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Aquatic fauna as indicators for Everglades restoration: Applying dynamic targets in assessments

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ABSTRACT

A major goal of the Comprehensive Everglades Restoration Plan (CERP) is to recover historical (pre-drainage) wading bird rookeries and reverse marked decreases in wading bird nesting success in Everglades National Park. To assess efforts to restore wading birds, a trophic hypothesis was developed that proposes seasonal concentrations of small-fish and crustaceans (i.e., wading bird prey) were a key factor to historical wading bird success. Drainage of the Everglades has diminished these seasonal concentrations, leading to a decline in wading bird nesting and displacing them from their historical nesting locations. The trophic hypothesis predicts that restoring historical hydrological patterns to pre-drainage conditions will recover the timing and location of seasonally concentrated prey, ultimately restoring wading bird nesting and foraging to the southern Everglades. We identified a set of indicators using small-fish and crustaceans that can be predicted from hydrological targets and used to assess management success in regaining suitable wading bird foraging habitat. Small-fish and crustaceans are key components of the Everglades food web and are sensitive to hydrological management, track hydrological history with little time lag, and can be studied at the landscape scale. The seasonal hydrological variation of the Everglades that creates prey concentrations presents a challenge to interpreting monitoring data. To account for the variable hydrology of the Everglades in our assessment, we developed dynamic hydrological targets that respond to changes in prevailing regional rainfall. We also derived statistical relationships between density and hydrological drivers for species representing four different life-history responses to drought. Finally, we use these statistical relationships and hydrological targets to set restoration targets for prey density. We also describe a report-card methodology to communicate the results of model-based assessments for communication to a broad audience.

1. Introduction

1.1. *Overview of aquatic indicators*

An important goal for restoration of the Everglades is to recover breeding populations of wading birds. Currently, wading birds are nesting in greatly reduced numbers, and at very different locations, than recorded prior to 20th Century modifications of the ecosystem (Ogden et al., 2003). For this reason, wading bird nesting success is an endpoint, or attribute, of most conceptual models developed as hypotheses motivating restoration of the Everglades (Ogden et al., 2005; Doren et al., this issue). These conceptual models present hypotheses of causal linkage between environmental drivers

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controlled by managers and engineers (i.e., hydrology and water quality), and restoration goals. In freshwater Everglades marshes, the environmental drivers are hydrological and linked to the timing and volume of water delivery and to water quality. Small-fishes and crustaceans are critical links of the food web that connect these hydrological drivers to wading bird nesting success. There is ample evidence that inadequate numbers of these animals at the right time and place limit wading bird nesting in South Florida marshes (Frederick and Spalding, 1994; Gawlik, 2002). This has led to the formulation of a Trophic Hypothesis for Everglades restoration: re-creation of historical (pre-drainage) linkages between rainfall and hydrology will restore dynamics of small-fish and crustacean communities permitting recovery of historic levels and locations of wading bird nesting (Fig. 1; RECOVER, 2004; Frederick et al., this issue).

Historic locations of rookeries are important for both management and ecological reasons. Former extensive rookeries in the southern Everglades National Park that are now absent or have dramatically reduced activity, have been replaced by rookeries located in less well-protected (i.e., not designated as Wilderness by the federal government) areas further north. This loss of the historic southern rookeries is associated with changes in water management that have altered historic qualities of the ecosystem, leading to a disruption of the linkage between small-fish and crustaceans, and wading birds. The disruption of this food-web linkage at the estuarine interface of the Everglades is the result of either diminished productivity of aquatic fauna or changed patterns of seasonal concentrations, making prey unavailable to wading birds.

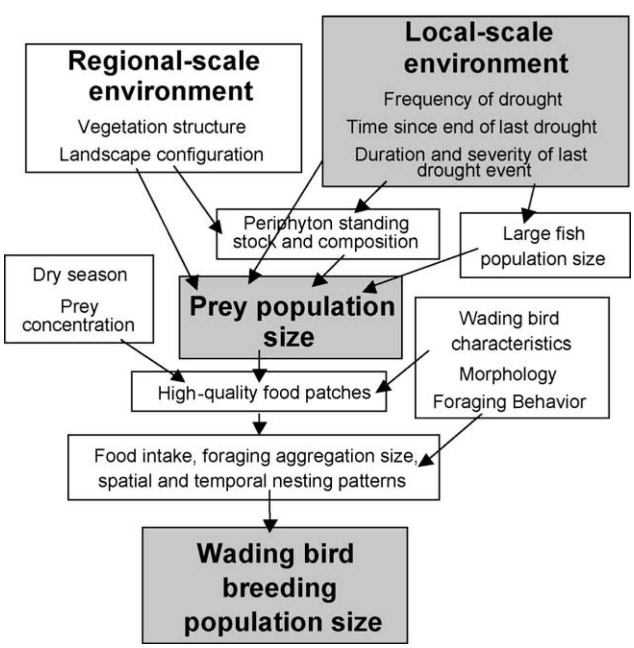

Fig. 1 – A simplified version of the Everglades Trophic Hypothesis illustrating the role of aquatic fauna in the restoration science plan. Arrows indicate key causal linkages. Gray boxes highlight focal components for assessment in this report: prey population size includes aquatic fauna; local-scale environment indicates environmental drivers under control of managers; wading-bird nesting rate is the goal of restoration activity.

Fish and freshwater crustacean community structure is very sensitive to hydrological conditions enabling it to serve as an indicator of the impact of hydrological alteration on aquatic faunal communities (Trexler et al., 2001, 2003). Research has linked three key aspects of Everglades' ecology to this indicator: (1) Top predators such as wading birds are directly dependent on prey density, especially fish and crustaceans (Frederick and Spalding, 1994); (2) Prey population structure, standing crop, and density are directly dependent on periphyton biomass, water depth, quality and distribution, the timing seasonal concentrations, and duration of drought conditions (Ruetz et al., 2005; Trexler et al., 2002; Turner et al., 1999); (3) Prey availability is directly dependent on prey density, water depth, timing of seasonal concentrations and duration of drought conditions (Gawlik, 2002). Therefore, the causal linkages of the Everglades Trophic Hypothesis for restoration are supported by past research.

