NPS, NOAA, RSMAS-UM

7th Annual Report:
IBBEAM – Integrated Biscayne Bay Ecological Assessment and Monitoring

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Comprehensive Everglades Restoration Plan - CERP
Restoration Coordination and Verification - RECOVER
Monitoring and Assessment Plan- MAP
Southern Coast Systems – SCS

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EXECUTIVE SUMMARY

The Integrated Biscayne Bay Ecological and Assessment and Monitoring (IBBEAM) program tracks and assesses the ecological status of central and southern Biscayne Bay's shallow nearshore zone. Our program goals are to gauge the effectiveness of the system-wide Comprehensive Everglades Restoration Project (CERP) and the CERP project closest to Biscayne Bay, the Biscayne Bay Coastal Wetlands (BBCW) project. Biscayne Bay is downstream from the Central and Southern Florida Water Management System and, therefore, affected by almost every major structural and operational change in the system under the Comprehensive Everglades Restoration Plan (CERP). BBCW is a CERP project dedicated to improving freshwater flow to Biscayne National Park and Biscayne Bay. BBCW now consists of two phases: Phase 1 is currently approved and is designed to improve the spatial distribution of freshwater flow and improve salinity conditions to the Bay by diverting portions of canal flow into coastal wetlands to enter the bay as sheet flow.[1]

Four elements make up the IBBEAM Project: (1) water quality (temperature and salinity); (2) submerged aquatic vegetation; (3) epifaunal fishes and invertebrates; and (4) mangrove-associated fishes. This annual report summarizes time series and spatial patterns in key ecological metrics from these four components and provides habitat suitability models (HSMs) for selected ecological indicator biota. IBBEAM data collected through calendar year (CYR) 2018 are covered in this report.[2] The study area experienced several environmental perturbations within the period CYR 2004-2018 that may have impacted the floral and faunal abundance patterns observed in IBBEAM. These include the hypersalinity events of the CYR 2004, 2009, 2011, 2014, and 2015 wet seasons, a severe cold snap of the CYR 2010 dry season, an algae bloom during the CYR 2013 wet season, and Hurricane Irma in September 2017. CYR 2016 was remarkable in terms of rainfall and the high volume of freshwater discharged into the Bay during the dry season, which resulted in the highest mesohaline index values ever recorded during that season.

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[1] Preparation for Phase 2 is being initiated with preparation of a Project Management Plan (PMP), facilitated by several conference calls with local area experts, interested parties and interaction with the Biscayne Bay regional Restoration Coordination Team. The PMP will provide a summary of tasks required to complete the Project Implementation Report (PIR). An initial version of the PMP will be prepared in time to support development of the PIR in 2020.The PMP will be revised at least yearly to reflect any needed changes to tasks and effort level.

[2] We follow the SFWMD's definition of the seasons, with the wet season spanning May through October, and the dry season spanning November through April. We label our sampling events by calendar year (CYR) because we have found that labelling by water year (WYR) invariably leads to confusion. Note that all wet season biotic sampling is conducted from July through September, and all dry season biotic sampling is conducted from January through March.

The dry season of CYR 2017 was typical of most dry seasons with low frequency of mesohaline conditions, especially in the northern portion of the study domain. However, passage of Hurricane Irma during CYR 2017 wet season resulted in high mesohaline index values throughout. The CYR 2018 dry season was characterized by a higher frequency of mesohaline observations than the previous dry season, while the CYR 2018 wet season closely resembled the CYR 2017 wet season in terms of magnitude and extent of mesohaline conditions. Below, some highlights of results are presented by IBBEAM project component.

Water Quality

Salinity and temperature data are collected every 15 minutes from 6 to 17 nearshore stations for the period of record (POR), 2004-2017. Frequency, variability and persistence of mesohaline (5-18) or hypersaline (>40) conditions are the main salinity regime characteristics followed. The number of salinity stations along the shoreline was increased over time to better represent nearshore conditions.

- While improved over the previous year's dry season, the CYR 2018 dry season was characterized by low mesohaline index values, especially for sites north of Black Point. Mesohaline values of the CYR 2018 wet season closely resembled those of the CYR 2017 wet season, likely due to the similarity in quantities of canal discharge volumes between years. Mesohaline conditions at salinity monitoring sites D2 and D6, downstream from the Deering Estate Flow-way, were low and unremarkable in the CYR 2018 dry season, much like the previous CYRs. However, during the wet season, the D2 site at Deering sites did experience slightly improved mesohaline conditions relative to our designated base year 2012, similar to CYR 2017.

Submerged Aquatic Vegetation

- The 11-year time series of *Halodule* and *Thalassia* abundance (occurrence and cover) showed high seasonal fluctuations of > 10% for *Thalassia* and > 15% for *Halodule,* with peaks in abundance generally in the wet season.
- The CYR 2010 cold snap clearly impacted both *Halodule* and *Thalassia*, resulting in a decline in occurrence of both species and a decrease in suitable habitat (proportion of domain with high cover) for both species. Habitat suitability recovered within a year for *Thalassia* and two years for *Halodule*.
- Hurricane Irma had significant impacts on the salinity and turbidity of nearshore habitats, but an analysis of percent cover of *Thalassia* and *Halodule* before (July-Sept 2017) and after (Oct-Nov

2017) the storm conducted at 28 sites showed no significant changes in cover for either of these species.

- While overall seagrass abundance over the POR (all species combined) has been fairly resistant and resilient to climatic extremes (2010 cold water anomaly), hypersalinity, algal blooms, and Hurricane Irma**,** the relative contribution of the two most abundant seagrass species is experiencing a shift that is contrary to CERP goals for this region. The mean abundance of *Halodule* has been in a declining trend since 2011-2012, reaching its lowest levels since 2008 (9.1 %) in the 2018 wet season. The opposite pattern has been documented for *Thalassia*, that has been increasing in cover since 2011.
- The 2018 wet season was the first time in the last 7 years where the cover of *Thalassia* exceeded that of *Halodule* in nearshore habitats (Figure 3*)*. *Syringodium* continues to be consistently low (5% cover) throughout our region of study.
- 2018 presented a very dynamic spatial pattern of habitat suitability that contrasts with the 2008-2017 seasonal averages. The northern portion of the study domain had areas unsuitable (i.e., 0% cover) for seagrass growth for both species in the 2018 wet season when 9% and 11% of the study domain had 0% cover of *Halodule* and *Thalassia* respectively. This is in clear contrast with the 2008-2017 period where no areas of low suitability were documented for both species in the wet season.
- The physical variables measured in this study, salinity, temperature, and depth are all key drivers of seagrass abundance. The scale of our monitoring only allows us to assess spatial correlations among SAV and physical variables, but previous experimental work has shown that salinity is in fact the main driver and the factor that can be modified through management. The acute disturbances that have affected our area (cold snap, hurricane) have impacted the whole domain equally so we are not able to tease apart detailed interactions between chronic and acute stressors.
- The factor that caused this spatially restricted decline was likely the inflow of large mats of the brown macroalga *Sargassum* that accumulated along the shoreline in the northern areas of the IBBEAM study area. *Sargassum* caused physical abrasion and shaded benthic macrophytes. As the *Sargassum* biomass decomposed, extreme low Oxygen values were also recorded.
- Current models suggest that increased mesohaline conditions, a desired target of CERP, will increase overall seagrass abundance and support co-dominance by *Halodule* and *Thalassia*, which may constitute higher quality habitat than homogeneous, single-species beds. However, recent

trends (declines in *Halodule* and increases in *Thalassia*) suggest that salinity patterns have been inadequate to reach these CERP goals.

Epifaunal Community

Indices of abundance (occurrence and density) with which to assess spatial and temporal variation in the epifauna community and potential effects of CERP currently are based on four epifauna taxa, assessed individually. These are goldspotted killifish (Floridichthyes carpio), Farfantepenaeus shrimp, gulf pipefish (Syngnathus scovelli), and grass shrimp (Palaemonetes spp.*). Plotted time series of occurrence and density continued to show annual and seasonal variation and correlation between abundance metrics. Time series of occurrence and density are well correlated within three of the four taxa. Statistical relationships of the abundance metrics with salinity varied among years initially but have become relatively consistent more recently, illustrating the importance of acquiring long time series on pre-project status prior to and into early implementation.*

- Gulf pipefish and pink shrimp recovered well from Hurricane Irma, reaching highest abundances in their periods of record in Dry CYR 2018, which was the first collecting period following the one that contained the storm (Epifauna sampling took place a few weeks following Irma's passage).
- Habitat suitability models revealed that salinity was a significant factor for all four focal epifaunal species, (goldspotted killifish, gulf pipefish, *Farfantepenaeus* shrimp and *Palaemon* shrimp). According to the models, Gulf pipefish are more abundant at intermediate polyhaline conditions, whereas *Farfantepenaeus* shrimp and goldspotted killifish are more abundant in low polyhaline conditions, and *Palaemon* shrimp are more abundant in mesohaline conditions. Examination of plotted predictions of species abundance, either occurrence or density, in relation to salinity since IBBEAM started preparing them indicate that the shape of the curve has become more consistent in recent years, even as more data and a wider range of circumstances have been added. The consistency of their relationships with salinity strengthens the value of these species as indicators.
- Season is a statistically significant factor explaining variation in abundance of Gulf pipefish and *Palaemon* shrimp. The seasonal relationship in pink shrimp, although significant, is not as strong as in the fore-mentioned species, and temporal variation in goldspotted killifish apparently is not related to season.
- Temporal patterns of variation in Gulf pipefish, *Palaemon* shrimp, and pink shrimp are strongly correlated, but temporal variation in the goldspotted killifish is not correlated with that of the other three focal species.

