Prey-Based Freshwater Fish Density Performance Measure
(Greater Everglades Aquatic Trophic Levels)

Last Date Revised: 03-05-10

Acceptance Status: Accepted

1.0 Desired Restoration Condition

The desired restoration condition is to maximize densities of small-sized freshwater fishes (less than approximately eight centimeters (cm) adult standard length) that characterized the pre-drainage Everglades ecosystem, namely the livebearers (poeciliids) and killifishes (cyprinodontids and fundulids). Restoration of native small-sized fish densities will help provide more natural, high-density prey patches for higher-level trophic consumers such as alligators, wading birds, amphibians, and larger fish. Assessing the health of small-bodied fishes in the Everglades ecosystem is thought to provide a general index of trophic conditions within the overall food web of the Everglades ecosystem (Trexler et al, 2004).

1.1 Predictive Metric and Target

This Performance Measure (PM) is based on an updated version of the Fish Habitat Suitability Index (HSI) originally developed by Florida International University (FIU), the United States Geological Survey and the South Florida Water Management District (Trexler et al, 2004) that predicts small-sized fish density based on simulated time since last dry down in the Everglades ridge and slough landscape. The original Fish HSI was applied across the greater Everglades ridge and slough landscape (Figure 1). This updated version differs from the original Fish HSI (Trexler et al, 2004) since the logistic regressions include the more recent Trexler et al throw trap data collected from 1996 through 2006, the model application is limited to those locations where the Trexler et al monitoring data has been collected, and provides a proposed target and a revised scoring methodology that can be used to evaluate Comprehensive Restoration Everglades Plan (CERP), Modified Water Deliveries (MWD), and other restoration project alternatives. In addition, this revised PM is calculated from the South Florida Water Management Model (SFWMM) 2 X 2 output post processed with a 500 meter (m) resolution hydrology method (4DHRH – Donalson, 2008) rather than computed solely from SFWMM 2 X 2 output.

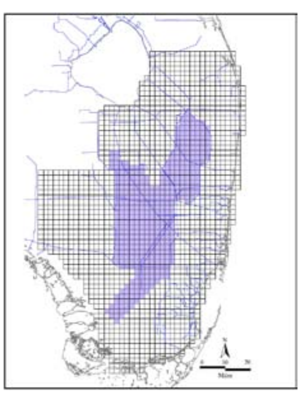

Figure 1. Cells (shaded) used by Fish HSI, Source: SFWMD, 2004

1.1.1 The updated small-sized fishes density model

The FIU long-term data set managed by Trexler provides a 10-year time series (1996-2006) of aquatic consumer data to identify relationships between aquatic food-web dynamics and hydropatterns. The data were gathered with a one-m^2 throw trap and standard sampling protocol carried out at monitoring sites in Water Conservation Areas 3A and 3B, Shark Slough, and Taylor Slough as depicted in Figure 2.

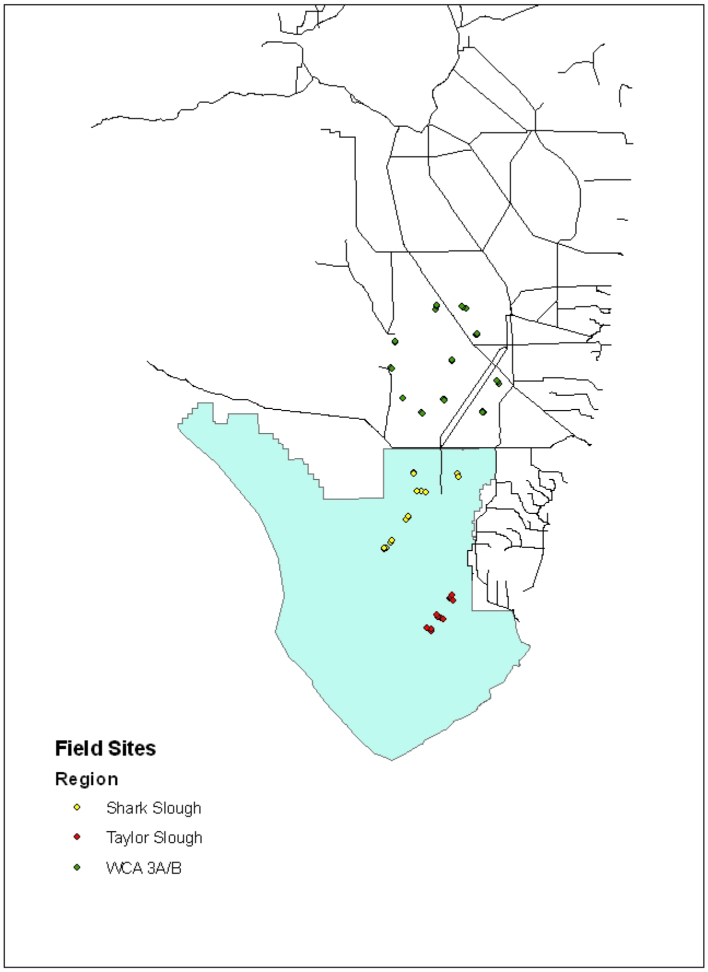

Figure 2. Trexler monitoring locations within WCA-3A, WCA-3B, Shark Slough, and Taylor Slough.