The most important factors affecting contemporary aquatic animal abundances are loss of habitat (including extent of areas inundated), altered hydroperiod, water depth, frequency of drought (water depth $\leq$ 5cm), and water quality (Turner et al., 1999; Trexler et al., 2005). Drought is a particularly important phenomenon influencing Everglades aquatic animal communities because as the marsh dries its surface is exposed, eliminating habitat for aquatic animals and causing high mortality of most species. Further, water management actions leading to increased drought frequency and severity lengthen the time required for fish and crustaceans to recover to levels considered representative of the historical Everglades (Trexler et al., 2003). It takes from 3 to 8 years following each drought in a long-hydroperiod marsh (on average > 1 year of continuous inundation) for fish and crustacean populations to stabilize (Turner et al., 1999; Trexler et al., 2005). When droughts occur repeatedly at less than a 3–8 year interval, fish and crustacean populations are continually recovering from past droughts and may fail to reach densities sufficient to sustain large predators (Loftus and Eklund, 1994; Turner et al., 1999; Trexler et al., 2005). In a particularly encouraging finding, Trexler et al. (2005) observed that when water management created wetter conditions in areas of Everglades National Park that were previously over-dried, but not nutrient enriched, small-fish populations recovered within a few years to the numbers and community structure that are indicative of historical conditions. In addition to the effects of drought, phosphorous enrichment can also have important effects on aquatic fauna populations.

Phosphorus enrichment increases fish density, at least at low and intermediate levels (Rader, 1999; Turner et al., 1999; Gaiser et al., 2005; King and Richardson, 2007). This is linked to an increase in macroinvertebrates that fish consume (McCormick et al., 2004; Smith, 2004; King and Richardson, 2007) and, as phosphorus loading increases, the periphyton mat breaks down, possibly permitting greater access to food sources in the mat (Liston, 2006). However, this appears to be a temporary phenomenon because as eutrophication develops, the food resources may be reduced because of oxygen depletion and loss of habitat structure provided by periphyton mats (Turner et al., 1999; McCormick et al., 2004; King and Richardson, 2007;

Liston and Trexler, 2008). In contrast to over-dry conditions, long time periods are required to mitigate the impacts of phosphorous enrichment on Everglades' aquatic plant and animal communities.

Models of differing levels of complexity have been developed to assess the impact of alternative hydrological scenarios on small-fish. The model ALFISH simulates fish density dynamics across the entire Everglades' landscape based on hydrological drivers (Gaff et al., 2000). Recent work has found good correspondence between ALFISH output and field collections (Gaff et al., 2004). Spatial models of trait-based community dynamics set in a food-web context are under development (DeAngelis et al., 2005). Simple statistical models have also been developed for assessments comparing observed data to hydrological model output, including the Natural System Model (NSM) that simulates hydrology of the historical ecosystem prior to addition of canals and levees (National Research Council, 2007:200; Trexler et al., 2003).

Assessment of management success in wetlands, such as the Everglades, is particularly challenging because they are inherently dynamic (Wilcox et al., 2002). Wetlands are periodically inundated and dried out, which provides a challenging environment for aquatic animals and necessitates adaptations to drought conditions (Sharitz and Batzer, 1999; Batzer and Sharitz, 2007). Thus, secondary succession following local drying events plays a major role in determining the aquatic animal composition in any part of a wetland at any time it is sampled. If assessment can be conducted by aggregating data over time scales that are long compared to the return time of drying events, the dynamic nature of wetlands is not such a problem for environmental assessment. However, application of adaptive management protocols requires assessment and feedback to managers on time scales set by fiscal years and construction schedules. In such management contexts, accounting for hysteresis is a major challenge and requires benchmarks for interpreting indicator data that are dynamic with respect to the time scale of hydrological and biological cycles. For example, the time in days since a site was re-flooded following the most recent drying event is an important parameter for explaining patterns in fish density in the Everglades because of its linkage to dispersal and post-drought population growth (Trexler et al., 2005).

In this paper, we propose a dynamic assessment method for the aquatic fauna indicator that links community responses to hydrological management. Our method focuses on indicators that are in the middle of the Everglades Trophic Hypothesis, a causal model linking hydrology to wading birds. Our goal is to evaluate restoration of conditions considered necessary for recovery of wading bird nesting to historical levels. Our assessment is 'dynamic' because our targets fluctuate with rainfall and seek to capture temporal dynamics of Everglades marshes that are considered critical to the historical mechanisms of production and concentration of wading bird prey.

1.2. *Hypotheses related to fish and crustacean indicator*

The Monitoring and Assessment Plan (MAP) of the Comprehensive Everglades Restoration Plan (CERP) includes the hypothesis that restoration of historical patterns (timing and quantities) of water flow will lead to the following effects for aquatic animals (RECOVER, 2004):

- Restore the density, community characteristics, size structure, and taxonomic composition of marsh fishes and other aquatic fauna to levels that support sustainable breeding populations of higher vertebrates;
- Shift the distribution of high density populations of marsh fishes and other aquatic fauna from artificially pooled areas (i.e., water conservation areas) to restored wetlands in the southern Everglades;
- Shift the foraging distribution of wading birds in response to expected trends in the density, distribution, and concentration of prey organisms.