Mangrove Fish

Distribution and abundance of three fish taxa associated with mangroves, goldspotted killifish (Floridichthys carpio), gray snapper (Lutjanus griseus) and yellowfin mojarra (Gerres cinereus), are currently the main emphases of this project element.

- The goldspotted killifish is a species of focus because its highest occurrence tends to correlate with salinities in the 15–25 psu range during the dry season (McManus et al. 2014). Abundance metrics of this species during CYR 2018 dry season were relatively high – a finding generally consistent with dome-shaped occurrence-salinity relationship reported previously for this species. No clear Hurricane Irma impacts on goldspotted killifish metrics were evident six to 12 months after this disturbance.
- The gray snapper is a species of recreational and commercial fishery value and its abundance metrics tend to be positively correlated with salinity. In our study domain, the occurrence and density of gray snapper have been relatively high over the last five years, including during CYR 2018. No clear Hurricane Irma impacts on gray snapper metrics were evident six to 12 months after this disturbance.[3]
- In general, yellowfin mojarra abundance metrics have been on an upward trajectory since the CYR 2010 cold snap. Its CYR 2018 occurrence and density were among the highest observed over the period of record. Addition of CYR 2018 data reinforced the linear, inverse occurrence-salinity relationship reported in our previous annual report, but yielded a parabolic density-salinity relationship, which differed from the linear inverse relationship that we reported last year. Such inconsistency among model results tends to support the idea that greater weight be given to patterns of occurrence than to density, at least for this species, when using multiple regression to reveal habitat affinities. No clear Hurricane Irma impacts on yellowfin mojarra metrics were evident six to 12 months after this disturbance.
- Spatial distribution mapping, comparing CRY 2018 wet and dry data to previous years, revealed: high dry season densities of goldspotted killifish along Biscayne Bay's entire southern mainland shoreline; patterns of gray snapper density-distribution were generally within the CYR 2008-2017 averages; and high abundances of yellowfin mojarra especially in the "canal zone" (Black Point to Turkey Point) during both the wet and dry seasons of CYR 2018.

[3] This is for all size classes of gray snapper observed in our visual surveys.

Deering Estate Analysis

The Deering Flow-way/Cutler Slough Rehydration Project (Deering Project), located adjacent to Biscayne Bay's western shoreline, directs seasonal water flow into a former freshwater wetland by means of a spur canal and pumping station. To detect any project effect on nearshore salinity, we performed a detailed analysis of Mesohaline Index changes at WQ Site D2. (For rationale, see Addendum 1 to IBBEAM 2014)

- The analysis of change across years detected an improvement in mesohaline conditions at D2, downstream from the Deering Estate restoration project, compared to other sites, in CYR 2013 Wet, compared to CYR 2012 Wet. Comparison of the same two periods at other sites indicated that the change at D2 was independent of widespread change due to rainfall.
- Modest reductions in salinity compared to the base year (2012) in some year- seasons were detected at Deering Estate D2, distinguishing it from other instrumented sites compared to their respective 2012 condition. Despite this detected improvement, Mesohaline Index values at D2 have remained low since the site was first instrumented in 2011. With the possible exception of dry 2016, pumped flows at Deering through CYR 2018 were not sufficient to have appreciable salinity effects on nearshore habitats.
- The planned change from pulse to continuous flows, even at the minimum rate of 25 cfs, as implemented in September CYR 2018, may reduce bay salinity at D2 further, however, an increase in the minimum rate may be necessary to approach mesohaline conditions. Further salinity monitoring, with feedback, in an adaptive management mode, along with concurrent monitoring of SAV, epifauna and mangrove fish, as is now going on, will help determine the quantity needed to bring about ecologically meaningful change.

With continued monitoring, IBBEAM has demonstrated that its chosen set of taxa are displaying consistent responses (in terms of change in abundance indices) to changes in salinity and other aspects of the environment. This indicates that the habitat suitability relationships IBBEAM has developed for these species are robust. Continuing data collection by IBBEAM is warranted and necessary for defining ecosystem restoration targets and judging the performance of indicator species in those bay habitats where CERP impacts are likely to be strongest. Habitat suitability relationships developed in IBBEAM provide robust tools for predicting outcomes of different freshwater inflow/salinity field scenarios in terms of suitable habitat gained or lost. IBBEAM is the best option for gauging CERP performance in Biscayne Bay because of its shoreline coverage, expanding time series and statistically well-supported ecological indicators. To date the restoration efforts have not made appreciable improvements to nearshore salinities; however, when those changes do occur, we expect the selected IBBEAM indicators to respond accordingly.

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1. INTRODUCTION

The Integrated Biscayne Bay Ecological Assessment and Monitoring program (IBBEAM) combines four elements: Salinity Monitoring Network, Nearshore Submerged Aquatic Vegetation (SAV), Alongshore Epifauna, and Mangrove Fish, funded by the Comprehensive Everglades Restoration Plan (CERP), Restoration Coordination Verification (RECOVER), Monitoring and Assessment Plan (MAP), Southern Coastal Systems (SCS) Module.

IBBEAM is designed to: (1) fill knowledge gaps about southwestern Biscayne Bay's nearshore biota that may be affected by CERP implementation; and (2) provide a scientific basis for the development of a suite of ecological performance measures for assessment and use in adaptive management. It addresses RECOVER objectives at the system-wide scale and Biscayne Bay Coastal Wetlands and C-111 Spreader Canal project objectives at the local scale. At both scales, an ecological goal of CERP is to restore, along the southwestern shoreline of Biscayne Bay, the historical diversity and abundance of submerged aquatic vegetation (SAV), fish, and invertebrate communities associated with mesohaline habitat (5-18 salinity units). Establishment of a salinity regime that maintains appropriate nearshore SAV and mangrove habitats and supports both resident and transient faunal communities over a broad spatial and temporal extent is a prerequisite to successful estuarine restoration as identified by CERP and the National Park Service (NPS). Healthy, heterogeneous SAV and mangrove habitats provide shelter and food for fish and invertebrates as well as direct benefits to water quality and the stabilization of substrate and shorelines.

IBBEAM provides the following metrics and tools to facilitate evaluation and assessment of water management changes by CERP with respect to successfully achieving estuarine conditions:

- Frequency and duration of mesohaline, hypersaline and high salinity variation conditions
- Seagrass occurrence and cover
- Faunal occurrence and abundance trajectories
- Quantifying relationships of biological variables to salinity and other habitat factors (i.e., Habitat Suitability Models).

IBBEAM objectives are to:

1) compare past and present salinity regimes, SAV communities, SAV-associated epifauna (fish and invertebrate assemblages), and mangrove-associated fishes to determine status and trends and enable before-after CERP comparisons
2) quantify key relationships with salinity (and other habitat variables) for the diversity, distribution, and abundance of SAV, epifauna, and mangrove-shoreline fishes
3) formulate appropriate performance measures and targets to assess the effectiveness of CERP projects and assist with adaptive management.
4) execute special analyses using IBBEAM tools to help evaluate CERP operations.

2. METHODS

The IBBEAM project domain lies in the nearshore[4] waters between Shoal Point and Turkey Point directly downstream from the Biscayne Bay Coastal Wetland Project (BBCWP, Figure 1). This will be the first area of Biscayne Bay that will be affected by changes in freshwater delivery to the Bay as part of CERP. The project area is affected by discharges from several large canals, most importantly C-103 (Mowry Canal) and C-1 (Black Creek). Sites south of Black Point receive inflow from C-1 (Black Creek at Black Point, C-102 (Princeton Canal), Military Canal, and C-103 (Mowry Canal). C-103 has the largest water flow south of the Miami River, resulting in large volumes of fresh water discharged into the coastal area over relatively short time periods. Presently, regulatory canal operations during the wet season and agricultural drawdown canal operations from the late wet season through early dry season create lower and more variable salinity between Black Point and Mowry Canal than anywhere else in the study area. The L-31E Culverts, a BBCW component, flow to the coast in this area. These culverts are charged by diverting water away from the Mowry Canal and the L-31E canal, reducing direct canal flow and replacing it with an approximation of sheet flow. The relatively low volume C-100 canal and the S-123 structure are located north of Black Creek The Deering Estate Flow-way was constructed in this area north of C-100 and began operation in December, 2012, with the S-700 pump station. The Cutler Flow-way, another BBCW component not yet constructed, also is located in this area.

[4] Nearshore is defined as area to 500m from shore.

2.1. STUDY SITES

In an intensive 1st-yr review, pre-existing biotic sampling sites were assigned to selected water quality sites of the Biscayne Bay Salinity Monitoring Network (Lirman et al. 2013). Assignment was by a nearest neighbor approach (Table 1). The WQ station locations became the "hubs" around which all biotic sampling takes place.

2.2. DATA COLLECTION

2.2.1 Water quality sampling

The 17 Biscayne National Park (BNP) water quality (WQ) stations located nearest to shore between Shoal Point and Turkey Point were identified from the original USACE-Biscayne National Park salinity network and selected to become the IBBEAM sites (Figure 1). These stations, which measure salinity, temperature, and water depth, capture a wide range of along-shore salinity environments and freshwater sources.

