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Synthesis Report – FINAL

Caloosahatchee Science Workshop

November 19 & 20, 2013

Cohen Center Ballroom, Florida Gulf Coast University

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1. EXECUTIVE SUMMARY

Florida Gulf Coast University's Coastal Watershed Institute, in association with the Consensus Building Institute and the South Florida Water Management District, sponsored a participatory science workshop November 19-20, 2013, on the Caloosahatchee system. The primary objective of this two-day scientific workshop was to review and synthesize the science relevant to the management of freshwater inflows to the Caloosahatchee River and Estuary. While hydrologic modifications to the Caloosahatchee have resulted in many benefits for flood control, water resource management, and agriculture, there has been a growing concern among citizens and scientists alike that the managed flow regimes have significantly altered the Caloosahatchee river ecosystem. Numerous projects have been conducted over the years to study ecosystem responses to the altered flow regimes in the Caloosahatchee, much of which will be summarized in this report.

A conceptual model of the Caloosahatchee Estuary ecosystem was developed as part of the Southwest Florida Feasibility Study and published by Barnes (2005). Conceptual models are useful communication tools, providing an explicit expression of the assumptions and understanding of a system for others to evaluate. While estuarine species are generally well adapted to cope with varying salinity conditions, larger shifts and timing of freshwater discharges can be a problem. Such changes can impact the community structure and function of phytoplankton, submerged aquatic vegetation (SAV), macroalgae, and the benthos - particularly oysters and fisheries. There are also secondary, or indirect, effects that must be considered, including impacts to manatee demographics and wading bird community structure. It is impossible to monitor all of these components all the time; it costs too much and takes too much time. Ecological indicators, however, can help describe and monitor ecosystems in simpler terms. When indicators are used effectively, they are expected to reveal conditions and trends that help in management, planning and decision-making. One purpose of this science workshop is to do a "check-up" on these indicators. Are these indicators telling us what we need to know? Are these indicators still appropriate? Understanding of the Caloosahatchee has increased since the original ecological model was proposed in 2005, are there other useful indicators we should be using? The remainder of the workshop focused on the above questions in regard to specific potential indicators: benthic, water column, and other candidate indicators.

Benthic indicators discussed in this workshop included tape grass, seagrass, and oysters. Ongoing studies have shown that tape grass beds have been nearly wiped out and there is concern that seed beds might be depleted. The die-off of *Vallisneria* was coincident with low flow conditions (<450 cfs) and high salinities (>10), especially during the drought conditions of 2007. Herbivory has been identified as a controlling factor in both the tidal and non-tidal portions of the Caloosahatchee, preventing *Vallisneria* from flowering. Recommendations included measures to fence/protect new stocks (in oxbows, etc.) to reduce impacts of grazing and boat wakes, as well as a need for nursery stock to improve restoration efforts. There is also a need to map out geographical extent of restoration efforts. Specifically, upstream restoration efforts (in/near tributary mouths as well) may benefit downstream sites. In terms of seagrass (primarily *Thalassia* and *Halodule*), we need to determine salinity/flow regimes that allow for *Halodule* to thrive in mid-estuary locations (need to define) without replacing *Thalassia* in the lower estuary. Simultaneously, we need to maintain salinities >30 in the lower estuary to support *Thalassia* growth.

Research on oyster distributions, physiology, and ecology has provided us with an initial estimate of a “sweet spot” for oyster growth (a salinity range of 15-30, corresponding to a flow range of 1000-3000 cfs). We do not have good spatial coverage for monitoring oyster reefs, nor do we have updated maps of modern reefs in the system. Historical data exist, but have not been compiled and mapped, so we do not have a good grasp of what historical distributions were. A primary question to be addressed is: Do we want to maintain current oyster reef distributions, or do we want to expand them to approach their historical extent? The answer to this question will help to devise management strategies.

Candidate indicators of water column communities that were discussed in the workshop included phytoplankton, zooplankton, cyanobacteria (blue green algae), and drift algae. Phytoplankton respond to flow, although it is unclear what portion of the response is due to salinity, residence time, or nutrient loading. Low flows result in high phytoplankton biomass in the upper estuary. As flows increase, the chlorophyll maximum moves downstream, likely being flushed out into the Gulf of Mexico at high flows (>3500 cfs?). Phytoplankton composition changes both downstream and as flow increases, although it is unknown if these changes will increase the threat of harmful algal blooms (HABs) in the Caloosahatchee. If phytoplankton were to be used as an ecological indicator by the District, the primary responses of concern would be 1) where should the chlorophyll maximum be located; and 2) can flow management be used to mitigate against HABs.

Zooplankton are responding to changing flow conditions. The high diversity of zooplankton can allow for the monitoring of both high and low flow conditions, as well as different salinity regimes along the estuarine gradient. The time frame of zooplankton stages (days to weeks) overlaps well with changing flow conditions. The larval/juvenile stages of many commercially or recreationally important species (e.g., blue crabs, red fish, bay anchovy) could be used to garner public support. More work needs to be done to devise specific management goals/targets based on links between zooplankton distribution and flow.

Cyanobacteria blooms are generally a problem at the end of the dry season as waters warm and remain retained behind the Franklin lock and dam. Low releases should alleviate this problem, but the minimum quantity of water needed is unknown. The associated toxicity of these blooms is of concern, not only to stakeholders and aquatic organisms upstream of S-79, but downstream estuarine populations as the cyanobacteria biomass moves downstream when releases are initiated at the beginning of the wet season. The fate of the toxins remains unknown. *Lyngbya* blooms in the lower estuary and San Carlos Bay may have a negative impact on seagrass populations and requires further study. Cyanobacteria may not be a good indicator group, but certainly serve as a canary in the coal mine – when they bloom, conditions are not conducive for the growth of other phytoplankton that would otherwise outcompete the cyanobacteria and prevent their proliferation.

A strength of drift algae as an indicator is its high visibility, especially when it washes up on beaches. Drawbacks are that its response to various drivers remains unknown thus making any management alterations to address it uncertain, the locations where significant accumulations occur (prior to beach stranding events) are unknown, and the geographical area (including the Gulf of Mexico) needed for study of both of these questions is immense. Given the public attention it draws, drift algae is a strong candidate for building a greater understanding to the above questions.

Other candidate indicators were also discussed at the workshop including fish, benthic invertebrates (besides the oyster), oxbows, and invasive/exotic species (specifically the green mussel). Fish are tolerant of changing hydrologic conditions and may respond more strongly to moving food sources that are responding to changing salinity. Habitat fragmentation must be reduced (preservation of natural river banks and shorelines). Fish abundance and diversity may be useful as ecosystem indicator tools, but timescales will be much longer (years) than flow regimes (weeks). The sawfish could serve as the "next manatee" to garner public support.

Benthic invertebrates are already an established ecological indicator in other regions, but are under-utilized in the Caloosahatchee. One reason for this could be the difficulty associated with the analysis (high variability, high taxonomic expertise needed, lack of knowledge of life histories of many organisms). Much background/baseline research would be needed to bring this group up-to-speed as a useful indicator.

Oxbows serve as an aesthetic and educational resource. The public, therefore, should be supportive of efforts to restore and protect oxbows. As remnants of the original river channel, oxbows could serve as a historical resource to better gauge how the system has changed over time. The secluded/protected nature of oxbows will be useful for *Vallisneria* restoration efforts (serving as a nursery) and could serve as test beds for other scientific studies relevant to the river (or natural oxbows). As each oxbow is relatively unique, however, it is hard to assess whether oxbows could be used as indicators of flow regimes on a consistent (or encompassing) level.

Green mussels were the only exotic species discussed in the workshop. They could be another stressor impacting oyster populations, although this scenario is most likely in subtidal regions where salinities are consistently >15. Green mussels could serve as an indicator of sea level rise; as water levels rise, more subtidal areas are created, salinities could be higher (or more consistent) – a scenario that could allow for the expansion of green mussels into the Caloosahatchee (and other shallow water bodies in southwest Florida).

Overall, the indicators that have been in place for many years now (oysters, tape grass, and seagrass) are providing useful and valuable data on ecosystem responses to managed flow in the Caloosahatchee. Unfortunately, the dwindling population of *Vallisneria* is severely hindering its continued use as an indicator, but perhaps restoration efforts will allow the population to rebound (especially if low salinities are better maintained and herbivory is kept in check). The candidate indicators (phytoplankton, zooplankton, cyanobacteria, drift algae, benthic invertebrates, fishes, oxbows, and invasive species) can also provide valuable information that can complement data and responses of the above three indicators. A common characteristic among many of the indicators is a preference for flow regimes between 500 – 3000 cfs. This conclusion is similar to recommendations made in the SWFFP several years ago. As was noted in the interviews conducted by CBI, many stakeholders believe we have gathered enough scientific data to proceed forward with action. This sentiment was also voiced by many attendees of this workshop. If flows through S-79 could be maintained in the above envelope, indicator populations should be maintained and possibly expanded.

2. INTRODUCTION

In early 2013, the South Florida Water Management District launched a public initiative to consider developing a Vision for the Caloosahatchee. The District engaged the Consensus Building Institute to conduct a series of interviews with stakeholders and to recommend a Process Design for some kind of visioning process or other collaborative effort. CBI conducted over 40 interviews with interested parties representing state and federal agencies, agriculture, universities, environmental groups and other non-governmental organizations. The key findings of these interviews were compiled in a report along with a Design Process that relied on six key components (CBI, 2013).

One of the key components was to conduct a science workshop. The report recommended that a workshop be convened early in the process to “review and synthesize existing documented scientific work and establish a common science-based platform for moving forward” (CBI, 2013). This workshop was intended to directly address CBI’s recommendation. However, as the Caloosahatchee is a complex system subject to multiple anthropogenic stressors and environmental challenges, follow-on workshops or other types of dialogues may be required to completely review and synthesize the science pertinent to these challenges.

3. OBJECTIVES

The primary objective of this project was to conduct a participatory, two-day scientific workshop that reviewed and synthesized the science relevant to the management of freshwater inflows to the Caloosahatchee River and Estuary.

Additional objectives of the workshop were:

1) Discuss the primary indicators for assessing environmental condition and progress towards resolution of environmental problems. As time allows identify secondary or additional indicators.
2) Identify gaps where more information would improve our ability to manage and restore the system.

4. CALOOSAHATCHEE SCIENCE WORKSHOP OVERVIEW

Florida Gulf Coast University's Coastal Watershed Institute, in association with the Consensus Building Institute and the South Florida Water Management District, sponsored a participatory science workshop November 19-20, 2013, on the Caloosahatchee system. While the District provided financial support and guidance, FGCU workshop organizers took the lead in designing, managing and executing the workshop. All errors and omissions in this Report are the sole responsibility of FGCU and CBI.

The workshop, held at Florida Gulf Coast University, had the following main purposes:

- Briefly introduce the major environmental challenges facing the Caloosahatchee system and review the pertinent scientific information relevant to the management challenges.

- Discuss the primary indicators for assessing environmental condition and tracking progress. The workshop focused most directly on ecological indicators for benthic and water column communities, as well as other ecological indicators such as ichthyofauna, invertebrates, invasive species and oxbows.

- Identify gaps related to the primary indicators where more information would improve the ability to manage and restore the system.

FGCU identified and recruited 14 panelists to present the latest science on key ecological indicators and engage with stakeholders in small-group discussions. The agenda was structured to include both technical presentations, as well as facilitated stakeholder dialogue.

Day One: November 19, 2013 (9 a.m. to 6 p.m.)

- ***Setting the Scene:*** Understand the context and primary drivers that shape the Caloosahatchee system and its major ecological stressors.
- ***Why Ecological indicators:*** Understand what constitutes good ecological indicators and how they can help us manage the system more effectively; take stock of current indicators.
- ***Ecological Indicators for Benthic Communities:*** Consider the strengths and limitations of tape grass, oysters and seagrass as ecological indicators; identify key gaps and uncertainties.
- ***Ecological Indicators for Water Column Communities:*** Consider the strengths and limitations of phytoplankton (including red tide), zooplankton, blue-green algae and drift algae as ecological indicators; identify key gaps and uncertainties.

Day Two: November 20, 2013 (9 a.m. to 6 p.m.)

- ***Ecological Indicators for Water Column Communities:*** Continue discussion of ecological indicators for water column communities from Day One.
- ***Other Ecological Indicators:*** Consider the strengths and limitations of other potential indicators of system health, including ichthyofauna (e.g., small-tooted sawfish, red drum,

etc.), invertebrates (blue crabs, bivalves), manatees, oxbows and others; identify key gaps and uncertainties.

