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Ecological indicators for assessing and communicating seagrass status and trends in Florida Bay☆

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ABSTRACT

A suite of seagrass indicator metrics is developed to evaluate four essential measures of seagrass community status for Florida Bay. The measures are based on several years of monitoring data using the Braun-Blanquet Cover Abundance (BBCA) scale to derive information about seagrass spatial extent, abundance, species diversity and presence of target species. As ecosystem restoration proceeds in south Florida, additional freshwater will be discharged to Florida Bay as a means to restore the bay's hydrology and salinity regime. Primary hypotheses about restoring ecological function of the keystone seagrass community are based on the premise that hydrologic restoration will increase environmental variability and reduce hypersalinity. This will create greater niche space and permit multiple seagrass species to co-exist while maintaining good environmental conditions for *Thalassia testudinum*, the dominant climax seagrass species. Greater species diversity is considered beneficial to habitat for desired higher trophic level species such as forage fish and shrimp. It is also important to maintenance of a viable seagrass community that will avoid die-off events observed in the past. Indicator metrics are assigned values at the basin spatial scale and are aggregated to five larger zones. Three index metrics are derived by combining the four indicators through logic gates at the zone spatial scale and aggregated to derive a single bay-wide system status score standardized on the System-wide Indicator protocol. The indicators will provide a way to assess progress toward restoration goals or reveal areas of concern. Reporting for each indicator, index and overall system status score is presented in a red–yellow–green format that summarizes information in a readily accessible form for mangers, policy-makers and stakeholders in planning and implementing an adaptive management strategy.

1. Introduction and background

Seagrasses are integral to the ecological function of Florida Bay and are considered a keystone community of the ecosystem (Zieman et al., 1989, 1999). For many decades during the 20th century seagrasses have been the dominant primary producer in Florida Bay and as of the early 1980s, seagrasses covered an estimated 5500 km^2 of the greater Florida Bay and Florida Keys area (Zieman, 1982). The predominance of seagrasses as a structural component of the ecosystem is well reported in scientific reviews (Fourqurean and Robblee, 1999), census and inventory reports (Tabb et al., 1962; Zieman, 1982), as well as in early anecdotal reports (cf. Zieman et al., 1999).

Thalassia testudinum, turtle grass, is the dominant species in both distribution and biomass and is the climax species in this system. *Thalassia* is often mixed with shoal grass (*Halodule wrightii*) throughout the bay. Manatee grass (*Syringodium filiforme*) occurs in generally deeper marine waters in the western bay near the Gulf of Mexico and widgeon grass (*Ruppia maritima*) occurs along the northern border of the bay within the mangrove transition zone through which passes fresh water en route to Florida Bay. Two relatively rare species are found in disparate locations: *Halophila engelmannii* (star grass) occurs in Barnes Sound in the eastern bay and *Halophila decipiens* (paddle grass) along the western bay border with the Gulf of Mexico. Together the seagrass and macroalgal communities form the important submersed aquatic vegetation (SAV) ecosystem component of Florida Bay. Due to data constraints discussed below, the SAV indicators developed here are based solely on rooted vascular plants and do not include

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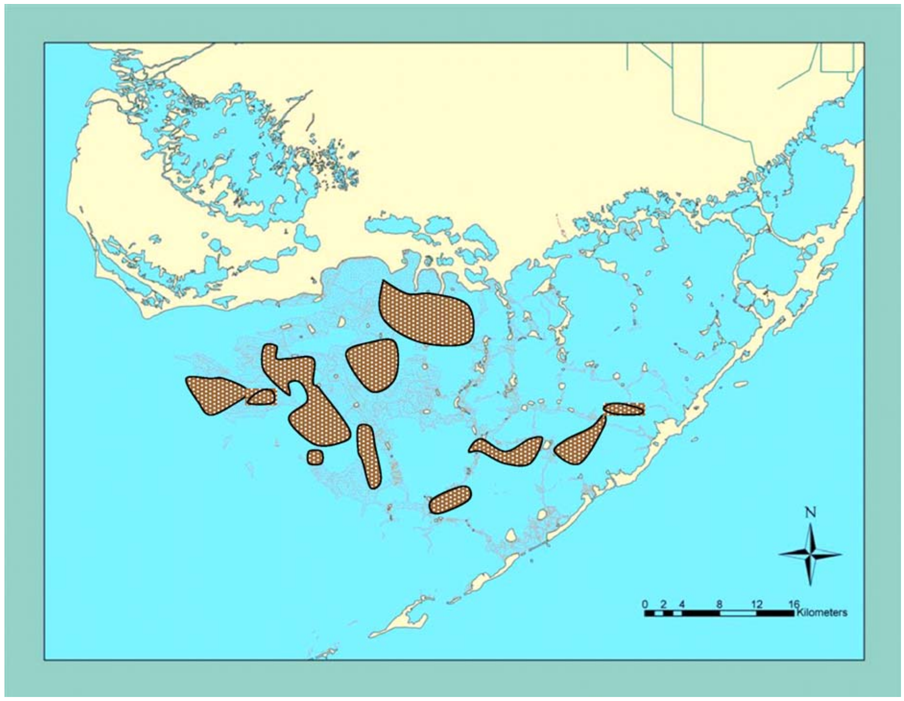

Fig. 1. Florida Bay showing areas of major *Thalassia* die-off during late 1987 (modified from Robblee et al., 1991).

macroalgae. Unless otherwise noted, the terms "seagrass" and "SAV" are used interchangeably throughout this document to refer to rooted vascular plants only.

As an ecological keystone of the Florida Bay system, seagrasses play a role in many important physico-chemical (Stumpf et al., 1999; Matheson et al., 1999), autotrophic (Fourqurean and Zieman, 2002) and higher trophic (Ley and McIvor, 2002; Lorenz et al., 2002) ecosystem functions. They are the dominant primary producer that supports high standing biomass, provides a food source and habitat (Bennett et al., 2005), binds sediment reducing turbidity, and enhances benthic primary and secondary production (Zieman, 1982). Seagrasses also provide a large nutrient sink, restricting nutrient availability to phytoplankton, thereby ameliorating potential algal blooms (Rudnick et al., 2005).

Consumptive water use and the construction of canals that drain and redirect water have reduced the percentage of fresh water in the Everglades that is delivered to Florida Bay to only about 20% of the total water in the catchment. Previously, closer to half the Everglades water budget was discharged to Florida Bay (Light and Dineen, 1994). Over the past century, freshwater discharge may have declined by as much as 60% (Smith et al., 1989), increasing overall bay salinity (Fourqurean and Robblee, 1999), reducing the estuarine character of the bay and moving it toward a marine-hypersaline lagoon (Brewster-Wingard and Ishman, 1999; Halley and Roulier, 1999).

Discharges that do flow into the northeast and central bay have become "flashy," and pulsed due to flood protection and water use criteria in the upstream watershed. Unnaturally large variations in flow and salinity (Rudnick et al., 1999) are stressful to hydrophytic plants including seagrasses (Koch et al., 2007a). The result has been the contraction or elimination of lower salinity species such as *Halodule*, *Ruppia*, *Utricularia* and *Najas* and fresh macroalgal species including *Chara* (Koch, 2009) in the ponds and creeks of the transition zone ecotone (Zieman et al., 1999). During periods of extended drought and hypersalinity, there is a tendency in the central and western bay toward development of monotypic stands of over-dense *Thalassia* at the expense of *Halodule* and other species (Zieman et al., 1999; Hall et al., 1999). The bathymetry and morphology of Florida Bay is characterized by a network of shoals, submerged and exposed banks that effectively isolate bay waters within dozens of interior basins. This morphology restricts circulation, increases the significance of evaporation and extends residence time of waters in the bay (Nuttle et al., 2000), exacerbating the development of hypersaline conditions.

In fall 1987, the seagrass community abruptly underwent a widespread mortality event (Robblee et al., 1991) that destroyed 4000 ha or about 5% of the *Thalassia* community (Fig. 1), and thinned an additional 23,000 ha (Robblee et al., 1991), resulting in a total impact on about 30% of the entire community (Hall et al., 1999; Durako et al., 2002). The mortality likely resulted from the convergence of multiple environmental stressors including high summertime temperatures, hypersalinity, high sediment sulfide combining to reduce productivity (Zieman et al., 1999; Koch et al., 2007b) and to deplete oxygen concentrations in the root zone and at the meristem (Borum et al., 2005). The collapse of the community occurred after years of quiescent marine/hypersaline conditions (Zieman et al., 1999) that had been favorable for *Thalassia* and it is hypothesized that excess development of standing crop may have outstripped the resource base and carrying capacity (Zieman et al., 1999) when the stressor event occurred. Continued sporadic SAV losses support this hypothesis, mostly occurring in the high-density beds (Zieman et al., 1999, Fig. 2) of the western bay, where seagrass abundance is greatest (Landry et al., 2005, Fig. 3).

