in conjunction with GIS data layers such as bathymetry and SAV sampling sites to predict areas within LO that are likely locations for SAV colonization when conditions become favorable based on water depth, light penetration, and turbidity.

5.3 Data Status/Availability for Submerged Aquatic Vegetation Hypothesis Cluster

A key objective of this long-term monitoring project is to understand changes in the SAV community in LO as they relate to changes in water level and transparency. More specifically, it is to provide data to evaluate the relationship of physical-chemical factors (*e.g.*, nutrient concentrations, light availability) to the spatial and temporal dynamics of SAV biomass and species assemblages within the community. Changes in the spatial and temporal extent of the SAV community are key PMs that will be available for use in CERP-related modeling and evaluation efforts. Data generated from the various SAV monitoring programs are analyzed to determine if the distribution and abundance of SAV is improving as a result of CERP implementation. Maps of areal coverage over time also will be generated.

Submerged Aquatic Vegetation Sampling

SAV is monitored at two different spatio-temporal scales. Both methods rely on in-water sampling, as areas with submerged vegetation are generally characterized by water that is highly colored by dissolved organics or suspended particles, which have thus far stymied attempts to use remote sensing techniques.

Effect of Extreme Events on Submerged Aquatic Vegetation Sampling

When hurricanes impact LO, strong currents are generated that run parallel to the shore (Havens et al. 2001), and along with wind-driven waves, can cause uprooting of submerged vegetation. Chimney (2005) documented large north to south seiches during Hurricanes Frances and Jeanne. Similarly, Hurricane Wilma caused large east to west seiches a year later. These seiches piled up large quantities of aquatic plants along the lake shore. Although monthly transect sampling data intimated that the SAV community had been severely affected by all three hurricane events, a direct cause/effect relationship could not be determined because sampling events did not occur sufficiently close to the passage of the storms. Development of a pre- and post- wind/wave driven sampling program needs to be implemented to better capture SAV responses to episodic wind and wave events.

Monthly Monitoring

In order to obtain relatively rapid quantitative estimates of plant species biomass, sampling is conducted at 78 sites located along 16 transects in areas of LO that support submerged plants (Figure 5-3). The sites represent a subset of sites that were sampled in the LO Ecosystem Study (Zimba et al. 1995) in the late 1980's and early 1990's. This allows for a comparison of historical data. Sampling frequency varies from quarterly to monthly depending on how dynamic anticipated changes in the plant population are expected to be (for example, more frequent sampling is done during periods of recovery from hurricanes). Samples are collected at sites along each transect, starting at the shoreline and progressing lakeward until a site is reached that has no plants. Plant sampling is accomplished using a tool constructed of two standard garden rakes bolted together at mid-point to create a tong-like device (Rodusky et al. 2005). The degree of opening is constrained by placing a chain between the two handles so three replicate samplings with the device remove ~1 m^2 of bottom cover. The harvested material is sorted by species, stripped of epiphyton, and analyzed for dry mass.

This sampling effort provides information on plant responses and relative plant distribution and density to changing water levels on a short time scale, and can be used as input to real-time operations.

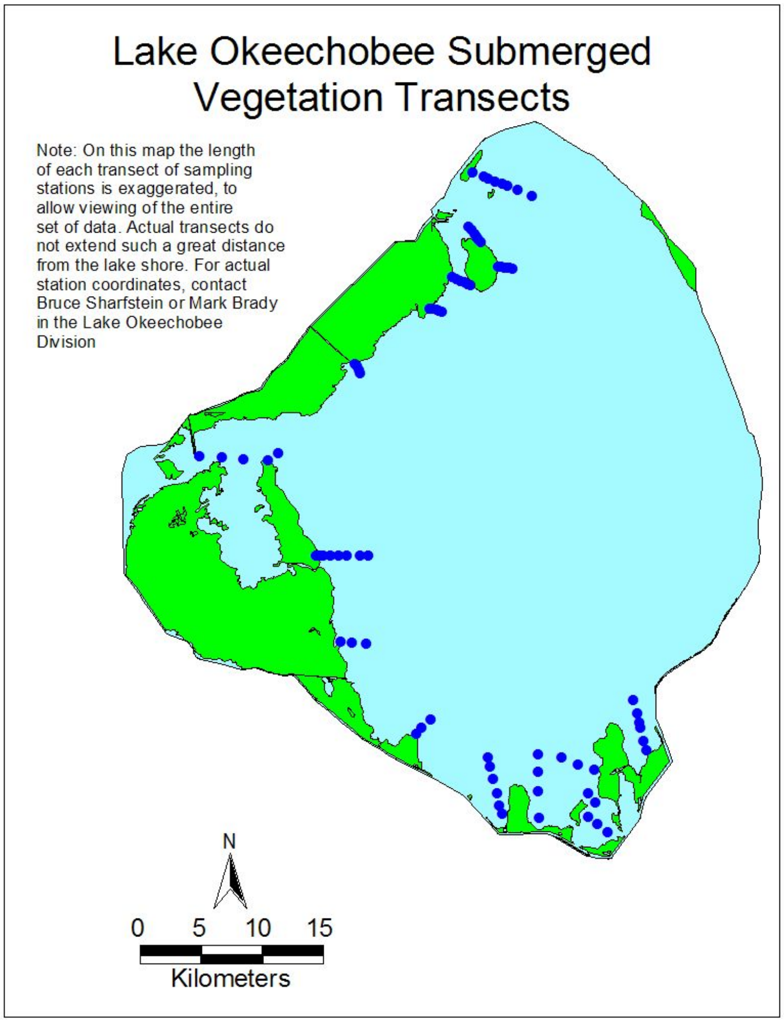

Figure 5-3: SAV Transect Locations in LO.

Annual Mapping

The total spatial extent, species distribution, and density of SAV is determined by an intensive sampling program (Figure 5-4) that is carried out at the end of the peak SAV growing season (every August-September). Rather than sampling random locations, the entire near-shore shelf area is sampled at a relatively fine spatial scale. A GIS coverage of LO's surface is overlaid onto a rectangular grid of 1,000 x 1,000 m cells in ArcInfo. A GIS coverage of the littoral zone is laid onto the map, and common cells are clipped from the final coverage, as is the deeper central pelagic region. This results in a near-shore grid of approximately 500 sampling sites. Coordinates for the grid cell center-points are loaded into Trimble Pathfinder Global Positioning System (GPS) units (differentially corrected) for use in navigating to the sampling sites. A simple program is set up in each data logger so that users can enter information regarding water depth, SD (a measure of water transparency), sediment type, presence versus absence of vegetation taxa, and a qualitative estimate of overall plant biomass (sparse, moderate, dense). Field data are downloaded from the GPS logger into ARC/INFO, where maps are developed for each of the measured attributes and spatial extents for each dominant plant species are calculated in acres.

This sampling effort provides information on the total number of acres of plants that LO gained (or lost) under the prevailing hydrologic conditions of a given growth cycle year.

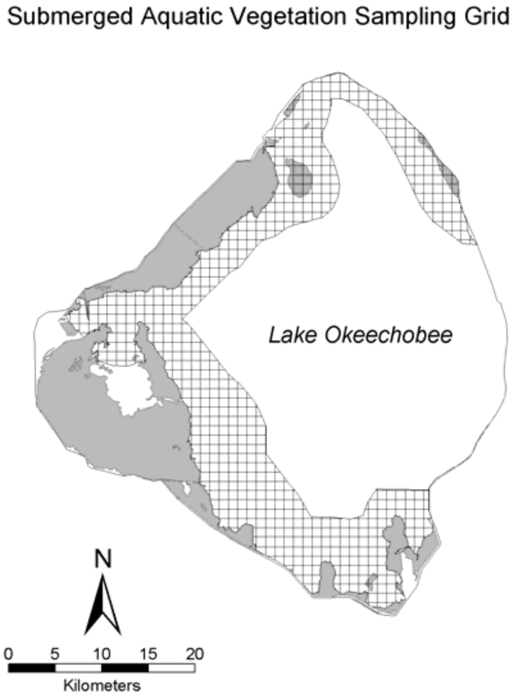

Figure 5-4: Annual Mapping Sampling Grid

Water Quality
Measurements of total depth (TD), SD, and sediment type are collected coincident with plant sampling. Data from the SFWMD water quality monitoring program, which includes stations in the vicinity of all SAV sampling sites, is used to identify other water quality conditions, including underwater irradiance and temperature profiles, color, chlorophyll *a*, total and soluble P, total and soluble N, and total and non-volatile suspended solids. The water chemistry data is important to understanding the light-attenuating properties of the water and explaining observed trends or patterns in submerged vegetation (and on the influence of SAV beds on water quality; an aspect of our monitoring approach not discussed in this assessment).