- ***Bringing it All Together:*** Take stock of key gaps and research needs based on workshop deliberations; consider indicators that, taken together, might represent a key set or constellation of indicators that reflect more the "system" as a whole.

A copy of the workshop agenda is provided as an attachment.

5. SETTING THE STAGE

A. Historical Context (based on the presentation by Michael Parsons, FGCU).

The Caloosahatchee was a shallow, sinuous river that originated in wetlands to the west of Lake Okeechobee near Lake Hicpochee. It meandered to the west discharging into the Gulf of Mexico via San Carlos Bay near present day Fort Myers. In 1881, a canal (C-43) was dredged, connecting the Caloosahatchee to Lake Okeechobee. More extensive modifications were made in the 1930s when levees were constructed along the north and south shores of the lake as flood control measures in response to the extensive flooding and associated mortalities due to the hurricanes of 1926 and 1928. Initial steps were also taken to straighten and deepen the river and canal at this time, along with the installation of the Moore Haven (S-77) and Ortona (S-78) Locks in 1935. Another major hurricane in 1947 resulted in more flooding and the loss of property and lives. In response, Congress passed the Flood Control Act in 1948, authorizing the initiation of the Central and South Florida (C&SF) Project. During this time frame (1949), the Florida Legislature created the Central and Southern Florida Flood Control District (the predecessor to the South Florida Water Management District) to manage the C&SF Project in conjunction with the U.S. Army Corps of Engineers.

Many flood control and prevention measures were taken over the subsequent decades: the river was widened, deepened, and straightened; the Hoover Dike was constructed around Lake Okeechobee; another lock (Franklin Lock, S-79) was installed; and an extensive plumbing system was constructed, extending from south of Orlando to Florida Bay. West (downstream) of

S-79, a navigation channel was dredged and a causeway built across the mouth of San Carlos Bay in the 1960s, both of which appear to have resulted in a more northward flow of Caloosahatchee water into Pine Island Sound and a decrease of flow southward through San Carlos Pass (Sheng, 2001). Additionally, historic oyster bars upstream of Shell Point were mined for use in the construction of roads resulted in oyster habitat destruction and hydrologic changes due to the removal of these shallow water features. Additionally, the Kissimmee River was channelized between 1962 and 1971 (the C-38 canal) as a flood control measure, which reduced riparian wetlands and natural water storage capacity. As a result, much of the freshwater received by the Kissimmee River basin was diverted to Lake Okeechobee. The Kissimmee River is now undergoing restoration, however, in an effort to regain wetlands and water storage capacity, and to reduce sediment and nutrient loading in the system. Lastly, the natural overbank flow along the southern shore of Lake Okeechobee into the Everglades and down to Florida Bay has now largely been diverted into the Caloosahatchee and St. Lucie rivers. While these hydrologic modifications have resulted in many benefits for flood control, water resource management, and agriculture, there has been a growing concern among citizens and scientists alike that the managed flow regimes have significantly altered the Caloosahatchee and St. Lucie river ecosystems. Numerous projects have been conducted over the years to study ecosystem responses to these altered flow regimes in the Caloosahatchee, much of which will be summarized in this report. Prior to these studies, however, it is worth examining the ecosystem processes and responses to perturbations in a generalized context to better "set the stage."

B. The Caloosahatchee Estuary Conceptual Model (based on the presentation by Darren Rumbold, FGCU).

A conceptual model of the Caloosahatchee Estuary ecosystem was developed as part of the Southwest Florida Feasibility Study and published by Barnes (2005). Conceptual models highlight what is known and not known and can be used to plan future work, and are easily modified as knowledge increases. They are useful communication tools, providing an explicit expression of the assumptions and understanding of a system for others to evaluate. The conceptual model for the Caloosahatchee Estuary devised by Barnes (2005) consists of four drivers, five stressors, fourteen effects, and six attributes (Figure 1). The four drivers (i.e., outside factors driving ecosystem responses) are: sea level rise; water management; land use & development; and navigation. The five stressors (i.e., immediate responses to the drivers) are: altered estuarine salinity; altered hydrology; input & elevated levels of nutrients, toxins and dissolved organics; boating and fishing pressure; and physical alterations to the estuary. Those parameters that are addressed in this workshop report are highlighted in Figure 1.

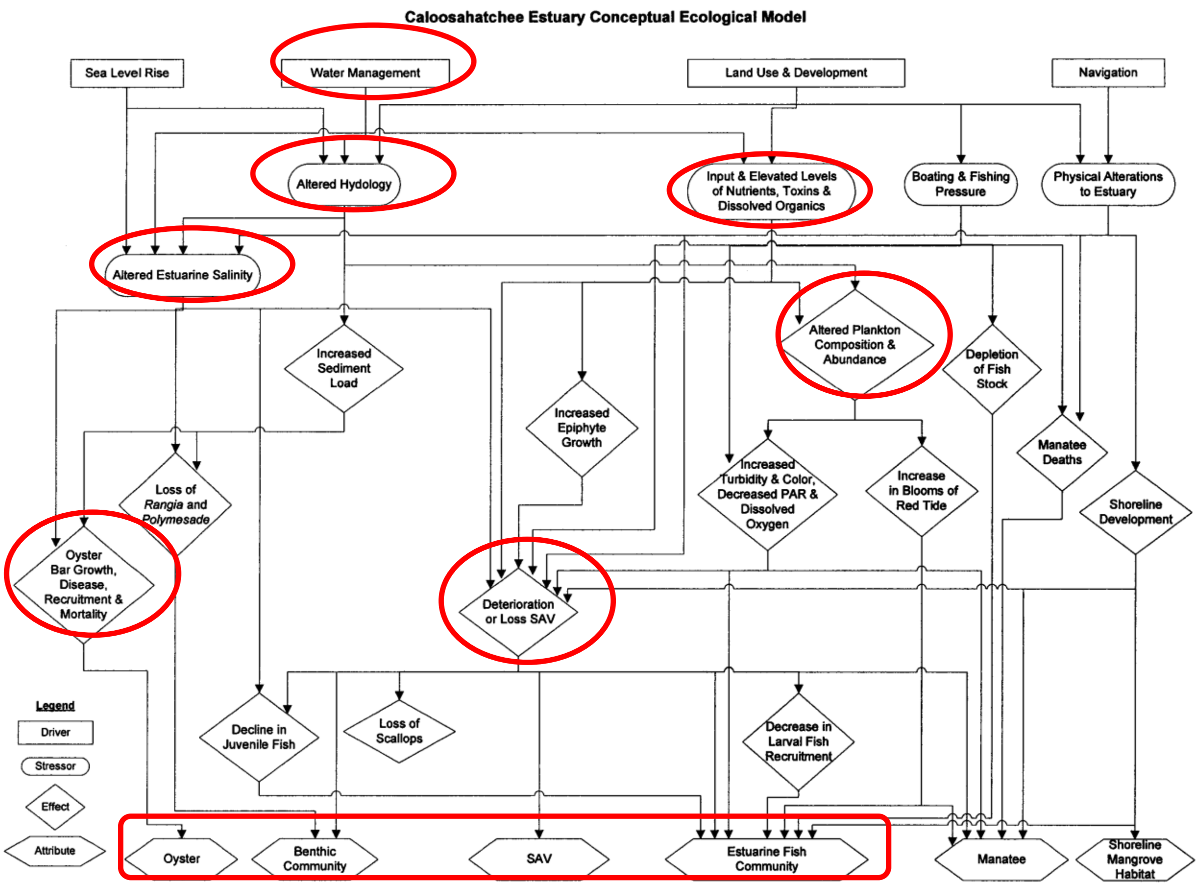

Figure 1. Caloosahatchee Estuary Conceptual Ecological Model Diagram (adapted from Barnes, 2005).

It is important to clearly identify and communicate cascading adverse effects caused by the stressors. Primary, or direct, effects occur when a stressor acts directly on the assessment endpoint and causes an adverse response. Secondary, or indirect, effects occur when the entity's response becomes a stressor to another entity. There are often a series of effects among a diversity of organisms and processes that cascade through the ecosystem, which may have greater ecological significance than primary effect (Figure 2). For example, consider the Altered Hydrology driver. While estuarine species are generally well adapted to cope with varying salinity conditions, larger shifts and timing of freshwater discharges can be a problem. Such changes can impact the community structure and function of phytoplankton, submerged aquatic vegetation (SAV), macroalgae, and the benthos - particularly oysters and fisheries. There are also secondary, or indirect, effects that must be considered, including impacts to manatee demographics and wading bird community structure. The Input & Elevated Levels of Nutrients, Toxins & Dissolved Organics stressor influences the growth and community structure of phytoplankton, macroalgae, and microbes (direct effects). This stressor also has indirect effects on SAV, zooplankton, fish and other aquatic organisms from: 1) light attenuation, 2) altered dissolved oxygen concentrations, and 3) biotoxins which, in turn, can have cascading effects on manatee, dolphins and wading bird community structure. Therefore, when constructing a conceptual model, one must be aware of the complexities involved, including indirect (secondary) effects, possible filters that may attenuate a stressor in an ecosystem, and appropriate management responses to mitigate/reduce the impacts of the stressor(s) (Figure 2).

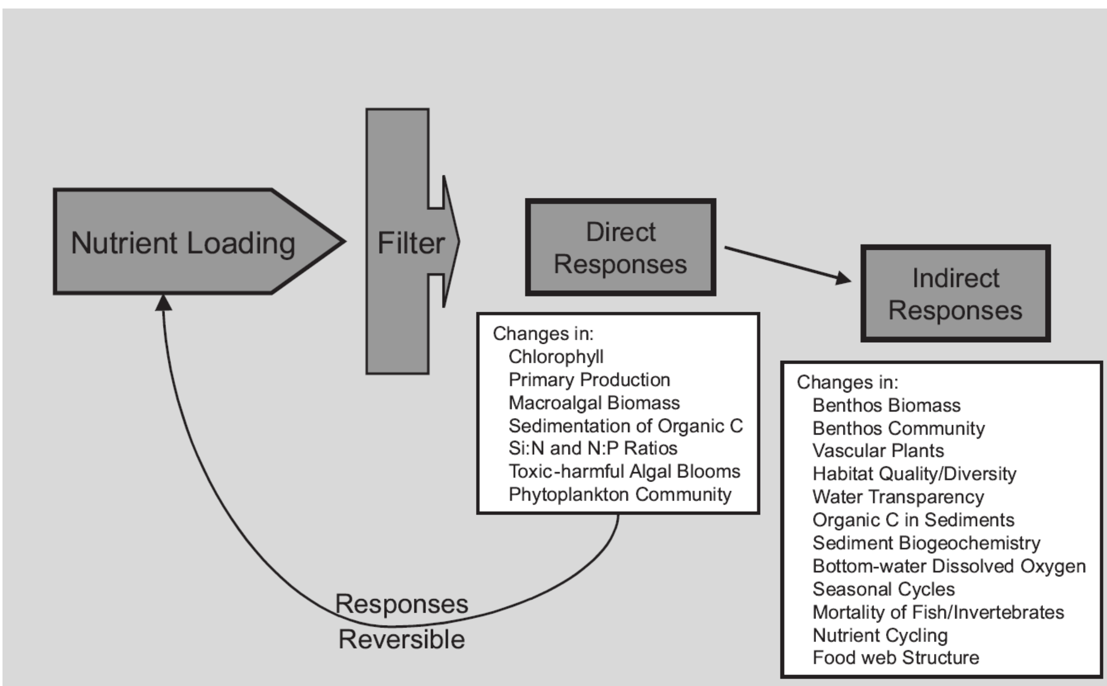

Figure 2. Schematic representation of a conceptual model depicting (1) a complex suite of both direct and indirect responses to change in a stressor (nutrient inputs); (2) system attributes that act as a filter to modulate these responses; and (3) the possibility of ecosystem rehabilitation through appropriate management actions to reduce nutrient inputs to sensitive coastal ecosystems (Cloern 2001).

Additional considerations must be given to the fact that different stressors may be significant at different locations (e.g., upstream versus downstream) and/or seasons (i.e., wet versus dry season), and that multiple stressors may be in play (Figure 3). Such factors increase 1) the complexity of both conceptual models and 2) the difficulty in ascertaining the role of the various stressors causing responses. As Breitburg et al. (1999) states, "The presence of multiple stressors may either increase or dampen the temporal and spatial variability seen in aquatic systems, depending on the interactions among stressors and the influence of background environmental conditions and sensitive species on the expression of stressor effects." Therefore, future efforts should improve and expand upon the conceptual model presented in Barnes (2005), especially in terms of predictive models linking stressors with eco-resources (valued ecosystem components). We can develop an analysis plan for research to fill data gaps, particularly on simultaneous effects of multiple stressors and indirect effects.