The widespread seagrass loss in 1987 was followed by a cascade of ecological effects. By 1992, frequent phytoplankton blooms began to appear in the central and western bay where none had been recorded previously (Fourqurean and Robblee, 1999; Boyer et al., 1999). Negative impacts extended to higher trophic levels, including 100% mortality of some sponge species (Fourqurean and Robblee, 1999; Peterson et al., 2006). Landings of spiny lobster (Butler et al., 1995) and pink shrimp at Tortugas Banks plunged in 1988 to their lowest levels in decades (Robblee et al., 1991), and game fish landings also declined (Fourqurean and Robblee, 1999). Blooms persist to the present (Richardson and Zimba, 2002; Glibert

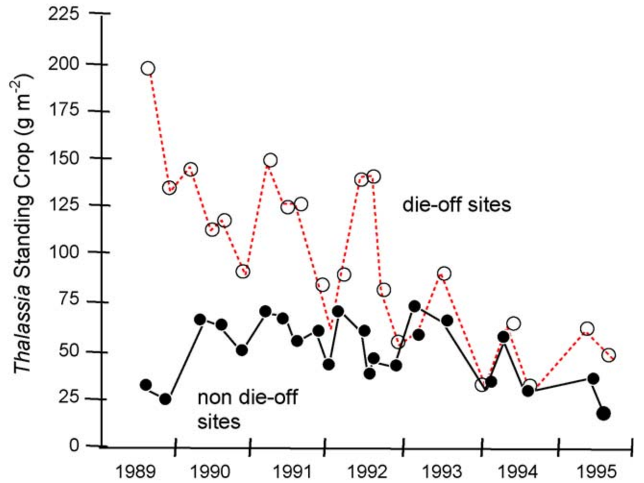

Fig. 2. Long-term record of changes in *Thalassia* standing crop following die-off event in 1987. Dark circles are averages of several stations with high density of *Thalassia*, lighter circles are averaged stations with low density (from Zieman et al., 1999).

et al., 2004) and recently the bloom "footprint" has expanded to include the eastern bay (Rudnick et al., 2006).

2. Comprehensive Everglades Restoration Plan goals and hypotheses

The ecological restoration of the Everglades ecosystem is being conducted under the aegis of the Comprehensive Everglades Restoration Plan (CERP), which is jointly operated by the South Florida Water Management District and the U.S. Army Corps of Engineers to develop a long-term program of ecological, hydrologic and water quality restoration (CERP, 2004). The REstoration COordination and VERification (RECOVER) (RECOVER, 2009) arm of CERP is a multi-agency team formed to support CERP goals by scientifically evaluating the goals and implementation of the restoration. RECOVER is charged with developing the quantitative performance measures for assessing ecosystem condition and characterizing restoration goals (RECOVER, 2004). The underlying RECOVER hypothesis regarding Florida Bay posits that restoration of the water delivery and salinity regimes will generate restoration of other ecosystem processes, particularly in the seagrass community, by increasing freshwater flows from the Everglades, with more natural timing and distribution leading to a more natural estuarine salinity gradient. RECOVER hypotheses specifically addressed by the seagrass indicator suite address the impact of salinity level and salinity variability on healthy benthic estuarine plant communities. The primary CERP hypotheses addressing this issue are:

1. Seagrass community structure, including cover, distribution, and composition, will change as a function of CERP implementation. Seagrass responses will depend upon the inter-related effects of salinity, nutrient availability, light, and other factors that directly and indirectly affected by freshwater inputs to Florida Bay (RECOVER, 2007);
2. Responses to CERP implementation will include an expansion of areas with shoalgrass (*H. wrightii*) and widgeon grass (*R. maritima*) and reduction in the dominance of turtle grass (*T. testudinum*), especially in the northern third of Florida Bay. It is expected that restoration of seagrass species diversity will result in improved seagrass habitat function (RECOVER, 2007).

RECOVER seagrass restoration targets are supported both by empirical evidence (e.g. Fourqurean et al., 2003; Koch et al., 2007b) and modeling projections (e.g. Fourqurean et al., 2003; Madden and McDonald, 2006). In addressing the issue of seagrass status assessment for restoration, the indicators developed for Florida Bay SAV consist of metrics related to how salinity regime controls seagrass distribution, cover and species composition throughout the bay.

Seagrass communities in many estuaries in the coastal US are being degraded due to eutrophication by anthropogenic nutrient inputs and light limitation, as in Pamlico Sound (Paerl et al., 2004; Biber et al., 2009), Chesapeake Bay (Kemp et al., 1983; Madden and Kemp, 1996; Kemp et al., 2005) and Narragansett Bay (Lee et al., 2004). In contrast, despite some indications of nutrient enrichment (Brand, 2002; Lapointe et al., 2002), Florida Bay seagrasses have historically shown little indication of stress due to algal blooms and epiphytic overgrowth (Zieman et al., 1999; Fourqurean and Robblee, 1999). The waters currently flowing from the Everglades watershed into Florida Bay are shown by long-term monitoring (Rudnick et al., 1999; Boyer et al., 1997) to be generally clear and low in phosphorus, the limiting nutrient for much of the Florida Bay plant community (Powell et al., 1989; Fourqurean et al., 1992; Johnson et al., 2006). This suggests that the observed deleterious effects on seagrasses, such as die-off, are not nutrient or light-driven (Fourqurean and Robblee, 1999) and that the most important controllable stressor in the region is salinity (Fourqurean and Robblee, 1999). Thus, in order to improve conditions

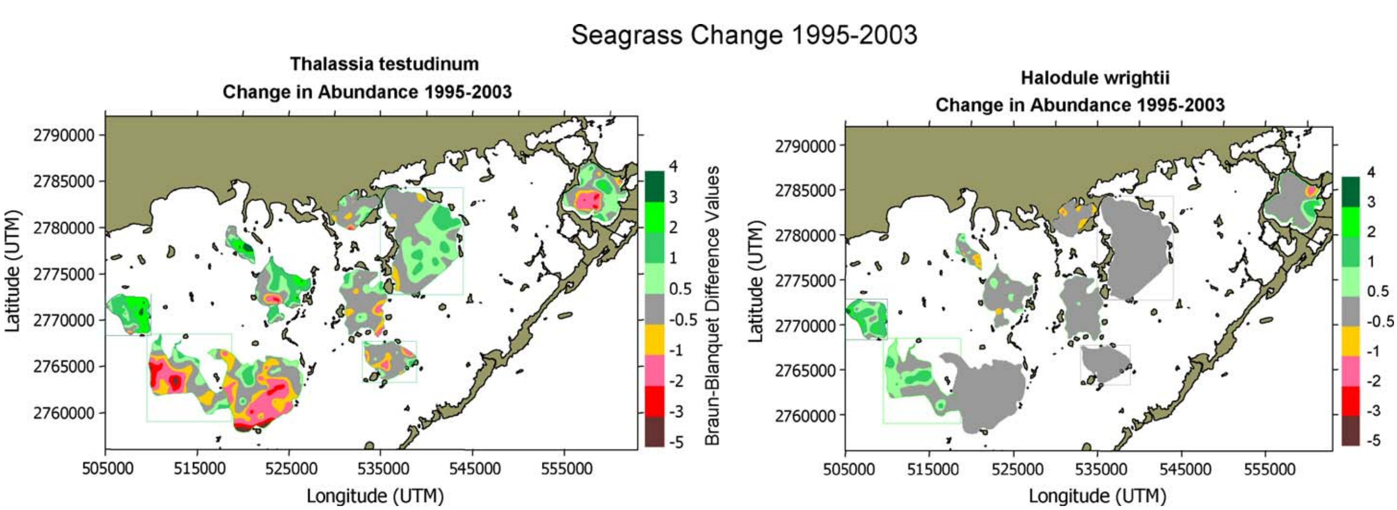

Fig. 3. Change in Braun-Blanquet values (BBCA) cover for *Thalassia* (left panel) and *Halodule* (right panel) between 1995 and 2003 (From Landry et al., 2005).

for survival, restoration goals for Florida Bay focus foremost on adjustments to salinity regime rather than on nutrient inputs (Hunt et al., 2006; RECOVER, 2005).

Hypersalinity has been shown to physiologically stress halophytic plants in Florida Bay (Koch et al., 2007b). Although seagrasses can survive at salinities of 60 PSU and greater, high salinity creates sub-lethal stresses and osmotic imbalance (Koch and Durako, 2005; Koch et al., 2007d) that reduces productivity and competitive ability, especially for plants that have overbuilt their carrying capacity. Hypersaline conditions, the primary anthropogenic stressor to the Florida Bay seagrass community, are linked to the reduced freshwater flow to the bay from the Everglades discussed earlier (Zieman, 1982; Wanless et al., 1994; CERP, 2004). Conceptual Ecological Models (CEM) developed for habitats of the Everglades (Ogden et al., 2005) and for the Florida Bay seagrass community (Rudnick et al., 2005; Boyer et al., 2007; Koch et al., 2007c, Fig. 4) have established the pathway of major system stressors from water management, consumptive use and draining of the Everglades to altered salinity regime and to negative impacts on seagrasses. These models indicate that dense *Thalassia* monocultures are less resilient to environmental variability than more diverse, lower biomass communities.

3. Ecosystem indicator development

This section describes the development of an assessment and scoring system that provides standard summary metrics to quantify and summarize data about Florida Bay seagrass community status. In addition to being critical ecosystem components, seagrasses are good indicators of the overall environmental condition and "health" of the ecosystem because they integrate more highly variable or undetected aspects of the system, such as pulses of nutrients or reduced sediment redox conditions. It is furthermore important to managers to know the status of SAV because it is a strong determinant of the status of other food web components and other system attributes (Sogard et al., 1989; Fourqurean and Robblee, 1999). The product of this project is a simple analytic tool and reporting scheme that makes scientific data on SAV status available to a broad audience in an accessible, consistent format.