1.3. *What areas of the Everglades does this indicator cover?*

Fish and crustaceans are found in virtually all of the Everglades freshwater wetlands and the southern estuarine areas. These areas include the following: RECOVER & SCG regional modules, Greater Everglades, Florida Bay and Southern Estuaries, Lake Okeechobee, and the Kissimmee River Basin (see Fig. 1 in Doren et al., in this issue).

1.4. *Why is this indicator important for Everglades restoration?*

1.4.1. *The indicator is relevant to the Everglades ecosystem*

Small-fish and crustaceans are ubiquitous in the Everglades and their productivity is tied to highly productive periphyton mats found there (Geddes and Trexler, 2003; Williams and Trexler, 2006; King and Richardson, 2007; Gaiser, this issue). Though high concentrations of small-fish and crustaceans are critical to sustain wading bird populations, their standing crop is unusually low outside of the dry-season conditions that concentrate their numbers into smaller pools. In a literature review, Turner et al. (1999) compared the Eltonian pyramid of biomass for periphyton, macroinvertebrates, and fishes from the Everglades to data taken from other aquatic systems. They found that natural characteristics of Everglades environments include extremely high values of algal standing crop and primary production, but quite low standing crops of macroinvertebrates and fishes compared to other aquatic systems. This appears to be the result of oligotrophy in the ecosystem, which sustains periphyton mats that are largely inedible or unavailable for consumption (Geddes and Trexler, 2003; Chick et al., 2008), and recurrent disturbance from drying (Turner et al., 1999). Recent work indicates that these patterns are replicated in Karst wetlands around the Caribbean basin.

Small-fish and crustaceans (in the Everglades, crayfish and grass shrimp) are prey for wading birds, though the relative contribution of each to wading bird diets varies among species. Also, the ideal size classes of fish for consumption vary among wading bird species, roughly proportional to their body size. There are two species of crayfish in the Everglades, the Everglades crayfish (*Procambarus alleni*) and the slough crayfish (*Procambarus fallax*). It is not clear if either is more commonly consumed by wading birds, but the Everglades crayfish have a larger terminal size and can be very dense in both short-hydroperiod (on average < 1 year of inundation) areas or for the first year following a drought. They have been shown to colonize long-hydroperiod marshes following system-wide droughts and persist at modest densities for a year or so (Hendrix and Loftus, 2000). The slough crayfish has a smaller terminal size and is widespread in the Everglades in sites that have not dried for at least a year; for example, in 12 years of sampling in Water Conservation Area 3A, over 99% of the crayfish taken were slough crayfish. Indices of productivity (abundance and standing stock) of small-fish (approximately <8-cm standard length), crayfish, and grass shrimp play a prominent role in most RECOVER Conceptual Ecological Models and in CERP Interim Goals because of their place as prey for wading birds. These indices are called Performance Measures (PMs) in CERP documents.

1.4.2. *The indicator is feasible to implement*

There already exist funded cooperative research and monitoring programs for small-fish, crayfish, and grass shrimp that include landscape-scale monitoring. Furthermore, there are long-term data records covering over 25 years for some sites in Everglades National Park (Loftus and Eklund, 1994; Trexler et al., 2005). Data collection is ongoing that will lead to model development for estimating fish densities in regions where historical databases do not exist, for example the Loxahatchee National Wildlife Refuge (Water Conservation Area 1). Fish and crustaceans are included in the CERP Food-Web Monitoring Component that includes an index of food-web function and landscape connectivity (‘‘intactness’’).

2. Application of the aquatic fauna indicator

2.1. *Indicator PMs and metrics*

We have identified four patterns of population-level responses to marsh drying in wading bird prey species of the Everglades. We believe that these responses represent different life-history strategies for coping with drought stress in marshes of the Everglades (DeAngelis et al., 2005) and have selected indicator species to represent groups of species with similar strategies. Three patterns are found in fish and grass shrimp (Trexler et al., 2001, 2005; Ruetz et al., 2005; DeAngelis et al., 2005). These are: (1) slow recovery following drought, possibly taking years to regain pre-drought density (typical of bluefin killifish *Lucania goodei*, least killifish *Heterandria formosa*, grass shrimp *Palaemonetes paludosus*); (2) maximum density attained soon after drying events and lower densities a year or longer after drying (typical of flagfish *Jordanella floridae* and marsh killifish *Fundulus confluentus*); (3) a weak relationship between density and time since drying at a local site (unique in the Everglades to eastern mosquitofish *Gambusia holbrooki*). A fourth relationship is seen in crayfish and probably differs from fish and grass shrimp parameters because of their ability to burrow and tolerate moderate amounts of marsh drying (Dorn and Trexler, 2007). Crayfish display little or no relationship between time since re-flooding and density, but average water-depth over the past 6 months does explain moderate amounts of variability in their density (Dorn and Trexler, 2007). Everglades crayfish are more abundant when recent water depths have been shallow or drying is frequent, and slough crayfish are more abundant in deeper water and longer-hydroperiod sites (Dorn and Trexler, 2007). We have selected bluefin killifish, flagfish, eastern mosquitofish, and Everglades crayfish to make assessments because they represent the four life-history strategies and are frequent enough in our samples to provide adequate statistical power to detect effects we believe are important.

Monitoring programs for the Everglades Trophic Hypothesis focus on small aquatic animals (fish and macroinvertebrates routinely retained on 2-mm mesh sieves) and are conducted in the Everglades by use of a 1-m^2 throw trap (Kushlan, 1981; Loftus and Eklund, 1994). Several papers support use of this technique based on comparative evaluations with alternative methods that examined bias and efficiency in sampling fishes (Chick et al., 1992; Jordan et al., 1997) and macroinvertebrates (Turner and Trexler, 1997; Dorn et al., 2005) in Everglades marshes. Wolski et al. (2004) found little impact of long-term visitation that accompanies throw-trap sampling at fixed sites in the Everglades, further justifying the technique's use for monitoring. A history of PM development and fish monitoring in Everglades National Park is provided in Trexler et al. (2003).