Samples were collected at each study site in five months of each year (February, April, July, October, December), yielding over 17,000 community samples with over 250,000 fish records for establishing relationships between biota and hydrological conditions. Quantitative data on fish and aquatic invertebrates (crayfish, shrimp, snails, and aquatic insects) were recorded from all samples, along with environmental data on emergent-plant stem density, floating mat volume (periphyton and floating vascular plants and macroalgae), and water depth. The methods, including estimates of sampling efficiency and evaluation of sources of bias, are described in several papers (Jordan et al. 1997; Wolski et al. 2004; and papers cited therein). The study sites and sample design are also described in detail in other publications (Trexler et al. 2001, 2003, 2005).

Trexler et al have been working on approaches using monitoring data to derive statistical relationships between biotic PMs and hydrological parameters. At present, a small-sized fish density model, based off of the fish density data collected by Trexler et al from 1996-2006 for all species less than approximately eight cm standard length, namely livebearers and killifishes, has been developed as an aquatic indicator for Everglades trophic dynamics. This indicator displays a strong monotonic relationship between small-sized fish density (all species summed per m^2) and the number of days between the time of sampling and re-wetting of the site after the most recent drying event. A dry down event is defined as an event when the daily average water depth is less than or equal to five cm since this is the approximate depth whereby fishes become trapped within the sediment and organic material (Ruetz III et al, 2005). Certainly, other factors also influence small-sized fish density (e.g., Trexler et al. 2005; Chick et al. 2004), but more than 60% of the sampling variation (and often more than 70%) has been explained by this single parameter (hereafter, days since last dry down [DSLDD]).

A logistic equation was used to model the relationships from the small-bodied fish monitoring data collected within the Water Conservation Areas 3A and 3B, Shark Slough, and Taylor Slough, respectively. The data were fit to three monitoring regions experiencing different hydropatterns: the Water Conservation Areas 3A and 3B, Shark Slough, and Taylor Slough. The different frequencies of dry down events within these regions are at least partially attributable to landscape differences and water management operations.

There is no particular reason to use a logistic model to describe these relationships, though this and related non-linear models better described the data than simple polynomials. Ecologists have often used the logistic equation to describe population growth and the parameters have traditional interpretations (r and K). Possibly an argument against using such a model is the temptation to interpret parameter estimates in this way when caution is necessary because immigration and emigration have not been independently accounted for and are certainly important factors influencing aquatic animals in the Everglades. However, excellent data descriptions from a phenomenological fit of this model have been found. Future work may lead to replacing the logistic model with a Gompertz model, because of limitations in the former (assumes symmetrical population growth at low and high ends of the relationship), but current work has revealed only minor benefit to the latter and only in some data sets.

The best fit logistic regression equation based on the Trexler et al monitoring data is provided in Equation 1. Table 1 provides the initial parameterization for the three monitoring regions.

Equation 1: LOG(TOTFISH +1)=K/(1+((K-Y0)/Y0)*EXP((-r*DSLDD)))

$$\mathrm{LOG(TOTFISH}+1) = \frac{\mathrm{K}}{\left(1+\left((\mathrm{K - Y0})/\mathrm{Y0}\right)^{(-r*DSLDD)}\right)}$$

DSLDD = days since last dry down
r = growth constant
TOTFISH = total small-sized fish density (number of individuals) per m^2
K=asymptotic density
Y0=Y intercept

Table 1. Trexler small-sized fish density logistic regression equation parameters per monitoring region

Monitoring region	WCA-3A/B	Shark Slough	Taylor Slough
K	2.901	2.757	2.625
r	0.097	0.006	0.003
Y0	0.300	1.486	1.08

Figures 3a-3c show the best logistic model fits for predicting small-sized fish density/m^2 recovery since last dry down event based on the Trexler et al monitoring data collected in the three respective monitoring regions.

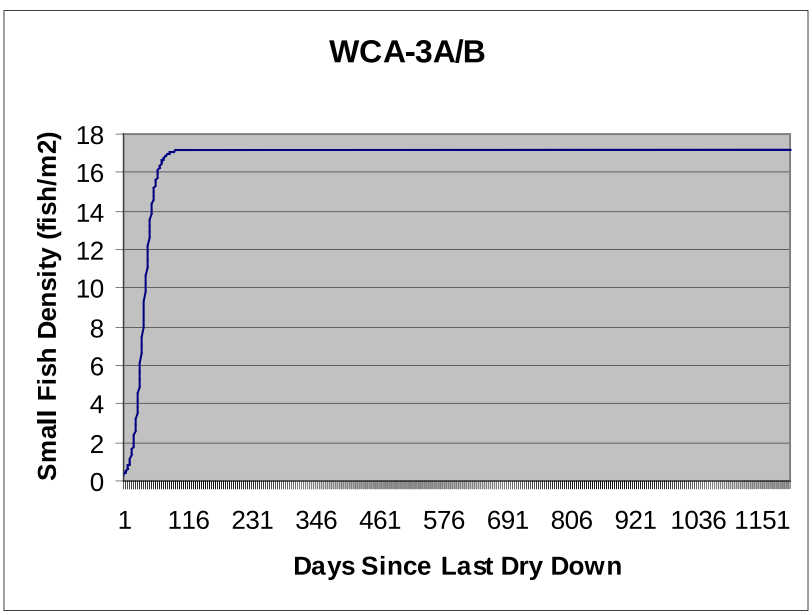

Figure 3a. Model fit for total small-sized fish density since last dry down event collected in WCA 3A/3B based on the Trexler (1996-2006) data