3.1. Areas of the Everglades system covered by this indicator

The indicators developed for SAV encompass the benthic seagrass community within Florida Bay. The target area is in the southern region of the CERP footprint and is adjacent to and influenced by the Florida Keys and the Greater Everglades (Fig. 5). Though the metrics developed here are specific for Florida Bay in the CERP Southern Estuaries Module, the concepts and methodologies of these metrics may be applicable to other Southern Estuaries areas including Biscayne Bay, Whitewater Bay, Ten Thousand Islands as well as other seagrass-dominated Florida coasts and regions such as reef tract of the Florida Keys National Marine Sanctuary and the euhaline areas of Estero Bay, San Carlos Bay, Pine Island Sound and Charlotte Harbor in the CERP Northern Estuaries-West Module.

3.2. Indicator history

Performance measures (PMs) and restoration targets were initially developed within the CERP RECOVER program (RECOVER, 2004, 2005) and the CERP Florida Bay and Florida Keys Feasibility Study (FBFKFS) as PM numbers SAV.B.PM-1,2,3, SAV.C.PM-1,2,3 and SAV.SC.PM1,2,3 (FBFKFS, 2002). The SAV PMs specify targets for seagrass species diversity and optimal bottom cover score from

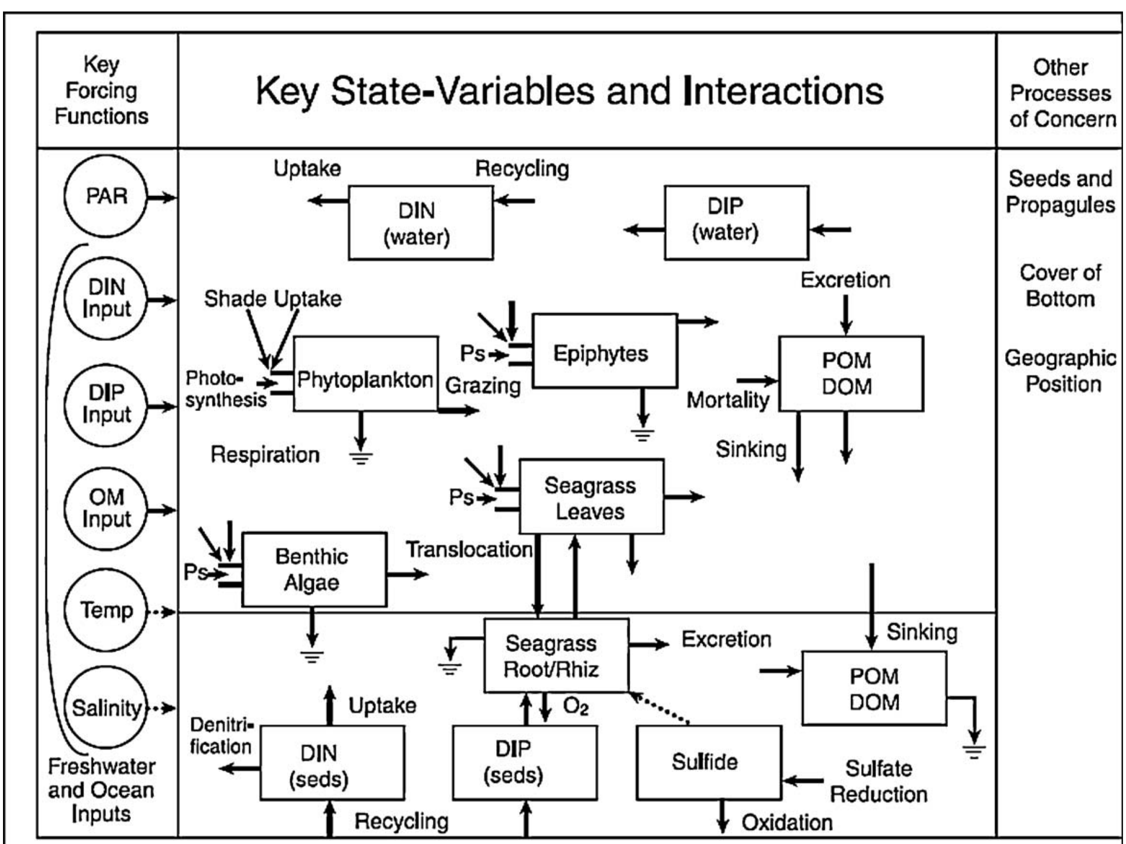

Fig. 4. Conceptual model for the Florida Bay seagrass community showing external forcing functions (circles), pools and stocks (rectangles), interactions (arrows) and processes (labels) (Boyer et al., 2007).

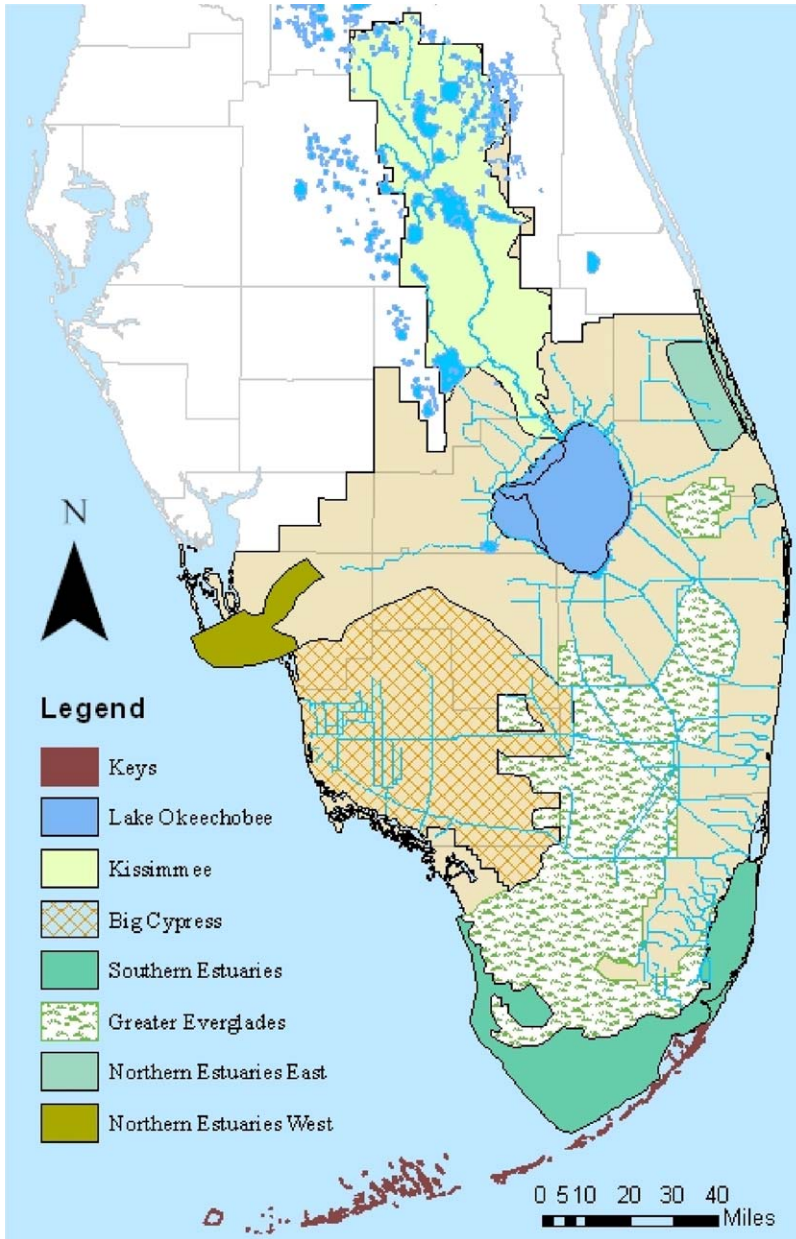

Fig. 5. Map showing Florida Bay and the Southern Estuaries module in the context of RECOVER regional modules within the CERP boundary.

Braun-Blanquet Cover Abundance (BBCA, described below) surveys on the spatial unit of 16 Feasibility Study Zones covering all of Florida Bay and the mangrove transition zone (FBFKFS, 2004). A target species is specified to be the optimal dominant bottom cover for each zone. RECOVER subsequently incorporated these Feasibility Study PMs and the system-wide indicators presented here for SAV derived from the RECOVER metrics. We refined and streamlined them by developing a quantitative scoring system to assess species diversity and target species, by establishing a three-tiered assessment system and by using a higher spatial resolution at the basin scale, comprised of 47 units, rather than the 16 larger Feasibility Study zones.

3.3. Data sources

The SAV assessment indicator reports are developed exclusively from derivations of BBCA data for seagrasses in Florida Bay taken over several years under a multi-agency monitoring program (Fourqurean et al., 2002). The BBCA method involves assessing the degree of bottom covered by each species observed within a haphazardly thrown quadrat. Species occurring within the quadrats are assigned a cover/abundance value according to the following scale:

BBCA score	SAV cover
0	Absence
0.1	Single individual ramet (less than 5% cover)
0.5	Few individual ramets (less than 5% cover)
1	Many individual ramets (less than 5% cover)
2	Any number with 5–25% cover
3	Any number with 25–50% cover
4	Any number with 50–75% cover
5	Any number with 75–100% cover

Average BBCA scores for each species are computed for all quadrats at a site to yield an average BBCA abundance estimate (RECOVER, 2007). These data are then analyzed for cover, abundance, and species diversity according to the metrics described below. Several agencies contribute data for the SAV monitoring program. A note about macroalgae, which is a significant component of Florida Bay bottom cover, is in order. Macroalgae distribution is tracked along with seagrass, however data for macroalgae are less robust than for seagrasses. Some non-attached macroalgal species are quite ephemeral and difficult to quantify, as they are easily moved by currents and winds. Physiological responses of macroalgae to environmental conditions are not well studied for all species and resource requirements and environmental stressors are more difficult to assess. For these reasons, macroalgae are not yet explicitly considered in this indicator protocol for Florida Bay SAV.