5.4 Analysis Framework for Detecting Change

Both the periodic transect sampling and the annual mapping effort are capable of detecting change, though the temporal scale of each method is different, so that transect sampling is typically better at detecting large scale short term perturbations whereas annual mapping is better at detecting annual trends on a larger, and consequently more reliable spatial scale.

Transect Submerged Aquatic Vegetation Mapping Results

The best example of transect mapping's ability to detect substantial short term perturbations occurred between July 2004 (pre-hurricanes) and October 2004 (post-hurricanes). Average SAV biomass, as measured at 78 quarterly monitoring sites, declined during this quarter from 32.3 (± 49.9 SD) to 4.7 (± 9.4 SD) g dry weight per m^2 (g dry wt m^{-2}), probably as a result of increased TSS and decreased light penetration (as SD:TD ratios) (Figure 5-11) brought about by direct wind, wave, seiche, and lake stage impacts. However, from January 2005 to June 2006, SAV biomass continued to decline from 4.46 g dry wt m^{-2} to less than 0.04 g dry wt m^{-2} (Figure 5-12). Although declines over the winter period are expected due to seasonal conditions such as lower temperatures, increased turbidity, and shorter photoperiod, the significant declines observed are primarily a result of long-term light deprivation related to water quality and lake stage effects.

Annual Submerged Aquatic Vegetation Mapping Results (Figure 5-5 through 5-8)

2005 (Figure 5-5)

SAV in August 2005 covered 10,872 acres of LO. This compares with a total of 54,857 acres in late summer 2004. The large decrease in SAV was a response to poor light conditions, physical disturbance (wind and wave-induced uprooting) and high water levels caused by the three hurricanes. It appears that the hurricanes stirred up fine sediments in LO resulting in a long exposure to very turbid, deep water column with very poor light penetration. After the hurricanes it was common to have SDs of less than 30 cm. The acreages of dominant plants in 2005 are as follows: *Chara*–247 acres, compared to 29,158 acres in 2004; *Vallisneria*-494 acres, compared to 8,154 acres in 2004; *Hydrilla*–7,166 acres, compared to 24,363 acres in 2004; *Potamogeton*–494 acres, compared to 6,671 acres in 2004; *Ceratophyllum*–7,166 acres, compared to 12,602 acres in 2004.

2004 (Figure 5-6)

The total SAV in August 2004 covered 54,857 acres of LO. This compares with a total of 31,135 acres in late summer 2003. The large increase in SAV was a response to better light conditions that resulted when water levels dropped to approximately 12.5 feet in spring to early summer of 2004. The acreages of dominant plants in 2004 are as follows: *Chara*–29,158 acres, compared to 8,895 acres in 2003; *Vallisneria*–8,154 acres, compared to 6,424 acres in 2003; *Hydrilla*–24,363 acres, compared to 15,320 acres in 2003; *Potamogeton*–6,671 acres, compared to 6,178 acres in 2003; *Ceratophyllum*–12,602 acres, compared to 11,120 acres in 2003; and *Najas*–4,448 acres, compared to 2,965 acres in 2003.

In summary, there was a substantial increase in the spatial extent of submerged plants in LO between August 2003 and 2004 in concert with favorable low spring-summer water levels. The community also contained a high percentage of desirable vascular plants that provide good habitat for fish and other wildlife. It is important to note that the acreages presented here, from the month of August, may be markedly different from what remained in October, after LO was impacted by wind, wave energy, and subsequent deep water from Hurricanes Charley, Frances, and Jeanne. There is ongoing work to estimate the extent of those impacts to the SAV community. Additionally, data reflective of more "typical years" (*e.g.* free of the influence of tropical weather systems) are needed to enable a robust statistical analysis to be conducted. As yet unidentified time lags involved with SAV biomass responses to changes in lake stage and associated water quality conditions provides additional constraints on the use of statistical analyses to perform predictive SAV growth assessments. This issue will be addressed with the development of an SAV evaluation model, whose time frame for completion is expected to be during FY 08.

2003 (Figure 5-7)

A total of 271 stations were sampled in 2003. The total SAV in August 2003 covered 31,135 acres of LO. This compares with a total of 43,000 acres in late summer 2002. It translates into a 28 percent reduction in total acreage, most likely due to the sustained high water that occurred in LO that year. High water reduces the amount of underwater light, which in turn, reduces the growth of SAV. The acreages of dominant plant species in 2003 are as follows: *Chara*–8,895 acres in 2003, compared to 21,500 acres in 2002 (59 percent reduction); Vallisneria–6,424 acres in 2003, compared to 7,910 acres in 2002 (20 percent reduction); Hydrilla-15,320 acres in 2003, compared to 8,155 acres in 2002 (88 percent increase); *Potamogeton*–6,178 acres in 2003, compared to 2,200 acres in 2002 (180 percent increase); *Ceratophyllum*–11,120 acres in 2003, compared to 7,165 acres in 2002 (55 percent increase); and *Najas*–2,965 acres in 2003, compared to 6,175 acres in 2002 (52 percent decline).

In summary, the results indicate a significant loss of total acreage of SAV in 2003, with most of the loss being due to *Chara*, *Najas*, and *Vallisneria*. The relative importance of *Hydrilla*, *Potamogeton*, and *Ceratophyllum* increased in the community in 2003.

2002 (Figure 5-8)

A total of 368 stations were sampled in 2002. The total SAV in July 2002 covered 43,000 acres of LO; this compares with a total of 34,800 acres in late summer 2001. The coverage of dominant plant species were as follows: *Chara*-21,500 acres in 2002, compared to 29,900 acres in 2001; *Vallisneria*-7,910 acres in 2002, compared to 6,920 acres in 2001; Hydrilla-8,155 acres in 2002, compared to 2,270 acres in 2001; *Potamogeton*-2,200 acres in 2002, compared to 0 acres in 2001; *Ceratophyllum*-7,165 acres in 2002, compared to 0 acres in 2001; and *Najas*-6,175 acres in 2002, compared to 0 acres in 2001.

In addition to a greater overall acreage, the 2002 data indicate a rise in importance of plants that provide good fish habitat, including *Hydrilla* and *Potamogeton*. Overall, these results indicate a continued positive response of the SAV community of LO to the favorable range of water levels that has occurred since fall 2001. The community observed in LO during 2000 and 2001, mostly dominated by small *Chara*, was a "pioneer community" that colonized the lake bottom as it began to recover from the harm caused by high water levels in the late 1990s. Once *Chara* became established, it may have helped clear the water and stabilize the sediments. This allowed the other, more desirable, plants to germinate from buried seeds and then expand their coverage, replacing *Chara* as the SAV community developed into a more mature state.

2001 (Not Shown)

In September 2001 there was approximately 35,000 acres of SAV. This compares with approximately 44,000 acres of SAV in September 2000, when more favorable (lake stage near 12 feet for three months) conditions existed for plant growth. Of the total SAV observed in September 2001, there was approximately 30,000 acres of *Chara*, 7,000 acres of *Vallisneria*, and 3,000 acres of *Hydrilla*. These results compare with 35,000, 11,000, and 7,000 acres of the same three plants, respectively, in September 2000. The 2001 sampling did not detect any *Potamogeton*, while in 2000, approximately 2,500 acres was observed. *Potamogeton* does presently occur in LO, but at a very low density and spatial extent.