Other monitoring methodologies focused on sampling larger fishes (approximately >8-cm standard length; Chick et al., 2004) and macroinvertebrates that pass through a 2-mm mesh (Turner and Trexler, 1997; King and Richardson, 2002; Liston and Trexler, 2005) have also been developed. However, these methods have not been adopted for monitoring the CERP Trophic Hypothesis because of technical challenges in applying them at the landscape scale. Large fishes cannot be sampled efficiently in areas inaccessible to airboats, which also are too slow to permit coverage of the entire Everglades ecosystem in a single wet season with a small number of field crews. Analysis of field samples of small macroinvertebrates is time consuming and our understanding of their linkage to hydrological management is still developing. Clearly, better understanding of these animals could yield powerful indicators of nutrient enrichment (King and Richardson, 2002, 2007; McCormick et al., 2004); however, periphyton-based metrics are already well developed for this role in landscape-scale monitoring of the Everglades (Gaiser, this issue).

2.2. *Making an assessment using the stoplight report-card system*

Assessments for the aquatic fauna indicator were made using forecasting modeling techniques that permit comparison of field-collected data to targets derived from hydrological restoration criteria (Trexler et al., 2003). This assessment protocol requires three steps: (1) gathering data on PMs though a monitoring program; (2) identification of PM target values by modeling that incorporates hydrological targets; (3) comparison of the PM target (model prediction using target hydrology) with the ‘‘observed’’ PM (model prediction using the observed hydrology).

Briefly, our protocol entails using observed rainfall data to generate hydrological targets from models derived by cross-validation (Hastie et al., 2001). Then, using generalized linear models (McCullagh and Nelder, 1989), we identify functional relationships between PMs and hydrological parameters, such as the number of days since a marsh site was re-flooded following the most recent drying event. We then use the equations of these estimated relationships and plug-in our hydrological targets to obtain predictions of the PM target.

To assess impacts we borrow concepts from the field of statistical quality control (SQC), which focuses on monitoring product quality in manufacturing. A goal of SQC is to determine whether variation of a process is due to chance sampling or an intervening cause (Messina, 1987); in other words, it seeks to characterize background variability in a process and identify when a new observation deviates more than is expected based on this background. To accomplish this, control limits are established that represent the normal variation of operations (i.e., not attributable to specific causes) for a given process (e.g., variation in the quality of product dispensed by a machine). The control limits are used to assess whether a process is ''in control'': variation in product quality is within the variation expected due to chance; or if the process is ''out of control'': variation of the process is outside of the control limits (i.e., there is something wrong that needs to be fixed). In our study, residuals from the model using the observed hydrology (observed PM minus predicted PM based on observed hydrology) are used to place control limits on how much variation we expect, given no change of management (i.e., in control). We use these limits to assess whether the target, the residuals of the model using the target hydrology (observed PM minus predicted PM based on target hydrology), deviates more than we would expect if there is no impact of management. This approach yields a simple transformation of hydrological targets into biological ones and the assessment protocol provides a visual illustration of biological function lost or gained by the success of managers to attain hydrological goals. A failure of the target to remain within the control limits may result because hydrological targets were not met or because the ecological model was incorrect.

We account for uncertainty and bias of the model fit used to calculate control limits because our models provide an imperfect fit to the original data that were used to generate the functional relationships for assessing impacts. This apparent ''lack of fit'' is because only hydrological drivers are included as predictor variables, though we know that biotic interactions, particularly predation, also affect fish and crustacean density (Trexler et al., 2005; Dorn and Trexler, 2007). These are necessarily purely management-based models focusing on direct management-to-PM causal linkages; predation effects are causally linked to management as well, but indirectly (hydrology to prey to predators). In addition to the quantitative challenge of including indirect relationships that are probably non-linear, we cannot routinely obtain data on predator density, so we have excluded predation from these assessment models. This does not appear to yield a major loss of information for most of the PMs because purely hydrological models can explain 60% or more of the observed variance; crayfish are the most apparent exception to this assertion (Dorn and Trexler, 2007).

To illustrate our assessment methodology, we used data from an 11-year (1996–2006) time series of monitoring data from 20 sites in Everglades National Park and Water Conservation Areas 3A and 3B. We evaluated the conformance of management between 2000 and 2006 to targets based on a series of very wet years that are indicative of historical conditions (1996 though 1999). Some aspects of water delivery operations to Everglades National Park were changed late in 1999, and officials there were interested in evaluating the impact of these changes on aquatic ecosystem function (SFNRC, 2005). We modeled the relationship between rainfall and surface-water depth at our monitoring sites in the target period, and used this relationship to project rainfall-based water-depth estimates into the assessment period (2000–2006). We then used hydrological targets derived from these predicted water-depths to generate the PM target.

Assessing whether there is an impact at our monitoring sites requires defining an ''impact'' based on the magnitude of deviation. We did this by estimating the following three control limit intervals that correspond to the deviation of the PM prediction, using the *observed* hydrology, from the observed PM: mean (baseline) $\pm$ 1.5, 2 and 3 standard errors. We evaluated impacts by determining whether the target interval (target $\pm$ 2 standard errors) fell within the control limit intervals. We defined two classes of impacts: individual years with extreme deviations (type A) and runs of consistent deviations outside the control limits (types B and C). We followed criteria similar to Allen et al. (1997) using concepts from control chart theory to define different criteria for determining an impact:

Type A: one year where the target interval is above the upper or below the lower 3 standard error control limit;
Type B: two out of three consecutive years where the target interval is above the upper or below the lower 2 standard error control limit;
Type C: four out of five consecutive years where the target interval is above the upper or below lower the 1.5 standard error control limit.