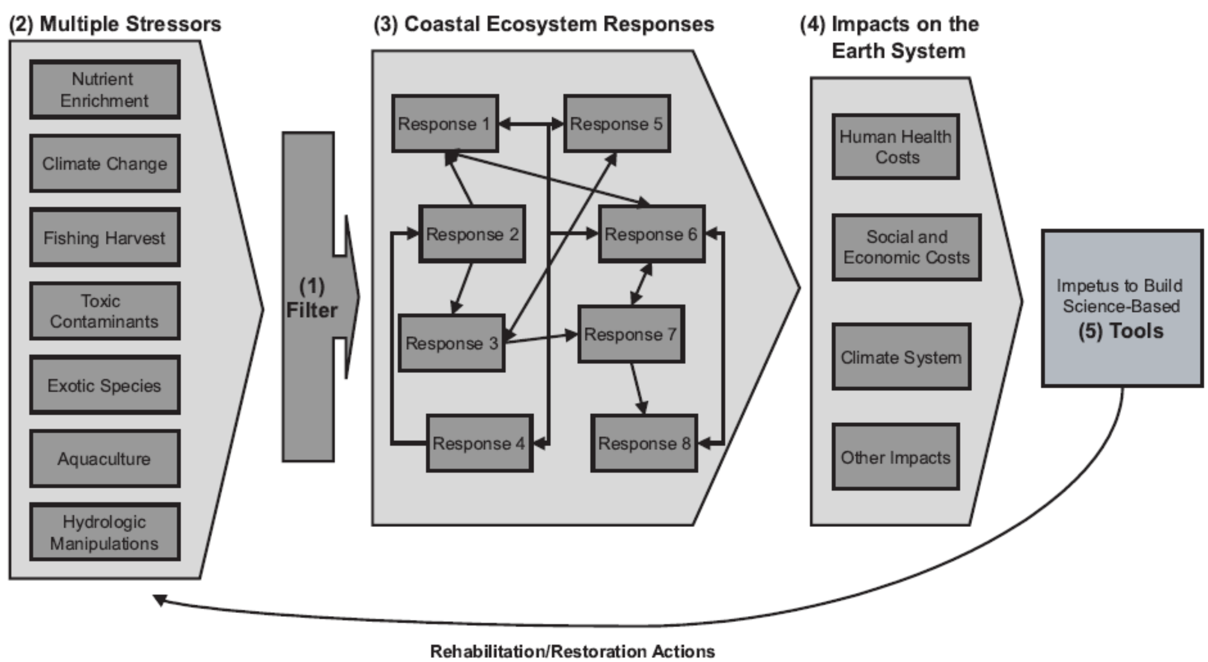

Figure 3. An example of added complexity caused by the role of multiple stressors (2) on a coastal ecosystem. The stressors may be attenuated (or amplified) by ecosystem attributes (1) causing a myriad of responses (direct and indirect; 3). The impacts may be regional (or global; 4). Only an understanding of the processes and impacts will allow the develop of tools to successfully rehabilitate and/or restore the ecosystem (5). Adapted from Cloern (2001).

C. Ecological Indicators (based on a presentation by Peter Doering, SFWMD).

Ecological indicators can be defined as quantitative representations of 1) the forces that drive a system; 2) responses to forcing functions; and/or 3) previous, current or future states of a system (Salas et al. 2006). As described above, ecosystems are complex and ecological indicators can help describe them in simpler terms. Indicators are used because it is impossible to measure everything all the time; it costs too much and takes too much time. When indicators are used effectively, they are expected to reveal conditions and trends that help in management, planning and decision-making. One question that arises in the use of indicators (and the ecosystem state the indicators are supposed to guide resource managers towards) is: "What defines a healthy (or desirable) ecosystem?" Rombouts et al. (2013) defines ecosystem health as "The system's ability to realize functions desired by society and maintain them over a long period of time." In this context, health is determined by *society* – what attributes of an ecosystem do we, as a society, want to protect and/or restore? As summarized in the Consensus Building Institute's report, many stakeholder interviewees share the strategic view that ecological indicators will be most effective if they (1) resonate and can be communicated easily with the broader public (i.e., charismatic indicators coupled with compelling visuals and accessible narratives); and, (2) demonstrate system-wide balance and health. Some also suggested there was likely more disagreement around indicators than meets the eye, and, as one interviewee put it, "nobody has a uniform and accepted definition of what's 'healthy.'" This is especially compounded when one tries to gauge ecosystem health in terms of a "historical baseline", as moving baselines hinder assessments of what truly "healthy" or pristine conditions were prior to human impacts. CBI compiled a list of ecological indicators that stakeholders suggested during the interview process (Table 1).

An indicator can be a single species or parameter (e.g., a roseatte spoonbill), a community (e.g., seagrass beds or oyster reefs) or an aggregated measure or index (e.g., Florida's Trophic State Index; the Index of Biotic Integrity). Noss (1990) provides seven criteria for assessing candidate indicators. A good indicator should be:

1. Representative of the system;

2. Sufficiently sensitive to provide an early warning of change;
3. Capable of providing a continuous assessment over a wide range of stress;
4. Relatively independent of sample size;
5. Easy and cost effective to measure, collect, assay, or calculate;
6. Able to differentiate between natural cycles and trends and those induced by anthropogenic stress; and
7. Relevant to ecologically significant phenomena.

Table 1. List of potential ecological indicators suggested by CBI Assessment interviewees

Candidate Ecological Indicators Suggested in the Assessment Process		
Estuarine Indicators	**Mid/Upper Estuary Indicators**	**Freshwater Indicators**
Seagrasses (shoal, turtle, and manatee)	Seagrasses	tape grass
Eastern oyster	Tape grass	water quality (Class I standards)
game fish (red drum, snook, tarpon, spotted sea trout)	beach usage at S-79	swimmable and fishable
blue crab	manatee health and abundance	large-mouthed bass
sawfish		oxbow restoration
zooplankton (larval crabs, shrimp)		presence/absence of algal accumulations
presence/absence of algal accumulations (drift algae)		
manatee health and abundance		
public health impacts		

Doren et al. (2009) and Salas et al. (2006) suggest other factors that should also be considered for a highly effective indicator including:

1. Its meaning should be easily communicated to many audiences;

2. It can form the basis for measurable targets to allow for assessments of success of restoration or management actions; and
3. It should indicate a feature specific enough to result in management or corrective action.

Due to the complexity of ecosystems, one indicator is unlikely to reflect all stressors and responses, so multiple indicators are probably necessary. Individual indicators provide discrete pieces of information about one, or perhaps a few constituents of the ecosystem, while a suite of indicators in combination is intended to reflect the status of the larger ecosystem (Doren et al. 2009). For example, within most estuaries, salinity varies spatially; being low at the head and high near the mouth. Different organisms occupy different portions of the estuarine salinity gradient (Figure 4). Multiple indicators, therefore, are required to reflect conditions along different portions of the salinity gradient.

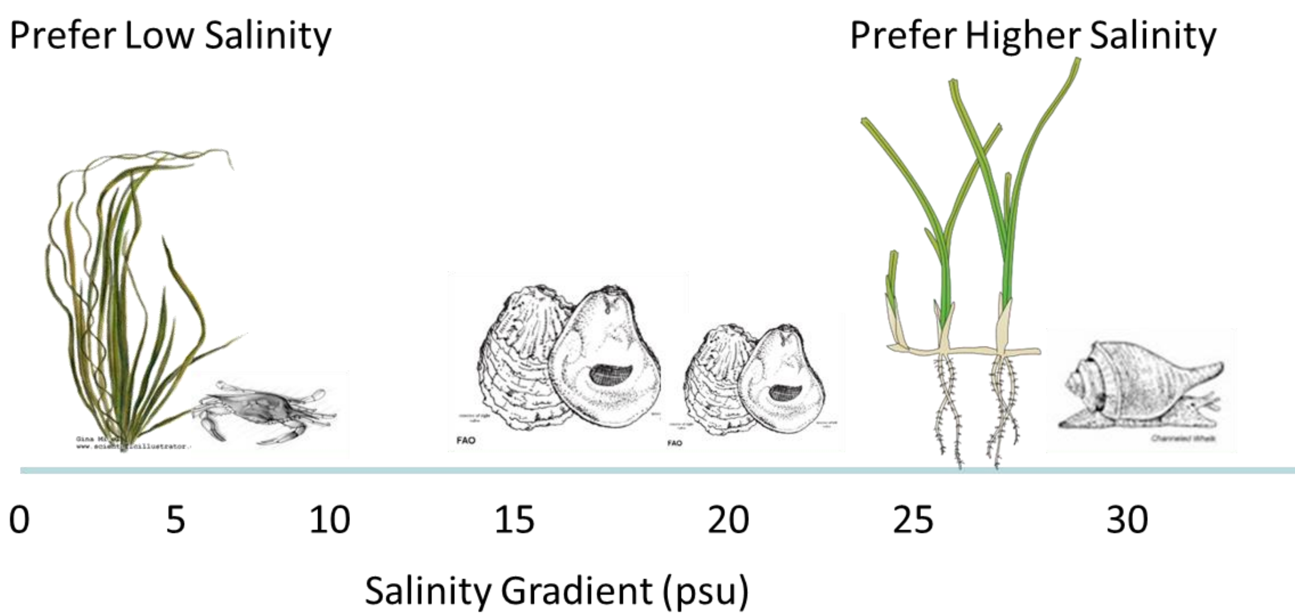

Figure 4. An example of a shift in species along a salinity gradient in an estuary.

The attributes presented in the conceptual model (Figure 1) meet many of the above criteria and can be considered candidate indicators. Several indicators are currently being utilized in the Caloosahatchee Estuary (Table 2), some for over a decade. One purpose of this science workshop is to do a "check-up" on these indicators. Are these indicators telling us what we need to know? Are these indicators still appropriate? Understanding of the Caloosahatchee has increased since the original ecological model was proposed in 2005. Are there other useful indicators we should be using?

Table 2. Ecological indicators currently being utilized in the Caloosahatchee Estuary.

Ecological Indicator	**Used By**	**For**
SAV (seagrass and tape grass)	SFWMD, RECOVER, CHNEP, FDEP	Freshwater Inflows, Ecosystem Condition, Goal/ Target, Water Quality (TMDL, NNC)
Oysters	SFWMD, RECOVER, CHNEP	Freshwater Inflows, Ecosystem Condition, Goal/ Target
Fish	CHNEP	Goal/Target

Given these questions, the workshop focused not only the indicators now being used to assess estuary health (the benthic indicators), but also included presentations on other candidate indicators. For each candidate indicators, experts were identified and asked to address the following three questions to help standardize a review of the various parameters:

1. What driver is the indicator sensitive to and is this ecologically relevant?
2. What are the strengths and limitations of this indicator
3. What more do we need to know?

The remainder of the workshop focused on the above questions in regard to specific potential indicators: benthic, water column, and other candidate indicators. Below is a synthesis of both the materials presented on each candidate indicator, as well as a synthesis of discussions and comments generated during facilitated breakout sessions with workshop participants.

6. BENTHIC INDICATORS

A. Seagrass and Tape grass (based on presentations by Melinda Brown, FDEP; David Ceilley, Johnson Engineering, Inc.; and James Douglass, FGCU).

What we know:

Seagrass and tape grass are valued ecological components (VEC) because they provide habitat for other organisms (including nursery habitat), forage for manatees and turtles, stabilize sediments, and attenuate wave action. *Vallisneria americana* is recognized as a good indicator species because it is nearly ubiquitous in North America, it is oligohaline (preferring no to low salinity), sensitive to anthropogenic disturbances, and can respond quickly to effective management practices. *Vallisneria* growth is most sensitive to CDOM and salinity. An examination of trends of *Vallisneria* in the Caloosahatchee indicates that its abundance decreased substantially from 1998 – 2001, during a time period when average mean salinity values in the upper estuary (CES04) were often >10. From late 2001 into 2006, mean monthly salinities stayed at or below 10, but *Vallisneria* did not show signs of recovery until 2004 (three years), but decreased substantially at the end of 2006 as drought conditions set in, resulting in average monthly flows through S79 below 450 cfs for the next nineteen months. *Vallisneria* has not recovered since, and monthly average salinities have exceeded 10 numerous times through 2012. Such periods of high salinity likely play a role in the lack of recovery in *Vallisneria* cover, but recent research also suggests that herbivory may play a factor reducing flowering and subsequent seed production. Efforts to reseed *Vallisneria* have been recommended as a counter-measure, although consistent salinities below 10 will also be needed.

