APPENDIX G
WATER RELEASES THROUGH S-197: DEFINITION OF ECOLOGICAL DAMAGE

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A White Paper by the South Florida Natural Resources Center of the National Park Service and the Everglades Section of the South Florida Water Management District for the Combined Operational Plan

A definition of "ecological damage" from water releases through S-197

Introduction

The coastal S-197 structure was built to prevent saltwater intrusion into Everglades National Park (ENP) and manage freshwater discharges during high water periods into Manatee Bay and Barnes Sound (Johnson and Fennema 1989, Light and Dineen 1994). The structure is the only coastal outlet of the C-111 basin, with a very large discharge capacity (2400 cubic feet per second). A portion of this very flat coastal basin forms the southeastern corner of ENP. The C-111 basin also spans beyond the boundary of ENP, eastward and northward into a predominantly agricultural portion of Miami-Dade County. This basin also contains the Florida Keys Aqueduct Authority's wells, which provide water supply to the Florida Keys. Managing water levels and discharges in this portion of the Everglades watershed, with concurrent goals of environmental protection, water supply, and flood control, present significant challenges. East of ENP, managers need to prevent flooding, but not drain the area so much that saltwater intrudes into the well-fields of the aqueduct authority. Adding to the complexity of managing this area is the clear relationship between water levels in Taylor Slough – a naturally formed drainage in ENP - and water levels in the coastal marshes of the C-111 basin. Any time that water stages in Taylor Slough are higher than the C-111 marshes, there is a net flow eastward towards the C-111 basin. As a result, if too much water is discharged from the basin through the S-197 structure, there is a net drainage effect on Taylor Slough. Since Taylor Slough is a headwater source for Florida Bay, the operations of the S-197 can decrease water flows down Taylor Slough and increase salinity conditions in Florida Bay.

This white paper is intended to identify the different types of ecological challenges and potential ecological damage that are presented by the C-111 basin's special combination of geography, geology, ecology, and societal demands. This document is authored specifically for the Combined Operational Plan (COP) Environmental Impact Statement. The COP will define system operations for the physical structures of the Modified Water Deliveries (MWD) and C-111 South Dade projects. The original request was to "define damage" associated with discharging the basin's water through the S-197 structure. Below, we widen the scope of the document to consider two categories of ecological damage, which entail considerations of different spatial scales. First, at the watershed scale, Taylor Slough and Florida Bay are damaged by the eastward diversion of water away from this natural flow path – in essence, the opportunity for existing water to benefit these areas is diminished. Second, estuarine organisms immediately downstream of S-197 are directly damaged by C-111 canal discharges, primarily by osmotic stress when salinity conditions in Manatee Bay and Barnes Sound rapidly change, but potentially by other consequent stresses, such as depleted dissolved oxygen at the bottom of these estuaries when large discharges yield density stratification of the water column.

Watershed scale risks

Taylor Slough, the Everglades Panhandle and Florida Bay have sustained decades of damage and degradation from a deficiency of freshwater flow. The COP, along with CERP projects (including the currently operational C-111 Spreader Western Project) intend to minimize the damage from a systemic loss of water to tide and realize long term improvement toward ecosystem restoration. In this context, S-197 discharges constitute losses from the watershed and an "opportunity cost" to restoration of Taylor Slough and Florida Bay, with damage from these discharges being indirect. Once water flows through S-197 into Manatee Bay, it is no longer available to extend marsh hydroperiods or reduce salinity in lower Taylor Slough wetlands, Little Madeira Bay, Joe Bay, or northeastern Florida Bay. Also, lowering C-111 canal stages with S-197 discharges can promote the eastward seepage of water from Taylor Slough, especially during the dry season, which decreases total down-slough flows and decreases flow toward the southwestern portion of the slough, which delivers water closest to central Florida Bay, where hypersaline conditions are most extreme and damaging (e.g., resulting in seagrass die-off). Protection and restoration of these areas within ENP is a priority of the MWD, C-111 South Dade projects, and CERP.