The Fish Habitat Assessment Program (FHAP) of the Florida Fish and Wildlife Conservation Commission (FWCC) has been sampling bottom cover in ten basins in Florida Bay since 1995. In 2004, RECOVER began funding the program under a cooperative agreement and expanded the region covered by FHAP to include the Shark Slough outfall region, Whitewater Bay, and Biscayne Bay. FHAP estimates benthic cover for individual seagrass species using a modified BBCA (Fourqurean et al., 2002). The BBCA survey is currently conducted once a year at 30 sites in each of 20 basins depicted in Fig. 6 in green. Eight haphazardly thrown 0.25 m^2 quadrats are scored at each site. The location of the site per sampling event is randomly selected using an EMAP stratified random sampling design (Hall et al., 1999).

The Miami-Dade Department of Environmental Resources Management (DERM) has also conducted benthic habitat surveys since 1995 in the areas of eastern Florida Bay and Southern Biscayne Bay. DERM's rapid assessment surveys are conducted quarterly within each of the twelve monitoring basins using a modified BBCA Index (Fourqurean et al., 2002). Basins monitored by DERM are depicted by the hash marks in Fig. 6. Total benthic cover and species-specific cover is estimated in each basin using four or twelve randomly selected sites (depending on the size of the basin) and four haphazardly thrown 0.25 m^2 quadrats at each site as in the FHAP protocol described above.

In addition to the DERM and FWCC monitoring programs, the National Audubon Society (NAS, Audubon) monitors SAV in the coastal ponds and shallow marshes of the mangrove transition zone of northeast and north central Florida Bay (Lorenz, 1999). Surveys are conducted approximately every 6 weeks using a point-intercept method to estimate percent cover at six sites along two transects (one along Taylor River and one through Joe Bay) on a salinity gradient from upstream to downstream with the last site on the transect located just inside Florida Bay.

Sampling in the Florida Keys National Marine Sanctuary (FKNMS) by the Seagrass Ecosystems Research Lab (SERL) at Florida International University (FIU) also provides applicable data about seagrasses on the western border of the bay (Fourqurean, 2005; Fourqurean and Rutten, 2003). The program has documented seagrass ecosystem status and trends since 1995 in the Sanctuary and southwest Florida Shelf and since 2000 at five sites in Florida Bay as part of the Florida Coastal Everglades Long Term Ecological Research (FCE LTER) Program. FKNMS monitoring assesses both inter-annual and intra-annual trends by conducting quarterly BBCA sampling at 30 permanent locations and annually by one-time sampling at several hundred synoptic mapping locations. Permanent stations are co-located with FIU water quality monitoring project stations and sampled annually for seagrass abundance and nutrient availability using the same sampling design as FHAP. Tissue nutrient content (carbon, nitrogen, and phosphorus) of all species is analyzed, providing a long-term baseline of seagrass species abundance, composition and nutrient content in western Florida Bay. Currently, the applicability of tissue nutrient status (Atkinson, 1983) for use as a seagrass indicator metric, as has been developed for Narragansett Bay (Lee et al., 2004), is being assessed for use in Florida Bay (Fourqurean et al., 1992; Fourqurean and Zieman, 2002; Herbert and Fourqurean, 2008).

3.4. Assessment units and spatial scale

The SAV indicator metrics are applied at three spatial scales in Florida Bay: at sub-basin scale (i.e. the individual sample site, between 4 and 30 sites per basin), the whole-basin scale, and the regional scale. Indicators can also be aggregated to derive a whole-bay measure of seagrass status. Our study adopts the basin boundaries as defined for the Flux Accounting and Tidal Hydrology

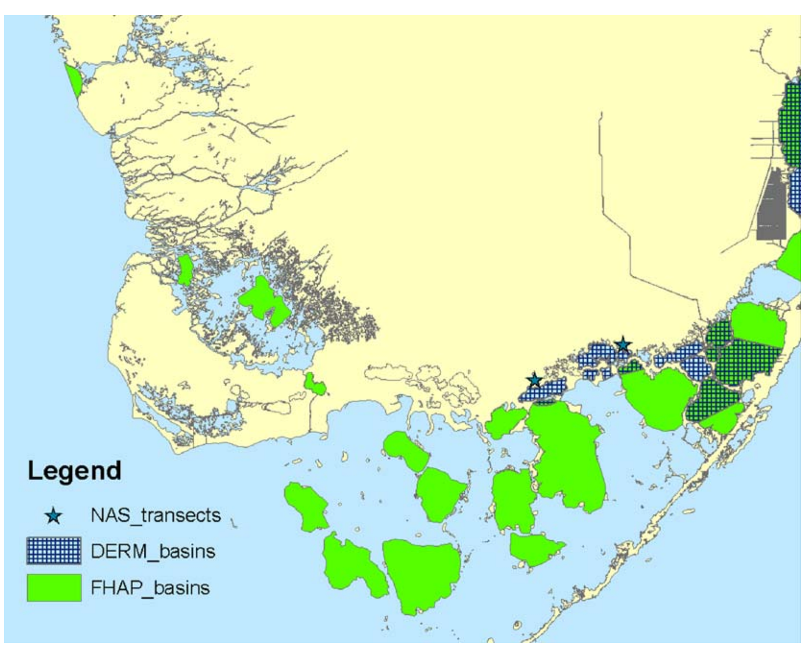

Fig. 6. Fish Habitat Assessment Program (FHAP, green), Miami-Dade Dept. of Environmental Resource Management (DERM, hatch marked) and National Audubon Society (stars) sampling sites for the SAV monitoring program. Some areas overlap and are used for inter-calibration of agency sampling procedure and sampling crews.

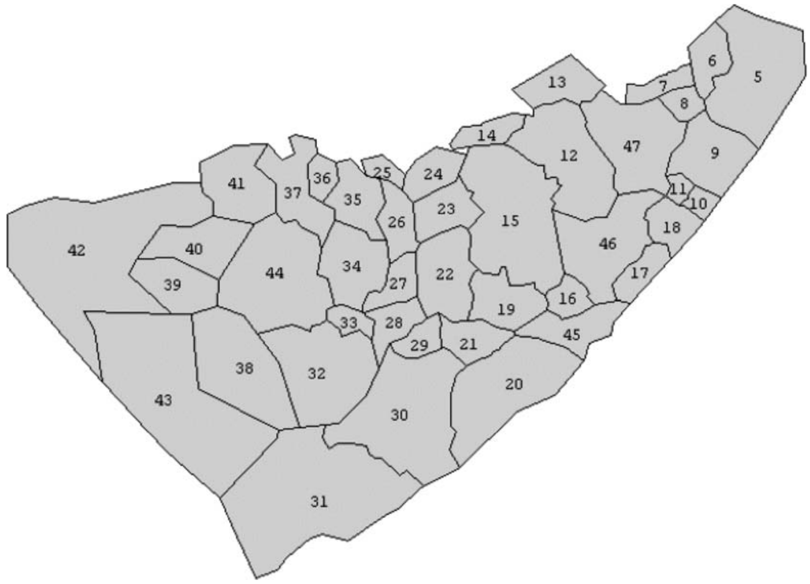

Fig. 7. Boundaries of FATHOM basins, corresponding to semi-isolated basins in Florida Bay (from Nuttle et al., 2000).

at the Ocean Margin (FATHOM) mass-balance model (Cosby et al., 1999) as the standard spatial unit (Fig. 7). The FATHOM map depicts 47 distinct, hydrologically coherent units each characterized by varying degree of hydrologic isolation from the others resulting in differential residence times, nutrient characteristics and ecological interactions (Nuttle et al., 2000). These naturally occurring basins each can reflect different water quality (Boyer et al., 1997, 2007), biological and physical traits (Nuttle et al., 2000) that impact the habitat suitability, population dynamics and restoration potential for seagrasses (RECOVER, 2006).

Water quality data show the bay to be comprised of five distinct zones (Fig. 8) based on patterns of salinity and nutrient distributions (Boyer et al., 1999, 2007), identified as Northeastern, Central, Western, Southern, and Transition zones. These zones largely reflect the source of hydrological and nutrient inputs (Rudnick et al., 1999), but are also determined by physical circulation (Nuttle et al., 2000) and supported by sediment and bottom type (Prager and Halley, 1997) and environmental characteristics (Zieman et al., 1999) all of which have a strong influence on the seagrass community. Sediment depth, seagrass metrics and restoration projections for expected salinity regime indicate that these larger zones are functionally coherent and differ significantly from each other. SAV indicator scores for basins are aggregated into the encompassing zones to provide a regional picture of SAV status.