Farther down the estuary, seagrass coverage has remained fairly consistent (and even increased) over the past eight years, except for decreases in abundance in 2005 in Matlacha Pass and San Carlos Bay during periods of high river discharge. As the seagrass meadows recovered since 2005, there was evidence of species shifts. For example, *Halodule wrightii* replaced *Thalassia testudinum* at the MP05 site in San Carlos Bay, following the high river discharges in 2005. Therefore, in the lower estuary, there is evidence that seagrass abundance decreases during periods of high river discharges, and that species more tolerant of the lower salinity (e.g., *Halodule*) replace species less tolerant of lower salinities (e.g., *Thalassia*). In the mid-estuary, *Halodule* increased in abundance during/following the drought conditions in 2006-7, likely in response to higher salinities (>10) present during this time frame. *Halodule*, a “mesohaline” seagrass species, may therefore increase its abundance in the lower estuary when flow is high, and increase in abundance in the mid- or upper estuary when flow is low. While spatial variation in salinity can increase diversity (i.e., transitioning from *Vallisneria* upstream to *Halodule* in the middle estuary, and *Thalassia* in the lower estuary along a salinity gradient), temporal variability can reduce diversity and abundance if changes in salinity are too extreme over too short of a time period (i.e., such as during flows <450 cfs or >2800 cfs).

The following gaps were identified by the speakers and in the subsequent breakout sessions:

1. Hydrologic stressors
    a. Tidal forcing (*Vallisneria*)
    b. Need to examine trends in and possible impacts of sea level rise and drought conditions which are expected to increase salinities, thereby increasing the difficulty in maintaining low salinities
    c. Extreme events need to be assessed and incorporated into modeling efforts (e.g., droughts, hurricanes, floods)
    d. Impacts of boat wakes
2. Biological stressors
    a. Impact of grazing pressure (*Vallisneria*)
    b. Role of grazers in controlling epiphyte populations (seagrass)
    c. Impact of drift algae collecting in seagrass beds on seagrass productivity
3. Multiple stressors
    a. Role of multiple stressors [salinity, light (CDOM and turbidity), grazing, boat wakes, etc.] working in conjunction
    b. Better understanding the time lag between extreme stressor exposure and mortality
    c. Studies from other regions have shown that high nutrient loading can lead to reduced seagrass productivity. Better understand the extent to which nutrient loading is having a direct impact on seagrass health versus the influence of indirect impacts (e.g., algal blooms (phytoplankton and macroalgae) reducing light levels)
    d. All water quality parameters should be examined in conjunction with seagrass data to better assess effects of various drivers/stressors.
    e. Factors affecting light penetration (CDOM, turbidity, chlorophyll) must be better studied to assess their impacts on seagrass health.

Stakeholders raised the following questions, comments and considerations in the breakout session following the presentation:

1. Is there a "baseline" year we want to aim for in recovery efforts?
2. Do we know the "zones" where the three prominent grass species (*Vallisneria*, *Halodule*, and *Thalassia*) should grow?
3. Can efforts be taken to reduce the "no man's land" between the zones? Perhaps reduce areal (longitudinal) extent of transition area between 10-20 salinity.
4. Extreme flows (<450 or >2800 cfs) seem to cause negative impacts. Should we simply strive to maintain flows within this flow envelope (450-2800 cfs) and monitor seagrass response?
5. Seagrass health is not simply a function of salinity and light; nutrient loading must be part of the equation.
6. There is enough scientific data available to start taking action. Specific targets (i.e., flow and salinity) should be set, and then our efforts should focus on how we can meet those targets.
7. Water storage will be important to better manage flow by reducing periods of high flow, conserving water during dry season, and to reduce flashiness in the system.
8. How strong is the relationship between flow and salinity? Has this been modeled along different stretches of the Caloosahatchee?
9. Similarly, how confident are we that minimum flow levels (450 cfs) are actually high enough to maintain low enough salinity conducive to *Vallisneria* growth?
10. Areal mapping needs to be done in conjunction with ground-truthing studies to better assess coverage of seagrass in the Caloosahatchee and receiving water bodies.
11. For how long can *Vallisneria* tolerate/withstand salinities >10?
    a. There are geographical strain differences – Caloosahatchee *Vallisneria* may have different tolerances than strains from other regions

Based on the scientific data presented, the discussions in the breakout sessions, and stakeholder feedback, the following Assessment of Indicator Status is provided:

Tape grass beds are nearly wiped out and seed beds might be depleted. The die-off of *Vallisneria* was coincident with low flow conditions (<450 cfs) and high salinities (>10), especially during the drought conditions of 2007. Herbivory has been identified as a controlling factor in both the tidal and non-tidal portions of the Caloosahatchee, preventing *Vallisneria* from flowering. There is a need to fence/protect new stocks (in oxbows, etc.) to reduce impacts of grazing and boat wakes, as well as a need for nursery stock to improve restoration efforts. There is also a need to map out geographical extant of restoration efforts. Specifically, upstream restoration efforts (in/near tributary mouths as well) may benefit downstream sites. In terms of seagrass (primarily *Thalassia* and *Halodule*), we need to determine salinity/flow regimes that allow for *Halodule* to thrive in mid-estuary locations (need to define) without replacing *Thalassia* in the lower estuary. Simultaneously, we need to maintain salinities >30 in the lower estuary to support *Thalassia* growth.

B. Oysters (based on the presentation given by Lesli Haynes, FGCU).

What we know:

Eastern oysters (*Crassostrea virginica*) are good ecological indicators because they are benthic, sessile (immobile) filter feeders (filtering 4-34 L/hr/oyster), which allows them to be used in cause-effect relationship studies. Additional characteristics that make them valued ecological components are that they create secondary habitat, used by many organisms important in the diets of many important sport fish, such as redfish (e.g., 45% of the gut contents from red fish contain prey items that live on oyster reefs; Wasno, in prep.). As well, the reef structure created as the shells of new individuals are fused onto older individuals helps to mitigate boat wakes and storm surge. Additionally, the filter-feeding capability of oysters creates important benthic-pelagic coupling in the ecosystem.

The primary stressors affecting oyster health in the Caloosahatchee estuary are salinity and temperature. The optimal range of salinity for oysters (especially in terms of reproduction) is 15-

30 (corresponding with a flow range of 1000-3000 cfs). Salinities higher and lower than this range can lead to a reduction or failure in gamete production and fertilization, as well as significant mortality of embryos and larvae. These impacts are exacerbated by higher temperatures (30 versus 25 C). The gonadal index (an indicator of gonad mass under production) is highest from May to October (i.e., during wet season), indicating that low salinities likely represent a bigger threat than high salinities in terms of gamete production and subsequent fertilization. On the other hand, exposure of spat to salinities outside of the 20-30 range for more than six days can lead to mortality (at 25 C), an effect that was again amplified at 30 C where only four days of exposure can lead to mortality. Therefore, high flows associated with the wet season can impact spat, as well as very low flows associated with the onset of the dry season (i.e., late October onwards). While adult oysters can thrive in higher salinities, such conditions lead to higher rates and intensity of dermo (a disease caused by *Perkinsus*) and higher rates of predation upon the oysters. Therefore, salinities ≤30 are preferred to reduce the disease and predation threats. Predation was otherwise significant on juvenile oysters (doubling mortality rates versus other, natural causes), and more prevalent farther downstream versus upstream.

The following gaps were identified by the speakers and in the subsequent breakout sessions:

1. While the above findings are important and thorough, they are primarily based on five sampling sites and with reduced replicates, both a result of decreased funding. Better spatial coverage and higher statistical power would be beneficial to provide a higher-level ecosystem picture of oyster reefs.
    a. Sparse data for Matlacha, Pine Island Sound, etc.
2. The role of multiple stressors remains understudied (e.g., nutrients, contaminants, harmful algal blooms).
3. Historical distributions of oyster beds
4. Role of water quality as a stressor
5. Limited substrate as a factor in terms of hindering expansion of oyster populations (spat need to settle on a hard substrate (preferably an oyster shell) to continue growth and development).

6. Impact of high hydrological variability now experienced in the Caloosahatchee on oyster populations
7. Role tributary flows play in influencing salinity downstream of S-79
8. Improved salinity mapping (and modeling) –typical (i.e., frequent) salinity ranges along different sections of the Caloosahatchee
9. Actions that can be taken to alleviate salinity stress if salinities are too variable at a given stretch of river (or either too high or too low)
10. We're still learning how the various life stages of oysters are differentially affected by environmental stressors (i.e., the various life stages have different tolerances to stressors).

Stakeholders raised the following questions, comments and considerations in the breakout session following the presentation:

1. Concerns that maps showing oyster reef distributions are old and need updating
2. The "sweet spot" between flow and morality in oysters should be determined (is 1000-3000 cfs a good starting point?).
3. Is sedimentation a stressor to oysters? Some upstream beds are buried by sediment at times – is this a problem? Does boat wake play a role?
4. Q: Is there a geographical (spatial) range we can use to establish salinity envelopes based on oyster bed distributions?
    a. A1: Right now, downstream of Iona Cove.
    b. A2: During dry season, predation impacts can extend up to the Midpoint Bridge (too far upstream?).
    c. A3: Lack of hard substrate hindering expansion of oyster populations to new areas.
5. Can historical distributions aid us in establishing a "roadmap" to restore oyster reef populations in the Caloosahatchee?
6. Oysters are not "sexy" enough to engage the public.
    a. Not endangered
    b. No direct economic value (we do not harvest oysters in the Caloosahatchee)
    c. Navigational hazard
7. Flows should be changed gradually to allow organisms to adapt (or move)

Based on the scientific data presented, the discussions in the breakout sessions, and stakeholder feedback, the following Assessment of Indicator Status is provided:

Research on oyster distributions, physiology, and ecology has provided us with an initial estimate of a “sweet spot” for oyster growth (a salinity range of 15-30, corresponding to a flow range of 1000-3000 cfs). We do not have good spatial coverage for monitoring oyster reefs, nor do we have updated maps of modern reefs in the system. Historical data exist, but have not been compiled and mapped, so we do not have a good grasp of what historical distributions were. A primary question to be addressed is: Do we want to maintain current oyster reef distributions, or do we want to expand them to approach their historical extent? The answer to this question will help to devise management strategies.

7. WATER COLUMN INDICATORS

A. Phytoplankton (based on the presentation given by Michael Parsons, FGCU).

What we know:

Phytoplankton are important ecological components because they are primary producers at the base of the foodweb, providing food for zooplankton and filter feeders (such as oysters). As phytoplankton contain chlorophyll, they are useful tools for monitoring water quality, as high chlorophyll concentrations (>20 µg/L) are indicators of eutrophication (excessive nutrient loading). When phytoplankton concentrations are very high (i.e., bloom conditions), they can discolor the water, and while the high levels of photosynthesis can oxygenate waters during the day, the same phytoplankton biomass can significantly reduce oxygen concentrations in the water during the night, leading to hypoxic (or anoxic) conditions that can stress animals (and cause mortalities such as fish kills). Some species of phytoplankton produce toxins (e.g., the dinoflagellate, *Karenia brevis*, and the cyanobacterium, *Microcystis*) that can cause human and ecosystem health problems when these species are abundant in the water column.

Phytoplankton growth is dependent upon ample light and nutrients, and in the case of rivers or estuaries like the Caloosahatchee, residence time (i.e., the amount of time a parcel of water remains in the system or region of the channel). For example, model simulations have suggested that when flows are 0-500 cfs, water masses (and the accompanying phytoplankton) can stay in the mid-stretches (15-33 km downstream of S-79) of the Caloosahatchee for over 30 days (Wan et al. 2013); ample time for phytoplankton to grow and obtain significant biomass. Model simulations have also predicted that as flows increase through S-79, the highest biomass of phytoplankton migrates downstream; this result has been corroborated by other studies (Doering et al. 2006; Parsons 2010; Andresen 2011). During high flow regimes, Doering et al. (2006) reported that the chlorophyll maximum was located approximately 30 km downstream from S-79 when flows were >4500 cfs, whereas Parsons (2010) observed that phytoplankton are flushed out of the estuary when flows >3500 cfs. Doering et al. (2006) also reported a positive relationship between nitrogen loading (30 day TN) and chlorophyll concentrations in the lower river and San Carlos Bay, a relationship that was absent farther up the channel, likely due to low residence times. Parsons (2010) observed the highest concentrations of chlorophyll in the lower river (i.e., near downtown Fort Myers) during moderate flows (1500 cfs). Therefore, phytoplankton biomass tends to be highest in the upper estuary (upstream of Beautiful Island) when flows are low (0-1000 cfs), with the chlorophyll peak migrating downstream (mid- to lower estuary) as flows increase (1000-3000 cfs), with phytoplankton flushing out of the system at higher flows (>3500 cfs). The location and amount of phytoplankton are not the only aspects of biomass affected by flow; the composition of the phytoplankton also changes. Parsons (2010) observed that diatoms tend to dominate in low flow conditions, whereas cyanobacteria become more dominant as flows increase, likely reflecting the export of freshwater cyanobacteria upstream of S-79 and the rapid growth rates of some cyanobacteria species that can still predominate in low residence time conditions.