This method ensures that we take into account any lack-of-fit of the original model to the data (i.e., control limits) when assigning an impact, yielding conservative estimates of impacts that are coded as red stoplights (i.e., we have attempted to minimize misclassifying areas as having an impact that actually lacked impacts by setting a high standard to assign red stoplights). We used red stoplights to communicate impacts that correspond to Type A, Type B, and Type C conditions (or a combination of these). Yellow lights indicate caution and correspond to years where the mean of the target is above or below the 1.5 standard error control limit. Finally, green stoplights correspond to years where there is no impact, and the target falls within the 1.5 standard error control limits.

In general, we found that the target intervals for many of the monitoring sites in Everglades National Park were outside of the control limits between 2000 and 2005, while there was more substantial overlap of the target intervals with the control limits in areas north of Everglades National Park. We use the bluefin killifish PM to illustrate our model predictions (Fig. 2A) and stoplight communication tool. In several cases, more than one type of impact triggered assignment of a red stoplight in a given year (see text below red stoplights in Fig. 2B). For this assessment, we observed marked deviation

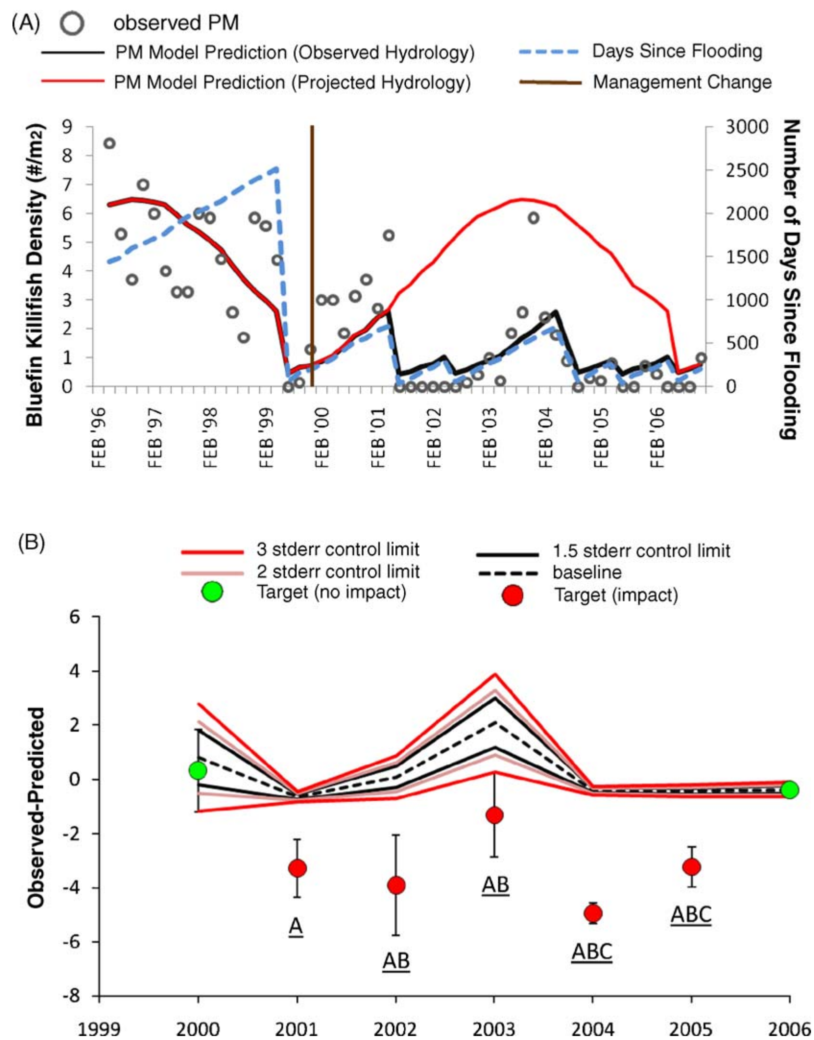

Fig. 2 – (A) An illustration of a time series from our monitoring data at site CP, plot A, using bluefin killifish as the PM. The observed PM correspond to the gray circles, the PM model prediction using the observed hydrology corresponds to the black line and the PM model prediction using the predicted hydrology corresponds to the red line. Hydrology is plotted as the observed cumulative number of days since the site was flooded (DSF) following most recent drying event (blue dotted line). Gaps in the time series for PM predictions and DSF are interpolated by taking the means of adjacent values. The brown line indicates when water management operations changed. (B) Standard error intervals for the deviation of observed and predicted values for the bluefin killifish PM at site CP from 2000–2006. The circles with standard error intervals indicate the target, the red and green circles correspond to years with impacts, and years without impacts, respectively. The letters below the red circles correspond to the type of impact (see text for more details). The lines correspond to the control limits: mean, ±1.5 standard error, ±2 standard error, and ±3 standard error.

between the observed and predicted values of the PM (value of PM based on projected hydrology) in the period after management was changed (Fig. 2A). When these impacts were summarized as annual stoplights, our criteria indicated impacts for this PM in years 2001 through 2005, but not in 2000 or 2006 (Fig. 2B). In some cases, more than one type of impact was noted in a year (some combination of types A, B, and C). These cases may deserve extra attention because they suggest both recent strong and persistent long-term impacts.