2000 (Not Shown)

At the end of the 2000 growing season, there are over 43,000 acres of submerged plants in LO. Included in this acreage is approximately 34,500 acres of *Chara*, 6,500 acres of *Hydrilla*, 10,600 acres of *Vallisneria*, 2,500 acres of *Potamogeton*, and 2,600 acres of *Ceratophyllum*. In many locations, more than one plant species occurred. Hence the acreages for individual species do not add up to the total provided above.

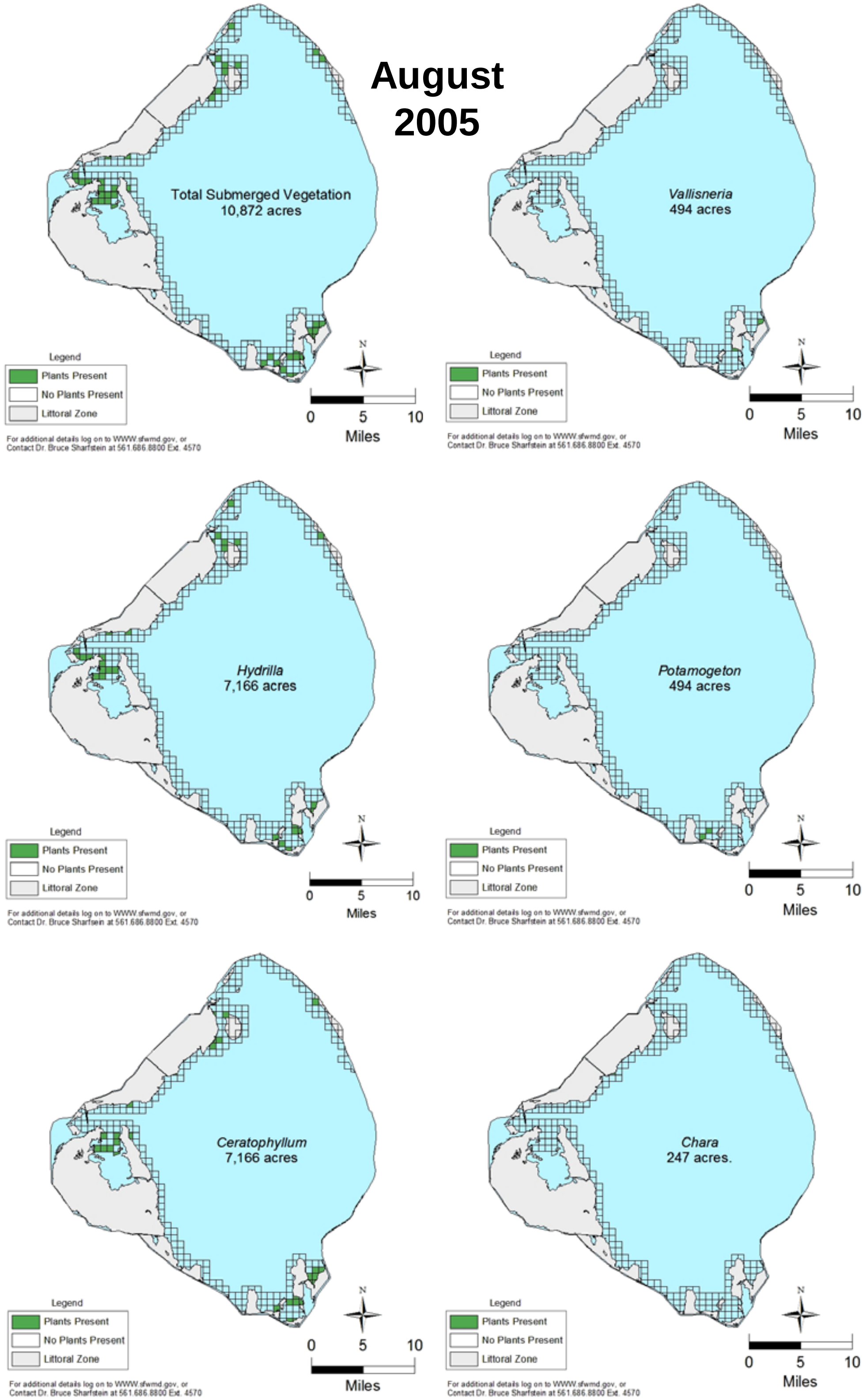

Figure 5-5: Annual Mapping Results for August 2005

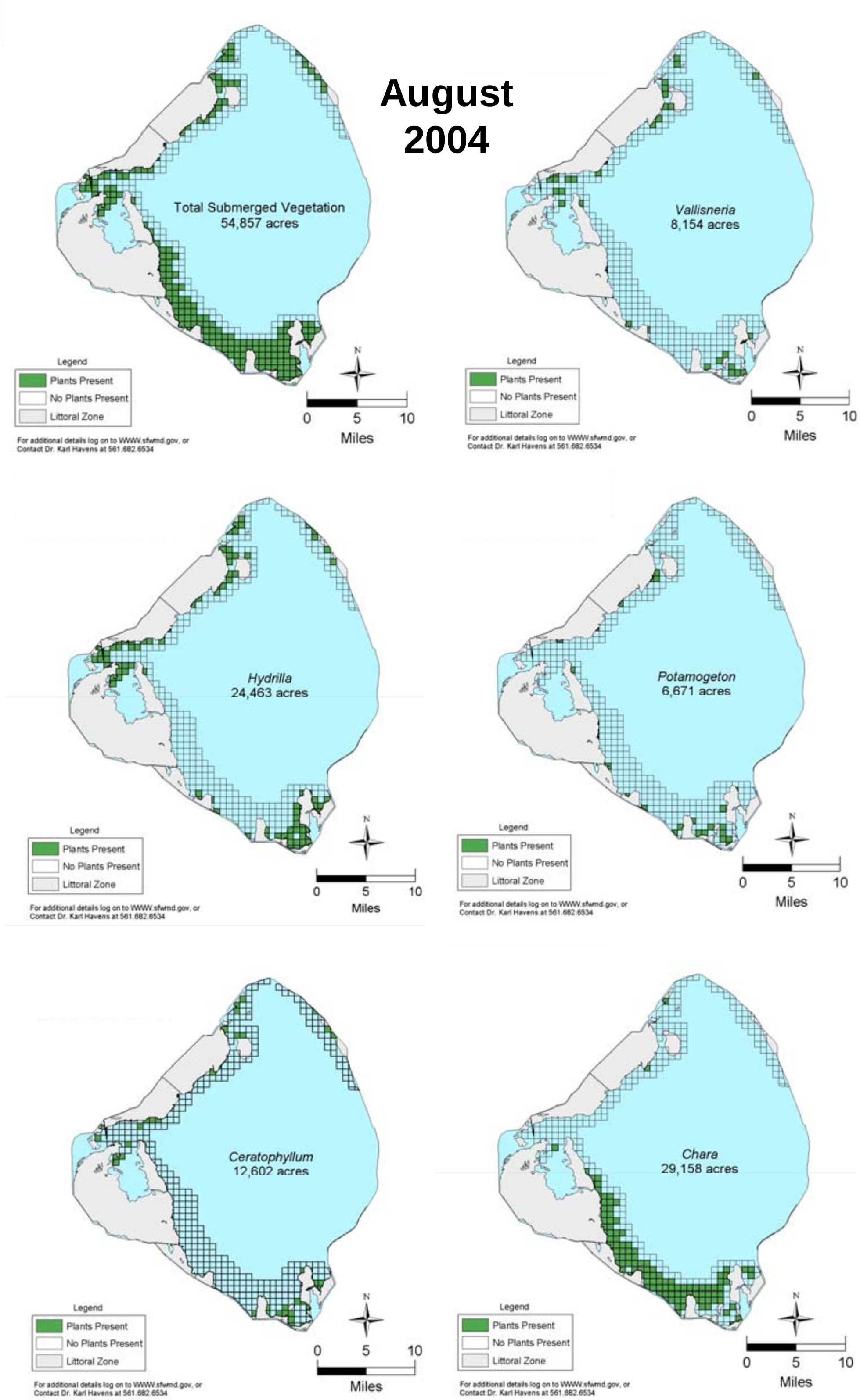