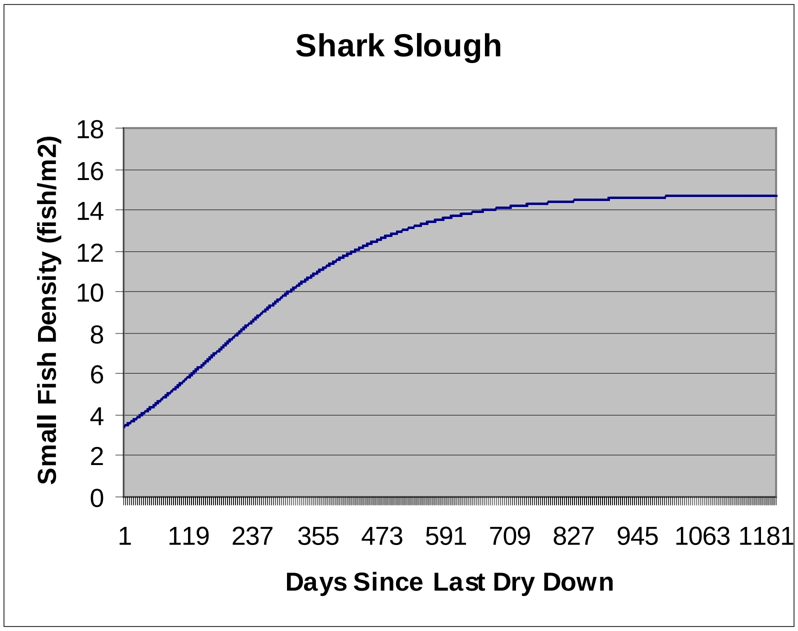

Figure 3b. Model fit for total small-sized fish density since last dry down event collected in Shark Slough based on the Trexler (1996-2006) data

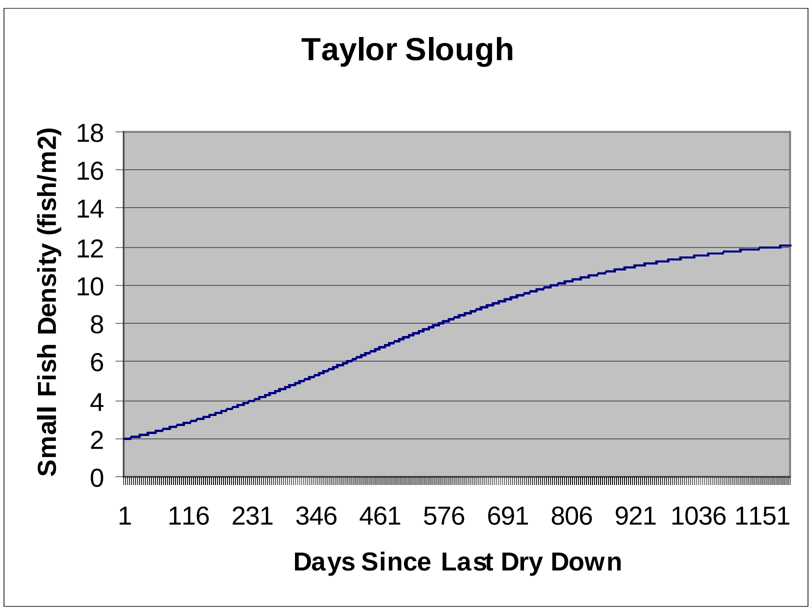

Figure 3c. Model fit for total small-sized fish density since last dry down event collected in Taylor Slough based on the Trexler (1996-2006) data

1.1.2 Application and targets of the updated small-sized fishes density model

The revised small-sized fish density PM applies the Trexler logistic equation to estimate daily small-sized fish density/m^2 from the SFWMM 2 X 2 output post-processed with the 4DHRH (Donalson,

2008) 500 m resolution hydrology. We are recommending this PM only be applied to those 4DHRH 500 m resolution cells where Trexler et al conducted the monitoring as illustrated in Figure 4a and Figure 4b since small-sized fish densities have been shown to vary across spatial scales within these geographic regions (Ruetz III et al, 2005) likely resulting from landscape differences as well as water management operations.