Basin-scale risks

While there are no current CERP restoration goals in Manatee Bay and Barnes Sound, several potential negative impacts of S-197 discharges on the area are being monitored. These include physiologically stressful rapid salinity decreases; stratification (capping) of a bottom water layer, which leads to a low dissolved oxygen condition (hypoxia or anoxia) that is fatal to fauna and flora; and organic and nutrient loading and enrichment. Data show that these effects may occur to different degrees with pulsed releases and that there is a minimum flow threshold where these begin to occur. An initial estimate suggests that a discharge rate above 800 cfs over a week's period may cause risks to flora and fauna in downstream water bodies, at least temporarily. The return frequency of the large pulsed discharge would also be an important factor in determining the impact on biota. Based on nearly three years of data, prudent guidance would indicate that two discharge events within six months of magnitude 800 cfs or more for a week would negatively impact the system and suggests that the optimal way to operate the S-197 structure would be to favor several smaller releases (e.g., <500 cfs) over large, pulsed releases.

Salinity decrease can cause damage in two ways: one, strong pulsed freshwater releases can cause an abrupt shift in the osmotic gradient around biota. When the biota cannot physiologically respond quickly enough to adjust to the shift in osmolality, this causes a damaging osmotic imbalance in the cells and increases respiration at the expense of production (a death spiral). Rapid salinity variation, both increasing and decreasing, as might occur when fresh and saltier water parcels move back and forth across the bottom, can also cause an inhospitable environment for biota attuned to a specific salinity or range of salinities. Mortality of the sessile organisms, especially sponges were found to occur throughout Florida and Biscayne Bays, including downstream of C-111, after Hurricane Katrina and coincident with local road construction (2009 SFER, Vol I, Chapter 12). Mortality from upper-basin runoff after Katrina may also may have been a function of organic loading into the bays and the development of anoxic bottom waters, as well as increased turbidity from local disturbance of the benthos from the construction activities of 2005. Even mobile organisms may be impacted directly when salinities change rapidly in the absence of other environmental cues that trigger movement. The time-frame of mortality directly caused by salinity change is sub-daily to daily.

Evidence of such salinity change impacts has been provided by laboratory studies that found rapid or frequent shifts in osmolality can damage seagrass species found in Manatee Bay and Barnes Sound and can lead to seagrass decline (Koch et al. 2007; Strazisar et al. 2015). Evidence from field sites is the observation of necrotic seagrass leaves locally around the mouth of C-111 canal (M.O. Hall, pers comm), while no such necrosis was observed away from the immediate area of the canal mouth. This indicates that Manatee Bay seagrasses near the canal may be harmed by pulses of low salinity canal water.

Another potential means of salinity disturbance occurs on longer timescales (weeks to months) when the salinity regime is chronically depressed outside the optimal or tolerance range of the biota. The biota loses competitive advantage and dies or is replaced by other species. Both *Thalassia* and *Halodule* exhibit broad salinity tolerances (~15-70 and ~5-65 psu, respectively; Kahn and Durako 2006; Koch et al. 2007) when salinity change is moderate (≤1 psu per day). During emergency releases in 2017, mean daily salinity decreased by ~12 psu with a maximum salinity change of 0.8 psu per day prior to Hurricane Irma (June-August 2017; Fig. 1). And while a shift from *Thalassia* to *Halodule* is expected when salinities decrease or become more variable (Williams 1987; Lirman and Cropper 2003), overall the long-term seagrass community has remained stable and healthy (Fig. 2, Hall et al. 2016; Lorenz et al. unpublished data).