The following gaps were identified by the speakers and in the subsequent breakout sessions:

1. The influence of Caloosahatchee discharges on red tides remains unresolved.
    a. There does not appear to be an immediate stimulatory effect.
    b. Need to better understand possible role of legacy nutrients (i.e., nutrients from the river that have already cycled through the system and are released from the sediments at a later date).
2. The impacts of harmful algal bloom (HAB) species within the Caloosahatchee system

   a. A bloom of the diatom, *Pseudo-nitzschia pungens,* was observed near Beautiful Island at the end of the dry season (May) in 2008. While this species is not toxic, other *Pseudo-nitzschia* species are, and they are present in the system and represent a potential threat.
   b. The dinoflagellate, *Akashiwo sanguineum,* was the dominant phytoplankton species observed in the study conducted by Parsons (2010). This is a known HAB species and could represent a potential threat to the Caloosahatchee ecosystem.
   c. Toxic cyanobacteria that often bloom at the end of the dry season upstream of S-79 are exported downstream during releases out of S-79 at the beginning of the wet season. Need to better understand the impact the toxins are (e.g., microcystins) having on the Caloosahatchee ecosystem
   d. Need to better understand which species are the “bloomers.”
3. How to manage flows to minimize phytoplankton bloom impacts.
   a. Low flow (<1000) is not good as biomass will build up in the upper estuary.
   b. Higher flows will move the chlorophyll maximum downstream, but the resultant impacts of such actions are unknown.
   c. Need to better understand whether HABs result if the chlorophyll maximum is moved downstream (most HAB species are marine dinoflagellates).
4. Better understand impacts of changing phytoplankton assemblages on foodwebs
   a. Diatoms are considered a good food source for zooplankton; cyanobacteria are considered a poor food source. Therefore, there can be foodweb impacts/repercussions related to shifting phytoplankton compositions.
5. Influence of top-down controls (grazers)
6. Role of micronutrients (e.g., iron)

Stakeholders raised the following questions, comments and considerations in the breakout session following the presentation:

1. What is the role of nutrients and TMDLs?
2. The need to better monitor bottom dissolved oxygen (DO) levels. Is DO a stressor for fish and benthic communities in the Caloosahatchee?

3. What HAB species are present?
4. Which phytoplankton species are potential bloomers?
5. Can we tease out the influence of salinity from nutrient loading and residence time?

Based on the scientific data presented, the discussions in the breakout sessions, and stakeholder feedback, the following Assessment of Indicator Status is provided:

Phytoplankton do respond to flow, although it is unclear what portion of the response is due to salinity, residence time, or nutrient loading. Low flows result in high phytoplankton biomass in the upper estuary. As flows increase, the chlorophyll maximum moves downstream, likely being flushed out at high flows (>3500 cfs?). Phytoplankton composition changes both downstream and as flow increases, although it is unknown if these changes will increase the threat of HABs in the Caloosahatchee. If phytoplankton were to be used as an ecological indicator by the District, the primary responses of concern would be 1) where should the chlorophyll maximum be located; and 2) can flow management be used to mitigate against HABs.

B. Zooplankton (based on the presentation given by Greg Tolley, FGCU).

What we know:

Zooplankton (primarily larval stages of benthic organisms and fish) are an attractive candidate indicator group because they are widely distributed in the Caloosahatchee with high diversity (over 208 species have been identified in the Caloosahatchee alone). They generally respond to environmental changes on the order of days or weeks, which is on a similar scale to changing flow conditions. The high diversity of zooplankton also translates into a capability for a wide-range of performance measures, as many species are euryhaline (tolerant of a wide range of salinities), while others are either oligohaline (low salinity) or polyhaline (high salinity) species. Sample collection is cost-effective, requiring a single sampling gear (plankton net) regardless of depth, habitat, or bottom type. Lastly, zooplankton are ecologically relevant as they are a trophic link to many commercially- and recreationally-important species.

A two-year study (May 2008 – Apr 2010) conducted by Tolley et al. (2010) documented the range of responses within the zooplankton community as flows transitioned between two cycles (dry seasons and wet seasons). While oligohaline species responded favorably to increasing flow (with opposite responses from polyhaline forms), there were broader, larger scale responses that raise important management issues: 1) centers of abundance; 2) impingement and habitat compression; and 3) flush-outs. Several species exhibited significant relationships between flow and their centers of abundance (i.e., the weighted mean of where in the river a given species is most abundant). Such relationships can be useful to address management questions such as "How can we keep this organism in contact with its food base?"; "How can we keep this organism away from areas prone to hypoxia?"; or "How can we maximize the habitat available for a given species?". The last question in particular segues into the observation of impingement and habitat compression in the Tolley et al. (2010) study. During the dry season, the low salinity zone (0.5 – 6) was isolated above the Franklin lock and dam. Therefore, species that would otherwise move/migrate within this salinity zone ended up being compressed in a small area just downstream of S-79, leading to impingement and habitat compression. Such conditions can lead to a lower carrying capacity (less habitat = lower carrying capacity) and higher predation rates, as predators and prey are now confined in a smaller area. Both situations are stressors to zooplankton communities. On the opposite end of the spectrum, several species show evidence of being flushed out of the system during periods of high flow (>3000 cfs). Therefore, in a similar context with phytoplankton, flow can be used to regulate where in the estuary the various zooplankton species will reside. Once again, the location should consider proximity to food sources, location of hypoxic areas, and the maximizing of habitat.

The following gaps were identified by the speakers and in the subsequent breakout sessions:

1. There is much error associated with the relationship between the centers of abundance of many species and flow (i.e., poor goodness of fit). Therefore, a management tool as described above is not yet feasible for many zooplankton species. More robust sampling should reduce error overcoming this hurdle.
2. Higher frequency sample (<monthly as in Tolley et al. 2010) is needed to examine short-term larval stages).

3. Need to better understand what happens to zooplankton that are flushed out into the Gulf of Mexico (e.g., Are they permanently lost from the estuary? Do they play a role in the productivity of the Gulf?)

Stakeholders raised the following questions, comments and considerations in the breakout session following the presentation:

1. Use of larval and juvenile fishes might garner more public support
2. A good exercise would be to compare 1986-1989 data with the 2008-2010 data to see how zooplankton populations have changed.
3. What is the link between flow, larval supply, and adult year classes?
    a. Blue crabs would be a good organism to study such linkages
4. Can a "sweet spot" be developed that encompasses the majority of zooplankton?

Based on the scientific data presented, the discussions in the breakout sessions, and stakeholder feedback, the following Assessment of Indicator Status is provided:

Zooplankton are responding to changing flow conditions. The high diversity of zooplankton can allow for the monitoring of both high and low flow conditions, as well as different salinity regimes along the estuarine gradient. The time frame of zooplankton stages (days to weeks) overlaps well with changing flow conditions. The larval/juvenile stages of many commercially or recreationally important species (e.g., blue crabs, red fish, bay anchovy) could be used to garner public support. More work needs to be done to devise specific management goals/targets based on links between zooplankton distribution and flow.

C. *Cyanobacteria (blue-green algae; based on the presentation given by Rick Bartleson, SCCF).*

What we know:

Cyanobacteria are prokaryotic organisms (simple cells; lack a nucleus) that photosynthesize in a similar fashion to eukaryotic photoautotrophs (more complex cells; contain a nucleus; photosynthesize) such as diatoms and dinoflagellates. Cyanobacteria contain photosynthetic pigments that give many of them a blue-green color (cyan), which when coupled with their prokaryotic nature explains their common names, cyanobacteria or blue-green algae. Many cyanobacteria are capable of nitrogen fixation, which allows them to thrive in environments low in nitrogenous compounds (but with ample supplies of phosphorus and iron). Many cyanobacteria also contain gas vacuoles, which allow them to grow at the surface of water bodies, obtaining nitrogen gas from the atmosphere, which is converted to bioavailable nitrogen species (e.g., nitrate) to support growth. As mentioned previously, some cyanobacteria can produce toxins and are therefore considered as HAB species.

Cyanobacteria can create noxious or toxic blooms capable of adversely affecting aquatic ecosystems. When those species that grow at the water surface bloom, they can significantly reduce light levels, hindering the growth of other phytoplankton, benthic algae, and SAV. As is the case with other phytoplankton, blooms of cyanobacteria can draw down oxygen levels during the night, leading to hypoxic or anoxic conditions, afflicting harm to other organisms. Cyanobacteria are also considered to be a poor food resource, which could impact secondary producers (e.g., oysters and zooplankton). In the Caloosahatchee, cyanobacteria tend to bloom when water temperatures are >25 C and when waters are stagnant. These conditions are most common at the end of the dry season upstream of S-79, if little or no releases occur for a period of time and waters begin to warm. Cyanobacterial blooms upstream of S-79 have consisted of HAB species including *Microcystis* and *Anabaena*, and microcystins (a toxin) have been detected. Advisories against fishing and swimming have been issued in such cases, as well as warnings to keep pets from the water's edge (animals have died drinking tainted water during cyanobacteria blooms in other regions). In Lake Okeechobee, cyanobacteria appear to have a growth advantage when nitrogen:phosphorus (N:P) < 22, likely due to their ability to fix nitrogen, overcoming the nitrogen limitation experienced by other phytoplankton species in the system.

The cyanobacteria blooms upstream of S-79 are freshwater phenomena, but there are cyanobacteria in estuarine and marine environments as well. *Lyngbya* is a filamentous cyanobacteria that forms macroscopic tufts that can cover seagrasses and seaweed. The impacts of this cyanobacteria on seagrass health are unknown. *Trichodesmium*, a marine, filamentous cyanobacteria, often blooms in the Gulf of Mexico creating large congregations in the Gulf (windrows) that can come ashore and accumulate on beaches. *Trichodesmium* is a nitrogen fixer as well, and is thought to play a significant role in the initiation of *Karenia brevis* blooms (red tide) by providing bioavailable nitrogen to stimulate *Karenia* growth. The *Trichodesmium* blooms in the Gulf, however, are thought to be related to eolian (wind-driven) dust transport of iron to the Gulf, which is needed for nitrogen fixation processes.

The following gaps were identified by the speakers and in the subsequent breakout sessions:

1. While cyanobacteria appear to proliferate when waters are stagnant, temperatures are >25 C, and N:P < 22, the role of nutrient loading remains unknown
    a. Especially in terms of *Lyngbya* blooms in the lower estuary and San Carlos Bay
2. When water is released at the beginning of wet season (often when a cyanobacteria bloom is occurring upstream of S-79), the fate of the associated toxins (microcystins, possibly other toxins) remains unknown.
    a. Are these toxins incorporated in the estuarine foodweb?
    b. Do they toxins harm species downstream?
3. The impacts of *Lyngbya* growing on seagrass blades (or covering seagrass beds) are unknown.
4. Incomplete understanding of minimum flow needed to eliminate cyanobacteria blooms.
5. Lack sufficient data to assess whether TMDLs put in place by the FDEP will reduce the prominence of cyanobacteria in the system
6. Satellite imagery can help detect cyanobacteria blooms.

Stakeholders raised the following questions, comments and considerations in the breakout session following the presentation:

1. Can scrubbers be used to reduce phosphorus inputs into the Caloosahatchee?
    a. Note: FDEP believes that measures put in place to reduce N inputs as part of the TMDL process will also reduce P inputs.
2. What is the minimum amount of flow needed to prevent cyanobacteria blooms upstream of S-79?