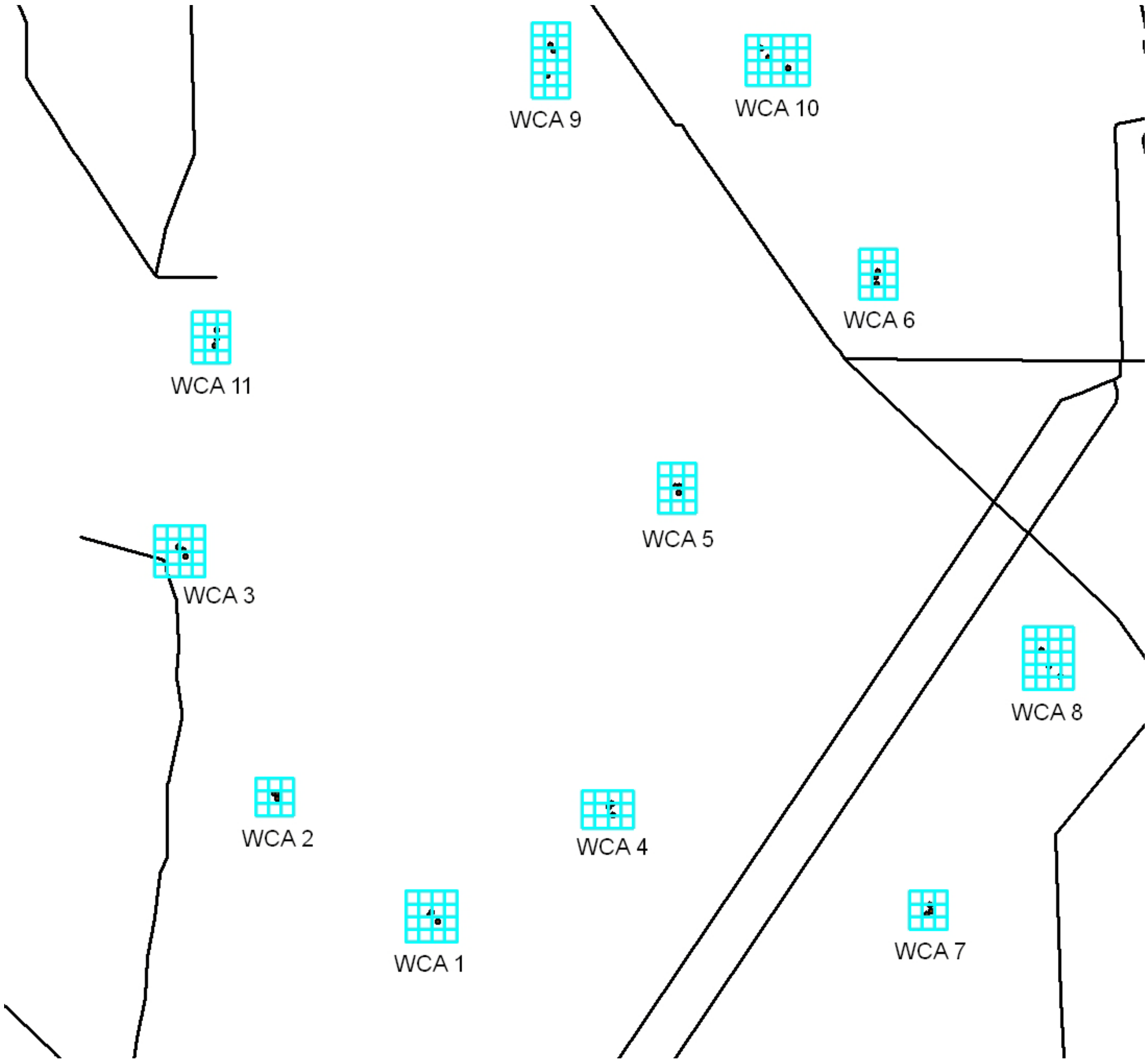

Figure 4a. 4DHRH 500 m resolution cells that enclose the Trexler et al 1996-2006 fish monitoring sites in WCA-3