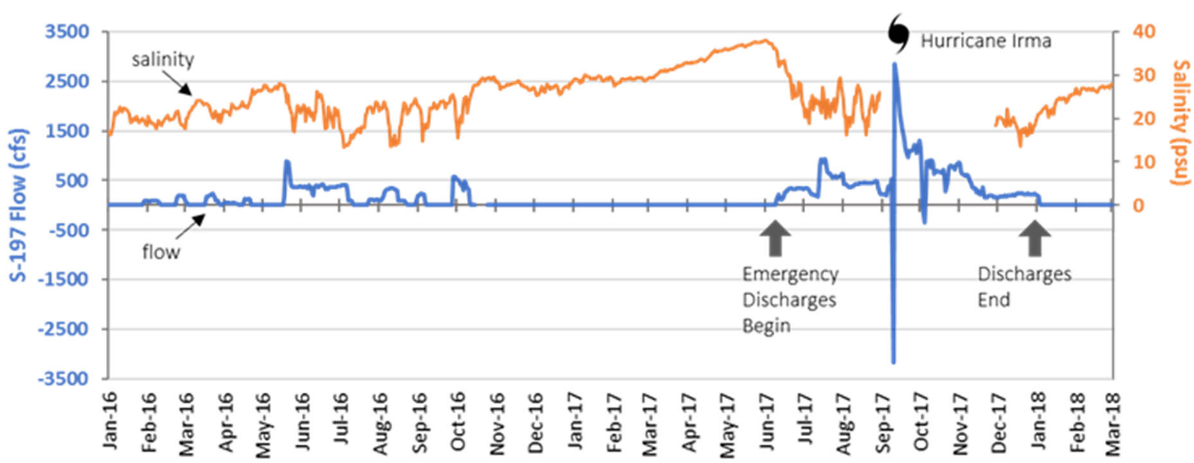

Figure 1. Daily average flow (blue line) through the S-197 structure and surface salinity (orange line) in Manatee Bay from January 2016-March 2018.

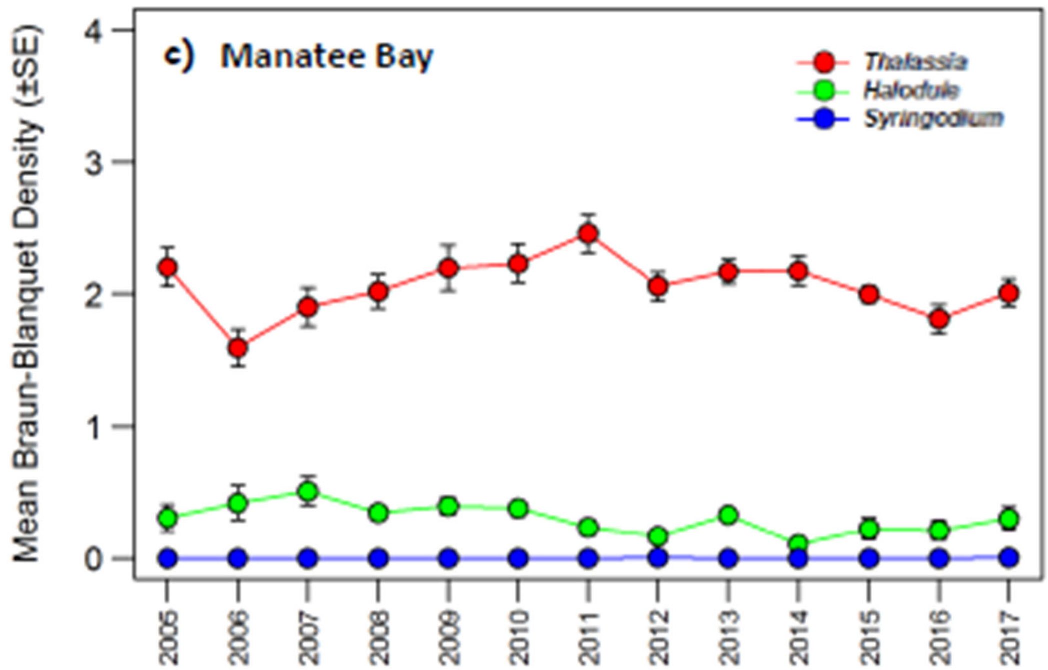

Figure 2. Seagrass stability in Manatee Bay.