We use all four indicator species representing different life histories to assess management performance at each long-term monitoring site, and all fish summed to provide a summary for fish. For long-term monitoring at fixed study sites, we have reported assessments by sites and plotted them on maps to permit the identification of the location of an assessment within a given region (Shark River Slough and Taylor Slough in Everglades National Park; Water Conservation Area 3A and B, north of the park; Fig. 3). It is evident in Fig. 3 that in 2005, the majority of impacts for bluefin killifish occur in Shark River Slough and Taylor Slough regions. With the exception of flagfish, where most of the impacts occur in the water conservation areas, the other PMs are consistent with bluefin killifish in that the majority of impacts are concentrated in Shark River Slough and Taylor Slough. To succinctly illustrate the status of the regions in our study, and display status trends across time, we created region-wide

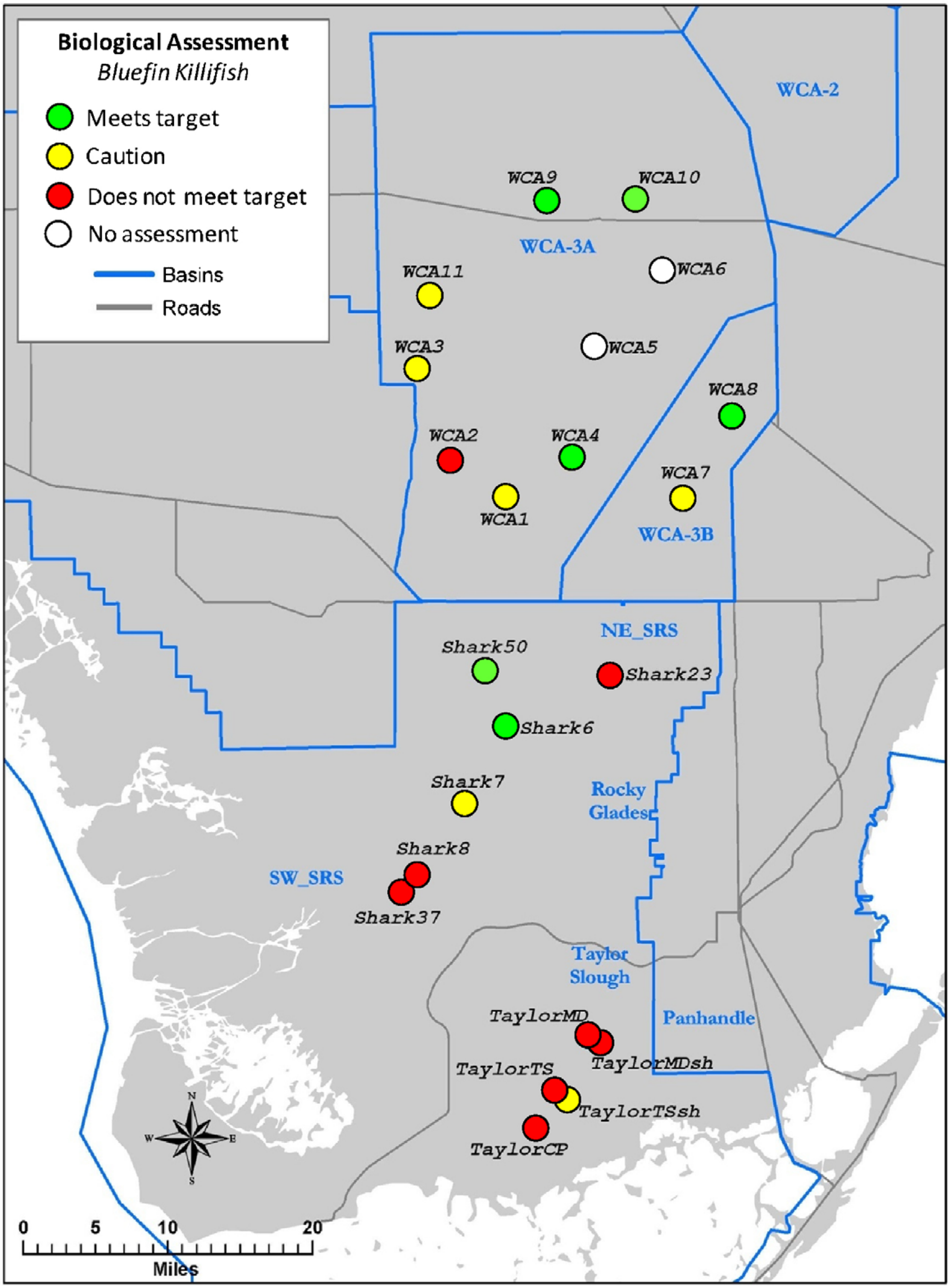

Fig. 3 – Regional assessment map with stoplight system for the bluefin killifish PM 2005 assessments are used to illustrate patterns. Final assessments will use more PMs than reported here.

stoplight assessment report cards across the entire time series (Fig. 4). The region-wide stoplight is calculated by ranking the stoplights (1 = green, 2 = yellow, 3 = red), taking the mean rank for the entire region, and assigning a status for the year in a given region. An overall diagnosis was determined by assigning a stoplight according to which type is in the majority for the time series. These suggest that additional evaluation is warranted in those regions with yellow stoplights, while the red stoplight for Taylor Slough indicates that this region merits immediate attention. Future assessments for the CERP

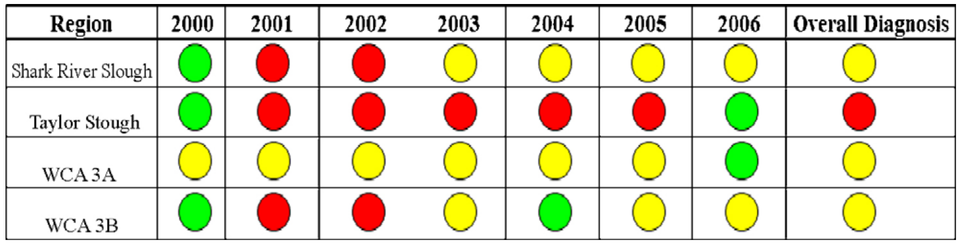

Fig. 4 – Stoplight assessment report card for bluefin killifish for all regions in the study. Regional stoplights were estimated by ranking the stoplights (1 = green, 2 = yellow and 3 = red) and taking the average rank for all sites in a given region. The overall diagnosis for each region was determined by choosing the stoplight type that appears in the majority of years in the time series.

program will use a landscape-scale monitoring program where over 150 sites are monitored each wet season (September through November; Fig. 5). Hydrological models will be used to generate targets for each PM at each sampling site, and observed data compared to those targets as described here. These results can then be mapped using kriging techniques (Goovaerts, 1997) to produce a truly landscape-scale assessment, similar to the map shown in Doren et al. (this issue) and Gaiser (this issue).