3. To what degree are cyanobacteria blooms natural?
4. Cyanobacteria blooms are highly visible, and this fact (coupled with the toxicity of the blooms) makes them a strong candidate for public attention as a key indicator.
5. Need more clarity on source of phosphorous; build on District's 2005 report (SFWMD, 2005).
6. Cyanobacteria blooms indicate that something is wrong, but it doesn't inform the response (given uncontrollable factors at play (sunlight, temperatures); more of a consequence than an indicator

Based on the scientific data presented, the discussions in the breakout sessions, and stakeholder feedback, the following Assessment of Indicator Status is provided:

Cyanobacteria blooms are generally a problem at the end of the dry season as waters warm and remain retained behind the Franklin lock and dam. Low releases should alleviate this problem, but the minimum quantity of water needed is unknown. The associated toxicity of these blooms is of concern, not only to stakeholders and aquatic organisms upstream of S-79, but downstream estuarine populations as the cyanobacteria biomass moves downstream when releases are initiated at the beginning of the wet season. The fate of the toxins remains unknown. *Lyngbya* blooms in the lower estuary and San Carlos Bay may have a negative impact on seagrass populations and requires further study. Cyanobacteria may not be a good indicator group, but certainly serve as a canary in the coal mine – when they bloom, conditions are not conducive for the growth of other phytoplankton that would otherwise outcompete the cyanobacteria and prevent their proliferation.

D. Drift algae (based on the presentation given by Eric Milbrandt, SCCF).

What we know:

Drift (unattached) algae is a common component of coastal ecosystems, including seagrass beds. They provide food and refuge for many organisms, have high levels of productivity, and contribute to the dissolved organic carbon (DOC) pool. Large accumulations of drift algae, however, can reduce light levels for seagrasses and can reduce seagrass shoot densities. Studies of drift algae in the region did not receive much attention prior to unprecedented algal accumulations on the shores of Sanibel Island and Fort Myers Beach in 2003, with other events occurring through 2007. As such large stranding events were not known to occur in the recent past (several decades), it was hypothesized that a threshold must have been crossed that resulted in the proliferation and accumulation of drift algae.

A study undertaken from 2007 – 2009 (Loh et al. 2011) and subsequent work (Milbrandt et al. 2011) indicated that much of the drift algae observed locally remain attached to the substrate initially settled on, such as a shell or worm tube. These substrates were dislodged at some point (perhaps heavy wave action associated with a passing storm, and/or buoyancy of the algae) to be transported by currents (up to 0.5 km/d in Indian River Lagoon; Holmquist 1994). But where do the algae come from initially? The populations of macroalgae differ between offshore and inshore sites. For example, *Hypnea spinella* (a species more common in inshore sites) has caused some biomass accumulation events on the beach, whereas *Sargassum* (an oceanic, plankton species) has caused others. These examples indicate that various drivers are in play at different times and places, and that there is no single driver causing these events. Additionally, inshore species respond at different times than offshore species (spring versus summer, respectively).

The drivers that affect algal growth (and therefore drift algae) include nutrients, light, temperature, and substrate. There appears to be sufficient nutrient concentrations in the lower Caloosahatchee to support year-round drift algae growth, but is there a threshold above which algal biomass would explode in growth? The answer to this question remains unknown. Drift algae abundance ebbs and wanes, but not at the same time or frequency as flow, suggesting that there is both a lagged response and other drivers at play. Light levels are out of phase with flow and nutrients, being lowest during high flows (due to CDOM and turbidity), and highest during dry season (when flows are low). Macroalgae may be light-limited during the wet season, but could experience photo-inhibition during the dry season when waters are clearer (especially in shallow regions). Temperature is likely to be an important driver, with temperatures >25 C possibly hindering algal growth. Collectively, the macroalgae examined appear to grow better when salinities are >30. Grazing can help to control algal growth, although lower salinities in

San Carlos Bay and the lower estuary during the wet season appears to prevent the establishment of significant sea urchin populations in the region to meet this role. Lastly, the algae need hard substrate to attach to at the beginning of their growth cycle. Therefore, areas consisting of hard bottom substrate, shells, or worm tubes are preferential substrate.

The following gaps were identified by the speakers and in the subsequent breakout sessions:

1. The relationship between river flow and algal growth remains unclear. Hypothetically, several factors that affect algal growth are influenced by flow including nutrients, light, and salinity. Yet, there are no strong relationships between algal biomass and flow yet established. More rigorous sampling and testing could provide the data needed to better test this relationship to determine if adaptive management practices can be used to reduce drift algae impacts.
2. There is a need to better understand the lag effect between flow and algal response. Could this be another example of legacy nutrients as was hypothesized for red tides?
3. The benthic areas examined for macroalgae abundance is small, and most of these are not monitored on a continual basis.
    a. Better mapping efforts are needed.
    b. Further research could reveal candidate sites and species to be used as indicators for drift algae population dynamics.
4. More studies need to be conducted to determine how the growth of the most common drift algae species is affected by light, temperature, salinity, and nutrients.
5. More personnel need to be trained in algal identifications to better monitor drift algae populations in the system.
6. Need to better understand the role of grazing as an important/effective top-down control.
7. Need to better understand the influence of Caloosahatchee discharge on nearshore (and offshore) in the Gulf of Mexico (i.e., the “estuarization of the Gulf”).

Stakeholders raised the following questions, comments and considerations in the breakout session following the presentation:

1. What defines a “healthy” drift algae population?
2. What role does nutrient loading have on drift algae abundance?

Based on the scientific data presented, the discussions in the breakout sessions, and stakeholder feedback, the following Assessment of Indicator Status is provided:

A strength of drift algae as an indicator is its high visibility, especially when it washes up on beaches. Drawbacks are that its response to various drivers remains unknown thus making any management alterations to address it uncertain, the locations where significant accumulations occur (prior to beach stranding events) are unknown, and the geographical area (including the Gulf of Mexico) needed for study of both of these questions is immense. Given the public attention it draws, drift algae is a strong candidate for building a greater understanding to the above questions.

8. OTHER CANDIDATE INDICATORS

A. Ichthyofauna (based on the presentation given by Gregg Poulakis, FWCC).

What we know:

Surveys were conducted for bony fishes between 2004-2007, comparing fish populations in the main stem of the Caloosahatchee versus backwaters (embayments, oxbows, and tributaries). The most common fish caught in the main stem (via seine nets) were mullet, spot, and pinfish. In the backwaters, marsh fishes, snook, and non-natives were most common. Bay anchovies, silversides, mojarras, and red drum were equally abundant in the two environments. As was the case for zooplankton, the center of abundance of fish changes with flow out of S-79. The center of abundance for red drum, for example, is approximately 40 rkm downstream of S-79 during high flows (6600 cfs), and approximately 15 rkm downstream of S-79 during low flows (100 cfs).

More extensive studies have been conducted on sawfish responses to flow (2004 to present). The smalltooth sawfish (*Pristis pectinata*) is endangered. With a historical range extending up the east coast to the Chesapeake Bay and in the Gulf of Mexico over to the Texas coast, the current population is currently limited to the south Florida coast. Sawfish have been encountered throughout the Caloosahatchee estuary from S-79 down to San Carlos Bay into the Gulf of Mexico. Peak recruitment of sawfish in the Caloosahatchee occurs in April-May. Sawfish catches occur in hotspots: at the U.S. 41 bridge, Iona Cove, Glover Bight (Cape Coral), and Cape Coral canals. Sawfish appear to have a preference for shallow water (<1 m deep), high temperature (>30 C) and high dissolved oxygen levels (> 6 mg/L). They have a preferred salinity range of 18-30, although some have been caught during high flow at salinities <10, indicating that (some) fish do not leave the river during high flows. However, during wet season, sawfish are much more prevalent in the lower estuary (downstream of the U.S. 41 bridge), whereas they are found throughout the main stem during dry season (an example of habitat compression?). Acoustic monitoring results indicate that sawfish move as salinity changes, albeit with a lag; i.e., sawfish move upstream as salinity increases during dry season and downstream as salinity decreases during wet season. The sawfish movements may reflect responses to moving food sources rather than physiological responses. An examination of the sawfish present at the hotspots mentioned previously indicates that the sawfish do have site fidelity; although they will leave (i.e., during a storm), they will come back at a later date. They also move from one hotspot to another.

In conclusion, the following recommendations can be made to manage river resources for fish populations:

1. Remaining natural main stem habitats must be protected (i.e., those that have natural banks; not hardened; reduce habitat fragmentation);
2. Backwaters need to be protected;
3. Consider backwaters in future freshwater inflow studies (i.e., for snook, bluegills, marsh fishes);

The following gaps were identified by the speakers and in the subsequent breakout sessions:

1. Nature of movement corridors
2. Tolerance for hydrodynamic change
3. Need for expanded acoustic stations into San Carlos Bay.

Stakeholders raised the following questions, comments and considerations in the breakout session following the presentation:

1. Should individual fish or the fisheries as a whole be used as indicators?
2. Different indicator taxa should be chosen for different stretches of the river for adaptive management practices.
3. Biggest impacts to fish are long-term habitat fragmentation.
4. Species richness and diversity indices could be used to choose areas for further study and/or management efforts.
5. What role does temperature play?
6. How does boat traffic affect sawfishes?

Based on the scientific data presented, the discussions in the breakout sessions, and stakeholder feedback, the following Assessment of Indicator Status is provided:

Fish are tolerant of changing hydrologic conditions and may respond more strongly to moving food sources that are responding to changing salinity. Habitat fragmentation must be reduced (preservation of natural river banks and shorelines). Fish abundance and diversity may be useful as ecosystem indicator tools, but timescales will be much longer (years) than flow regimes (weeks). The sawfish could serve as the “next manatee” to garner public support.

B. *Invertebrates (based on a presentation given by Jim Culter, Mote Marine Laboratory).*

What we know:

Benthic invertebrates (excluding oysters in this discussion) could serve as useful ecological indicators. They respond to changing salinity and alterations in flow and are often present in an upstream-downstream gradient. Other influencing factors include bottom type (substrate), substrate organic matter content, coarseness of sediments, and dissolved oxygen concentrations. They generally do not tolerate stagnant waters. They have been used as indicators in numerous other studies, including before-after-control-impact (BACI) studies. Whole community analysis allows for the examination of multiple stressors. The primary limitations in their use are that samples are difficult and time-consuming to process, sample variability is high, and there are limitations in taxon identification. Additionally, the most sensitive fauna may have already been lost from the system.

While there are some data on Caloosahatchee benthic invertebrates (1986-1989, 1994-5), more extensive studies were conducted in the Peace (1998-2001) and Alafia (1999, 2001) Rivers from which many of the below conclusions are drawn. In this study, the Peace River is considered a “healthy” river, whereas the Alafia is considered an “impaired” river (the Caloosahatchee will also be treated as an impaired river). Benthic surveys in the Peace and Alafia Rivers indicate the following differences and similarities in the two systems. Species richness is higher in the Peace River (70% more species) than the Alafia. There are more taxa present in Alafia during the dry season versus the wet season. Some groups (e.g., amphipods) are more abundant in the dry season versus the wet season, whereas others (e.g., mysids) show little variation. Common species are generally associated with higher salinities (>15), whereas the rarer species tend to be more prominent at salinity extremes (some at 0; others at >20). The largest area of river bottom habitat in the Alafia is located between river kilometers 1-5. Maintenance of tolerable salinities in this stretch could result in higher benthic invertebrate abundances and diversity.

A comparison of benthic taxa present in the Caloosahatchee versus other water bodies in southwest Florida (coastal Venice down to Estero Bay) indicates that the Caloosahatchee is in the lower third in terms of number of taxa and organism densities. San Carlos Bay, however, was in the upper third in terms of number of taxa and had the highest organism densities of all the water bodies in the comparison (n = 10). The Caloosahatchee has a diverse benthic substrate (outside of the channel) dominated by sand (Dial Cordy and Associates, Inc. 2012). In the lower estuary and into San Carlos Bay, there is an increase in silty sand and shell material.

Benthic invertebrates do respond to changing flow conditions, and many are substrate-dependent. However, while rare species may provide useful information regarding salinity tolerances, their rarity makes them poor indicators. Abundant species are likely too tolerant of changing conditions to be useful as well. Crustaceans may be useful as mobile “keystone” species, whose movement can be used to indicate responses to changing hydrodynamic conditions, whereas sedentary species may be useful as indicators of recent (past) conditions.

The following gaps were identified by the speakers and in the subsequent breakout sessions:

1. Life history details for most species are sparse.
2. Lack of comprehensive ecological information.
3. High spatial and sample variance means that large sample numbers are needed to detect differences/changes.
4. The intertidal river is an important (understudied?) environment.
5. Limited sampling in oxbows.
6. Better understanding the role of bacteria and predation

Stakeholders raised the following questions, comments and considerations in the breakout session following the presentation:

1. There is a need for benthic characterizations during different flow regimes.
2. Core sediment samples should be examined to reconstruct historical conditions/assemblages.