3.5. Indicator metrics

The seagrass indicators consist of a set of metrics that reflect attributes of the SAV community considered essential to assessing community health and restoration success: spatial extent, seagrass abundance, species dominance and presence of desired target

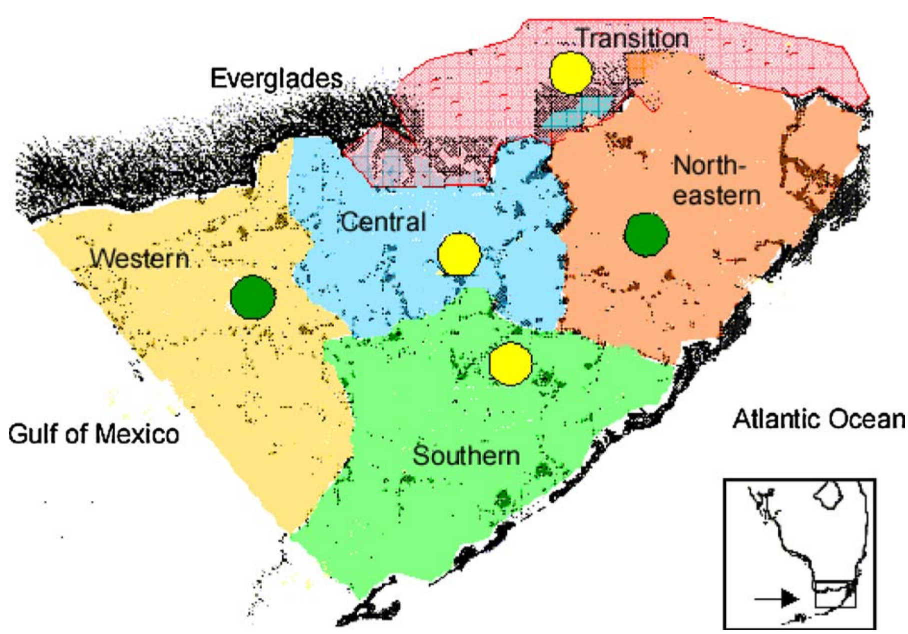

Fig. 8. Map of five SAV indicator zones (Northeastern, Central, Western, Southern, Transition) with current status indicators for summary index C (carrying capacity index) combining abundance and species indexes. Zones are derived from Florida Bay water quality/salinity zones (from Nuttle et al., 2000; Boyer et al., 2007).

species. These four metrics combine to produce a single index which reflects the status of the community. Of the six seagrass species that occur within Florida Bay – *T. testudinum*, *H. wrightii*, *S. filiforme*, *R. maritima*, *H. engelmannii* and *H. decipiens* –, three of them, *T. testudinum*, *R. maritima* and *H. wrightii*, are specific RECOVER restoration targets (RECOVER, 2006). All six species are evaluated in the calculation of the metrics.

3.5.1. Spatial extent index

The spatial extent index metric is an index of the *proportion of seagrass bottom cover* per basin. The metric is not species-specific. Spatial extent (SE) is derived from the frequency of observations within a basin where any seagrass is detected as represented by a non-zero Braun-Blanquet value for any species. The algorithm for calculating the SE metric is the number of BBCA samples positive for seagrass, divided by the total of all quadrat "throws:"

$$\mathrm{SE} = \frac{n_{seagrass}}{n_{TotalObs}}$$

where $n_{seagrass}$ is the number of observations where at least one species of seagrass is observed and $n_{TotalObs}$ is the total number of observations. The metric ranges from 0 to 1, representing least to most desirable status of extent as the decimal fraction of the basin area with seagrass cover, regardless of density. Because the BBCA identifies a single short shoot of seagrass as its smallest unit of positive abundance, it is possible for a basin to be covered by extremely sparse seagrass and still be considered to have 100% spatial coverage, albeit at a low abundance score.

3.5.2. Seagrass abundance index

The abundance metric is an index of the average density of *seagrass bottom cover* per basin where seagrass is present. The seagrass abundance index (SA) is not species-specific and represents an average of Braun-Blanquet values for all seagrasses in the basin, calculated as follows:

$$\mathrm{SA} = 0.2 \times \frac{\sum \mathrm{SC}_i}{n_{seagrass}}$$

where SC_i (seagrass cover) is the Braun-Blanquet score for species *i* per quadrat site, then summed for all sites within a basin, and divided by $n_{seagrass}$, the total number of observations where at least one species of seagrass was observed (samples with zero scores are excluded in the denominator). Applying a coefficient of 0.2 scales this metric to range from 0 to 1 (converting from the BBCA scale of 0–5) yields the average seagrass abundance for all vegetated areas within a basin. The spatial unit for this metric is the sub-basin scale. That is, it quantifies the abundance of plants only in those areas supporting seagrass. It does not average the abundance over the entire basin.

3.5.3. Species dominance index

The species dominance metric is a measure of the *degree to which a single species dominates* in each basin. This species-specific metric is calculated from first a determination of the relative species composition, a dimensionless index that is the average Braun-Blanquet cover score for each seagrass species divided by the total number of quadrats with seagrass present.

Mean relative abundance of each species in the basin is calculated as

$$D_x = \frac{\sum X_i}{n_{seagrass}}$$

where D_x, the average abundance of a species x, is the sum of X_i, the pooled BBCA scores for species *x* over the entire basin, and $n_{seagrass}$ is the number of observations where at least one species of seagrass is present.

Then the relative species composition (RSC) for each species is determined by dividing the *D* for each species by the total *D* summed for all species in the basin:

$$\mathrm{RSC}_x = \frac{D_x}{D_{TT} + D_{HW} + D_{SF} + D_{HD} + D_{HE} + D_{RM}}$$

TT: *T. testudinum*, *HW*: *H. wrightii*, and *SF*: *S. filiforme*, *HE*: *H. engelmannii*, *HD*: *H. decipiens* and *RM*: *R. maritima*.

The resulting RSC_x gives the relative species composition within a basin for each species *x*; the total of all RSCs for each site therefore sum to 1. An advantage of this algorithm is that it includes all potential local species in the denominator, enabling use of the same equation for the entire bay, and obviating the need to develop separate metrics for each region. Where certain species are not present, they simply represent null values in the equation. This form is also flexible because additional species or groups (such as macroalgae) may be later added as data become available without disrupting the integrity of the indicator or compatibility with past data.

If for a monotypic stand only one species is present, the RSC is 1.0; if a species is absent, its RSC is zero. If there are two species of equal density, each will have an RSC of 0.5. An RSC value of 0.9 for *Thalassia* indicates that is strongly dominant at a particular location and there is minor presence of one or more other species. Without having to know the underlying BBCA abundance, densities or even species at a site, the RSC index gives information about how monotypic or mixed the seagrass community in a particular basin is.

The six seagrass species currently found in Florida Bay are all considered to have the potential to occur in a given sample. Because there could be from one to six species equally present in the denominator of the RSC calculation, the range of values for the *dominant* species' RSC extends from 1 (for a monotypic basin) to as low as 0.17 if all six species were to be present in equal density. The dominant RSC value yields much information about the species diversity for a basin. As an example, an RSC index of 0.33 for the dominant species at a site indicates that the strength of the dominant species' density score represents a third of the aggregate density scores of the entire species complex at a site, with no other species attaining a higher proportion than 0.33 to sum to unity. If one of the non-dominant species did in fact have a score lower than 0.33, then that would indicate that at least four species must be present, with no other species' score as high as 0.33.

The relevant point of this metric is the degree of dominance of the dominant species only, so the next calculation step focuses the RSC on the single most dominant species. A low score for the dominant RSC indicates that all species present are evenly abundant (no clear dominant) and a high score reflects a strongly dominant species as the RSC approaches unity. A diverse species composition is a desirable restoration goal for Florida Bay and managers would be targeting low RSCs for any dominant species. In order to harmonize the indicator range and vector with those of our other seagrass indexes on a 0–1 scale, we invert the RSC by subtraction from 1, and multiply by the coefficient of 1.2 to scale the indicator as the others, from 0 to 1. The multiplier 1.2 is applied due to the fact that the maximum RSC would equal 0.833 (or 1–1/6), not 1.0 if all six possible species are represented equally. The product scales the metric from 0 to 1 which becomes the operational metric, termed species dominance index (SD), with zero being less desirable (dominance by a single species) and 1 being most desirable (mixed composition) as follows:

$$\mathrm{SD} = 1.2 \times (1 - \mathrm{RSC}_{\mathrm{DOM}})$$

DOM represents the dominant species at the site.

As research on this indicator proceeds and as data permit, the inclusion of desirable macroalgal species in the calculation of the index will be considered. In practice, all seagrass species will likely never be present in the same quadrat due to wide geographic and niche separation of seagrasses across the bay, and in fact it is highly likely that at most two or three species will occur together in a healthy restored basin. The scoring for this metric takes this into account in assigning the boundaries of ranges for poor, fair and good species composition (or dominance), setting a fairly low threshold for the target mix of species for each basin.

3.5.4. Target species index

This metric is a measure of the frequency of occurrence of the *desirable non-dominant SAV species* that are expected to increase with CERP implementation, resulting in improved SAV habitat quality. *R. maritima* is expected to increase in frequency in the Transition zone and *H. wrightii* is expected to increase in frequency elsewhere in Florida Bay. The site-specific target species frequency index (TS_f) is the percentage of seagrass observations that include one or both of the two target species. It is the proportion of total species represented by any of the two target species present in the sample, calculated as

$$TS_f = \frac{n_x}{n_{seagrass}},$$

where n_x is the number of observations where the target species were reported and $n_{seagrass}$ is the number of observations where at least one species of seagrass was reported. Larger scores indicate greater abundance of a targeted species other than *Thalassia*.