3. Discussion

The RECOVER Conceptual Ecological Models identify three major stressors to wetlands that affect populations of fish and crustaceans: water management practices (affecting hydrology and water quality); agricultural and urban development (affecting habitat loss, hydrology, and water quality); invasive exotic species (affecting habitat loss, abundance, and community composition) (RECOVER, 2004). Our assessment protocol focuses on isolating the first of these, water management, as a key driver of wading bird prey dynamics. While not explicitly focused on in our assessment, urban and agricultural development is intimately linked to water management, and is an important driver of water management activities. Exotic fish species are not currently included in our assessment protocol because at present there is no evidence that they directly affect wading bird prey species (Trexler et al., 2001). However, this may not be true in estuarine areas, where some exotic species (particularly Mayan cichlids *Cichlasoma urophthalmus*) can reach high densities and relative abundance. Future assessments that explicitly consider Mayan cichlids (or other temperature-sensitive exotic fish species) should include annual minimum temperature, which has been shown to be a key driver for their populations, in assessment models (Trexler et al., 2001).

3.1. *Effectiveness of fish and crustaceans as indicators of ecological restoration*

The Everglades National Park and the Water Conservation Areas are situated west of large areas of short-hydroperiod wetlands (marl prairies) that have been converted into agricultural and urban areas, and represent a large loss of habitat (Craighead, 1971). These areas, previously supporting fish, crustaceans and other aquatic fauna that fed wading birds, are irreversibly lost because of land-use changes and may have had a major impact on both the abundance and structure of aquatic communities (Loftus et al., 1992; Kobza et al., 2004). To mitigate these effects, hydrological restoration is needed.

Hydrological restoration is expected to improve habitat for fish and crustaceans in both long- and short-hydroperiod wetlands. In long-hydroperiod wetlands, restoration is expected to reduce the incidence and severity of marsh drying, enhancing populations that serve as sources for immigrants to short-hydroperiod marshes. In short-hydroperiod marshes, improved water management is expected to provide sufficient water levels to maintain more aquatic refuges such as solution holes, which also provide dry-season refuge and immigrants at the onset of the wet season (Kobza et al., 2004). Lengthening hydroperiod is also expected to lengthen the life span of fishes and permit larger fish species to attain increased density (Chick et al., 2004). Both effects can change the size distribution and age structure of populations and communities, potentially altering the role of biotic interactions in aquatic communities. Ultimately these changes will create a diversity of size ranges of prey available for wading birds to consume, with fish ranging from 6 to 8 cm being the preferred prey for larger species of wading birds, particularly Wood Storks (Kushlan et al., 1975).

Exotic plants and animals may negatively impact populations of fish and crustaceans in the future. Exotic fish predators, such as the black acara and Mayan cichlids, have the potential to directly impact native populations (Kobza et al., 2004; RECOVER, 2004), particularly during the dry season when animals are concentrated in refuges (e.g., alligator holes, solution holes). Increased mortality in the dry season could reduce population resiliency by reducing numbers of animals returning to short-hydroperiod marshes in early wet-season flooding events. Exotic plants may affect these populations by altering the native vegetation and hydrological characteristics of wetland areas. For example, melaleuca can replace open grassy wetlands with forest and raise soil levels, reducing the area of inundation and water flow. Including indicators of these potential drivers of future ecosystem function should be a priority for future development.

3.2. *Communicating the aquatic fauna indicator*

The stoplight system provides a simple and visual method to communicate assessment results. In this paper, we have not