Based on the scientific data presented, the discussions in the breakout sessions, and stakeholder feedback, the following Assessment of Indicator Status is provided:

Benthic invertebrates are already an established ecological indicator in other regions, but are under-utilized in the Caloosahatchee. One reason for this could be the difficulty associated with the analysis (high variability, high taxonomic expertise needed, lack of knowledge of life histories of many organisms). Much background/baseline research would be needed to bring this group up-to-speed as a useful indicator.

C. Oxbows (based on a presentation given by Chloe Delhomme, USF).

What we know:

Oxbows are U-shaped water bodies on each side of the river channel and are remnant beds of the original river. They were formed when the river was straightened and channelized, with the river bends being "cut out" from the main channel, resulting in the formation of the remnant oxbows. They are useful components of the river system, not only for aesthetic and recreational reasons, but they represent past riverine conditions that could be useful in establishing baseline conditions as well as studying how the river channel has changed over time (including impacts of dredging and widening activities). They can also serve as a great platform for environmental education activities.

There are 37 oxbows located between Franklin Lock and the City of LaBelle. Fifteen oxbows disappeared due to widening of the channel between 1944 and 1980. Many of the oxbows currently experience stagnant water conditions in their interiors, coupled with bank erosion near the river channel (Delhomme et al. 2013). These conditions not only have water quality and associated ecological impacts, but erosional processes can affect turbidity and light penetration downstream as well. Stagnant water conditions are causing low oxygen conditions, cyanobacteria blooms, and build-ups of water hyacinth in the oxbows. Efforts are underway to restore and protect oxbows by 1) excavating and dredging the muck at the bottom of the oxbows (to improve water quality and reduce biological oxygen demand); 2) removal of exotic plants; 3) native planting; and 4) riverbank stabilization and oxbow reorientation (i.e., redirecting the oxbow channel in relation to the canal to reduce erosion and improve water flow). Oxbow health is assessed by examining water quality parameters (dissolved oxygen, turbidity, phosphorus and nitrogen concentrations), biotic components (macro-invertebrates, amphibians, reptiles, fishes), and oxbow geomorphology (core samples, cross section surveys). Future plans include the restoration of more oxbows and additional field data collection (longitudinal surveys, erosion rate estimations, sediment analyses, ecological surveys, and flow measurements).

The following gaps were identified by the speakers and in the subsequent breakout sessions:

1. Impact of boat traffic on bank erosion
2. Potential to be used in tape grass restoration efforts.
3. Need for more flow measurements and baseline data for the oxbows.
4. Better understanding how oxbows respond to changing flow regimes
5. Better understanding how fish utilize oxbows, and which species (natives and exotics)

Stakeholders raised the following questions, comments and considerations in the breakout session following the presentation:

1. Can sediment cores be taken to study historical conditions such as water quality >50 years ago?
2. Are there land use impacts?
3. What is the role of tributaries into oxbows?
4. Not only useful for *Vallisneria* nurseries, but could harbor other scientific studies (outside the main channel and away from boat traffic and the public).
5. As these oxbows are remnants of the natural river bends and channel, they could serve as test beds for river (and natural oxbow) studies.
6. Consider actions to minimize damage to oxbows (improve wake management, foster maintenance program)

Based on the scientific data presented, the discussions in the breakout sessions, and stakeholder feedback, the following Assessment of Indicator Status is provided:

Oxbows serve as an aesthetic and educational resource. The public, therefore, should be supportive of efforts to restore and protect oxbows. As remnants of the original river channel, oxbows could serve as a historical resource to better gauge how the system has changed over time. The secluded/protected nature of oxbows will be useful for *Vallisneria* restoration efforts (serving as a nursery) and could serve as test beds for other scientific studies relevant to the river (or natural oxbows). As each oxbow is relatively unique, however, it is hard to assess whether oxbows could be used as indicators of flow regimes on a consistent (or encompassing) level.

D. Invasive species (based on a presentation given by Katie McFarland, FGCU))

What we know:

Invasive species can cause ecological impacts as they often have no pathogens or predators in the invaded ecosystem that can keep their populations in check. As invasive species evolved in different ecosystems, they also do not necessarily "play by the rules" by occupying specific niches or by avoiding direct competition with other organisms. When introduced species become invasive with the capability to outcompete native species, another stressor is added that the native species must contend with. Several invasive exotic species have been introduced into the Caloosahatchee ecosystem, including African jewelfish (*Hemichromis letourneuxi*), Mayan cichlids (*Cichlasoma urophthalmus*), Ornoco sailfin catfish (*Pterogophichthys multiradiatus*), non-native apple snails (*Pomacea insularum*), and green mussels (*Perna viridis*) to name a few. Green mussels will be used here as a case study on the threats of an introduced species, and how they respond to changing environmental conditions in the Caloosahatchee.

Green mussels are native to the Indo-Pacific region in (sub)tropical, subtidal waters (Vakily 1989). They were first observed in Tampa Bay in 1999, likely introduced via ballast water discharges or biofouling of ship hulls (Benson et al. 2001; Ingrao et al. 2001). Their free-swimming larval stage has allowed them to spread quickly through southwest Florida, including the Caloosahatchee. There are concerns that green mussels will be invasive, causing economic and ecological impacts to local coastal ecosystems. As biofouling organisms, they can coat boat hulls, docks, and pilings. As a bivalve, they may compete with local bivalves (especially oysters) for substrate and food. Oysters generally form three-dimensional structures (reefs) composed of younger oysters fusing their shells onto older oysters (or old shell) below. As mentioned earlier, oyster reefs serve as habitat for many other organisms and also have economic value. Green mussels form more of a two-dimensional structure (individuals do not stack on top of each other as much as oysters do), and their valves disarticulate upon death, meaning no reef structure develops over time. If green mussels settle on oyster reefs, they can prevent new recruitment and settlement of oysters, thereby preventing the reef from growing (or even maintaining to counter bioerosion, physical processes, etc.). Therefore, there is concern that green mussels can reduce oyster populations through substrate competition. For example, Tampa Bay has experienced a near 50% displacement in the oyster population due to green mussels (Baker et al. 2012).

Studies were undertaken (2010-present) to determine the environmental limitations of green mussels, the data of which can help predict the potential spread of this introduced species. Three parameters were examined; salinity, desiccation, and temperature. Salinity studies demonstrated that green mussels were unable to reach osmotic equilibrium at salinities of either 5 or 10, indicating that low salinities are stressful (oysters could reach equilibrium within 24 h at a salinity of 10; and within a week at a salinity of 5). Green mussels also had a significantly lower clearance rate (i.e., a proxy for filter feeding) at 10 and 15 salinity versus 25 and 35 salinity. Green mussels could not tolerate rapid changes in salinity, exhibiting poor survival below 20 and 100% mortality at salinities of 5 and 10. If salinity was changed gradually (a drop of 3 every other day), there was 97% survival down to a salinity of 9. At a salinity of 3, however, there was 100% mortality after only 13 days of exposure. Green mussels were intolerant to desiccation, exhibiting 97% mortality as temperatures rose above 25 C. Field observations indicated that green mussels do not appear to be capable of handling desiccation in colder conditions either, as intertidal mussels settled in December 2011 were all dead by the next month. An intolerance to desiccation in cold air temperatures is also documented in the literature (Firth et al., 2011; Urian et al., 2011). Green mussels appear to be sensitive to red tides (brevetoxin), likely due to the lack of sufficient co-evolution and lack of exposure to *Karenia brevis* in the past.

Green mussels are unable to adapt to rapidly changing salinity. If changes are gradual, however, they could recruit farther up the Caloosahatchee (to areas with salinities down to 10). Green mussels are unable to tolerate desiccation well, meaning they will not survive in intertidal areas (including intertidal oyster reefs). Deep water (subtidal) sites that maintain a salinity >15, however, could be settled. Oysters, on the other hand, are well adapted to the changing environmental conditions typical of southwest Florida estuaries, and are likely to remain the dominant bivalve in local ecosystems.

The following gaps were identified by the speakers and in the subsequent breakout sessions:

1. Lacking larval and juvenile stage studies on environmental tolerances.
2. Mapping of suitable (candidate) habitats to monitor for mussel expansion in the future.
3. Population distribution in the region is unknown.

Stakeholders raised the following questions, comments and considerations in the breakout session following the presentation:

1. Are there similar die-offs in Tampa Bay versus the Caloosahatchee? A: not well-documented; word of mouth stories indicate red tide and low temperatures can cause die-offs. Also reported in Baker et al. (2012).
2. What are the predators for green mussels? A: stone crabs, blue crabs, sheepshead.
3. What effect will sea level rise have on green mussel settlement? A: Increase in subtidal areas and salinity could benefit green mussels.
4. How will river management strategies affect invasive species?
5. What about other invasive species such as lionfish, Cuban tree frogs, *Melaleuca*, *Hydrilla*, etc.?
6. Green mussels could be used as secondary indicators (e.g., an indicator of high salinities).
7. Do exotic apple snails out-compete native ones?

Based on the scientific data presented, the discussions in the breakout sessions, and stakeholder feedback, the following Assessment of Indicator Status is provided:

Green mussels could be another stressor impacting oyster populations, although this scenario is most likely in subtidal regions where salinities are consistently >15. Green mussels could serve as an indicator of sea level rise; as water levels rise, more subtidal areas are created, salinities could be higher (or more consistent) – a scenario that could allow for the expansion of green mussels into the Caloosahatchee (and other shallow water bodies in southwest Florida).

9. STAKEHOLDER FEEDBACK

There was an initial question and answer session following the above three "Setting the Stage" presentations. The first topic addressed the usefulness of indicators; indicators can signify impairments, which can then be addressed to formulate possible solutions. The example that was provided was the expansion of water storage capability to deal with freshwater flow impacts (i.e., protect against too little flow in dry season versus too high of flow during wet season). The second topic delved into the potential role of politics in the recommendation and decision making process. As this workshop was organized specifically to discuss scientific knowledge, however, it was recommended that this question would be better dealt with in an upcoming Community Forum (more information on which is provided in the Conclusions section of this report). Negative impacts of both high and low flow were briefly discussed (e.g., how low flow hinders *Vallisneria* grow), and such topics are presented in more detail under the various indicators in this report. Many stakeholders expressed a desire for more action, e.g., restoration targets. While this view is commendable, the purpose of the workshop was to raise awareness and to get everybody on the "same page" from which future discussions can proceed from a common, science-based platform. There were concerns about ecosystem complexity – we cannot possibly know everything – which again was a purpose of this workshop; i.e., to assess the use of indicators to monitor ecosystem health and to evaluate if changes needed to be made in this approach. There were discussions about data availability. Currently, the CHNEP Water Atlas and DBHydro are data resources – should other avenues be explored (resource constraints were noted as a hurdle)? There was agreement that the Conceptual Model was getting "long in the teeth" and was in need of revision. This Scientific Workshop could be a first step towards such efforts.

A second question and answer session was organized after lunch on Day 1 of the workshop, following welcoming remarks by SFWMD Executive Director, Blake Guillory. There was interest from stakeholders in the status of the Plan 6 option of the Comprehensive Everglades Restoration Plan (CERP), which would send the majority of Lake Okeechobee water south into the Everglades rather than down the Caloosahatchee and St. Lucie Rivers. A second topic that was discussed was if a baseline water reservation could be set aside for the Caloosahatchee to ensure adequate flows are maintained during the dry season. This topic may require a more comprehensive examination of the watershed to determine what is feasible. Discussions concluded with further emphasis on a need for action. Several ongoing projects were noted (e.g., the Kissimmee River restoration and the C-43 reservoir) that should help alleviate some of the impacts of both high and low flow.

A panel discussion was convened at the end of Day 2, which included a final question and answer session. The panel consisted of James Evans (City of Sanibel), Jennifer Carpenter (FDEP), Judy Ott (CHNEP), Pete Quasius (Audubon of Southwest Florida), and Keith Kibbey (Lee County Environmental Laboratory). The panel felt that the indicators currently being utilized are appropriate (tape grass, seagrass, and oysters), but that secondary indicators could provide valuable supplemental information (e.g., water column indicators including phytoplankton and zooplankton). The lack of an adequate low salinity zone in the upper estuary (approaching S-79) is causing big impacts (e.g., loss of *Vallisneria* and habitat compression for fish and zooplankton), and efforts should be enhanced to restore *Vallisneria* and its seed banks. They also voiced concerns about plankton being flushed out of the system during high flows; where do they go? Do they move back into the estuary? What impacts do they have on coastal foodwebs? The panel believed that the indicators are providing useful information, which could allow the implementation of salinity envelopes on various sections of the Caloosahatchee to support different organisms (e.g., *Vallisneria* upstream; *Halodule* and peak phytoplankton abundance mid-stream; oysters and *Thalassia* downstream).