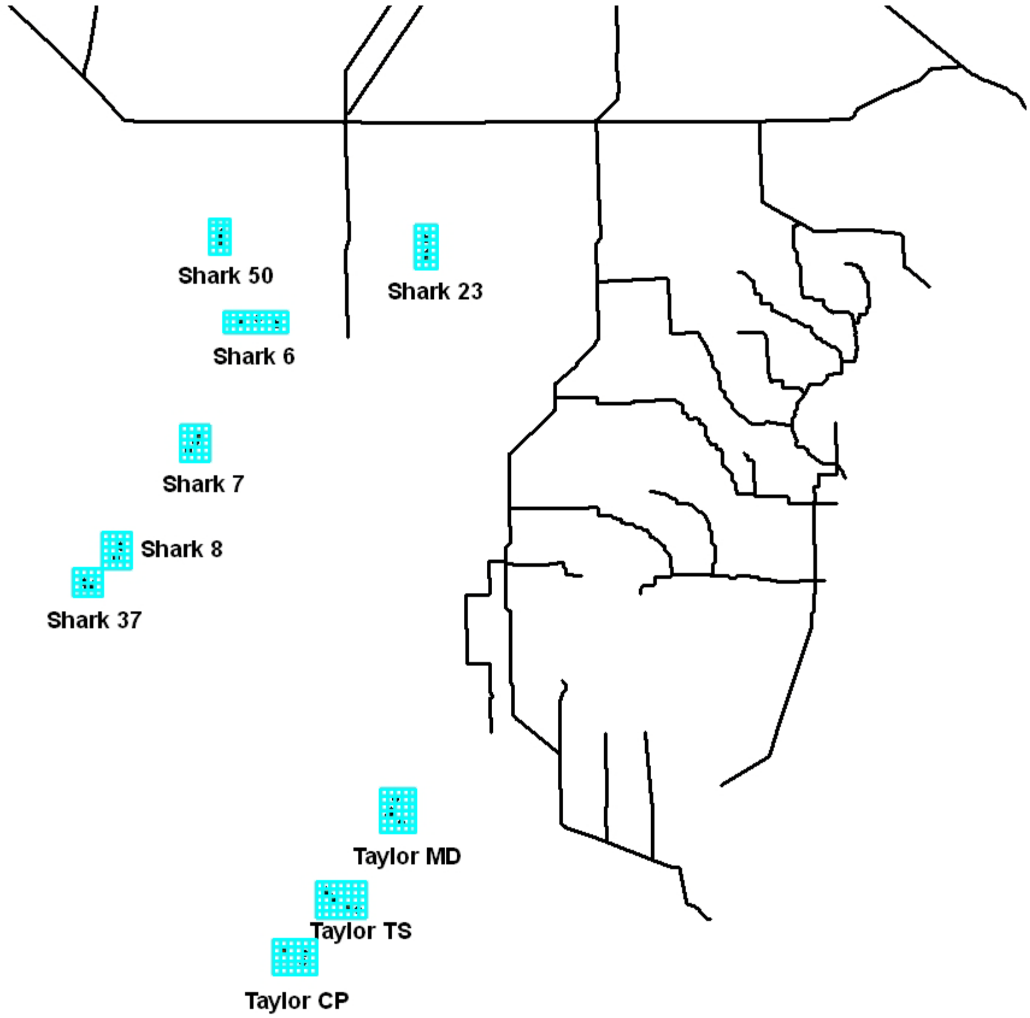

Figure 4b. 4DHRH 500 m resolution cells that enclose the Trexler et al 1996-2006 fish monitoring sites in Shark and Taylor Sloughs.

As an initial target for the updated PM, we are recommending that the small-sized fish densities be maximized within the best fit model curves (Figures 3a-3c) for each respective monitoring region (WCA-3, Shark Slough, Taylor Slough). Thus, we are recommending the small-sized fish density at the asymptote of the best fit model curves shown in Figures 3a - 3c be used as the PM targets for each respective monitoring region (but see discussion of targets present in section 4.4 Uncertainties).

For detailed information on how to apply this PM to evaluate CERP, MWD project, and other restoration projects within the geographic confines of this PM, please refer to Section 4.0, Evaluation Application.