Different restoration targets apply to the various species found in the bay. One RECOVER restoration goal for *Thalassia* is to prevent the overbuilding of the community (excessively high BBCA scores) which promote a potential set-up for subsequent die-off (Zieman et al., 1999). The restoration goal for *Ruppia* and *Halodule* is to promote their growth and areal expansion in the appropriate areas, with the former expected to expand at the northern boundary (Transition zone) of the bay and the latter expected to expand elsewhere (RECOVER, 2004). Likewise, the increased seasonal variation in salinity with more natural schedules of freshwater input, should create greater niche space, allowing *Halodule* to increase in abundance and extent throughout the more saline areas. Other seagrass species are not specific restoration targets but it is considered beneficial to habitat value to have a greater number of seagrass species in a given area (RECOVER, 2006). These species will be accounted in the metrics that measure total seagrass cover (non-species-specific), species diversity and species dominance.

3.6. Setting ranges for the indicators

Performance targets and indicator ranges vary spatially and are basin and zone-specific. Data from monitoring studies beginning in 1995 to the present were used in determining recent historical means and ranges for each basin (Table 1), applying the assumptions described below. Analysis of BBCA monitoring datasets (RECOVER, 2006) and expert knowledge (FBFKFS, 2002) of expected potential ranges provided the technical foundation for performance measures and target ranges based on desired restoration trajectories and using modeling predictions (Madden et al., 2007).

Generally, restoration targets for spatial extent (SE) call for as much of the unconsolidated bottom as possible to have seagrass cover. Basins in the Transition zone tend to exhibit some bare areas unrelated to die-off. The sparseness is likely related to high variability of salinity, oxygen and temperature. We view such variable landscape patterns as the natural response to a higher variability environment. Similarly, basins in the nutrient-limited Northeastern zone are not expected to support high density of seagrass under any restoration strategy because of the thin sediment layer and low nutrient supply. For both areas, lower extent and density of seagrass are hypothesized to have existed historically (Hall et al., 1999) and are expected to continue under restored conditions. Thus the ranges and threshold values of the spatial extent (SE) indicator are scaled to that reduced expectation (0.30–0.50 for a "fair" score). For the Central, Southern and Western zones, a higher threshold value (0.60) is required for a score of "fair" and 0.80 for "good" in the spatial extent index.

Similarly, the goal for seagrass abundance (SA) metric is to maximize the cover score to the extent possible. Restoration includes the goal of prevention of extreme densities of *Thalassia* to prevent outstripping the carrying capacity of the system. However, the resolution of the abundance indicator (SA) is not sufficient to gauge this, as the indicator is not species-specific. A 1.0 score could indicate an abundant but healthy mix of several species or a bed dominated by *Halodule*, neither of which is considered problematic. Even though a bed may be highly dense, if the bed is diverse,

Table 1

Basin-specific targets for Florida Bay seagrass status metrics nominally based on 10-year monitoring program record for each FATHOM basin, although some target ranges were calculated based on shorter datasets. The zone within which each basin lies is indicated (NE, northeastern; S, southern; W, western; C, central, TR, transition). Numbers in each column represent the bound between "poor" and "fair" scores left of the comma, and between "fair" and "good" scores to the right. Zero and one are the lower and upper bounds for all ranges.

FATHOM basin	Name	Zone	Spatial extent (1)	Seagrass abundance (2)	Species dominance (3)	Target species (4)
5	Barnes Sound	NE	0.4, 0.6	0.1, 0.3	0.2, 0.5	0.1, 0.3
6	Manatee Bay	NE	0.4, 0.7	0.1, 0.2	0.2, 0.5	0.1, 0.3
7	Long Sound	TR	0.4, 0.7	0.1, 0.4	0.3, 0.7	0.1, 0.5
8	L. Blackwater Sound	NE	0.5, 0.7	0.1, 0.3	0.2, 0.6	0.1, 0.3
9	Blackwater Sound	NE	0.4, 0.6	0.1, 0.3	0.2, 0.7	0.1, 0.3
12	Nest Keys Basin	TR	0.4, 0.6	0.1, 0.4	0.3, 0.7	0.1, 0.5
13	Joe Bay	TR	0.4, 0.6	0.1, 0.4	0.3, 0.7	0.1, 0.5
14	L. Madeira Bay	TR	0.3, 0.6	0.1, 0.4	0.3, 0.5	0.1, 0.5
15	Tern Key Basin	NE	0.4, 0.7	0.1, 0.3	0.2, 0.5	0.1, 0.3
21	Captain Key Basin	S	0.6, 0.8	0.5, 0.7	0.1, 0.4	0.1, 0.4
22	Russell Key Basin	C	0.6, 0.8	0.4, 0.6	0.2, 0.4	0.1, 0.4
24	Madeira Bay	C	0.6, 0.8	0.4, 0.6	0.2, 0.5	0.1, 0.4
32	Twin Key Basin	S	0.6, 0.7	0.5, 0.7	0.1, 0.5	0.1, 0.4
34	Whipray Basin	C	0.6, 0.7	0.4, 0.6	0.2, 0.5	0.1, 0.4
37	Rankin Lake	C	0.6, 0.7	0.4, 0.6	0.2, 0.6	0.1, 0.4
38	Rabbit Key Basin	W	0.6, 0.8	0.5, 0.8	0.2, 0.5	0.1, 0.3
39	Johnson Key Basin	W	0.6, 0.8	0.3, 0.5	0.3, 0.5	0.1, 0.3
40	Catfish Key Basin	W	0.6, 0.8	0.3, 0.5	0.3, 0.5	0.1, 0.3
47	Duck Key Basin	NE	0.3, 0.5	0.1, 0.3	0.2, 0.6	0.1, 0.4

it is likely to be more stable and resilient, and unlikely to experience die-off. Moreover, the BBCA sampling method does not have sufficient resolution to distinguish between high and extreme abundances—all coverage values between 75% and 100% have a BBCA score of 5. Given these uncertainties, the scoring system is designed not to penalize for high SAV abundance (scores near 1.0), meaning that a 1.0 is an optimal SA score. Our indicator framework places a greater emphasis on community diversity (scored via the species dominance indicator, SD, discussed below) than on targeting reduced plant abundance as a means of ameliorating potential danger to the carrying capacity. As with spatial extent, target ranges for seagrass abundance in basins of the Northeastern and Transition zones have lower thresholds for abundance requirements (from 0.2 to 0.4) for a status of "good." In basins of the Central, Southern and Western zones, higher values are targeted (0.5–0.8). In the nutrient-sufficient Western zone, much higher seagrass abundance occurs relative to in the Northeastern zone and is expected to continue under restoration projections.

The species dominance indicator (SD) is basin and zone-specific. Species composition tends to be naturally dominated by *Thalassia* in the marine Southern and Western zones and to be more mixed in other parts of the bay. In basins of the Central, Northeastern and especially the Transition zones three species – *Thalassia*, *Halodule*, and *Ruppia* – may potentially co-exist within the same basins along the salinity gradient. Ranges for the species dominance indicator are set to recognize this, with higher dominance levels (lower indicator scores) allowed within the "good" range for Western and Southern basins (0.4–0.5) than for the more estuarine basins where greater species diversity is expected (0.5–0.7). We expect that as restoration proceeds and freshwater flow increases, areas in the northeastern bay presently inhabited by *Thalassia* and/or *Halodule* will be replaced by a *Ruppia*–*Halodule* mix or pure stands of *Ruppia* (Fourqurean et al., 2003). Elsewhere in the bay, we expect that hydrologic and salinity variability will reorganize the community structure, potentially converting dominant stands of *Thalassia* to a *Thalassia*–*Halodule* mix.

The target species indicator (TS_f) favors the presence of multiple species appropriate to targeted salinity conditions and gives a lower score for monotypic stands. It indicates whether community composition is moving in the desired direction in response to increased freshwater flow. A minimum of 0.10 is considered the target for sub-dominant species for "fair" status for all basins, while between 0.30 and 0.60 is the threshold for "good" status, depending on the basin. A higher requirement was set for a "good" species diversity score for the basins of lower and more variable salinity in the Transition and Northeastern and Central zone basins. In these more estuarine areas, *Ruppia* is specified as a desired target for enhanced cover. Within all basins, *Halodule* is expected to increase its presence according to the target species index, more in the Northeastern and Central zone basins than in others. *Halodule* is expected to increase in abundance but not to replace *Thalassia* as *Ruppia* will likely do in the basins of the Transition zone.

3.7. Conceptually aggregating the metrics

Toward the goal of aggregating information from individual indicators into an integrated index, we conceptualize the four indicators as residing on two sets of linking axes (Fig. 9). The extent and abundance indicators are combined in a compound metric we call the seagrass abundance index A, which incorporates spatial and abundance qualities of beds at the basin scale. The species dominance and target species indicators are combined in a compound metric called the seagrass species index B, integrating scores for the presence and diversity of beneficial species in a basin. The paired indicators on these axes are combined via conditional logic-gates to yield "poor," "fair" and "good" scores for the aggregate indexes, indicated by red, yellow and green symbols. The scoring matrix for determining index A is shown in Table 2. This index is conservative, indicating the criticality of having both extent and abundance of SAV. When combining the pair for index A, the lower score determines the aggregate score. A score of green for both of the *A*-axis indicators satisfies the condition for a good overall score. Green and yellow yields yellow; green and red, yellow and red or two red scores will trigger a combined red score.

Index B tracks the diversity and presence of sub-dominant species relative to *Thalassia* and follows the logic gates depicted in Table 3. This index is a bit less conservative than index A in that the better score in each pair determines the aggregate score. Yellow and green yields green; yellow and red yields yellow and so on. This biases the aggregate score upward in recognition of the positive effects of either a particular target species or a diversity of species to the community.