Figure 5-6: Annual Mapping Results for August 2004

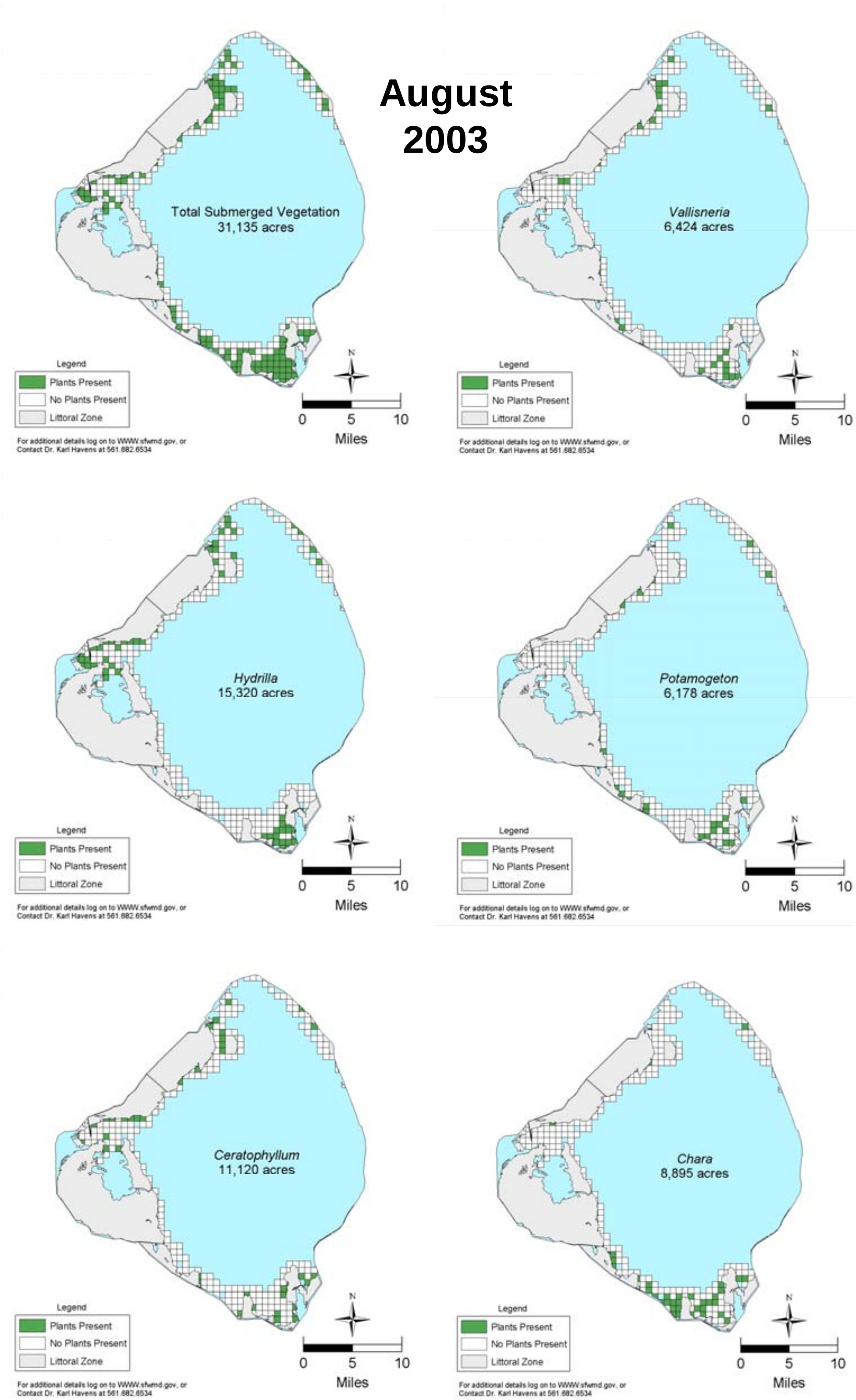

Figure 5-7: Annual Mapping Results for August 2003

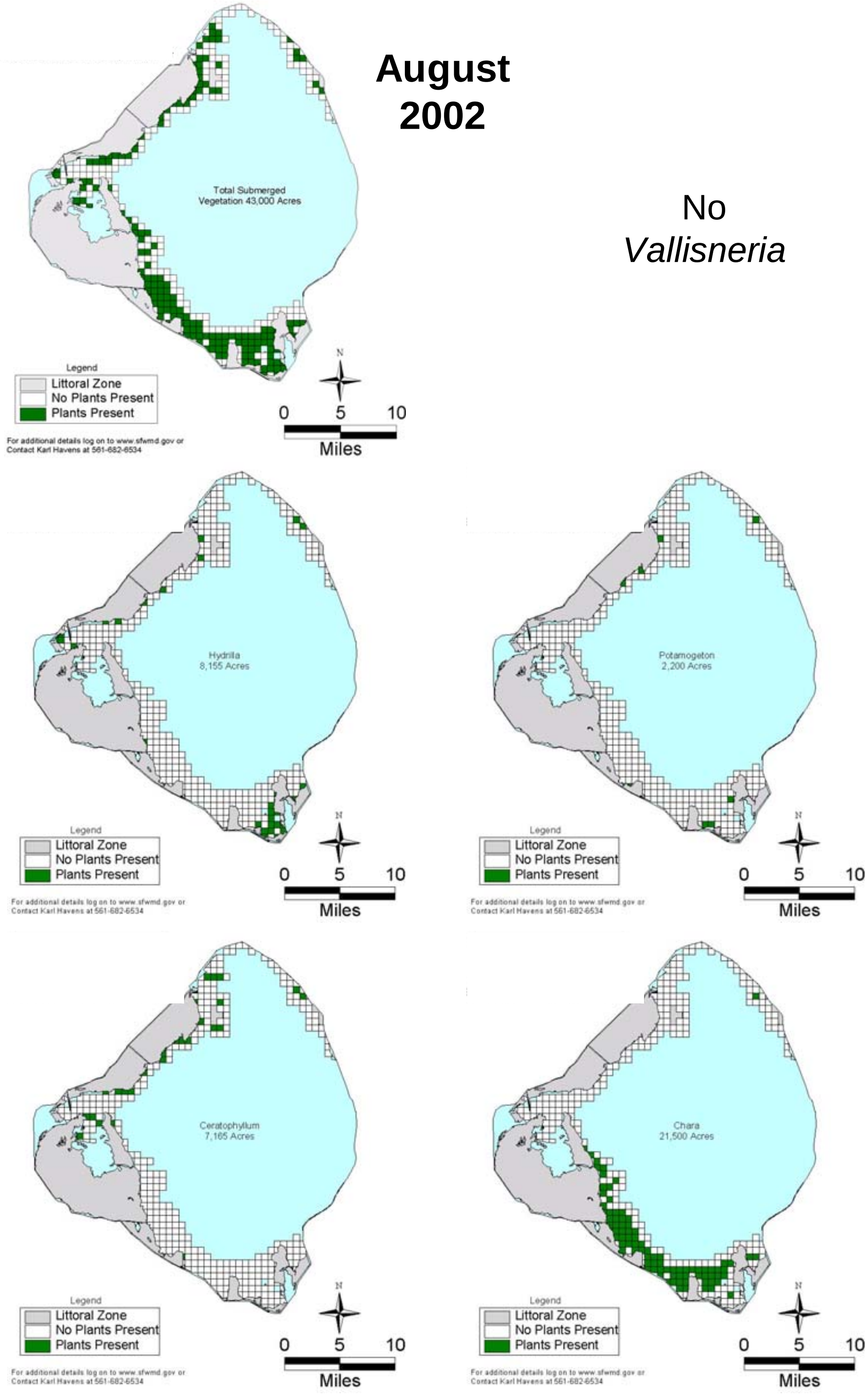

Figure 5-8: Annual Mapping Results for August 2002

Mapping Limitations

Among the challenges associated with the assessment and modeling of SAV in large, shallow lakes are: 1) their large spatial extent, 2) the sometimes great spatial heterogeneity in plant abundance and environmental conditions, and 3) the inability to detect plants with remote sensing if the water is turbid.