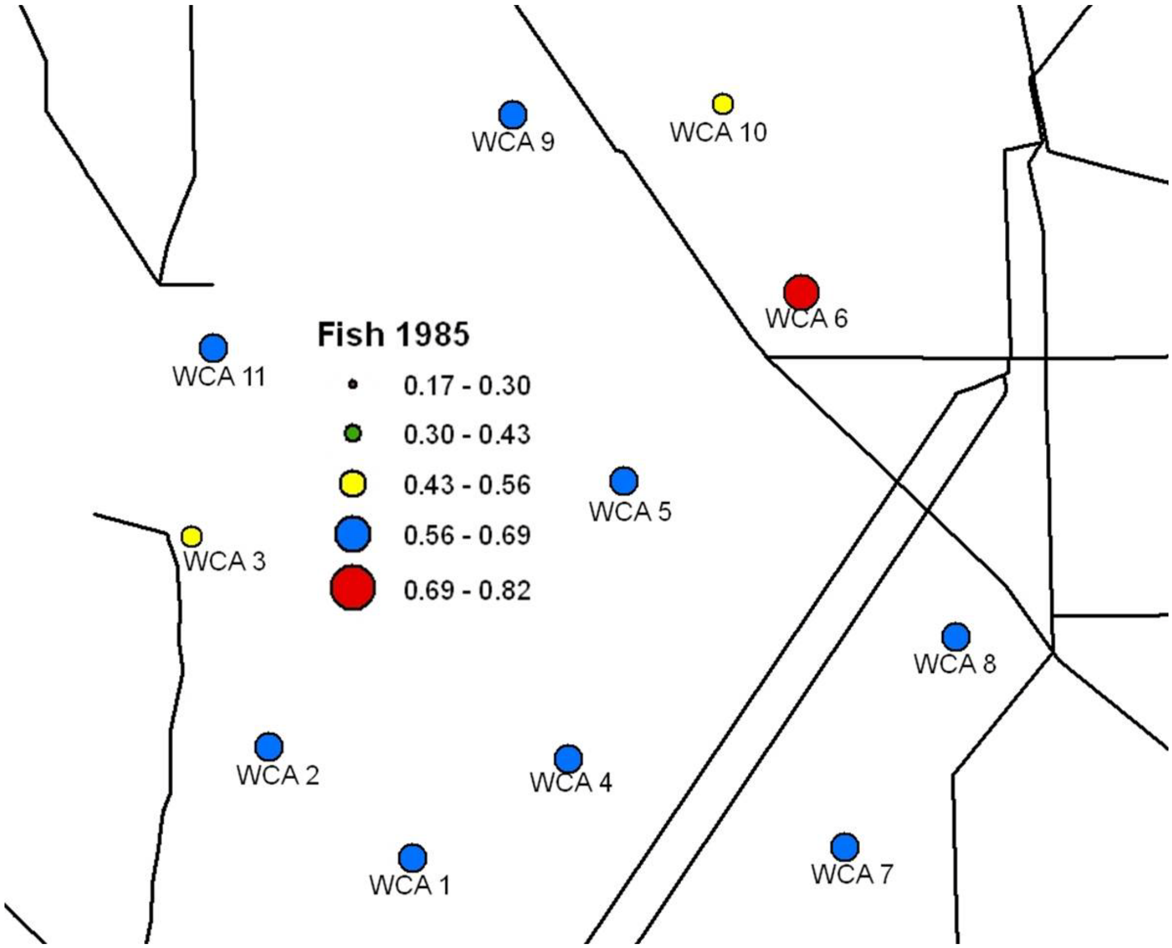

Figure 5. Demonstration of Trexler model in WCA-3 for, SWMM Verification run year 1985. Values are the ratio of the average fish density for that year to the maximum value that area (which for WCA3=17.19).

Figure 5 is an initial test demonstration run of the revised small-sized fish density PM from the SFWMM Verification run year 1985. This shows the results for both WCA-3A and WCA-3B. The projected small-sized fish density ratios range from 0.43 to 0.82, which translate to densities ranging from 7.4 to 14.1 total small-sized fish density/m^2.

1.2 Assessment Parameter and Target

Continued field work and analysis of existing historical datasets by Dr. Joel Trexler's FIU research group will provide assessments and comparisons of model results and aid in the refinement of both models being used for this PM. Funding for Dr. Trexler's research was provided under Cooperative Agreement J5284060020, "Synthesis of Existing Data on Aquatic Communities in Everglades National Park in a Framework for Ecosystem Assessment and Evaluation" through the Critical Ecosystem Studies Initiative (CESI) program.

2.0 Justification

Fishes are the most abundant vertebrates in the Everglades and Big Cypress ecosystems of southern Florida. The small-bodied species, particularly the livebearers and killifishes, dominate the community by sheer abundance (both biomass and numerical abundance). They constitute an ecosystem component whose biomass is the major energy resource for higher trophic levels, especially wintering and breeding wading birds (Ogden 1994, Crozier and Gawlik 2003). Systematic, human-induced changes in hydrology over the last several decades have altered hydroperiods in most wetland areas, thereby diminishing this fish forage-base or changing the pattern of its availability. Lack of sufficient biomass and availability of prey is thought to be a major cause in the decline of wading bird nesting at traditional Everglades' rookeries (Ogden 1994), and recovery of historic fish productivity is a primary goal for restoration of southern Florida wetlands (Ogden et al. 2003).

The strongly seasonal rainfall pattern of this region creates a cycle of wet and dry seasons. Because of the flat landscape, relatively small differences in mean water level amplify into large differences in the amount of wetted area and flooding duration, which affect many plant and animal communities. The wetland small-sized fish community is strongly influenced by seasonal hydrologic fluctuations (Loftus and Kushlan 1987, Trexler et al 2002).

3.0 Scientific Basis

3.1 Relationship to Conceptual Ecological Models

Abundant large vertebrates and aquatic prey bases are listed as a defining ecosystem characteristic in the Total System Model (Ogden et al 2005) and marsh fishes are identified as key ecological attributes of that defining characteristic. A number of aquatic trophic levels are included as ecological attributes in the Everglades Ridge and Slough Conceptual Ecological Model (Ogden 2005). This PM is currently focused on a subset of both the Total System and Ridge and Slough models (marsh fishes).

3.2 Relationship to Adaptive Assessment Hypothesis Clusters

3.2.1 Greater Everglades Hypothesis Cluster – Predator-Prey Interactions of Wading Birds and Aquatic Fauna Forage Base

The collapse of wading bird nesting colonies in the southern Everglades is attributed to declines in population densities and seasonal concentrations of marsh fishes and other aquatic prey organisms. Restoration of natural hydrologic conditions will re-establish distributions of prey densities and concentrations across the landscape that in turn will support the return of large, successful wading bird nesting colonies to the southern Everglades.

Hypothesis 1 – Aquatic Fauna Wet Season Prey Population

The wet-season density, size structure, and relative abundance of marsh fishes and other aquatic wading bird prey are directly related to the time since the last dry-down and the length of time the marsh was dry. Aquatic prey populations are further affected by salinity in coastal ecotones, and by site nutrient status. At the level of individual species, and prey base fish communities, responses are known to be logistic functions of days since last dry-down (physical process). It is hypothesized that the shape/slope of these linear functions is affected by slough habitat connectivity (spatial dependency), eutrophication (causing trophic cascades through impacts on periphyton), and perhaps other factors.