The WQ data at the 17 sites are collected at 15-minute intervals using YSI 6600 Data Sondes. Salinity is calculated from conductivity and temperature measurements. Instruments are rotated approximately monthly. Instrument calibration is performed in the laboratory before (i.e., just in from the field) and after deployment (IBBEAM Annual Report 2013 - Addendum I, Calibration methods). Instruments are sequentially deployed with data overlap of a minimum of four readings (one hour), which are used in quality control analysis. The retrieved instruments are transferred to the laboratory for data download and post calibration.

Environmental parameters are part of the biotic sampling protocol at each of the 47+ (see below) biological sampling sites. Recorded parameters include date, time of sampling, water depth, salinity, and temperature. Instantaneous water quality parameters are obtained a few centimeters above the bottom by deploying the instruments from the boat prior to any field personnel entering the water. A YSI Pro instrument is used to measure salinity, temperature, and dissolved oxygen (DO). Water depth is measured with a marked (1-cm increment) PVC pipe. These data, *inter alia*, are included so that biological data can be examined in relation to water quality parameters not included in the long-term salinity sampling network and to compare salinity recorded at the biological sampling sites to that recorded at 15 minute intervals at the nearest long-term salinity monitoring locations (IBBEAM Annual Report I, Addendum II (2013)).

2.2.2 Biotic Parameters

The 47 co-located biotic sampling sites from the long-term sampling protocols are situated along the mainland shoreline from Shoal Point to Turkey Point. The 47 co-located sites represent a reduction in sampling effort from the former (pre-IBBEAM) sampling regime as former biotic sampling sites north of Shoal Point and south of Turkey Point are not a part of the new integrated effort[5]. Mangrove sites start next to the mangroves and extend 30 meters parallel to the shore. Associated epifaunal and SAV sites are within 50 meters of the shoreline at < 1 meter of depth (Figure 1).

The following biological metrics are collected at each co-sampled biotic site (Figure 1): SAV (taxonomic identity, percent cover of seagrass and macroalgae, seagrass canopy height, sediment depth), epifauna (taxonomic identity, abundance, and size of all fish, decapods, and echinoderms captured), and mangrove fish (taxonomic identity, abundance, and size-structure (minimum, mean and maximum total length of all fish observed). These basic data are used to calculate taxon-specific abundance metrics (occurrence, concentration, and density) (see data analysis 2.3). Biological sampling takes place within the SFWMD-defined dry (November-April) and wet (May-October) seasons, specifically all dry season biotic sampling is conducted from January through March and wet season biotic sampling is conducted from July through September. Water years (WYR) start with the wet season (i.e., in May) and extend through the dry season (i.e., through April) of the following year; they are named according to the latter year (e.g., wet season of 2014 and dry season of 2015 represent the Water Year 2015). Calendar years (CYR) run from January through December (e.g., dry season of 2014 and wet season of 2014). Sites are accessed by boat at high tide and at idle speed, or while drifting to minimize disturbance of motile biota.

<u>(a) Submerged Aquatic Vegetation (SAV)</u>

The SAV community is characterized using two sampling protocols: (1) SAV is co-sampled with epifauna twice a year, wet season and dry season, to correspond with the faunal sampling schedule, providing essential data to analyze faunal abundance in relation to SAV characteristics; and (2) 100 random sites are surveyed within a range of 500 m from shore in the wet season for large-scale mapping. Visual assessments of 10 quadrats (0.5 m^2 each) deployed haphazardly are conducted at each site to determine percent cover (0-100%) of each SAV taxon as described by Lirman *et al.* (2008). In addition, canopy height (maximum blade length of seagrasses) and sediment depth are assessed within each quadrat to provide an estimate of habitat topography for SAV-associated epifauna. A site-averaged value is used in analyses

[5] The 45% reduction in funding resulted in a 35% reduction in the spatial sampling domain.

with faunal and WQ data. The selection of sites (n = 100) sampled in the expanded wet-season surveys is determined based on a stratified-random selection process (Lirman *et al*., 2008a). The survey domain encompasses the nearshore (up to 500 m from shore) habitats between Matheson Hammock and Turkey Point. This area is divided into 5 100-buffers (0-99 m from shore, 100-199 m, 200-299 m, 300-399 m, 400-500 m). The buffers are further divided into 20 N-S cells to provide a total of 100 cells (5 buffers x 20 latitudinal cells). Random survey locations are selected within each cell for a total of 100 survey sites where SAV data are collected as described.

<u>(b) Epifaunal Community (EPI)</u>

Sampling is with a 1-m^2 throw-trap consisting of an open-ended rigid-sided square aluminum box measuring 1 m^2 by 45-cm deep, with panels of nylon netting (1.6-mm stretch mesh) attached on parallel edges at the top of the throw-trap (IBBEAM Annual Report 2013 - Addendum I). Attached net panels are used to cover the top of the throw-trap when the trap is fully submerged. The trap is thrown three times to sample a total 3-m^2 area at each site. A 1.6-mm mesh sweep net (framed seine) of the same length, height, and mesh-size as the trap is pulled through the trap interior four times to collect the trap contents. Samples are kept cool in the field and frozen later, then thawed for processing. The three sets of throw-trap contents from each site are processed and recorded separately. The initial database of number caught, by species, records each of the three throw-trap samples for each site. These data are later collapsed into a single record for each site for summarization and most statistical analyses but may be used as separate data records for special analyses. Laboratory processing follows Griefen (2010). Identifications are to species level for most fishes and to at least genus level for shrimps, crabs and echinoderms. Identifications are based on Dawson (1982), Robins and Ray (1986), Abele and Kim (1986), Kaplan (1988), Nelson *et al.* (2004), and other guides and are supported by reference specimens, as well as special guides developed by the epifauna team.

Farfantepenaeus data are recorded as *Farfantepenaeus* spp., *Farfantepenaeus aztecus* (brown shrimp), *Farfantepenaeus duorarum* (pink shrimp), *Farfantepenaeus brasiliensis* (spotted pink shrimp), or *Farfantepenaeus notialis* (southern pink shrimp). For time series and other analyses, as of CYR 2014 and retroactively, we combine data from positively identified pink shrimp (mainly individuals with carapace length CL >8mm). Few Farfantepenaeus specimens in our samples were identified as *F. aztecus*, *F. notialis*, or even *F. brasiliensis*, which may occur more abundantly in other parts of the bay. Because our study area is a nursery ground, we do not want to separate members of the smallest cohorts from the larger *F. duorarum*. Therefore, we include both *Farfantepenaeus* duorarum and *Farfantepenaeus* spp. categories in our abundance calculations. By including the individuals that were too small to be identified with certainty to the species level, we reduce the potential for identification error and obtain higher density values and fewer zeros, which support more robust analyses and are inclusive of all life stages that inhabit areas potentially affected by changes in freshwater management.

(c) Mangrove Fish Community (MF)

The mangrove shoreline fish assemblages are characterized and quantified using the visual "belt-transect" survey method described by Serafy *et al.* (2003) (IBBEAM Annual Report 2013 - Addendum I). This entails snorkeling 30 m-long transects parallel to the shore and recording the taxonomic identity, number, and size-structure (minimum, mean and maximum total length) of fishes observed. Belt-transect width is 2 m, thus area surveyed per transect is 60 m^2. All visual surveys are conducted between 09:00 and 17:00 hrs to minimize detection problems caused by low light. For each survey, single recordings of water quality and depth are obtained, with water temperature and salinity measured using a YSI multi-probe instrument and depth measured along each transect (i.e., at 0, 15 and 30 m) using a 2 m-long PVC pole marked off every 2 cm.

2.3. DATA SELECTION AND ANALYSIS

Analyses presented in this project were primarily conducted with SAS/STAT® software and displayed with SigmaPlot. SFWMD data and displays used in our analyses were downloaded from the dbhydro data base (*http:/my.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu)*. Data developed within the project are described below.

2.3.1 Water Quality - Salinity Indices

2.3.1.1 Index Definition

Quality-controlled, 15-minute resolution time series data for each of the 17 nearshore WQ stations were summarized by season and water-year (e.g., May-Oct 2004 and Nov-Apr 2005 = water-year 2005). The water-year periods follow the South Florida Water Management District (SFWMD) definition, which characterizes each water year (WYR) as beginning in May based on analyses of historical rainfall. The term “wet season” is synonymous with “rainy season”, which may not necessarily translate into immediate lower salinity in receiving waters because, depending upon the groundwater deficit and water management, there can be a lag of one or more months between rainfall and downstream salinity changes. Rainfall in October and November can be high in some years, while dry season salinity conditions may persist into June or later due to water management and evaporation. The need to change (i.e., shift by one or two months) the component months within the wet and dry seasons of the water year has been discussed; however, we will use the SFWMD delineation until general agreement within CERP-RECOVER on another delineation is reached. Data also are presented on the basis of calendar year (CYR).