An underlying premise in the annual SAV mapping of LO is that the spatial extent of plants measured in August-September represents the yearly maximum. If the timing of the most active "growing season" (a function of photoperiod and lake surface elevation) varies from one year to the next, this may introduce a bias into the inter-year comparison. Therefore, the yearly mapping provides information most applicable for evaluating long-term trends in SAV distribution, whereas the monthly sampling of SAV along transects is better suited for identifying changes at sub-year time scales.

It is assumed that data collected at the center-point of a grid cell is representative of the entire cell. While this may introduce error into the results, it is a necessary assumption given the large spatial scale of sampling.

Plants are physically removed from LO's bottom and sorted on the boat for species identification; therefore, documentation of presence/absence is not affected by environmental conditions that could interfere with more commonly used alternative methods, such as aerial photography.

Transect Sampling Limitations

The in-water method, using a diver with a quadrat frame, is one of the most commonly used and accepted SAV harvesting methods, however, this method proved to be time intensive and potentially dangerous, due to generally poor water column visibility and the associated chance of encountering alligators. This method was implemented during the first year of transect sampling but it immediately became evident that an alternate method of sampling needed to be identified and implemented due to resource, time, and safety constraints.

A study was conducted to compare the precision of biomass collection between boat-based (ponar dredge versus rake apparatus) and in-water (diver with quadrat frame) sampling methods, to identify a suitable replacement for the in-water method (Rodusky et al. 2005). Statistical analysis revealed that there were no significant differences in sampling precision across a range of plant species, plant densities and sediment types for either of the boat-based methods. Use of the rake method is limited to a maximum depth of approximately two m and may not be as effective in collecting very small or very sparse plants (Figure 5-9); however, considering the advantages the rake method offers in terms of both increased sample collection efficiency, relative to the quadrat and ponar dredge, and increased worker safety, relative to the quadrat sampling, the rake method proved to be the preferred sampling method for long-term, high frequency and intensity SAV assessment. Given the long-term nature of the SAV ecological assessment as components of the PMs for LO, the quick, reliable, easily replicated and safety-oriented attributes of the rake method best facilitate the acquisition of long-term data.

Transect sampling also represents a relative, rather than an absolute approach to documenting the state of SAV on LO. It is particularly important to understand this distinction during periods when SAV density and areal coverage is low, since under these circumstances, transect sampling may find that there are no plants at any transect site, whereas a more general, and less spatially constrained reconnaissance of LO will almost invariably locate some viable plant beds.

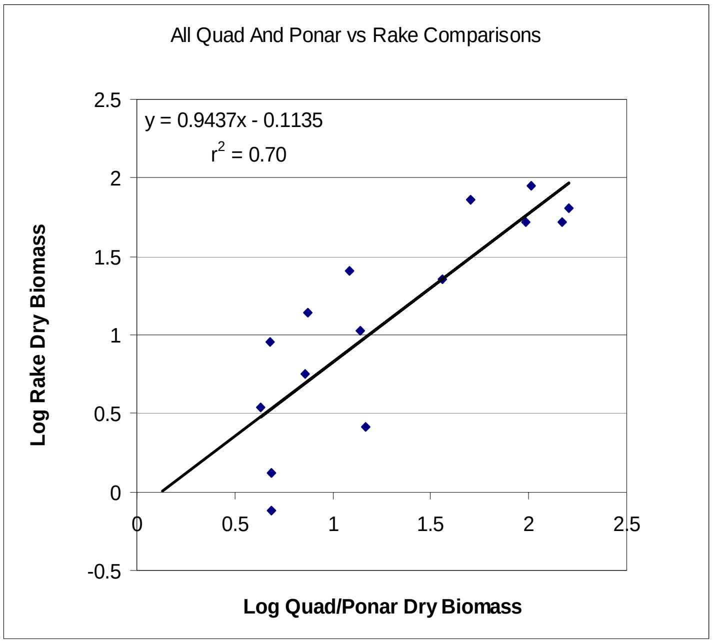

Figure 5-9: Quadrat/Ponar-rake Biomass Relationship and Regression Equation

5.5 Present Conditions and Trends for Lake Okeechobee Submerged Aquatic Vegetation Hypothesis Cluster

Except for anecdotal information, the only quantitative SAV data available for LO prior to 1999 is the work of Zimba et al. (1995) in the late 1980's and early 1990's. The current SAV transect sites are a subset of the sites that were sampled in that study. This allows for some degree of comparison and use of the historical data in the assessment of baseline conditions. However, the last six years of mapping and transect data indicate that LO's SAV community is extremely dynamic and highly sensitive to environmental perturbations as demonstrated by the nearly five fold change in areal coverage that has been observed between 2000 and 2005. Consequently, the concept of an appropriate baseline may be better expressed as the degree of variability reflected in the last five years of data while CERP targets may need to reflect both an acceptable areal distribution and species composition for SAV (as expressed in RECOVER PM LO-12) and a persistence or duration goal (for example, inter-annual variability in areal coverage and species composition around the target goal of 49,000 acres of not more than 15 percent).

Published Data

Previous studies of SAV in LO identified water depth and transparency as key environmental variables (Steinman et al. 1997, Havens et al. 2002). Using transect data from the first three years of the monitoring effort, Havens (2003) determined that water depth and the concentration of TSS most strongly correlated with SAV biomass. Results also indicated that if water depths in the shoreline region of LO could be maintained at <2 m and TSS held below 20-30 mg L^{-1}, there might be favorable conditions for more widespread SAV growth. This, in turn, might lead to water quality improvements.

Total Suspended Solids Lake Level Model

An SAV model has been developed to begin identification of the driving forces behind SAV presence or absence (Figure 5-10). To date the model uses water depth and TSS values to predict a corresponding SD (water transparency). The assumption is that if the SD to TD ratio is greater than half the water column some percentage of PAR can reach the bottom sediments, thereby permitting SAV growth. In the future the model will be expanded to include other parameters such as sediment type, seed bank, and water quality. Also planned is a temporal component that will address the length of time environmental conditions must be favorable to encourage SAV growth and the presumptive difference between conditions that allow re-colonization or expansion of SAV and those that allow the persistence of already established beds. It is important to note that at this time the model only predicts *potential* area available for SAV growth, and is not intended to predict finite growth areas. It is also important to note that while the results indicate conditions where SAV cannot occur (constraints), they do not indicate clearly whether or not SAV will attain high biomass under favorable conditions.