Because Manatee Bay exchanges freely with the large volume of water in Barnes Sound, freshwater deliveries to Manatee are quickly distributed over a large area, reducing the long-term impact on salinity locally. Flows <800 cfs over 30 days coincided with a modest decrease in salinity in Manatee Bay from 20-25 psu to 10-16 psu in August-September 2018 (Fig. 3). Barnes Sound water exchanges with Biscayne Bay water to the north and over the past two years, during the largest freshwater pulses, we have seen reductions in salinity in the system temporarily by an average of 10 psu, and then a return to nominal salinity within a few weeks to months. (Fig. 4). These reductions are not outside the normal salinity range for the flora and fauna species in Manatee and Barnes, and moreover, the system seems to be hydrologically resilient. Modeling studies (FATHOM) show that average residence times of these basins are short, on the order of one month for Manatee Bay to two months for Barnes Sound (Cosby unpublished data) so impacts of hyposalinity (low salinity) are rapidly attenuated. Thirty days after 2017 emergency flows ceased, which persisted for six months and included Hurricane Irma, salinities returned to more typical dry season levels (20-30 psu; Fig. 4).

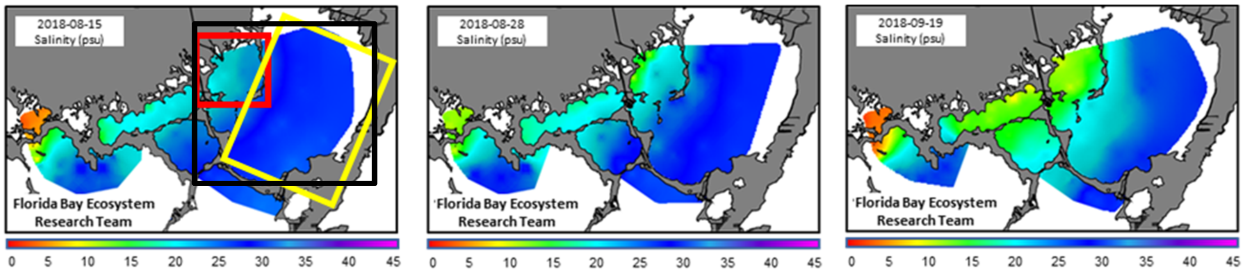

Fig. 3 Salinity contours in Manatee Bay (indicated with a red box in left panel) and Barnes Sound (indicated with a yellow box in left panel) during August-September 2018. Flows <800 cfs over 30 days coincided with a modest decrease in salinity in Manatee Bay from 20-25 psu to 10-16 psu.