The IBBEAM team developed six salinity regime indices (Table 2). These indices are based on the required conditions to support estuarine biotic communities, as desired by CERP, and are based on the Venice System (Anonymous, 1959). Computed for each season of each year, they are as follows: (1) mesohaline (M) index (proportion of salinity observations ≥ 5 and <18); (2) hypersalinity (H) index (proportion of salinity observations >40); (3) salinity variability (V) index (proportion of days where salinity range is > 5 within a day); (4) mesohaline persistency index (maximum duration, in days, of uninterrupted mesohaline conditions), and (5) hypersaline persistence index (maximum duration, in days, of uninterrupted hypersaline conditions). Indices 1, 2, and 3 were combined to calculate (6), a salinity regime suitability index (SRSI, Equation 1):

$$SRSI = \sqrt[3]{[M * (1 - H) * (1 - V)]}$$

(Equation 1)

We recently have generated four additional salinity indices derived from Venice System. These additional salinity indices are the Oligohaline Index (frequency of observations <5), the Oligo-Mesohaline Index (<18) and the Oligohaline and Oligo-Mesohaline persistency indices (maximum duration, in days, of uninterrupted Oligohaline and Oligo-Mesohaline conditions, respectively). These latter indices were generated for exploration purposes and have not, as yet, been incorporated into any formal analyses.

2.3.1.2 Habitat suitability scaling

A site from the Coastal Wetlands Monitoring and Assessment Project in Florida Bay (J. Lorenz, Florida Audubon Tavernier Science Center, unpublished data) was chosen as a “salinity regime reference station” against which salinity patterns at all nearshore Biscayne Bay WQ stations were compared. The present-day salinity regime at this reference site (Downstream Joe Bay, designated DJ, located in northeast Florida Bay) was considered a surrogate for the salinity regime that existed along Biscayne Bay’s western shoreline prior to construction and operation of the coastal canal system (Pitts et al. 2017). Although not considered ideal for upstream Florida Bay, salinity conditions at this selected reference site appear to approximate conditions that might be associated with the performance measures described in the Southern Estuaries Salinity Documentation Sheet for Biscayne Bay. This choice was supported by the biotic community existing at the location (J. Lorenz, unpublished data). In addition to having a high-resolution WQ data set exhibiting desired salinity conditions for alongshore Biscayne Bay, the DJ station (25.21665 N and -80.55563W) has a dataset demonstrating the biotic (seagrass, fish and invertebrate) communities that can be supported by such conditions and can be considered representative of the target communities for the Biscayne Bay shoreline.

Salinity index matrices were prepared using 15 min-resolution data (see Section 2.3.1.1.) from each Biscayne Bay nearshore WQ station and hourly data from the DJ reference site. Index values were color-coded green, yellow, and red to signify optimal, adequate, and unsuitable conditions, respectively (Table 3). The color scheme was implemented using the 'conditional formatting' feature in Microsoft Excel 2007. This feature uses color blends (i.e., between red, yellow and green) to highlight differences in index values in space and time. The color scaling was such that optimal values (green) were the seasonal mean values at the DJ site; unsuitable (red) was the minimum (or maximum, depending on the metric) value in the entire matrix; and adequate (yellow) was the mid-way (50%) value between optimal and unsuitable. Color blends of green, yellow and red represented intermediate index values.

Data from six nearshore water quality stations were available for the period 2004 to 2010. Starting in January 2010, WQ data collection began at 11 additional nearshore stations. The index values in a given matrix cell were considered meaningful if data sets were ≥ 75% complete in a given (seasonal) time period

2.3.2 Habitat Relationships and Predictions

Relationships among physical metrics, SAV, and fauna were examined with logistic and conventional ordinary least squares regression models using SAS statistical software. Our datasets consist of data collected by each effort: SAV (2008-2018 CYR) and Epifauna (2005-2018 CYR), from Shoal Point to Turkey Point; and Mangrove Fish (1998-2018 CYR) from Matheson Hammock to Manatee Bay. Average taxonomic richness, species-specific frequency of occurrence (proportion of surveys positive for the focal species) and densities (average density of positive captures) (Table 2) were examined to determine relationships with water salinity (Sal), temperature (Temp), and depth and SAV canopy height (CH), cover of *Thalassia* (Thal), *Halodule* (Hal), and *Syringodium* (Syr) (Equation 2). Analyses of SAV and mangrove fishes included only salinity, depth, and temperature (Equation 3). Results of these analyses identified an initial subset of biological metrics (out of the dozens of individual species or community metrics being collected in the field) that were significantly related to salinity, or to other variables related to salinity (e.g., a seagrass species found to be related to salinity).

$$Epifauna = Sal + Temp + Depth + CH + Thal + Hal + Syr + Sal^2 + Temp^2 + Depth^2 + CH^2 + Thal^2 + Hal^2 + Syr^2$$

(Equation 2)

$$Mangrove\ Fish/SAV = Sal + Temp + Depth + Sal^2 + Temp^2 + Depth^2$$

(Equation 3)

Following Serafy *et al.* (2007), Serrano *et al.* (2010), and McManus *et al.* (2014), a stepwise multiple regression was performed to evaluate species occurrence and density/cover in relation to the environmental factors. A square term for each factor was included to allow the possibility of a relationship to be parabolic rather than linear. A backwards elimination approach was taken whereby factors and their square terms were removed sequentially, beginning with the highest order terms, if their P-values were ≥ 0.05. Final model fit was judged from adjusted R^2-values or concordance index (*C*) values for ordinary least squares and logistic regression, respectively. Prior to regression analyses, biological abundance data were transformed via log- or arcsine-conversion or transformed to binary (presence/absence) data.

2.3.3 Deering Estate Analysis

Quality-controlled, 15-minute-resolution time series of water quality data for the WQ stations D2 and D6, both immediately offshore the Deering Estate component of BBCW, were analyzed using SAS/STAT® software. Salinity data were summarized by season and calendar-year (CYR).

We examined the salinity data for potential changes using our “mesohaline index”, one of several salinity indices introduced in our 2013 IBBEAM report (Lirman et al. 2013). These indices recognize the plan of RECOVER to restore conditions in nearshore western Biscayne Bay to support an estuarine biotic community. The index definitions follow the Venice System, in which mesohaline waters are defined as within the salinity range 5 – 18. The IBBEAM mesohaline index is the proportion of salinity observations within a given period that are ≥ 5 and <18, divided by the same statistic for a reference site (see full description in salinity index section).

Flow-data from the new pump (S-700) were downloaded from the DBHYDRO Database managed by SFWMD as average daily cubic foot per second (cfs).

2.4. DATA PRESENTATION

The set of biological and physical data to support our selected metrics were displayed in a Geographic Information System (GIS, ESRI 2011 ArcGIS) and interpolated to develop abundance (density, occurrence, cover, etc.) contours along an approximated shoreline strip to convey the spatial distribution of taxon-specific metrics along Biscayne Bay's western shoreline. Similar spatial analyses were conducted with the salinity indices. The contours reveal spatial distributions and provide the background for our Habitat Suitability models. Three dimensional data visualizations of regression model results were generated using SigmaPlot 11 software. All results are presented in calendar-year (January - December). In our time series plots, we identified periods (year-seasons) characterized by extreme or unusual conditions using semi-transparent, vertical color bars. These included marked year-seasons of hypersalinity (2004, 2011, 2015), the cold snap of 2010, unusual algal blooms that occurred during 2013 wet season, and Hurricane Irma that occurred in the 2017 wet season. Our designation of seasons as hypersaline was based on the data recorded in our multi-station nearshore YSI network (Table 4). We considered a given season as hypersaline if its average hypersalinity index value (i.e., across all operating YSI stations) exceeded 0.08. This 0.08 index threshold value roughly corresponds to salinity conditions > 40 psu occurring for two weeks of the 6-month season.

3. RESULTS

3.1. SALINITY INDICES

The full suite of salinity metrics are presented in site x season matrix form in Appendix A Table 1-10). The mesohaline index revealed that only a few of our sampled areas are optimal (Figure 2 and Appendix A Table 1-10) in terms of preferred water quality restoration characteristics prescribed by RECOVER[1] for nearshore western Biscayne Bay.

From the standpoint of the mesohaline index, the CYR 2018 dry season was characterized by a higher frequency of mesohaline conditions than the previous (CYR 2017) dry season, especially in the southern half of the IBBEAM sampling domain (Appendix A Table *1*). This was a consequence of relatively high canal discharge during the CYR 2018 dry season (Appendix C Figure *2*). The CYR 2018 wet and CYR 2017 wet seasons were very similar, with relatively high MI index values at most shoreline sites. High mesohaline values usually reflect high local rainfall; however, high mesohaline (and high canal discharge) values can emerge in the absence of particularly high rainfall, as was the case for the CYR 2018 dry season (Appendix C Figure *1* and 2). Hypersalinity is a major ecological concern that presently does not occur every year in southern Biscayne Bay. Hypersaline conditions were not observed during either the dry or wet season of CYR 2018 (Appendix A Table *4*).

The spatial pattern of the Variability Index (VI) during the dry season of CYR 2018 resembled that of CYR 2016, when rainfall and canal discharge quantities were among the highest in the last decade (Appendix A Table *5*). Relatively high VI values also characterized the CYR 2018 wet season, with among the highest values ever recorded at the southern sites A8 and 14. Sites north of Black Point continued to be relatively stable in terms of salinity variability during CYR 2018. The area north of Black Point has only one canal, with relatively low flow and, before the Deering Estate flow-way was implemented, received fresh water mainly as rainfall.