A final aggregation step combines index A and index B into a grand summary score for each basin via what we term the carrying capacity index C. Index C tracks the extent and abundance of SAV, and in extensive, densely populated beds, assesses whether the dominance score of *Thalassia* would cause concern that monotypic dominance could lead to die-off. High density in itself is not a

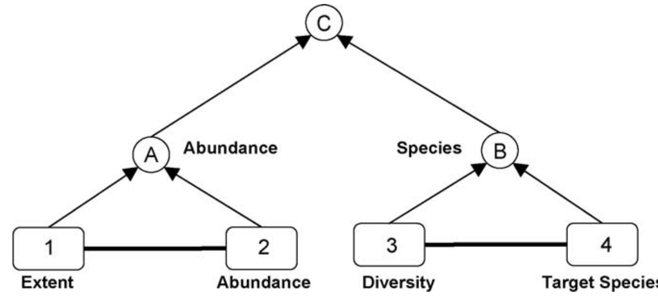

Fig. 9. Conceptual model of the aggregation of four SAV indicators (#1–4) into two indexes (A and B) and subsequent aggregation into a summary carrying capacity index (C).

Table 2
Lookup table of decision gates for abundance index A, aggregating extent and abundance indicator metrics at zone scale. This is a conservative combining of the two supporting indicators (e.g. green + yellow = yellow).

Case	Extent metric (1)	Abundance metric (2)	Abundance index A
1	Green	Green	Green
2	Green	Yellow	Yellow
3	Yellow	Green	Yellow
4	Yellow	Yellow	Yellow
5	Yellow	Red	Red
6	Green	Red	Red
7	Red	Green	Red
8	Red	Yellow	Red
9	Red	Red	Red

Table 3
Lookup table of decision gates for species index B, aggregating dominance and target species indicator metrics at zone scale. This is a more liberal combining of the two supporting indicators (e.g. green + yellow = green).

Case	Dominance metric (3)	Species metric (4)	Species index B
1	Green	Green	Green
2	Green	Yellow	Green
3	Yellow	Green	Green
4	Yellow	Yellow	Yellow
5	Yellow	Red	Yellow
6	Green	Red	Yellow
7	Red	Green	Yellow
8	Red	Yellow	Yellow
9	Red	Red	Red

Table 4
Lookup table of decision gates for carrying capacity index C, aggregating abundance and species indices (A and B) at the basin scale (e.g. green + yellow = green).

Case	Abundance index A	Species index B	Carrying capacity index C
1	🟢	🟢	🟢
2	🟢	🟡	🟢
3	🟡	🟢	🟢
4	🟡	🟡	🟡
5	🟡	🔴	🟡
6	🟢	🔴	🟡
7	🔴	🟢	🟡
8	🔴	🟡	🟡
9	🔴	🔴	🔴

negative condition—for example dense *Ruppia* in the freshest part of the system is not known to be deleterious and dense *Thalassia–Halodule* mixtures have not historically led to die-off. Likewise, even monotypic beds of *Thalassia* are not necessarily on a track for collapse, especially over relatively short periods of 1 or 2 years. However, a large expanse of highly dense seagrass composed entirely of *Thalassia* that persists over many years is hypothesized to create greater system instability and the potential for bed collapse. The carrying capacity index is designed to capture information pointing to that probability.

The logic matrix for index C, as shown in Table 4, is the same as for index B in that the index is biased toward the better of the combined scores of index A and index B. This less conservative approach is taken for several reasons, first of which is not to double-count the stricter bias already imposed by index A. Secondly, as discussed, because of the long timescales sometimes involved in manifesting carrying capacity problems (multi-annual to decadal), and because the system is, to an extent self-correcting, conditions in an overbuilt system may dissipate before a catastrophic collapse occurs. Finally, though dense monotypic beds may become problematic over long time frames and under specific conditions, even beds of low diversity are preferable to sparse or absent seagrass.

3.8. Spatially aggregating the metrics

For scaling metrics from basins to zone-based assessments, Indicator ranges were assigned to zones based on simple numerical average of upper and lower thresholds for all basins pooled within each zone (Table 5). In combining the basin scores into regional scores, size of basin is not taken into account and scores are not area-weighted. Although some basins in Florida Bay are not sampled in the monitoring program, the distribution of basins sampled covers a representative area of each zone in the bay and encompass the fresh-to-salt salinity gradient as well as the east-west nutrient gradient.

Aggregation of the three compound indexes across the five zones derives a single bay-wide score for each of the three indexes. Spatial aggregation for the indexes A, B or C, and any underlying indicator is done by numerical averaging of the five zone scores using the following values: red = 0, yellow = 0.5, green = 1.0. The sum for the five zones is divided by five to determine a bay-wide average for any index A, B and C, and a score for each is assigned as follows: poor (red): 0–0.3; fair (yellow): 0.3–0.7; good (green): 0.7–1.0. Index C thus aggregated provides a bay-wide system status indicator for SAV.

3.9. Current status of Florida Bay SAV

The SAV assessment indicators were applied to Florida Bay for 2007 and compared to scores for 2006, as a proof-of-concept test of the evaluation and scoring methodology. The summary index

Table 5
Seagrass indicator metrics and ranges for zones. These ranges are the averages of incorporated basin-level scores.

	Northeastern	Central	Western	Southern	Transition
Spatial extent (a)					
🔴	0.0–0.40	0.0–0.60	0.0–0.60	0.0–0.60	0.0–0.40
🟡	0.40–0.65	0.60–0.75	0.60–0.80	0.60–0.75	0.40–0.60
🟢	0.65–1.0	0.75–1.0	0.80–1.0	0.75–1.0	0.60–1.0
Abundance (b)					
🔴	0.0–0.10	0.0–0.40	0.0–0.45	0.0–0.50	0.0–0.10
🟡	0.10–0.30	0.40–0.60	0.45–0.65	0.50–0.70	0.10–0.50
🟢	0.30–1.0	0.60–1.0	0.65–1.0	0.70–1.0	0.50–1.0
Species dominance (c)					
🔴	0.0–0.20	0.0–0.20	0.0–0.25	0.0–0.10	0.0–0.30
🟡	0.20–0.55	0.20–0.55	0.25–0.50	0.10–0.45	0.30–0.70
🟢	0.55–1.00	0.55–1.0	0.50–1.0	0.45–1.0	0.70–1.00
Target species (d)					
🔴	0.0–0.10	0.0–0.10	0.0–0.10	0.0–0.10	0.0–0.10
🟡	0.10–0.30	0.10–0.40	0.10–0.30	0.10–0.40	0.10–0.50
🟢	0.30–1.0	0.40–1.0	0.30–1.0	0.40–1.0	0.50–1.0

scores for each zone are presented in Table 6. Three zones showed good SAV abundance indexes in 2007 improving against both 2006 and the 10-year trend with exceptions in Central zone and Southern zone. The target species index in the Transition zone was poor, reflecting the absence of *Ruppia* in 2006 and 2007 while other zones showed increased diversity. The status of the carrying capacity index C is projected onto the zone map in Fig. 8 and shows a status of fair in the Transition, Central and Southern zones and good in the Northeastern and Western zones.

The underlying abundance indicator (spatial coverage and abundance) in Table 6 is in generally good condition or on an improving trend except in the Central and Southern zones. These zones had previously exhibited loss of SAV through die-off and have since become sites of recurring algal blooms which may hamper re-vegetation. The Northeastern zone metric has declined during a 2-year bloom, though slightly above the "good" threshold.

The target species indices (species diversity and presence of specific target species) in the Transition zone have shown clear decline in the *Ruppia* target species over the past 2 years. Northeastern, Southern and Transition zones have shown some improvement in this indicator due to increased *Halodule* presence. The Northeastern zone has generally low SAV abundance but high spatial coverage and species diversity of *Thalassia*, *Halodule* and *Ruppia*. The Transition zone has mixed populations of *Thalassia–Halodule* and *Ruppia*. The Southern zone has high occurrence of mono-specific *Thalassia* stands while *Thalassia* and *Halodule* co-occur in the Central zone. The Western zone is productive with dense, diverse stands of *Thalassia*, *Syringodium*, and *Halodule*. It is expected that as additional freshwater is introduced to the system through restoration implementation, *Ruppia* will expand farther into the bay and *Thalassia* and perhaps *Halodule* will decline in the Transition zone as Long Sound, Joe Bay, Little Madeira Bay and Terrapin Bay are expected to lose higher salinity species. *Thalassia* may decline in abundance and/or extent in the northeastern bay and the central bay in response to lower salinity.

4. Discussion

This suite of SAV status metrics consists of four indicators of the seagrass community that are considered important ecosystem and SAV diagnostics. The metrics are directly related to SAV RECOVER restoration targets and can be calculated from standard field measurements (Braun-Blanquet Cover Abundance) widely used in monitoring programs throughout coastal Florida. The indicators

Table 6
Application of the indicator scoring system for Florida Bay SAV for 2006/2007.