Hypothesis 2 – Aquatic Fauna Dry Season Prey Concentration
The concentration of marsh fishes and other wading bird prey into high-density patches where wading birds can feed effectively is controlled by the rate of dry-season water level recession and local topography/habitat heterogeneity.

4.0 Evaluation Application

4.1 Evaluation Protocol

4.1.1 Small-sized fish density

The yearly average small-sized fish density/m^2 will be estimated by modeling the dry down events simulated from the SFWMM 2 X 2/4DHRH on a daily basis during the entire 36-year period of record (1965-2000) with the logistic equations that best fit the Trexler et al monitoring data as described in Section 1.1.1. using the updated small-sized fish density model. The steps below describe the general pathway followed to arrive at the small-sized fish density/m^2 estimates and recommended methodologies to score the metrics so that they can be used to readily compare CERP, MWD and other restoration alternatives within the geographic confines of this PM.

The following steps all need to be performed for the SFWMM 2 X 2/4DHRH existing conditions baseline (ECB) run as well as all respective restoration project alternative runs:

1) Model the daily small-sized fish density/m^2 throughout the entire period of record at each 500 m resolution cell that encloses the Trexler et al. fish monitoring locations shown in Figure 3, using the logistic Trexler equations described in Section 1.1.1.

2) Compute the yearly average fish density for each of the cells.

3.) Using the averages for each cell, compute the yearly averages for each of the 20 sub-regions (shown in Figures 4a and 4b) and the averages for each of the regions (WCA-3A, WCA-3B, Shark Slough, Taylor Slough)

4.) Compute the percent of target achieved (%) for each project alternative for the regions described in numbers 2 and 3 (above) by following the equation below:

% of target achieved = z/t ;

where

z = project alternative small-sized fish density/m^2

t = target small-sized fish density/m^2. As described in Section 1.1.2, the density target is the asymptote on the graphic that maximizes fish density/m^2.

Thus, final scores comparing project alternatives will be provided for the four geographic regions of WCA-3A, WCA-3B, Shark Slough, and Taylor Slough, respectively but in addition, the data used to compute those large scale averages will also be available to the planner. The percent change between existing conditions and the project alternative in question will also be computed by following the equation below.

% change from existing conditions = z/b;

where

z = project alternative small-sized fish density/m^2

b = existing base condition small-sized fish density/m^2

Output format for this measure will be the same as previously described.

Note: For CERP and MWD projects, it is also recommended (if possible) that another evaluation be performed that includes the project alternative in a run with other restoration projects to examine the cumulative effect of the project in conjunction with other restoration actions. This will describe whether the project alternative can work together in concert with other restoration actions to provide incremental benefits.

4.2 Normalized Performance Output

The exact format of the output has yet to be developed. However, most output will require little post processing. Some post processing software may be developed to scan the output to flag any large discrepancies either in space or time. This will ensure that scientists are aware of any critical differences across space or time that might be lost during later averaging.

4.3 Model Output

The model will provide output at a 500 m resolution over the coverage shown in Figures 4a and 4b. As described above, output will include all individual cells, each of the sub-regions, and the four main regions. All data will be output in a .csv format that can be directly read into ArcMap, as well as a NetCDF format. Details of the output formats are to be determined and will be included in the model documentation.

4.4 Uncertainty

The growth dynamics of small-sized fish populations under static conditions is relatively well understood. However, under the seasonally varying hydrology of the Everglades, where the amount of flooded area can change drastically with time, and where both the resource base of small fishes and the effects of interactions of small fishes with piscivorous fishes is difficult to assess. These factors interact to create a high level of uncertainty in predicting absolute values of fish population density and biomass per unit area. The fish dynamics are also sensitive to the errors in both the simulated water elevations and the simulated reference elevations. This uncertainty is reduced and the PM provides very useful information when different scenarios are compared, the metrics are aggregated into averages, and when the general spatial patterns are considered.

The Everglades is a system adapted to constant flooding followed by dry-downs, and many of the species are dependent upon that cycle, including the wading birds that depend on the fish populations. Therefore, fish density alone is not sufficient to define an evaluation protocol for aquatic species in the

Greater Everglades system. Instead, it must be a combination of fish density, water timing, water quality, water depth, and potentially other factors.

The targets adopted for this Performance Measure are not intended to be interpreted as a prescription for restoration. As discussed in section 1.1.1 (page 3) of this document, this model does not explicitly account for emigration, immigration, eutrophication, impacts of non-native fish, or other factors which may influence directly observed fish densities in different areas across the landscape. We anticipate that we may need to re-evaluate these shapes as the restoration process proceeds. The targets devised for this Performance Measure have, however, been developed in an objective and rigorous manner and the specific aspects of this development process which give us confidence in the use of these targets are:

1. Use of a long time-series of data, where sampled areas were repeatedly visited.

2. The ability of the observed data to be analyzed with statistically rigorous methods.

3. The hypothesis-testing approach that was used to link fish density to an explanatory variable (in this case Days Since Last Dry-Down (DSLDD)) is based on a conceptual model, and has resulted in the failure to reject the null hypothesis that the explanatory variable is not related to prey base fish density. In addition to the hypothesis testing result, the explanatory variable explains a significant fraction of the variability in the response variable.