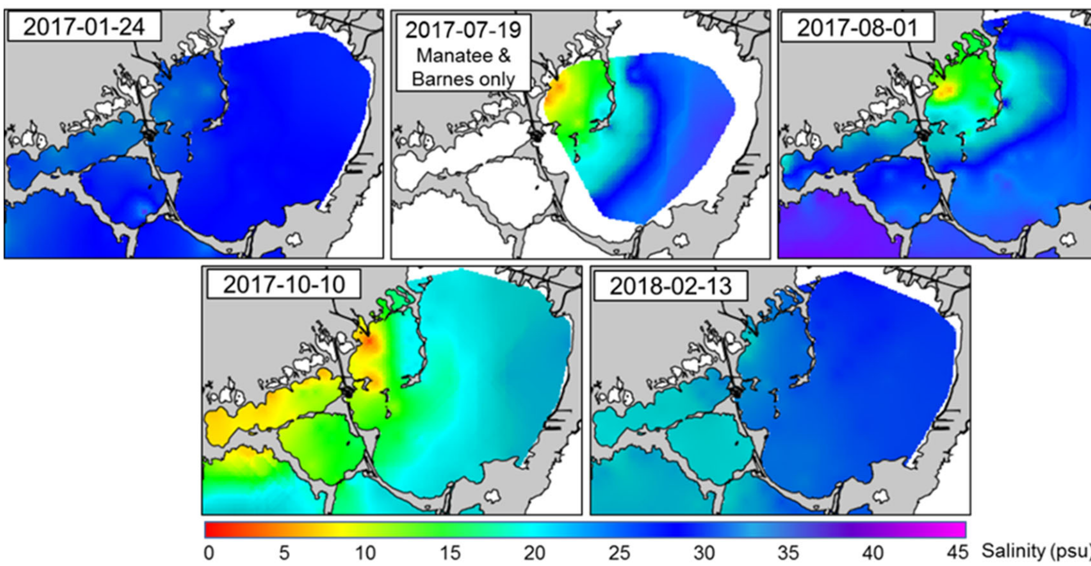

Fig. 4 Salinity contours in Manatee Bay and Barnes Sound from January 2017-February 2018. Emergency flows were initiated in June 2017 and continued through January 2018.

Stratification of the water column also can occur with large S-197 discharges and can have two distinct effects: one negative and one positive. These discharges create a stratified water column in Manatee Bay, where the relatively light (low density) discharged fresh water “floats” in a layer above the heavier denser, bottom layer of saline water. The presence of a stable upper layer isolates the lower water layer from the atmosphere, inhibiting gas (most importantly oxygen) exchange. Stratification is more likely to occur at a time with low wind mixing. Stratification can cause damage to the benthos by blocking aeration of bottom waters where decomposition and respiration reduce dissolved oxygen (DO) levels. If oxygen is not replenished from atmospheric diffusion or mixing of the water column, a hypoxic condition can occur especially during high temperatures when high respiratory demand for DO in the bottom water layer could yield anoxia, high sulfide, and if prolonged, mortality of benthic flora (e.g., Hall et al. 1999; Johnson et al. 2018). The timeframe for DO deficiencies and ecosystem damage due to stratification is days. Recently, increased ammonium concentrations measured in Manatee Bay may be evidence for stratification and reducing conditions in the water column. Hypoxia has not been observed in Manatee Bay or Barnes Sound, although elevated temperatures above 31°C can persist in summer months, reducing bottom water DO (e.g., June-August 2017), and Miami-Dade DERM measured low DO in this region following Hurricane Katrina.

The positive benefit to stratification is that the lower layer of the water column is buffered from the effects of the fresh lens overriding it in the upper water column, thereby protecting benthic biota from the full impacts of a pulsed salinity decrease. Sonde data from 2017 during S-197 releases, indicated that bottom salinities can remain 50% higher (Table 1).

Table 1. Depth profile of salinity in Manatee Bay.

	Manatee Bay Region			
	C-111 mouth	**C-111 mouth**	**Central**	**Southeast**
Date	8/1/2017	10/10/2017	10/10/2017	10/10/2017
Water Depth (m)	0.70	1.05	1.05	1.50
Surface Salinity	7.63	3.40	2.06	2.0
Middle Salinity	8.24	3.19	2.10	2.05
Bottom Salinity	11.46	5.21	2.50	2.09

Finally, if discharges through S-197 contain excess nutrients and organic matter, the loading may trigger harmful algal blooms, shifts in phytoplankton community structure (species composition and biomass), and increased turbidity and light attenuation. Ecological impacts of nutrient enrichment can accumulate over time, and biological responses may be muted until a threshold is reached, eventually triggering widespread blooms of algae and/or reduced DO levels. These impacts may be more severe during storm events (Fig. 5). This form of damage may be hard to immediately recognize without detailed observations of phytoplankton community responses to pulses of nutrient deliveries. The time frame for effect is days to weeks as nutrients and organic matter are distributed in the system. Usually blooms are minimal and dissipate quickly; however, following tropical storms the effect is more pronounced and persistent (Fig. 6).

Changes in nutrient stoichiometry (e.g., TN:TP; NO4:NOx) and physical water quality parameters caused by discharges may shift phytoplankton community structure from diatom to cyanobacteria-dominated communities, some of which may produce toxins (Fig. 6; this topic is still not well understood in this region). For example, increase in NH4:NO3 ratio combined with high water temperature can stimulate growth of cyanobacteria, especially after tropical storms, which increase internal and external nutrient loadings ("cyanos like it hot"; Wachnicka et al. 2019).