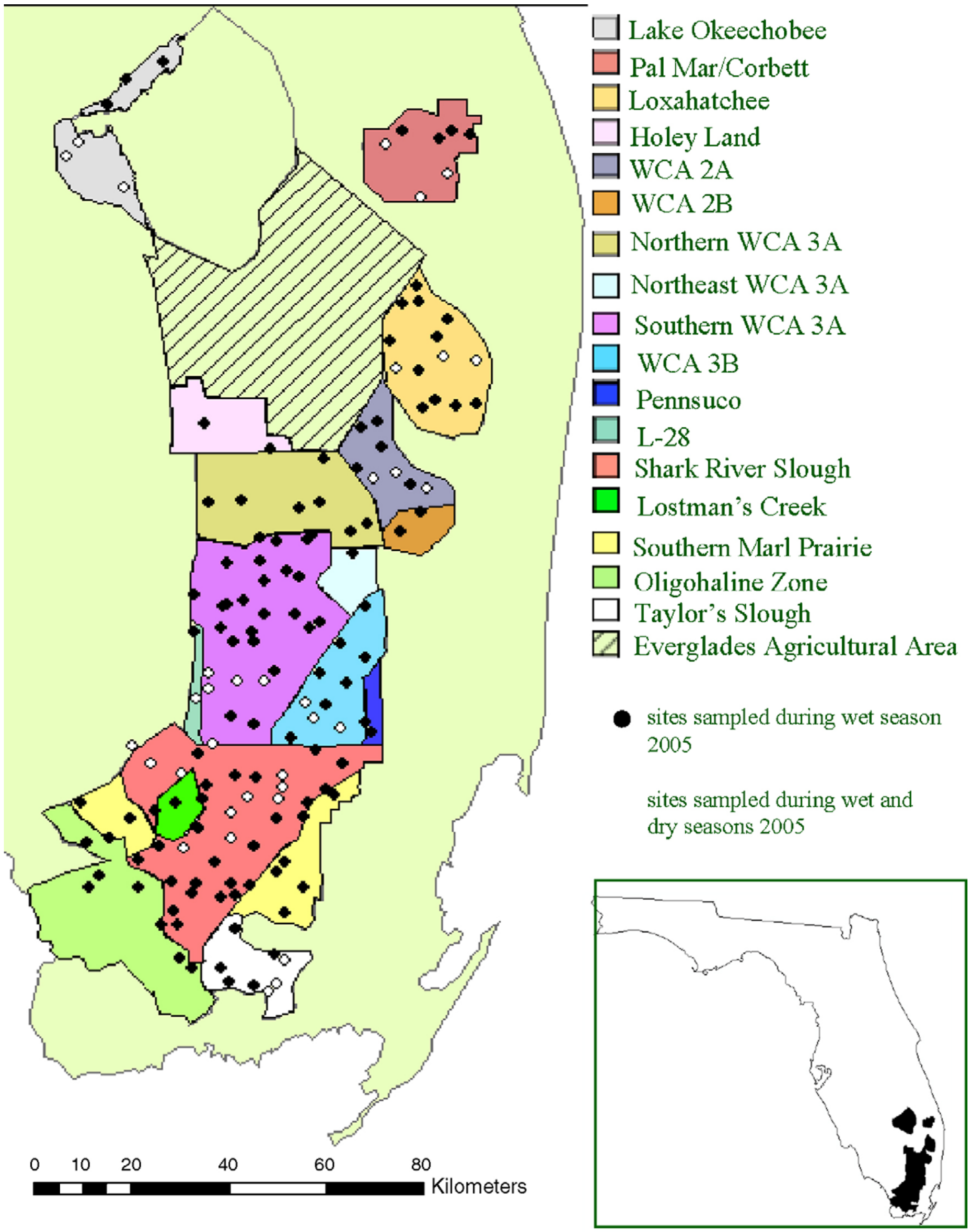

Fig. 5 – Map of 250 potential CERP monitoring sites for aquatic fauna and periphyton. Some sites are excluded in each sampling event based on ability to sample in vegetation, and water-depth (no water or too deep), so that 150 sites are typically visited. Data from these sites can serve as the basis for a report-card assessment at the landscape scale. Habitats are color coded to indicate one possible scheme of regional aggregation of data.

provided a lone summary metric that combines information from our four indicators, as is done in protocols for metrics such as the Index for Biotic Integrity (Karr and Chu, 1999). When reporting assessment in the report-card format, we will use the density of all small-fish species summed (total fish density) for an overall metric, with assessments for each of the four life-history-based assessments as indicators of specific hydrological conditions. We have not chosen to create a weighting scheme for the four indicators because there is currently no basis for applying weights. At present, we have no information on the relative sensitivity of each indicator to deviations from desired hydrological conditions. By providing more detailed information with each assessment in the form of time series analyses, technical reviewers can find the empirical basis for each evaluation. Future work may provide more detailed information on the link of these PMs to wading bird foraging. With such information, we may come to an a priori basis to up-weight or down-weight individual PMs. Future assessments using the CERP-MAP sampling design will permit quick landscape-scale visual presentation of the results through maps.

3.3. *Long-term science needs*

Basic biology of fish and crustaceans in the Everglades, and ways to monitor their responses to hydrological management effectively, is relatively well established. However, continued work is needed to improve monitoring techniques in very short-hydroperiod habitats where throw-traps do not provide useful data. Current monitoring techniques for fishes use a throw trap to sample in freshwater habitats and drop traps in mangrove environments. While these techniques are excellent for much of the Everglades, there are limitations. For example, neither technique can be used effectively in the Rocky Glades, where soil is absent and the rocky ground surface is highly uneven. Alternative techniques for sampling fish and crustaceans in this landscape are not well established, and require studies of their sampling efficiency and bias. This is unfortunate because these short-hydroperiod habitats are important areas for restoration and management, and monitoring of aquatic communities in these locations is valuable for assessment and evaluation. Fortunately, habitats excluded from throw trapping are a relatively small proportion of the total landscape.

The development of additional PMs is an area of ongoing work. Metrics that delineate and track non-native taxa should be added to the current hydrologically based indicators, as should metrics of the size distribution of fishes relative to those preferred by wading birds. Research is also needed to permit us to monitor the implications of canals and levees for PMs, yielding improved assessments of the effects that removing these artificial man-made features will have on the ecosystem (National Research Council, 2007). This research needs to incorporate signatures of fish movement in response to hydrological fluctuation. Radio tracking of Florida gar (*Lepisosteus platyrhincus*) has shown that they make long-distance movements to reach canals before Everglades' marshes dry (Trexler et al., unpublished data). The relative contribution of the slough crayfish and Everglades crayfish to wading bird diets is also a source of uncertainty. Much of the wading bird foraging research in the Everglades where diet was assessed was completed before we knew that two crayfish species were found there. The distribution and biology of these crayfish species is now known to differ as a function of hydrology. If one species were much more important than the other in sustaining bird nesting, there would be implications for management that should be reflected in assessment methodology.

Finally, all of the effort to establish informative indicators for Everglades' management and restoration will be wasted without good data from consistent and well-managed monitoring programs (e.g., Keeling, 2008). Existing monitoring programs and projects need to be continued to capitalize on the developing time series information on fish and crustaceans that can be used in impact assessment. Gaps in time series greatly diminish their usefulness in tracking changes in dynamic systems with marked hysteresis (Trexler et al., 2003). Because of its cost, obtaining a continuous record of aquatic communities at the landscape scale may be the biggest challenge for future assessment of Everglades Restoration.

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