4. The explanatory variable is an effective representative of a known stressor (hydrology) of an important ecosystem attribute (prey base fish density).

The underlying relationships between prey base fish density and days since last drydown may change in the context of alterations made to the ecosystem which are either directly caused by CERP construction efforts or an indirect consequence of the changes to the landscape which are a constant feature of a shifting mosaic of ecosystem properties. While this is the case, the close association of this Performance Measure with an established CERP monitoring program is likely to provide sufficient information which allows us to recalibrate the targets as appropriate based on quantitative data with robust statistical methods. For these specific reasons, this performance measure provides RECOVER and CERP participants to utilize objectively determined targets for the first time, in contrast to the simulation based targets (mostly NSM) which have been used for all Performance Measures with predictive capability in the Greater Everglades sub-team for CERP to date. The approach of using objective targets is a desirable and more direct method for evaluation than the use of simulation targets. Objective targets should be employed as frequently as possible for evaluation of CERP projects and operations.

4.4.1 Evaluation Strategies

Evaluating CERP projects is intellectually challenging, and subject to a variety of types of uncertainty (Lall et al. 2002). As a result, the strategy used to evaluate anticipated effects of CERP projects has important implications for how the ecological effects of altered hydrology are described. In practice, the Evaluation Team uses a hierarchical approach to evaluate ecological effects. The existing system is first differentiated into regions that are determined by impoundment patterns, and then each impoundment may be further differentiated into sub-regions based on prevailing ecological conditions. Finally, the hydrologic information is reported by sub-region, and the ecological effects of the hydrologic conditions are described in the context of the existing conditions in the region. This approach was utilized in the Band 1 regional evaluation (RECOVER 2009).

Recently, Trexler and Goss (2009) have developed an approach to the assessment of aquatic fauna. This approach was developed entirely in the context of assessed performance of the system, and it uses many of the predictive relationships that are used in this performance measure. The combination of applying statistical processes to differentiate performance between different years and a simple red-yellow-green status description produced to report system status meet the both the requirements of applying a rigorous approach to evaluation and producing an easy to understand summary graphic. Adapting this approach for application to Evaluations of project alternative scenarios is under consideration. It is desirable to ground evaluations in statistically rigorous approaches, but the team of evaluators has yet to consider how to adapt this approach in the most effective manner.

5.0 Monitoring and Assessment Approach

5.1 MAP Module and Section

Greater Everglades Module Section 3.1.3.11

5.2 Assessment Approach

The strategy for the integrated assessment of wading bird/aquatic fauna predator prey relationships is to annually track the production of aquatic fauna populations during the wet season, the concentration of those populations during the subsequent dry season, and distribution and size of wading bird nesting colonies in response to the prey populations (RECOVER 2007).

5.2.1 Recommendations for the enhancement of the assessment approach

While the ability to meet the goals described in section 5.2 have been demonstrated by the monitoring module, there are other important hypotheses about the factors influencing the production of aquatic fauna which it is desirable to address. These include, but are not limited to:

1. The role of eutrophication in affecting population productivity rates and/or population density asymptotes for prey base fish communities.

2. Does landscape type (ridge and slough vs. slough vs. wet prairie vs. open water) influence population productivity rates and/or population density asymptotes for prey base fish communities?

Alteration of the assessment module in order to address these questions is subject to budgetary and schedule constraints. Even so, addressing these recommendations is desirable in order to develop cause-effect relationships between habitat structure and trophic dynamics. These goals are stated here in case scientists external to the existing research program are willing and able to contribute the restoration goals of CERP as represented by the authors of this document.

6.0 Future Tool Development Needed to Support Performance Measure

6.1 Evaluation Tools Needed

The scoring methodology recommended in this documentation sheet needs to be added to the coding in the original model. Also, the Interagency Modeling Center (IMC) has proposed revisions to the two currently used methods to generate 500 m hydrology. Thus, based on interagency consensus, the 500 m hydrology tool may require modification in the future. However, until any new high resolution hydrology methods are fully vetted and tested, the 4DHRH method is recommend for use with this PM.

The researchers focused on prey-base fish communities and their primary foraging communities (periphyton) have clearly indicated that they have collected sufficient information to predict the effects of eutrophication on prey base fish communities. The only barrier to using this type of information for evaluation is the ability to conduct regional simulations of project effects with simulation models that make explicit predictions about soil, periphyton, and water column nutrient concentrations. Conducting simulations and considering scenarios that make explicit predictions of hydrologic conditions as well as soil, periphyton and water-column nutrient concentrations is necessary, desirable, and would cause the evaluations of project-level ecological effects to be more realistic and meaningful. This approach could also contribute to the development of a CERP implementation strategy which is adequately flexible to accommodate the known risks associated with directing inflows from the Kissimmee River and Lake Okeechobee basins into the Everglades Protection Area.

6.2 Assessment Tools Needed

None have been identified.

7.0 Notes

This PM has been developed to assess the health of small-sized fishes within select ridge and slough IRs and does not attempt serve as a PM to assess the health of all species within these IRs.

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