In general, the CYR 2018 Salinity Regime Suitability Index (SRSI) values (Appendix A Table *6*), which are composites of the mesohaline, variability, and hypersaline indices, indicated: (1) improved dry season salinity conditions at northern sites (i.e., north of Black Point), except the two northernmost sites (i.e., D6 and D2); and (2) good wet season salinity conditions throughout most of the entire study domain. The CRY 2018 wet season pattern ranked among the better wet seasons observed in our study. Poor SRSI during CYR 2018 is mostly explained by lack of mesohaline conditions and high within-day variability, while high SRSI values are due to high mesohaline index values as the other contributing factors were generally unremarkable.

3.2. BIOTIC VARIABLES

3.2.1 Submerged Aquatic Vegetation (SAV)

Halodule wrightii and *Thalassia testudinum* are the main components of the nearshore (< 100 m from shore) seagrass communities of western Biscayne Bay from Matheson Hammock to Turkey Point, with only minor contributions from *Syringodium filiforme* (Figure *3*). *Halodule* is the dominant species in terms of occurrence (found, on average, at 87 % of sites), compared to *Thalassia*, which was found at 70% of nearshore sites on average over the period of record. The co-occurrence of *Halodule* and *Thalassia* at the same sites (a desired goal of CERP) was observed, on average, at 59% of sites. The decline in occurrence of *Halodule* from 2017-2018 reversed an increasing trend that started in 2015. *Thalassia* occurrence, which had been on a general increasing trend since 2013, started declining after the 2016 wet season, reversed this pattern, and showed an increase in 2018. The occurrence of *Halodule* and *Thalassia* is high, but the benthic cover of these species is, on average, low. The average cover was 16.7 % for *Halodule*, 9.3 % for *Thalassia*, and only 0.15 % for *Syringodium* from 2008-2018 (Figure *3*).

Even when inter-annual fluctuations have been recorded, overall seagrass abundance over the POR (all species combined) has been fairly resistant and resilient to climatic extremes (2010 cold water anomaly, hypersalinity events, algal blooms, and Hurricane Irma (Figure *3*)). This is in clear contrast with the large-scale seagrass losses reported for Florida Bay (2015) and the 79th St Basin in Miami Beach. **However, the relative contribution of the two most abundant seagrass species is experiencing a shift that is contrary to CERP goals for this region.** The mean abundance of *Halodule* has been in a declining trend since 2011-2012 (peak mean abundance = 20 %), reaching its lowest levels (9.1 %) in the 2018 wet season. The opposite pattern has been documented for *Thalassia*, that has generally increased in cover since 2011. In fact, the 2018 wet season was the first time in the last 7 years where the cover of *Thalassia* exceeded that of *Halodule* in nearshore habitats (Figure *3*).

Cover data for the two dominant seagrass species, *Thalassia* and *Halodule,* collected from 2008-2018 from the 47 IBBEAM sites were incorporated into interpolated surface contours that help identify, spatially, areas with higher or lower habitat suitability of the dominant seagrass species (Figure *5*). 2018 presented a very dynamic spatial pattern of habitat suitability that contrasts with the 2008-2017 seasonal averages. The most notable finding is that **the northern portion of the study domain had areas unsuitable (i.e., 0% cover) for seagrass growth for both species in the 2018 wet season** (9% and 11% of the study domain had 0% cover of *Halodule* and *Thalassia* respectively). This is in clear contrast with the 2008-2017 period where no areas of low suitability were documented for both species in the wet season (Figure *5*). Given that *Halodule* and *Thalassia* have generally opposite salinity affinities, it is unlikely that salinity was the factor driving the lack of both species at the same time. **The factor that caused this spatially restricted decline was likely the inflow of large mats of the brown macroalga *Sargassum*** (Figure *4*). The floating mats of *Sargassum* that entered Biscayne Bay through the Safety Valve accumulated, mainly in the northern areas of the IBBEAM study area, along the shoreline. **When present in large quantities, the *Sargassum* caused physical abrasion of the bottom and shaded benthic macrophytes. In addition, as the *Sargassum* biomass decomposed, extreme low Oxygen values were recorded.**[6] These factors contributed to the loss of both seagrass species documented here. The low salinity recorded during both the dry and wet seasons in 2018 (reflected in favorable values of our Mesohaline Index) resulted in an increase in the proportion of favorable habitat (> 30% cover) for *Halodule* from 6% of the area in 2008-2017 to >20% in the 2008 dry season (Figure *5*). *Thalassia* also appeared to have benefited from the lower

[6] See Wang et al. [2019; Science 365 (6448): 83-87].

salinities as it increased its area of favorable habitat (> 30% cover) from 0% in the 2008-2017 to >6% in the 2008 dry season. This increase in favorable *Thalassia* habitat was limited to areas N of Black Point and S of Convoy Point and likely represents a mitigation of hyper-salinity conditions often seen in these areas removed from the influence of canals.

3.2.2 Epifaunal Community (EPI)

The 2018 dry season was the first collecting season after the wet season collections that followed (by 22 days, October 2 and October 6-13) Hurricane Irma's south Florida passage on 10 September 2017. The 2018 wet season is the first wet season collecting period after the one that immediately followed Irma. The hurricane sideswiped Biscayne Bay as its eye made Florida landfalls at Cudjoe Key and Marco Island and proceeded up the Gulf coast. Studies are underway at SEFSC, using 2018 data, looking at possible effects of the hurricane's passage on the epifauna community. The focus here is on 2018 collections.

In 2018 dry season epifaunal sampling, Shoal Point to Turkey Point, we found 1,622 fish, 132 crabs, 531 *Farfantepenaeus* shrimp, and 3771 caridean shrimp in 141 (47x3) sampled square meters. Of the 24 fish taxa, the most numerous was rainwater killifish *Lucania parva* (1078), followed by Gulf pipefish *Syngnathus scovelli* (157), code goby *Gobiosoma robustum* (83), goldspotted killifish *Floridichthys carpio* (67) and hardhead silverside *Atherinomorus* stipes (65). The common blue crab *Callinectes sapidus* (62) was the most numerous of the 10 crab taxa, followed by the lesser blue crab *C. similus* (34), the Florida grassflat crab *Neomanope packardii* (14), and the longnose spider crab *Libinia dubia* (8). Penaeids present were all in the genus Farfantepenaeus. *Farfantepenaeus* shrimp that could not be identified to species made up the largest group (453) and were likely pink shrimp, *F. duorarum*, which was the most numerous identified group (67). There were also 7 spotted pink shrimp, *F. brasiliensis*, in our samples. The presence of F. brasiliensis in Biscayne Bay has previously been reported, but there is no indication that it uses the bay as a nursery ground, and the species has been much less numerous than *F. duorarum* in identified samples collected in the current project. Caridean shrimp in samples consisted of 15 taxa, the most numerous of which was *Hippolyte zostericola* (1327), followed by *Hippolyte pleuracanthus* (1063), and other *Hippolytes* not identified to species (914*). Palaemon mundonovus* (previously *Palaemonetes intermedius*) was present with 199 identified to species. Thirty-four and 6 additional Carideans were identified as *Palaemon* spp. and Palaemonidae, respectively.

Sampling epifauna at alongshore IBBEAM sites during the 2018 wet season yielded 1458 fish in 14 taxa, 50 crabs in 5 taxa, 302 Farfantepenaeid shrimp in five taxa, and 145 caridean shrimp in 9 taxa. The most numerous fish species was the rainwater killifish (1072), followed by hardhead silverside (170) and goldspotted killifish (100). The unspecified hermit crab taxon Paguroidea was the most numerous crab taxon (33), followed by lesser blue crab (9) and common blue crab (5). The most numerous *Farfantepenaeus* shrimp was *F. duorarum* (67), followed by undistinguished *Farfantepenaeus* spp. *Paelomon mundonovus* (106) was the most numerous caridean, followed by *Palaemon* spp. (10) and *H. pleuracanthus* (10).

From the long-term perspective, occurrence and average density of our four focal epifauna species varied from year to year (Figure *6*). Seasonality of density was statistically significant in three of the four taxa tested with regression analysis (Gulf pipefish: R^2=0.821, P<0.0001, *Palaemon*: R^2=0.500, P =0.0007; Pink shrimp: R^2, 0.208, P=0.0148), as suggested in time-series plots starting with CYR Dry 2005 (Figure *6*). Seasonal variation in occurrence also was statistically significant in the same three taxa (Gulf pipefish: R2=0.886, P=<0.0001; *Palaemon*: R2=0.716, P=0.0002; Pink shrimp: R2=0.2814, P=0.0037). An effect of the shift toward late-season sampling, which allowed us to encounter more extreme conditions, was significant in explaining variation in both density and occurrence of *Palaemon* (statistics given above for this taxon included shift effect) and occurrence of Goldspotted killifish (0.1716, P=0.0284). Seasonal and year-to-year variation in the two abundance indicators was most consistent for Gulf pipefish and least consistent for *Farfantepenaeus* shrimps (with correlation coefficients between occurrence and concentration of 0.930 for the pipefish, 0.684 for *Palaemon* shrimps, 0.523 for goldspotted killifish, and 0.562 for *Farfantepenaeus* shrimps. (We used concentration instead of density to compare with occurrence in the correlation analysis because density=occurrence x concentration, and we did not want to compare occurrence to a variable in which occurrence was a component.)