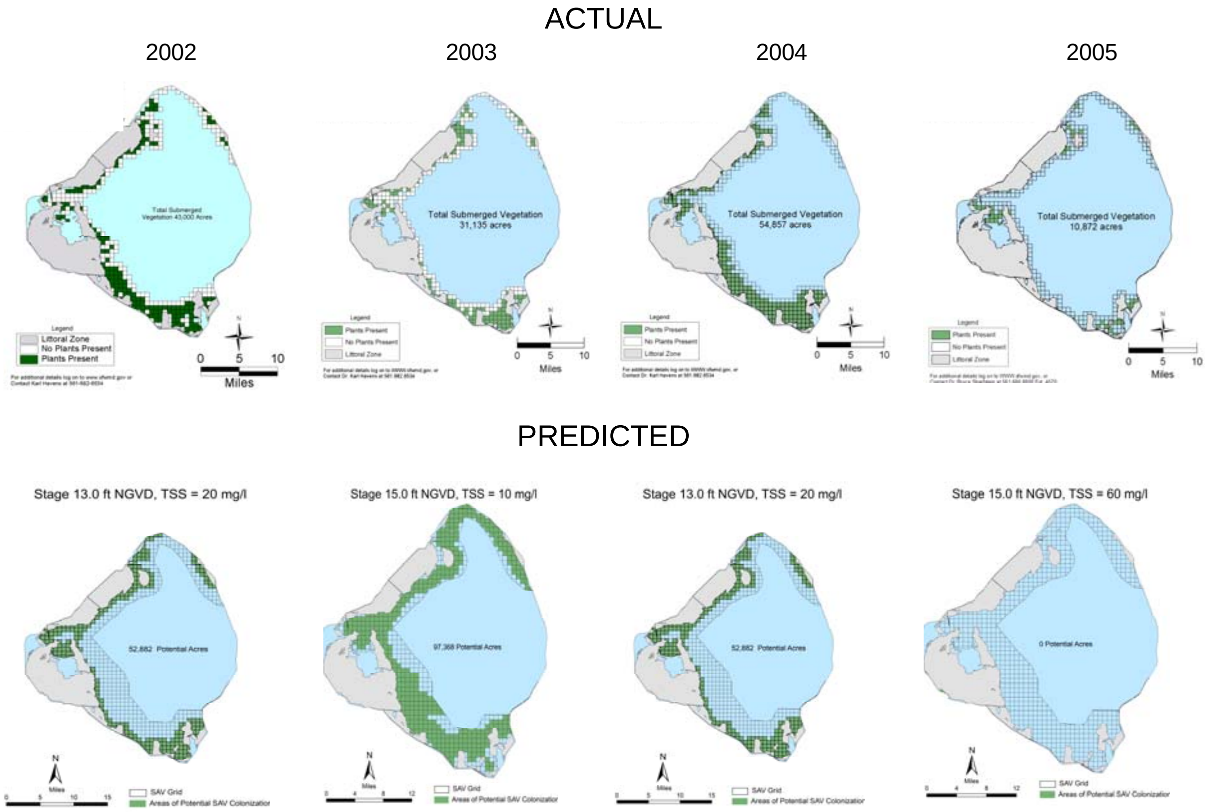

Figure 5-10: Comparison of Actual SAV Biomass versus Model Predicted Biomass (n.b. 2003 predicted map should be 64,000 potential acres).

Future Developments

For the foreseeable future, periodic transect and annual mapping data will continue to be collected. A number of mesocosm experiments designed to provide inputs for model development will be conducted on subjects including minimum light requirements for individual species growth, seed germination requirements, and species succession. These activities will be utilized as follows:

- Transect data provides results for making short term management decisions (AM) and provides data to elucidate the relationships between SAV growth dynamics and environmental variables.
- Annual mapping provides a yardstick against which to develop and measure realistic baseline conditions and future goals and targets as well as providing data to elucidate the relationship between SAV growth dynamics and environmental variables.

- Experimental results will be used to supplement field data for the development of an empirically based evaluation tool that can be used to predict SAV responses to changing lake conditions.

5.6 Measuring Change from the Pre-Comprehensive Everglades Restoration Plan Reference Condition

Hypothesis 1

Lake stage is a major determining factor in the areal extent and density of SAV in the littoral pelagic fringe zone of LO. Previous studies on LO have shown that the biomass of submerged plants is negatively correlated with water depth and positively correlated with water transparency (Hopson and Zimba 1993; Steinman et al., 1997). Our transect data results are consistent with these findings (Figure 5-11).

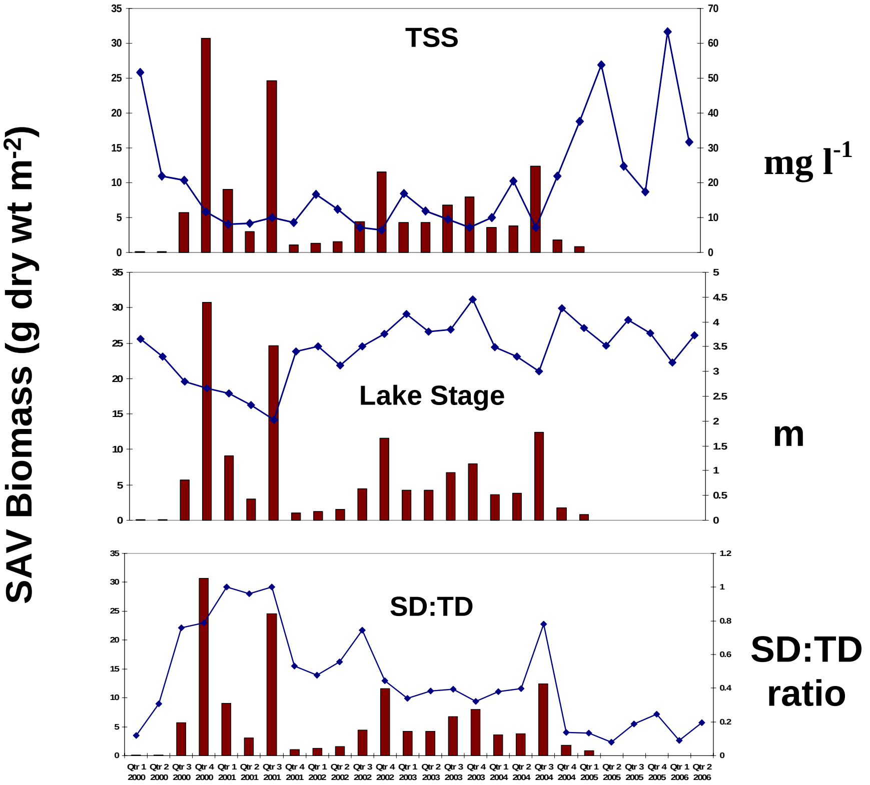

Figure 5-11: SAV biomass (g dry wt m^{-2}) plotted against TSS (mg l^{-1}), lake stage (m), and SD:TD ratio from January 2000 to June 2006.

Hypothesis 2

Major wind and wave events can result in large scale destruction of SAV by direct physical tearing and uprooting of plants. Following hurricanes Frances and Jeanne in 2004, and Wilma in 2005, observational and monitoring data indicated a rapid and nearly instantaneous decline in SAV density and distribution. Although this phenomenon would occur sporadically and is independent of CERP effects, it has potential major consequences for the ecological health of LO. The extent of the damage; a reduction in lake wide SAV coverage from 54,875 acres in late summer 2004 to 10,872 acres in late summer 2005, was revealed during the 2005 annual SAV mapping survey. Similarly, the full extent of the damage caused by hurricane Wilma will not be known until the results of the 2006 annual mapping survey are completed. However, monthly transect data (Figure 5-12) suggest that there has been no post recovery of SAV since the 2005 annual mapping exercise and that additional losses of SAV may have occurred as a result of the influence of the hurricanes.

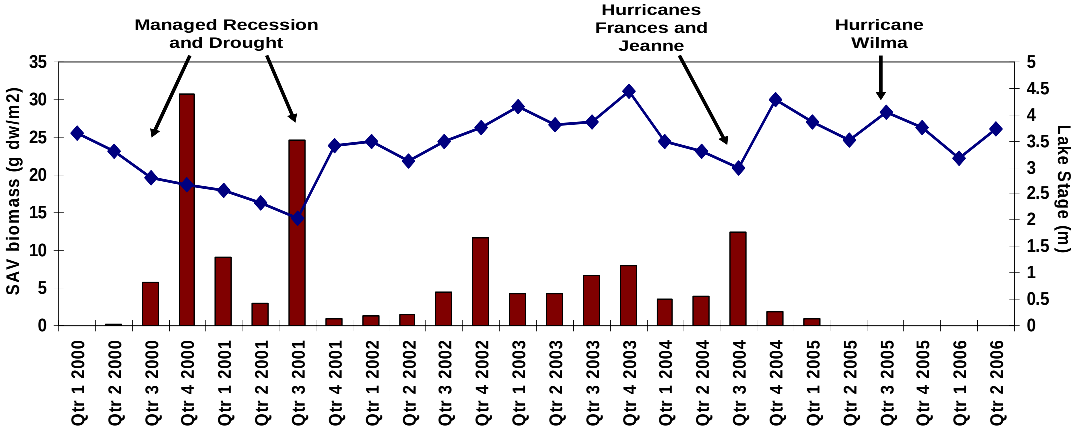

Figure 5-12: SAV biomass (g dry wt m^{-2}) plotted with lake stage (m) and showing major environmental perturbations.