The panel noted several needs or additions to be considered. Indicators that can capture public interest and/or that have economic impacts should be utilized (e.g., harmful algal blooms;

sawfish; larval fish). Indicators that work on different time scales would be useful (e.g., phytoplankton respond in days to weeks; zooplankton in weeks to months, etc.). Chlorophyll measurements are easy and are indicators of phytoplankton biomass; this attributes might make it a good parameter to monitor for. Game fish could be good candidate indicators (e.g., snook). They have economic value and public interest/awareness. The panel concluded by discussing the next steps to take on monitoring the Caloosahatchee. They stressed that monitoring should not be done just for the sake of monitoring, but that efforts should target specific purposes (e.g., indicators of salinity versus nutrients, etc.). The Conceptual Model needs to be updated and we need to figure out what streams of data are missing that are important (e.g., the gaps presented here and the arrows in Figure 1). Perhaps a Caloosahatchee Monitoring Group could be established to determine where there are gaps and overlaps, and how data is being used so that resources can be used most effectively.

10. OVERALL ASSESSMENT OF ECOLOGICAL INDICATORS

How does our current suite of indicators measure up?

The indicators that have been in place for many years now (oysters, tape grass, and seagrass) are providing useful and valuable data on ecosystem responses to managed flow in the Caloosahatchee. Unfortunately, the dwindling population of *Vallisneria* demonstrates that current environmental conditions are not conducive for it growth, but perhaps restoration efforts will allow the population to rebound (especially if low salinities are better maintained and herbivory is kept in check).

What additional information can the candidate indicators provide?

The candidate indicators (phytoplankton, zooplankton, cyanobacteria, drift algae, benthic invertebrates, fishes, oxbows, and invasive species) can also provide valuable information that can complement data and responses of the above three indicators. For example, zooplankton respond on time scales (days to weeks) relevant to water management practices and inflow variability. This indicator can give us an idea of the appropriate flow envelope based on the nursery function of the estuary, which is a critical function. Zooplankton was named by many of the panelists as an indicator to consider adding to the monitoring suite and/or to be used to help refine the target flow envelope. Fishes were also identified as a potential good addition to the suite of indicators. Long-term datasets exist and they also respond to flow changes in response to prey movement.   Macroalgae and HABs are not only ecologically important, but also very visible and high profile to tourism and therefore linked to economics. These may be effective “negative indicators” that could be used to demonstrate problems to the public. They respond to flow, salinity, light and nutrients. Phytoplankton has a lot of potential to be a very informative indicator of ecological responses to the combination of drivers (flow, salinity, nutrients, light). Table 3 summarizes the thresholds and tolerances of all of the indicators discussed in the workshop in terms of flow and salinity (where applicable or available) as well as other important stressors and other factors to be considered.

Table 3. Summary table of indicators providing salinity ranges, recommended flow regimes, temperature tolerances, other important stressors to consider, and proposed use to management.

Indicator	preferred salinity	recommended flow regime	optimal temperature	other stressors	use to management
Vallisneria	<10	>450 cfs		grazing; light	low salinity indicator; upper estuary and freshwater sections of the Caloosahatchee
Halodule	20-30		20-30	light	moderate salinity indicator; mid- to lower estuary
Thalassia	>30	<2800 cfs	20-30	light	high salinity indicator; lower estuary and San Carlos Bay; climax species; indicator of an established bed
oysters	15-30	1000-3000 cfs	<30		moderate salinity indicator; mid- to lower estuary
phytoplankton		1000-3000 cfs		high residence times	moderate flow indicator; establishment of productivity “sweet spot” in mid-estuary. Chlorophyll is an indicator used in regulatory programs (TMDLs) and is used to link nutrients to phytoplankton to light attenuation on seagrasses
zooplankton		0 < x < 3000 cfs			moderate flow indicator; establishment of productivity “sweet spot” in mid-estuary.
cyanobacteria		>0 cfs	>25	high P	canary in the coal mine; stagnant waters
drift algae	>30		<25	grazing	canary in the coal mine; nutrient loading too high?
bony fishes					habitat fragmentation; zooplankton/food movements and location
sawfish	18-30		>30		food movements in river
oxbows					historical resource; use for backwater/protected water studies; nursery for *Vallisneria*
green mussels	>15		<30	desiccation; cold temperatures	SLR indicator; subtidal indicator

There are several commonalities in the indicator responses and tolerances that are worth high-lighting.

- One consistent result is that flows <3000 cfs are beneficial to many indicators (*Thalassia*, phytoplankton, zooplankton, and oysters).
- Another finding is that there should be some flow through S-79 in the dry season, minimally to prevent cyanobacteria from blooming upstream of S-79 and to reduce habitat compression and impingement for zooplankton and fish. Minimum flows of 450 cfs were recommended to maintain *Vallisneria* downstream of S-79. (As this target has often been unobtainable in the past, it is unclear whether or not this flow is adequate.) Oyster and phytoplankton responses indicate that minimum flows of 1000 cfs are desirable, even if that flow level has not been realized in recent years. The lack of flow in the dry season is resulting in adverse impacts; reduced *Vallisneria* cover, habitat compression, cyanobacteria blooms, phytoplankton blooms, oyster disease, and oyster predation to list a few.
- The indicators that are in place, as well as the candidate indicators introduced above, indicate that a flow envelope of 500 – 3000 cfs would be most beneficial to the indicators, and likely the Caloosahatchee ecosystem itself.
- Attempts to stay within the flow envelope should meet with success (proliferation or maintenance of indicators), at which adaptive management practices can be used to “tweak” the system to gain improvements or more to the next steps (restoration and renewal). For example, adaptive management practices could be used to ensure a “zone of productivity” is maintained in the mid-estuary (phyto- and zooplankton).

What do we know and what have we learned?

1. Our ecological indicators are telling us that the alterations to the watershed of the Caloosahatchee and the physical changes to it have led to significant and persistent impacts to the ecology of the system. Jim Culter described the Caloosahatchee as the “poster child for alterations”. We have doubled the watershed by directly connecting the river to Lake Okeechobee, we have ditched and drained the watershed and increased its impervious surface percentage, leading to a flashy system.
2. We do know quite a bit about the Caloosahatchee system. We understand what the main drivers of the system are (freshwater inflow and its alterations; salinity dynamics, nutrient loads, and physical alterations). We have a conceptual model describing those drivers and the direct and indirect responses that result. However, it is also very evident that the system is complex. We heard that from many of the presenters. Different segments of the system respond differently and have different requirements (e.g., flow, nutrients, light), and therefore multiple indicators are needed along the salinity gradient. Our current indicators do give us information about the response of important components of the biological community to the main drivers.
3. We have a flow target envelope that looks reasonable based on SAV, seagrass & oyster targets and for reducing HABs upstream of S-79. Meeting these target flows would go a long way toward moving us from the “rainbow of death” to the “sweet spot”. We also have a nutrient reduction target based on seagrass light requirements (Tidal Caloosahatchee TMDL).
4. We have learned that recovery of components of the estuary after extreme events (high and low flows) can take years.
5. We have learned from zooplankton research that during some dry seasons the important low salinity zone does not exist. This can have profound effects on the nursery function of the estuary. Additionally, high flows can decrease reproduction of benthic organisms and can separate larvae of ecologically and economically important species from their settlement habitat. High flows are also “estuarizing” the shelf.
6. Altered flows and nutrient loading can also create shifts in species assemblages of phytoplankton toward less ecologically desirable taxa (favoring cyanobacteria and HAB species).

7. Fish are responding to movement of their food as flows change.
8. Negative indicators (HABs and drift algae) can be important in demonstrating the problems in the river and getting the general public interested.

What are the identified critical gaps/needs in scientific data?

The gaps for the individual indicators are provided earlier in this report. Gaps that are common to multiple indicators include:

1. Hydrology
    a. Impacts of high hydrological variability
    b. Role that tributary flows play in influencing salinity downstream of S-79
    c. The "estuarization" of the coastal waters during high flows
    d. Impacts of boat wakes
    e. Impacts of sea level rise
    f. Climate Change – will droughts become ever more frequent in the future? Hurricanes? Will they be accounted for in modeling efforts?
    g. What is the role of groundwater in terms of freshwater and nutrient inputs to the Caloosahatchee (especially downstream of S-79)?
2. Role of stressors on organisms
    a. Multiple stressors – we need to better understand the collective impact of multiple stressors and interactions and the cascading effects of stressors
    b. Time lag between stressor and response - we need to better understand the recovery and resiliency of the system to extreme events and the time lags associated with those. We should be working toward a more robust system that that is more resistant to extremes (which will continue to occur) and resilient in the face of damage
    c. Nutrient loading – direct (phytoplankton, seagrasses, drift algae) and indirect (light, dissolved oxygen); work with FDEP?
    d. Light availability (seagrasses, *Vallisneria*, drift algae)
    e. Influence of top-down controls (grazers)

3. Upstream of S-79
   a. How effective are BMPs in the upper watershed of the Caloosahatchee?
      i. What indicators are available?
      ii. Could the Stream Condition Index be utilized?
   b. What impacts are evident and require further attention and action?
      i. river bank erosion
      ii. invasive species like jewelfish (*Hemichromis letourneuxi*), armored catfish (*Pterogoplichthys* spp.), and the exotic apple snail, *Pomacea insularum*
      iii. riparian zones
4. Other data needs
   a. Better spatial coverage of distributions (seagrasses, oysters, mussels, sawfish, drift algae)
   b. Historical data (oxbows, oyster reefs, seagrass beds)
   c. Salinity mapping (and modeling) – what are typical (i.e., frequent) salinity ranges along different sections of the Caloosahatchee?
   d. Quantifying economic value of the system and economic impacts of damage to the system is important for moving restoration efforts forward

How can these gaps/needs be addressed?

Some of the gaps will require more research. Others will require compilation of available data and synthesis of results. Some will likely involve collaboration with other agencies (e.g., FDEP and CHNEP). All will require additional resources.

11. CONCLUSIONS

A common characteristic among many of the indicators is a preference for flow regimes between 500 – 3000 cfs. This conclusion is similar to recommendations made in the SWFFS several years ago. As was noted in the interviews conducted by CBI, many stakeholders believe we have gathered enough scientific data to proceed forward with action. This sentiment was also voiced by many attendees of this workshop. If flows through S-79 could be maintained in the above envelope, indicator populations should be maintained and possibly expanded. Such a success story would allow successive questions to be asked such as:

What is our vision of what we want the Caloosahatchee ecosystem to look like? Do we realistically expect to "restore" the various indicator populations to historical levels? Do we know what historical levels were? What should be our targets?

The gaps listed above do address these questions to some degree (a need for better spatial coverage; a compilation and review of historical data). Other gaps primarily address multiple stressors, which are likely secondary to flow and salinity impacts at this juncture. Therefore, measures to regulate flow between 500 – 3000 should provide a degree of ecosystem stabilization from which the secondary stressors can be better examined and assessed. Those that are deemed critical (and manageable) can then be considered for regulation through adaptive management practices. It is clear that the Caloosahatchee ecosystem is responding to flow and the accompanying changes in salinity. Until these responses can be dampened through improved flow management, restoration and protection efforts cannot move forward.

In order to proceed towards such goals, the next step in this process will be to develop a science framework based on our current state of knowledge about the Caloosahatchee River and Estuary to guide community forums and other relevant discussions. The Caloosahatchee Community Forums will be open workshops that meet on a regular basis (e.g., quarterly) involving multiple agencies, non-government organizations, academic institutions and local governments with the following objectives:

1. Foster open and on-going dialog between the District, other governmental agencies, and stakeholders on issues concerning the Caloosahatchee;
2. Provide a continued opportunity to share information, ideas, and knowledge;
3. Verify ecological indicators and Caloosahatchee science and identify data gaps;
4. Allow for discussions on complex issues affecting the Caloosahatchee and identify potential strategies to mitigate effects;
5. Provide for an opportunity to garner support for projects and to identify and seek funding to assist with project implementation; and

6. Help with implementation of existing restoration plans such as the Caloosahatchee River Watershed Protection Plan under the Northern Everglades and Estuaries Protection Program and the Caloosahatchee Basin Management Action Plan.

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