Highest values occurred in the wet seasons for goldspotted killifish and in the dry seasons for the other three species (Gulf pipefish, *Farfantepenaeus* shrimps, and *Palaemon* shrimps). The seasonal pattern of each species was interrupted by extreme events (indicated on time series plots in Figure *6* by colored vertical bars), including periods of hypersalinity in the wet seasons of 2011 and 2015, a severe cold snap in January of 2010, a widespread algal bloom in the wet season of 2013, and Hurricane Irma in the wet season of 2017 (Table *4*, Figure *6*). To these, we can also add the *Sargassum* intrusions of the wet seasons of 2015 and 2018.

Coming out of the 2017 wet season, which experienced the September 20 hurricane, 2018 dry season density was the highest on record for pink shrimp and gulf pipefish, unremarkable for *Palaemon* shrimp, and poor for goldspotted killifish. Occurrence also met an all-time high for pink shrimp and was near the all-time high for gulf pipefish. Goldspotted killifish occurrence was poor in relation to the period of record, but *Palaemon* occurrence was above its long-term dry-season average.

Density and occurrence of pink shrimp and goldspotted killifish were substantially higher in the wet season of 2018 than they had been in the previous wet season, which had experienced Hurricane Irma. Density and occurrence were also higher than the long-term average for pink shrimp, but only occurrence was higher than the long-term average for goldspotted killifish. Results were mixed and differences small comparing the 2018 wet season density and occurrence of gulf pipefish and *Palaemon* shrimp to 2017 wet season and long-term averages.

Temporal patterns of change in the abundance metrics were well correlated across taxa for three taxa--gulf pipefish, *Farfantepenaeus* shrimp, and *Palaemon* shrimp--but the goldspotted killifish departed dramatically from the others. For occurrence, correlation coefficients were 0.712 between Gulf pipefish and *Palaemon* shrimp, 0.470 between Gulf pipefish and *Farfantepenaeus* shrimp, and 0.697 between *Palaemon* shrimp and *Farfantepenaeus* shrimp. For density, correlation coefficients were 0.657 between Gulf pipefish and *Palaemon* shrimp, 0.513 between Gulf pipefish and penaeid shrimp, and 0.289 between *Palaemon* shrimp and *Farfantepenaeus* shrimp. This was not much different from the previous year. Occurrence correlation coefficients were -0.038 between goldspotted killifish and Gulf pipefish, -0.041 between goldspotted killifish and Palaemonetes shrimp, and 0.029 between goldspotted killifish and penaeid shrimp. Density correlation coefficients were -0.157 between gold spotted killifish and Gulf pipefish, 0.112 between goldspotted killifish and *Palaemon* shrimp, and -0.227 between goldspotted killifish and *Farfantepenaeus* shrimp.

Spatial abundances of the four epifaunal focal species varied from year to year, although averaging the spatial data across time (CYR 2008 to CYR 2017), as in left two shoreline strips in Figure *7* (a, b, c, and d), erased evidence of spatial variation, showing only that all four species were present (1 to 15) at all monitored sites sometime within the 10-yr period (2008-2017). The spatial strips of density for the dry and wet seasons of 2018 revealed seasonal variation in spatial distributions and differences among species. Especially notable are the three high-density patches of pink shrimp north of Black Point (Figure *7*C) in D2018 and the one high-density patch in *Palaemon* shrimp near Turkey Point (Figure *7*D) in D2018. The patchy distributions of the focal taxa along the shoreline from Shoal Point to Turkey Point probably relate to spatial variation in factors determining habitat quality.

3.2.3 Mangrove Fish Community (MF)

There were no obvious lingering impacts of Hurricane Irma (CYR 2017) on the abundance of the three focal mangrove-fishes. During CYR 2018, mangrove-associated goldspotted killifish continued to occur most frequently during the dry season and to a lesser extent during the wet season, and density followed the same general pattern (Figure 8A). Goldspotted killifish occurrence during the CYR 2018 dry season was somewhat elevated as might be predicted from the elevated mesohaline index values observed relative to the previous year (Appendix A Table *1*). Mangrove-associated gray snapper abundance metrics (occurrence and density) tend to be highest in the wet season versus the dry; their values during CYR 2018 were similar between seasons and similar in magnitude to the previous four years (Figure 8B). For mangrove-associated yellowfin mojarra (Figure 8C), occurrence and density continue to steadily increase since the CYR 2010 cold event with CYR 2018 values being among the highest observed since the project's inception.

All three mangrove-fish indicator species displayed substantial spatial variation, being concentrated in some areas and absent from others (Figure 9). The CYR 2018 dry season was characterized by high densities (i.e., relative to 2008-2017 seasonal averages) of goldspotted killifish along Biscayne Bay's southern mainland shoreline (Figure 9A). In contrast, goldspotted killifish density-distribution during the CYR 2018 wet season closely resembled the 2008-2017 average. Spatial patterns of gray snapper density-distribution during CYR 2018 generally fell within the CYR 2008-2017 seasonal averages (Figure *9*B). However, high abundances of yellowfin mojarra in the "canal zone" (i.e., Black Point to Turkey Point) were observed during both seasons of CYR 2018 wet season (Figure 9C).

3.3 BIOTIC/ABIOTIC RELATIONSHIPS - GENERAL LINEAR MODELING

Statistical relationships among organism abundance and habitat variables were examined using general linear models and logistic regression models. SAV data and Mangrove Fish (MF) data were regressed against salinity, temperature, and depth. Epifaunal data were additionally linked with the SAV dataset to examine potential relationships among epifauna abundance and canopy height or *Halodule*, *Thalassia*, and *Syringodium* cover. The relationships we found provided the basis for habitat suitability models.

3.3.1 Submerged Aquatic Vegetation

Regression-model results and predictions for *Halodule* and *Thalassia* are shown in Figure 10 (2D-plots), Appendix B Table 1 A-B. Second-order relationships were documented between *Halodule* occurrence and cover, salinity, water depth, and temperature (Figure 10A, Appendix B Table 1). *Thalassia* occurrence and cover were significantly related ($P<0.05$) to salinity, depth and temperature (Figure 10B, Appendix B Table 1). *Thalassia* occurrence and cover increased asymptotically with increasing salinity and increasing temperature.

***Halodule* occurrence and cover are robust and consistent indicators of nearshore salinity conditions.**

3.3.2 Epifaunal Community

The four focal epifaunal species were significantly related to salinity and other variables (Figure 11 and *Appendix* B Table 1). The regression coefficients that were significant appear in Appendix B Table 1 and apply to the equations that prepared the plots in Figure 11. Values in the final column that might be used to compare model fit between occurrence and density are not exactly comparable because the R^2-values start from a lower possible baseline than the C-values. The C-values used to describe model fit in logistic equations, applied to occurrence (Appendix B Table 1A), can only range between 0.5 and 1.0, whereas the Adjusted R^2 values (R^2-value) used to describe model fit in linear equations, applied to density (Appendix B Table 1B), can range from 0 to 1. Relationships with salinity were parabolic, having salinity optima within the plotted salinity range, for both occurrence and density of goldspotted killifish (Figure 11A), Gulf pipefish (Figure 11B), and *Farfantepenaeus* shrimp (Figure 11C). The regression relationship with salinity was negatively linear for both occurrence and density of *Palaemonetes* shrimp (Figure 11D). Occurrence and density salinity optima were 20 and 22, for *Farfantepenaeus* shrimp, 20 and 20 for goldspotted killifish, and 26 and 24 for Gulf pipefish; however, the broad, near-flattened tops of the parabolas for both *Farfantepenaeus* shrimp and goldspotted killifish suggested wide salinity tolerance ranges (Figure 11A, C). The regression models suggested that Gulf pipefish are favored by intermediate polyhaline conditions, whereas *Farfantepenaeus* shrimp and goldspotted killifish are associated with low polyhaline conditions, and *Palaemon* shrimp are associated with mesohaline conditions. Examination of plotted predictions of species abundance, either occurrence or density, since IBBEAM started preparing them with data through 2008 indicate variation in the shape of the curve during the first few years that has become more consistent in recent years as more data and a wider range of circumstances have been added.

Regression models suggested that *Halodule* cover influenced both occurrence and density of all four focal taxa (Figure 11 and Appendix B Table 1A, B). *Halodule* cover was optimum for occurrence and density at 45% and 40%, respectively, for goldspotted killifish (Figure 11A); 35% and 35% for gulf pipefish (Figure 11B); 40% and 45% for *Farfantepenaeus* shrimp (Figure 11C); and 50% and 45% for *Palaemonetes* shrimp (Figure 11D). In no case was a cover of greater than 50% *Halodule* advantageous.

Occurrence and density of SAV-associated focal species are indicative of salinity conditions: Gulf pipefish are favored by intermediate polyhaline conditions, whereas *Farfamtepenaeus* shrimp and goldspotted killifish are associated with low polyhaline conditions, and *Palaemonetes* shrimp are associated with mesohaline conditions.