For example, algal biomass was significantly higher in September 2017 (after Hurricane Irma) compared to November 2017 and January 2018, and this was especially pronounced in Barnes Sound (Fig. 6). Cyanobacteria were highly abundant after the hurricane in Manatee and Barnes Sound, and the adjacent NE Florida Bay (Wachnicka et al. 2019). In the following months, cyanobacteria were outcompeted by diatoms, a dominant phytoplankton group prior to the hurricane (Wachnicka et al. 2019). The persistence of the bloom, however, was not solely based on C-111 inputs as the storm uprooted large amounts of biomass, resuspended bottom sediments and nutrients and land runoff increased generally. The more characteristic response is the dissipation of an elevated algal biomass (~3 ug/L chla) within weeks (Fig. 7).

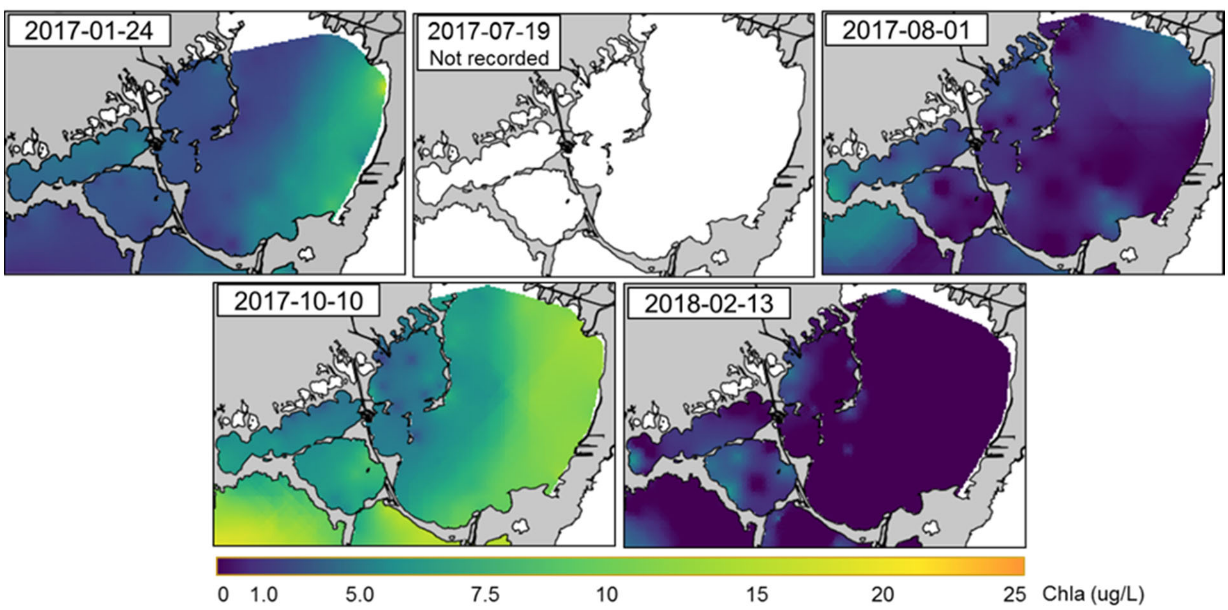

Figure 5. Chlorophyll-a contours in Manatee Bay and Barnes Sound from January 2017-February 2018. Emergency flows were initiated in June 2017 and continued through January 2018.