Hypothesis 3

Under physical conditions that results in low light levels the exotic SAV species *Hydrilla* may have a competitive advantage over more desirable native SAV species. Mesocosm experiments conducted under natural light indicate that *Hydrilla* has a lower light requirement (Figure 5-13) than both *Vallisneria* and *Chara*, the major SAV species tested from LO to date (Grimshaw and Sharfstein in preparation). The minimum light requirements for *Hydrilla*, *Vallisneria* and *Chara* are 1.8, 4.1, and 4.7 percent of incident PAR, respectively (Grimshaw et al., 2002; 2005).

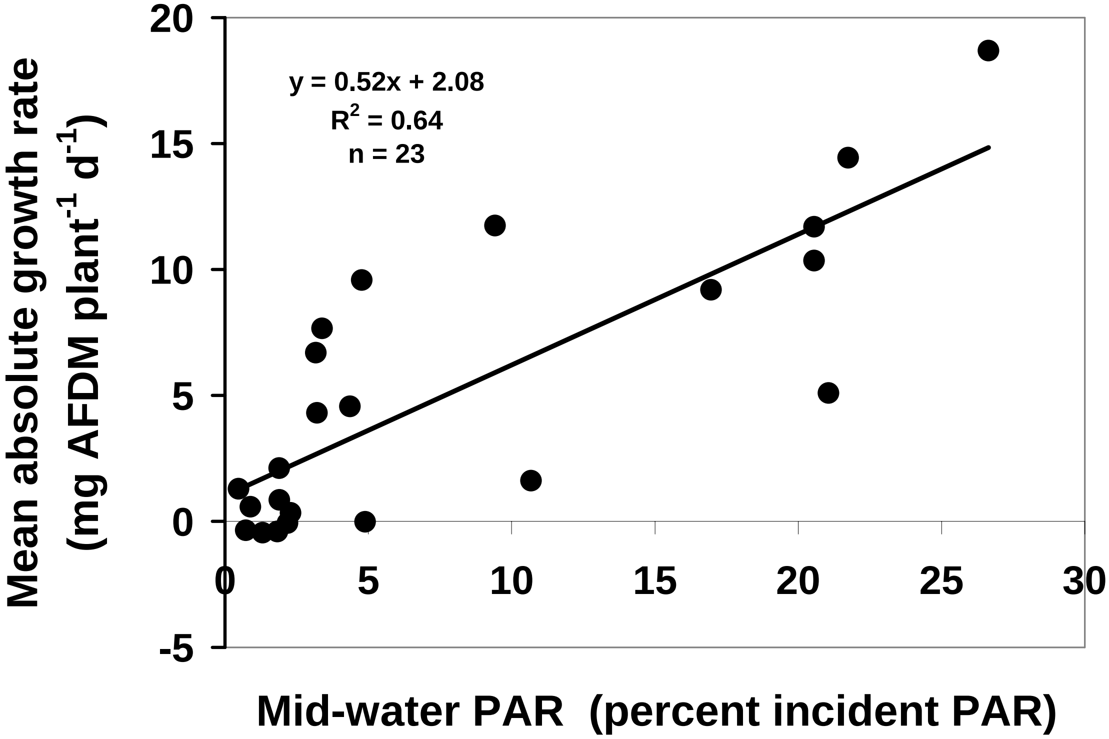

Figure 5-13: Linear regression of mid-water PAR versus the absolute growth rate of hydrilla from mesocosm experiments.

Hypothesis 4

It is hypothesized that changes in the extent of mud sediments in the pelagic-littoral fringe zone of LO, resulting from changes in runoff and nutrient loading, influence the potential area available for colonization by SAV. Results to date seem to contradict this statement (Figure 5-14). *Hydrilla* and *Ceratophyllum* will colonize mud sediments if they are in an area where sufficient light is reaching the bottom but the more desirable native *Vallisneria* appears to prefer sand and peat substrates. The major colonizer of rock substrate is the non-vascular macroalga *Chara*.

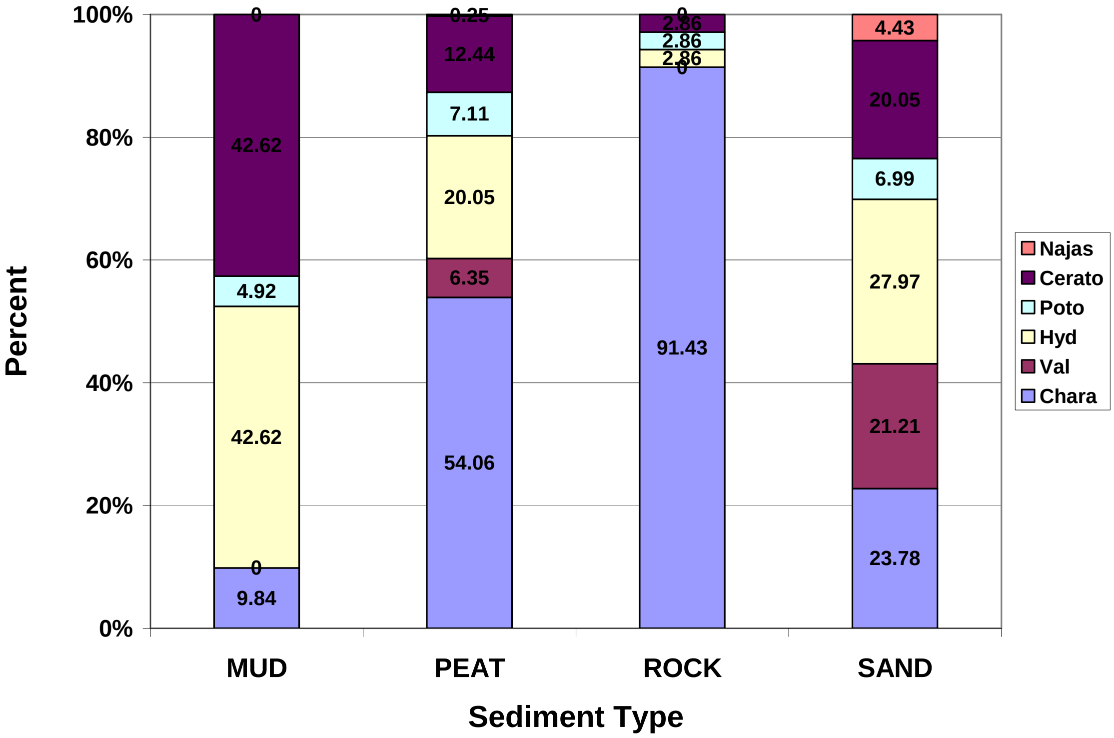

Figure 5-14: Percent of each SAV species as a function of sediment type from the 2001 to 2005 annual mapping data.

5.7 Predicting Response to Comprehensive Everglades Restoration Plan Implementation: Models and Tools

There are many tools available to help predict the response of LO to CERP implementation. These tools and models bring together research and monitoring within the south Florida ecosystem and place them into an AM framework for the evaluation of how CERP is affecting LO and the development of restoration targets. Ecosystem conceptual models were developed for LO restoration planning purposes. These models indicate, *via* box-and-arrow diagrams, how key communities within the ecosystem are affected by water level and nutrient management activities. The models for LO are complex because LO is comprised of three distinct components that have dramatically different structure and function: a littoral marsh, a near-shore region, and an open water (pelagic) region. The lake conceptual models were developed in the context of this heterogeneity. The models also reflect LO's present spatial extent, rather than the larger historical boundaries.