3.3.3 Mangrove Fish Community

For the most part, relationships found previously between mangrove-fish abundance metrics (i.e., occurrence and density) and salinity were reinforced upon inclusion of CYR 2018 mangrove-fish data into the larger database. Based on the absolute magnitude of regression coefficient values, temperature continues to exert the strongest effects on occurrence and density levels for all three focal mangrove fish species (Appendix B Table 1). However, significant salinity effects on the abundance metrics of all three species are evident after temperature and depth effects are taken into account. For example, goldspotted killifish density and occurrence continue to both be related to salinity in parabolic fashion, with highest values at intermediate (20-25) salinities (Figure 12A, Appendix B Table 1). And gray snapper occurrence and density remain highest at the highest salinity levels (Figure 12B, Appendix B Table 1). While yellowfin mojarra occurrence continues to decline as salinity increases, its densities follow a similar parabolic pattern as those of the goldspotted killifish, with highest values at intermediate (15-20) salinity levels (Figure 12B, Appendix B Table 1). The latter yellowfin mojarra results differ from the linear pattern presented in our previous annual report, demonstrating that the abundance-salinity relationships for this species may not persist as more data are incorporated into analyses. In contrast, addition of new data on goldspotted killifish did not change the parabolic pattern of abundance to salinity that has been consistently presented in previous reports and McManus et al. (2014). Inconsistency in model results between years tends to support the idea that greater weight be given to patterns of occurrence than to density when using multiple regression models to reveal habitat affinities (McManus et al. 2014), at least with respect to the mangrove fish community.

Occurrence and density of mangrove-associated goldspotted killifish are good indicators of intermediate (15- 25 psu) nearshore salinity conditions.

3.4 DEERING ESTATE ANALYSIS

The Deering Estate Flow-way, an early component of Biscayne Bay Coastal Wetlands Phase I of the Comprehensive Everglades Restoration Project (CERP), began operation in December 2012 and is the first CERP component to potentially affect salinity patterns in Biscayne Bay. The purpose of BBCW is to recreate a more natural distribution of freshwater flow to the Bay by spreading its delivery along the coastline more diffusely, through wetlands and creeks, not only as point discharge through canals. Although BBCW was not designed to eliminate canal flow, it will redirect into coastal wetlands some of the surface flow to the bay that would otherwise enter the bay directly from canals. Local refinements in the canal network and a pumping station (S-700) divert water from the South Florida Water Management District canal system into the Deering Estate flow-way. Figure 13A shows the pumping record at S-700 from implementation through October 2018. The comb-tooth appearance of the plot of flow is due to the 12-hrs-on-12-hrs-off pumping schedule. Matching the flow chart with the plot of salinity at D2 in the nearshore bay suggests that the infrequent high-amplitude pumping at S-700 was more effective than the usual low amplitude pumping in lowering salinity in bay waters.

IBBEAM assessed the effect of S-700 pumping on salinity in nearby areas of Biscayne Bay, recognizing that IBBEAM salinity monitoring sites D2 and D6 could be used to characterize local salinities in the bay immediately downstream of the Deering Estate flow-way (see Figure 1 map for water quality site locations). D2 is in the bay near the mouth of the southernmost creek leading from the Deering Flow-way and was used in analyses of the effect of the flow-way on bay salinity in 2014 and 2015 reports (Lirman et al. 2014, 2015). D6, in the bay near the mouth of the northern creek off the Deering Estate flow-way, has a shorter record but expands the ability to determine pumping influence in the years of its availability. In Figure 13B, 15-minute salinity at D2 is plotted on the same time scale as the pumping plot in Figure 13A. Local salinity minima (Figure *13*B) appear to roughly correspond to periods of high amplitude pumping (Figure *13*A); conversely, the highest salinity peak occurred near the end of a period of low to no pumping (e.g., in 2015). The lowest salinity in the period of this record was in July of 2018 (Figure *13*B). It corresponds with several consecutive days of high-amplitude pumping at S-700 (Figure *13*A). Figure 14A is a point plot of daily salinity recorded at D2, separated by a vertical line before and after Deering Estate implementation (December 2012) and showing the mesohaline zone (5-18 psu) as a horizontal light blue-green band. Figure 14A, also showing the mesohaline band, is a box plot of 15-min daily salinity at site D2. The mesohaline zone, with salinity between 5 and 18, is considered optimal habitat for the Biscayne Bay western nearshore area. Only a few of the daily values in Figure 14A or the summarized 15-min salinity values in Figure 14B are low enough to reach the mesohaline band.

The Mesohaline Index (MI), one of several nearshore Biscayne Bay salinity indices developed by IBBEAM and described previously in this report, is useful in summarizing salinity conditions for comparisons among stations and times. Figure 15 shows the wet season (A) and dry season (B) MI for CYR years 2010 to 2018 at D2, D6 and 10 other water quality monitoring sites from Deering south to approximately the Princeton Canal. Note that the D2 and D6 MI are similar and substantially lower than the MI at the other sites, although the two trajectories depart in Wet 2016, suggesting that the two sites can respond differently to the same pumping.

Annual variation in rainfall and runoff (Appendix C Figure 1) makes it difficult to determine effects of S700 pumping on salinity in the nearby downstream bay, as measured at D2 and D6. Direct comparison of D2 and D6 MI's to that of other water quality sites is equally non-useful because there are such big differences in salinity conditions among sites, and most other sites had much higher MI's than D2 and D6 in wet (A) and dry (B) seasons of most years. Direct comparisons were further confounded by a special operation initiative in CYR 2012 that took advantage of exceptionally high rainfall and resultant availability of fresh water in the water management system (Appendix C Figure 1) to route fresh water to Biscayne Bay through all SFWMD canals along the western coast of south-central Biscayne Bay between sites D6 and 40

To overcome these complications to simpler analyses, the approach taken in this report was to compare annual seasonal percent change in MI, plus or minus, from CYR 2012 at D2 and D6 in each post-implementation year (2013 to 2018) (e.g., 100 $[(MI_{2013}-MI_{2012})/MI_{2012}]$) to corresponding percent change in MI from 2012 at each of the other 10 salinity recording stations. In other words, each station was compared for percent change between the last pre-S700-pumping year (CYR 2012) and each of the post-S700-pumping years. Wet season and dry season percentages were calculated separately (Figure 16 and Figure 17, respectively). We now have a record that includes six years with pumping at S700. In Wet CYR 2013 and again in Wet CYR 2017 and Wet CYR 2018 (Figure 16A), the D2 percent change in MI from Wet CYR 2012 was the only positive change at any site, suggesting responses to S700 pumping during those three wet seasons. A slight increase from CYR Wet 2012 in continuous mesohaline duration at D2 in CYR Wet 2013, 2017 and 2018 (Appendix A Table 7: 4.60, 5.01, and 4.14 days, respectively, vs. 3.51) supported the improvement in mesohaline index and provided more perspective. The response was not related to rainfall because it only happened at a site that could have been affected by S700 pumping. Interestingly, there was no positive response relative to 2012 at D6, although the negative response was less there than at the other stations. There were no remarkable differences in percent change from CYR 2012 at either D2 or D6 in dry season MI's from CYR 2013 through CYR 2015 or in CYR 2017 or CYR 2018. However, in Dry CYR 2016, the percent change in MI from 2012, although positive at all 12 salinity monitoring sites, was so much higher at D2 and especially at D6 than at the other 10 sites (Figure 17D) that it suggested a positive effect of S-700 pumping on nearshore Biscayne Bay salinity conditions off the Deering Estate Flow-Way and associated creeks at that time. In contrast, the following dry season, Dry CYR 2018, responses to pumping were especially poor at D2 and D6. Differences among years in salinity responses at D2 and D6 were undoubtedly a function of the rainfall regimes of each year-season but may also have been a function of pumping schedule variations in response to water availability in each year-season.

In addition to providing perspective on the effect of Deering Estate pumping on nearby nearshore bay salinities, figures used in this section of the IBBEAM Annual Report (Figure 13-17) demonstrate the positive benefits on bay salinities of special operations in response to exceptional availability of fresh water. For example, the operations experiment conducted in CYR 2012 suggested that directing more freshwater flow to the coast near the end of the wet season would ameliorate, well into the dry season, conditions caused by little or no rainfall. Perhaps special operations responded to high rainfall in Dry CYR 2016 with higher pumping rates to enhance mesohaline conditions in the nearshore bay all along the south-central western Biscayne Bay coast from D6 to C2. Our preliminary conclusion was that relatively high pumping rates at S-700 are necessary to appreciably lower salinity conditions in the nearshore bay. However, it is likely that continuous operation of the pump, as proposed by Bahram Charkhian, SFWMD, pers. comm.) even at the present lowest applied pumping rate, 25 cfs, would be more effective in reducing salinities in the nearby bay. Responding to salinity records at both inshore and Bay stations, the SFWMD adopted a continuous pumping regime with at least 25 cfs (cubic feet per second) on 6 September 2018 (Bahram Charkhian, SFWMD, pers. comm.). This should yield some improvement, although boosting the minimum continuous flow rate to at least 50 cfs or even 100 cfs may be necessary to establish mesohaline conditions. Participating in the adaptive management strategy, we will report results of the new continuous flow schedule in our next annual report.