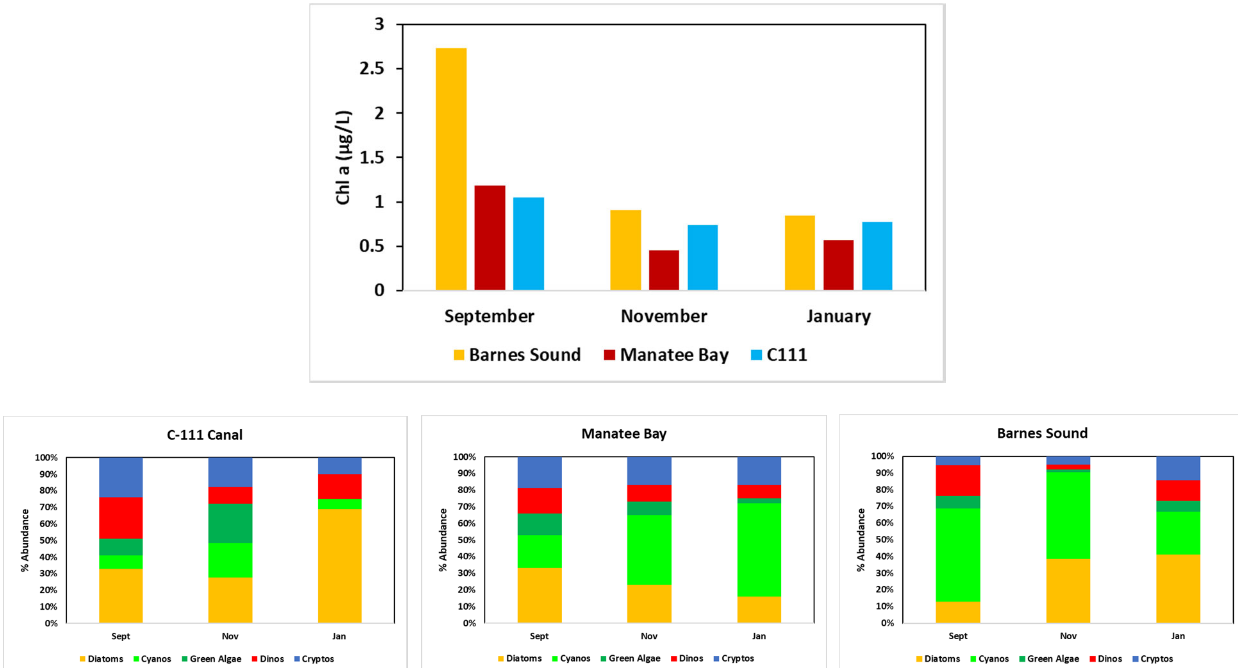

Figure 6. Usually blooms are minimal and dissipate quickly; however, following tropical storms the effect is more pronounced and persistent. Manatee Bay chlorophyll-*a* concentration (top graphs) and phytoplankton community composition of dominant algal groups (bottom graphs) following Hurricane Irma in September (2 weeks after Irma) and November 2017 (9 weeks after Irma) and January 2018 (18 weeks after Irma) (Wachnicka et al. 2019).

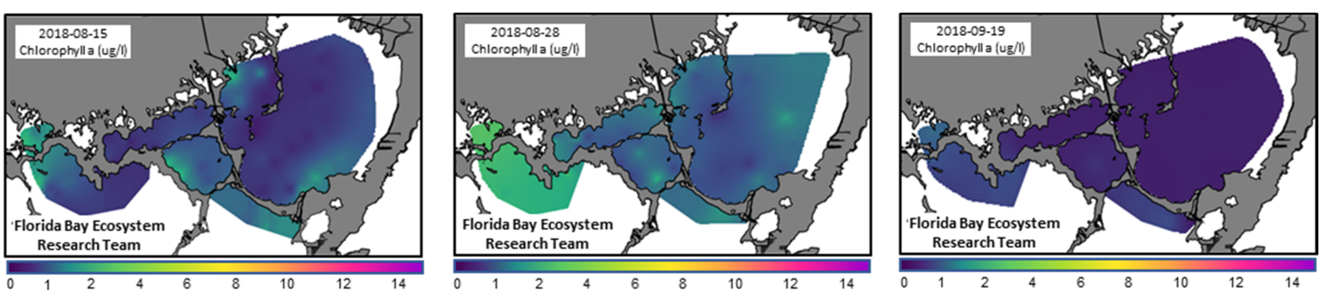

Figure 7. Chlorophyll-a contours in Manatee Bay and Barnes Sound during August-September 2018. The characteristic response is the dissipation of an elevated algal biomass (~3 ug/L chla) within weeks.

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