CERP will eventually provide alternative water treatment, storage, and disposal facilities that are expected to reduce the range of water level variation in LO as well as reducing nutrient inputs to the lake from the surrounding watershed. These changes are expected to have a positive effect on the distribution and abundance of submerged plant communities. Because SAV is a keystone component of LO's ecosystem, providing habitat for fish and wildlife and directly affecting water quality by nutrient uptake, sediment stabilization, and a variety of other processes, the ability to quantify and predict how changes in water and nutrient management strategies will affect both water quality and the SAV community, is critical to CERP and the state's Lake LOPP.

Models have been developed and applied to LO since 1981 to determine loading goals of P, guide lake research, and help predict impacts of management actions. The 1989 Surface Water Improvement and Management Plan applied the first of these models, the modified Vollenweider model, to set target P loads for LO. Subsequently, a more complex model was developed, the Lake Okeechobee Water Quality Model (LOWQM), to investigate the impact of P and water management on water-column nutrient concentrations and algal blooms in LO. Additionally, a water quality model is being developed based on the existing Lake Okeechobee Hydrodynamic Model platform. The objective is to develop, calibrate, and validate a Lake Okeechobee Environment Model (LOEM)-a spatially explicit hydrodynamic, sediment-transport, water quality model of the ecosystem.

5.8 Relationship to Interim Goals

The current IG/IT for LO are hydrologically based, with the ultimate goal of using operational flexibility to facilitate benefits to the environment without impacting other uses of LO. Although there are no biologically based IG/IT and this time, the development of goals and targets based on LO's SAV community would be an important development since the areal extent, density, and species composition of SAV in LO may be the single most important biological indicator of the lake's overall ecological health. The LO SAV sampling program has indicated that SAV can cover more than 40,000 acres when water levels are favorable (*e.g*., August 2000, 2002, and 2004), as compared to <5,000 acres during periods of prolonged high water levels (*e.g*., 1996 to 1999). Therefore, the LOPP restoration target is to sustain at least 40,000 total acres of SAV (vascular and non-vascular) with at least 20,000 acres contributed by vascular plants while the proposed RECOVER PM sets this target at 49,000 acres. Under existing lake management constraints, this spatial extent is attained in certain years, although in a relatively high percentage of years it is lower due to sustained high water levels or major physical disturbances (hurricanes). This leads to the inescapable conclusion that an inter-annual variability factor needs to be included in SAV goals and targets to capture the ability of CERP related changes to promote the long-term maintenance of quality SAV habitat.

Existing Performance Measures

Ecological PMs are measures of ecosystem attributes that have quantifiable targets (restoration goals or expectations). A set of PMs has been developed for extreme low lake stage, extreme high lake stage, and stage envelope. Because SAV is one of the primary ecological attributes affected by lake stage variations and is in itself a major determinant in providing quality habitat for many other trophic guilds, it should be an important PM. Assuming that the hydrologic PMs used in the planning process reflect conditions that are beneficial to the ecosystem, the overall 'scores' of ecological PMs such as SAV should increase as the project is completed.

Extremes in High and Low Lake Stage (LO-1 and LO-2)

Extreme high or low lake levels of any duration, or moderate high or low lake levels of prolonged (>12 months) duration, can cause significant harm to the ecosystem. In contrast to the harmful effects of extremes, a certain degree of natural variation in lake stage, between 12 and 15 feet National Geodetic Vertical Datum (NGVD), has been shown to benefit the ecosystem. The direct effects of high lake stage include increased near-shore wave energy, greater horizontal mixing in the near-shore zone and flooding of the western and southwestern marshes. Increased turbulence results in elevated P concentrations and turbidity in the near-shore zone, which can exacerbate damage to SAV and further stimulate cyanobacterial blooms. Increased wave energy has direct negative impacts on emergent vegetation, such as bulrush, in the near-shore zone, and encourages the formation of a near-shore organic berm that can block fish migration into and out of the marsh. As a consequence of its effects on SAV and emergent plants, high lake stages may result in loss of habitat for fish, birds and other aquatic fauna.

While the occasional occurrence of extreme low lake stages can be beneficial to SAV, bulrush and other emergent plants, it can also accelerate the spread of exotic and nuisance invasive vegetation. Alternately, extreme low lake stages can encourage the occurrence of brush fires that may help to control these invasive species. Prolonged or frequently repeated extreme low lake stages can have negative impacts on SAV, allowing the emergent marsh to be invaded by terrestrial vegetation, and resulting in habitat loss for fish, birds, alligators and other aquatic fauna.

Stage Envelope (LO-3)

Considerable research summarized in Havens et al. (2002) has documented the benefits of seasonally variable water levels within the range of 12.5 feet (June-July) and 15.5 feet (November-January) NGVD on the plant and animal communities of LO. Falling water levels in late winter to spring benefit wading birds by concentrating prey resources in the littoral zone where those birds forage (Smith et al., 1995), water levels near 12.5 feet benefit submerged plants and bulrush by providing optimal light levels for photosynthesis in the summer months (Havens et al. 2004), and variation in the prescribed range results in annual flooding and drying of upland areas of the littoral zone, which favors development of a diverse emergent plant community (Richardson et al. 1995).

By providing a reduction in the frequency of extreme high water levels (stage > 17 feet and stage > 15 feet for more than 12 consecutive months) and low water levels (stage < 11 feet and stage < 12 feet for more than 12 consecutive months) and an increase in the frequency of spring recessions (yearly stage decline from near 15.5 feet in January to near 12.5 feet in June, with no reversal > 0.5 feet) an increase in the biomass and spatial extent of SAV is expected.

5.9 Present Conditions and Trends of Lake Okeechobee Module Hypotheses

Phytoplankton

Routine monitoring of chlorophyll *a* and phytoplankton taxonomy and biovolume in LO has been ongoing since the mid 1990s. A very large data set currently exists but no long-term data analyses or trend assessments have been performed.

Littoral Zone Emergent Vegetation

Emergent vegetation maps based on aerial photography for the entire LO marsh and for the western bulrush fringe has been collected since the mid 1990s and comprises a thorough baseline data set. However, the emergent vegetation community in LO, much like SAV, appears to be very dynamic, responding in a relatively short time frame to changes in water depth, physical perturbations such as hurricanes, and exotic and invasive control operations. Additional research into herbicide treatment effects, seed germination and viability and hydrologic impacts on the recruitment of bulrush and torpedo grass are also being pursued to better understand the changes documented by ongoing mapping activities.

Fish

At present there is inadequate LO fish baseline data. Currently, RECOVER is funding a three year study by the Florida Fish and Wildlife Conservation Commission (FFWCC) to collect fishery data on LO by trawl and electrofishing. Methods being employed are identical to those used by the FFWCC in previous surveys, some of which date back to the early 1990s. The possibility of analyzing the 30+ years of creel data possessed by the FFWCC is also being investigated as a way to acquire earlier baseline information on the sport fishery on LO.

Macroinvertebrates

At present there is inadequate LO benthic macroinvertebrate baseline data. Currently, RECOVER is funding a three year study of LO benthic fauna with the purpose of establishing this baseline. Current study methods and sampling locations are identical to those used by Warren et al. (1995) in a previous study conducted from 1987 to 1991, thus it may be possible to elucidate recent trends in macroinvertebrate population dynamics from RECOVER's work.

Integrated Studies

A five year trophic index study looking at the fish, macroinvertebrate and amphibian populations in the three dominant SAV communities and the two dominant emergent vegetation communities in LO is currently underway. It is anticipated that results from this study coupled with results from a recently completed two year study looking at fish and macroinvertebrates in spike rush and torpedograss habitat will allow the expansion of the SAV and emergent vegetation assessment tools currently under development to include additional trophic guilds.

5.10 Conclusions

Based on currently available data, it should be possible to perform assessments on LO's SAV, phytoplankton, and littoral zone emergent vegetation hypotheses clusters. The earliest dates by which assessments could be performed on the macroinvertebrate and fish hypothesis clusters are 2008 and 2010, respectively.

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