Zone/performance measure	Last status[a]	Current status[b]	2-Year prospects	Current status[a]	2-Year prospects
Northeastern					
Abundance	🟢	🟢	🟡	Abundance is good in all basins monitored in the Northeastern Zone with a composite score of 0.81 (max = 1) for extent and abundance of SAV.	Projections are fair; transient reduction in abundance may continue as effects of a persistent algal bloom impact SAV.
Target species	🟡	🟢	🟡	A score of 0.81 (good) is measured for current (2007) species mix and presence of subdominants *Halodule* and *Ruppia*, up from 0.63 in 2006.	Projection is for increased species diversity and increasing niche creation with additional freshwater inflows, further enhancing diversity are offset near-term by possibility of continued drought.
Transition zone					
Abundance	🟢	🟢	🟢	Highest scores for abundance are found in basins in the Transition Zone, increasing from 0.83 to 0.91 in 2006–7.	Continued high abundance is expected with current conditions or increased freshwater flow.
Target species	🔴	🔴	🔴	Generally good species mix in 2006 was reduced in 2007 due to dominance by either *Thalassia* or *Halodule* in areas and reduced co-occurrence of the two. Good Dominance scores are offset by lack of target *Ruppia* in this zone.	Scores are expected to be more variable in this region due to salinity extremes and variable nature of freshwater input. Restoration of freshwater flow and *Ruppia* will not occur within 2 years.
Central					
Abundance	🟡	🔴	🟡	Abundances in Central Zone basins were marked by low scores throughout, based mostly on low density, trending lower in several basins in this zone in recent years. Spatial coverage was generally very good.	Caution is indicated for this area as it is prone to hypersalinity and algal blooms that can reduce SAV cover. Restoration is designed to improve conditions but 2 years is likely too short a time to manifest positive impacts.
Target species	🟡	🟢	🟢	Increasing presence of sub-dominant target species (*Halodule*) has improved in this region though a slight reduction in species evenness was noted.	Prospects for continuing improvements in diverse species composition are good even under current conditions.
Southern					
Abundance	🟢	🟡	🟡	The Southern Zone shows high spatial extent (0.88) but a low score for the SAV abundance index (avg. 0.34) with slight decline into the yellow criterion in one basin.	Recent phytoplankton blooms may be reflected in lower abundance scores; even with increased flows improvements in SAV abundance not likely.
Target species	🔴	🟡	🟡	In the Southern Zone region basins monitored, *Thalassia* dominance is reflected in a poor, though improving, dominance score (0.25).	Conditions have improved but are not expected to change appreciably in this region in the near term.
Western					
Abundance	🟢	🟢	🟢	Western Zone basins are marked by high scores (1.0) for both extent and abundance.	Trends have been of continuing improvement over the long-term average and are expected to continue.
Target species	🟢	🟢	🟡	Although on average, the zone has very high scores for dominance (0.75), one area has shown losses in diversity and decline of target sub-dominant species in 2006.	Caution reflects some decline of diversity and target species in a component (Johnson Basin) of overall Western Zone score over 2 years.

All zones for which calculations are made are based on 10-year datasets.
[a] 2006 data.
[b] 2007 data.

provide a summary of the status and trends of Florida Bay seagrasses over a very broad area (roughly 2000 km^2).

4.1. Summary of indicator use and relevance

An effective set of ecosystem restoration indicators applies across relevant temporal and spatial scales and provides a comprehensive summary of ecosystem status and trends. The development of metrics and their target ranges is based on relationships expressed in the Conceptual Ecological Model for Florida Bay (Rudnick et al., 2005) that link hypersalinity (and other factors) to overly dense monocultures of *Thalassia* and to seagrass community die-off. Restoration management of Florida Bay freshwater inputs from the Everglades aims for both seagrass community survival and for improving habitat value through achieving appropriate density, extent and diversity targets. Indicator ranges are assigned at the basin level according to site-specific conditions and targets, then combined spatially and conceptually to aggregate information for the entire bay.

Temporal frequency of monitoring for system-wide seagrass indicators is quarterly to annually, commensurate with the nature of seagrass growth and the timescale on which a meaningful response to stressors occurs and can be detected. Seagrass, especially *Thalassia*, is a relatively slow response ecosystem component compared to water quality measures (e.g. turbidity) or phytoplankton. *Thalassia* can withstand adverse conditions for significant periods as evidenced by mesocosm stress experiments (Koch et al., 2007d) and nutrient insufficiency can be compensated by internal stores (Fourqurean and Robblee, 1999). Seagrasses integrate ecological processes and conditions over timescales of weeks to months or even years and *Thalassia* is likely to be the slowest-reacting component of the SAV group. The response times of components of the seagrass community range from relatively rapid responses in *Halodule* (days to weeks) to slower responses in

Thalassia (months to seasons). It is expected that significant community-level change would be detectable on an interannual basis.

4.2. Significance of the indicator to Everglades restoration

As restoration proceeds, the effect of increased freshwater input is expected to be beneficial to SAV (RECOVER, 2006) by encouraging species diversity and preventing overshooting the carrying capacity. Progress will be assessed both qualitatively and quantitatively in expansion of seagrass coverage, increased abundance, and increased diversity in the seagrass community. Incremental assessment of progress toward (or away from) restoration goals in a format readily accessible to mangers, policy-makers and stakeholders is critical to planning and implementing an adaptive management strategy.

The causality of environmental impacts on seagrasses is not explicitly revealed by these metrics. System-wide Indicators merely provide an early warning; ancillary data and the interpretation of the metrics and their trends can give additional information as to the causes of adverse effects, including salinity, nutrient enrichment, turbidity, low oxygen or other stressors. Nutrient enrichment may become an issue by creating conditions of increased epiphyte and phytoplankton development, reducing light and increasing BOD in the sediments. Evidence of diseases such as the parasitic slime mold *Labyrinthula* (Durako and Kuss, 1994) may also indicate areas requiring further monitoring and research.

4.3. Communicating the seagrass indicators

The indicator summary is intended to be part of the System Status Reports regularly reported to the U.S. Congress as part of the RECOVER updates (Doren et al., 2008). Status of "good," "fair" and "poor" condition is illustrated in the stoplight report card format (green, yellow and red, respectively) with explanatory text and an underlying detailed report. Trends relative to previous time points describe "improving," "stable" and "declining" conditions, also using the tri-colored diagrams. This interpretation system is intended to foster both understanding and outreach to community and government agencies to increase awareness of problems and solutions for the ecosystem. A comprehensive analysis of system-wide indicators will accompany the "rolled-up" summary metrics in the form of a technical report that evaluates relationships between the system-wide indicators and ambient/antecedent environmental conditions. The underlying report will detail the timescale of recent and projected system changes and of the efficacy of restoration activities.

4.4. Modeling and long-term applications of indicators

In addition to continued monitoring, further research and model development is needed is in order to understand cause and effect relationships in seagrass community ecology and to build reliable predictive capabilities. In particular, the dynamics of *Halodule*, *Ruppia*, and other SAV species are not as well understood as those of *Thalassia*, nor are the inter-specific interactions of the plants. Modeling studies (Madden and McDonald, 2005, 2006) have indicated the importance of nutrient–salinity interactions within the benthic community and these interactions need to be quantified in order to accurately predict SAV population dynamics. These interactions likely involve microbial and abiotic reactions (e.g. phosphorus-carbonate chemistry) within sediments and seagrass roots. Competition among SAV species and with phytoplankton for nutrients and light is another area ripe for research.

While statistical models (Thayer and Chester, 1989; Thayer et al., 1999; Johnson et al., 2005) indicate the importance of habitat quality to higher trophic levels, the habitat value of different types of SAV beds (density and species composition, especially for *Ruppia* and nearshore species) has yet to be experimentally quantified. Dynamic ecological models now exist for the *Thalassia*, *Halodule* and *Ruppia* communities of the bay and are being used to predict the likely target species and demographics of the community (Madden et al., 2007). In turn, the metric ranges and thresholds defined in the system-wide indicators project provide a unified framework within which to assess and interpret seagrass model output.

The bay is considered to be moderately enriched by nutrients (Rudnick et al., 1999; Bricker et al., 2007) and simulation modeling reveals that the seagrass community can be adversely impacted by increased nutrient inputs (Madden et al., 2007). As evidenced by the persistent phytoplankton bloom in the eastern part of Florida Bay (Rudnick et al., 2006), even transient nutrient increases can have wide-ranging and long-term impacts. A phytoplankton bloom in the oligotrophic eastern bay has persisted since October 2005. Peak chlorophyll *a* concentrations near 30 ug/L greatly exceed values recorded in this area through 17 years of coastal water quality monitoring. Water quality monitoring indicates that the eastern bloom coincided with a large and not-fully understood increase in total phosphorus (TP) in the bloom area. This bloom along with diminished light penetration appears to have caused temporary SAV loss ($\sim$2 years) in the two basins where the eastern bloom is centered (Rudnick et al., 2006). Simulation models of seagrass and phytoplankton dominance (Madden et al., 2007) indicate that the ecosystem is fairly sensitively poised and can be tipped toward a less desirable pelagic regime by nutrient enrichment.

5. Conclusion

The SAV indicators developed here are based on a history of monitoring data and analysis about the key functions and ecosystem services provided by the seagrass community. It is of prime importance to the restoration program that a set of standardized metrics be used to give a regular assessment of the health and trends of the resource, measured at the proper spatial and temporal scale. Water quality improvement in the Florida Bay estuary and fisheries management in Florida Bay and the Florida Keys National Marine Sanctuary will depend strongly on the status of the seagrasses. Current analysis indicates that the SAV community is of variable status, generally good in the Northeastern and Western zones and fair in the Transition, Central and Southern zones. Under an Adaptive Management protocol, the system-wide indicators will be regularly evaluated and updated as to their effectiveness and utility as a science-based planning and communications tool. We expect that the bay's water quality and its overall system productivity, both primary production and secondary production, are likely to reflect the state of the SAV indicators.

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