4. CONCLUSION

IBBEAM results through incorporation of CYR 2018 data continue to indicate that Biscayne Bay's nearshore environment has not yet become the consistent, expansive mesohaline habitat that CERP seeks to re-establish. The Bay's shallow nearshore zone is still occupied by floral and faunal species assemblages operating below their productive potential. In part, this deficiency is due to inadequate and unnatural freshwater flows that limit the duration and spatial extent of mesohaline conditions, thus limiting the native diversity and abundance of species characteristic of South Florida estuaries. The shallow waters of Biscayne Bay are sensitive to any event that could influence salinity (i.e., rainfall or freshwater inflow), and the biota are sensitive to change in salinity levels, ranges, and variability. The desired shift toward more productive estuarine flora and fauna along the Bay's western shoreline will not be realized without increased freshwater flow to maintain mesohaline salinities for a substantial part of the year (i.e., 3 to 5 months). While mesohaline conditions during the wet season of CYR 2018 were generally improved over those of the wet season of CYR 2017 and, by their relative increase from wet CYR 2012 at D2, compared to other instrumented stations, showed an effect of pumping at S700, they were insufficient to support estuarine species along Biscayne Bay's western shoreline. The experiment in CYR 2012 demonstrated that considerably greater volume of freshwater can contribute to goals of increased pumping and reduced salinities at the Deering Estate by redirecting high flows to the Deering Estate pumping facility when they are available. The habitat would be improved if additional freshwater inflow were provided to limit or prevent occurrence of high salinity conditions and support rapid establishment and maintenance of mesohaline salinity conditions at the onset of the wet season. Continued monitoring of salinity, flora, and fauna in the nearshore bay is important to bay ecosystem restoration. Continued tracking and possibly expanding the suite of ecological indicators and salinity indices developed by the IBBEAM team is the best option for gauging CERP performance in Biscayne Bay. We presently are exploring use of community indices linked to salinity affinity. Such an index seems especially appropriate in this case, where the goal is reestablishment of a mesohaline-habitat-associated community.

For the most part, lengthening our data set with more sampling strengthened our HS models. The major algal bloom that occurred in Biscayne Bay in the summer of 2013 may have affected some species we follow, possibly confounding modeling results for those species that year, but most appear to have recovered. Continued sampling will improve the predictions (i.e., reduce uncertainty) and enable future assessments to separate CERP affects from other influences. Incorporating the 2018 data into the analysis, by providing another year of bi-annual data and revealing indicator responses to a new set of conditions, improved the fits of Habitat Suitability Models for most species, while making the models applicable to a wider set of future conditions. These models are promising predictors of biota-salinity relationships for use in predicting and explaining CERP implementation results.

Adding more data to our established suite of analyses incorporates events and responses that are important to record[7]. Sampling during CYR 2017 and CYR 2018 enables examination of potential responses to the surge and intense, long-duration rainfall associated with passage of a hurricane (Irma). For seagrass and mangrove-fishes, hurricane effects were not obvious six to 12 months after that disturbance. Some epifauna species may have benefited from the hurricane. For example, pink shrimp and Gulf pipefish, although depressed in number immediately following the hurricane, rebounded to higher abundance than previously seen in this period of record by Dry CYR 2018, approximately six months following the hurricane. As we add new data in future years, our perspective on the range and variability of conditions in Biscayne Bay's nearshore area will expand to better represent long term conditions. This long-term dataset will allow us in the future to compare pre-CERP data to changes due to CERP, while identifying changes from other causes, such as hurricanes, storm events, cold events, and sea-level rise. We have demonstrated that incorporation of additional sampling data into our analyses strengthens our power to detect change (Dolan et al. 2016) as this is highly dependent on sample size. Lengthening the data set improves understanding of the potential range of annual variation in rainfall, canal discharge, temperature and other influencing factors, including sea level rise, that continually introduce variation in spatial and temporal salinity patterns. Lengthening the data set also expands the possible set of biotic responses to habitat and climate variation that must be understood to distinguish CERP effects from other sources of change.

The Deering Estate analysis demonstrated the sensitivity to change of our Mesohaline Index, reinforcing our confidence in the Mesohaline Index as a good indicator for assessing CERP salinity effects. Our analysis of cross-year change at D2 (and later, D6) compared to the other sites was successful in detecting a change at WQ Site D2 in Wet CYRs 2013, 2017, and 2018 and at D2 and D6 in Dry 2016 that was independent of the widespread effects of weather (i.e., rainfall). Results differed among years, even within seasons, because of differences in water availability and the response of pumping operations to conditions at the time. It is helpful to know that the water quality sites nearest to Deering Estate and the Mesohaline index are sensitive to change, and the salinity record at these sites can be used to represent

[7] Information on Hurricane Irma impacts are included in the 2018 report. Hurricane impacts on the indicators are also highlighted in the temporal trends in density and occurrence of all the indicators in Appendix A (e.g., Figs. 3, 6, 8).

pre-implementation conditions. We are grateful that salinity data from these sites, as well as our comments about the ecological importance of reestablishing mesohaline conditions in the nearshore bay, helped influence the recent decision of the SFWMD, through Bahram Charkhian, to establish a continuous pumping regime at S-700 in 2019, in place of the pulsed (12-hr on, 12-off) regime employed since beginning operations. The coming years and new analyses of the lengthening data streams provided by continued sampling will help determine the salinity and biotic changes restoration will bring. To see a description of the BBCW Project, Phase I, including Deering and L-31E Culverts), and SFWMD analyses of implementation through water year 2018 (May 2017 – April 2018) go to https://apps.sfwmd.gov/sfwmd/SFER/2019_sfer_final/v3/appendices/v3_app2-3.pdf

Continued monitoring of salinity, SAV, seagrass-associated epifauna, and mangrove-associated fishes is warranted to (1) help distinguish CERP effects from the effects of episodic events such as the CYR 2010 cold snap, the CYR 2013 algal bloom, and CYR 2017 Hurricane Irma, (2) support CERP's commitment to early detection (and reversal) of any impairment to the habitat, forage base, general ecology, and fishery recruitment that CERP activities may unintentionally cause, (3) increase statistical power to detect departures and differences from reference values, and (4) improve and refine habitat suitability models, which are key to comparison of different freshwater flow scenarios in ecological terms.

5. IBBEAM OUTLOOK

The following objectives will be addressed in the future:

1) Examine the impacts of Hurricane Irma on benthic resources and salinity.
2) Integrate monitoring to quantify changes in water quality and biotic responses to facilitate adaptive management (ongoing).
3) Assist with analyses that compare relative impacts of selected management scenarios on areal extent of suitable habitat (as described by McManus *et al.* 2014).
4) Evaluate faunal groups in terms of affinity for mesohaline, polyhaline, euhaline or other salinity-related habitat.
5) Coordinate our work with SFWMD and Miami-Dade County work in the Deering Estate and L-31E project areas. Use our salinity metrics and key species indicators to assess the effects of water flow changes to these areas.

6. REFERENCES

Abele, L. G. and W. Kim. 1986. An illustrated guide to the marine decapod crustaceans of Florida. State of Florida. Department of Environmental Regulation 8(1): i-xvii, 225 p.

Anonymous. 1959. Symposium on the classification of brackish waters. Venice 8-14th April, 1958.Archivio di Oceanografiae Limnologia Volume11. Supplemento (Simposiosulla Classificazione del la Acque Salmastre. Venezia8-14, Aprile, 1958).

Bulger, A.J., B.P. Hayden, M.E. Monaco, D.M. Nelson and M.G. McCormick-Ray. 1993. Biologically-based estuarine salinity zones derived from multivariate analysis. Estuaries 16:311-322.

Dawson, C.E., 1982. Family Syngnathidae. The Pipefishes. In Fishes of the Western North Atlantic (ed J.A. Böhlke), pp. 4–172. Memoir 1, Part 8, Order Gasterosteiformes, Suborder Sygnathoidei. Sears Foundation for Marine Research, Yale University, New Haven, Connecticut.

Dolan TE, PD Lynch, J Karazsia and JE Serafy. 2016. Statistical power to detect change in a mangrove shoreline fish community adjacent to a nuclear power plant. Environ Monit Assess (2016) 188:184 1-16. DOI 10.1007/s10661-016-5177-7

ESRI. 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Fourqurean, J. W., J. N. Boyer, M. J. Durako, L. N. Hefty, and B. J. Peterson. 2003. Forecasting responses of seagrass distributions to changing water quality using monitoring data. Ecological Applications 13: 474-489.

Griefen, A. 2010. Biscayne Bay throw trap surveys: a guide to lab sorting and species identification. NOAA National Marine Fisheries Service, Southeast Fisheries Science Center, Miami, Florida. 12 pp.

Kaplan, E. H. 1988. *A field guide to southeastern and Caribbean seashores: Cape Hatteras to the Gulf coast, Florida, and the Caribbean.* Houghton Mifflin Co. Boston, MA. USA. 425 pp.

Lirman, D., G. Deangelo, J. Serafy, A. Hazra, D. Smith Hazra, J. Herlan, J. Luo, S. Bellmund, J. Wang, and R. Clausing. 2008. Seasonal changes in the abundance and distribution of submerged aquatic vegetation in a highly managed coastal lagoon. Hydrobiol. 596, 105–120.

Lirman, D., G. Deangelo, J. Serafy, A. Hazra, D. Smith Hazra, and A. Brown. 2008. Geospatial Video Monitoring of Nearshore Benthic Habitats of Western Biscayne Bay (Florida) Using the Shallow-Water Positioning System (SWaPS). Journal of Coastal Research. 24, 135-145.

Lirman, D., T. Thyberg, R. Santos, S. Schopmeyer, C. Drury, L. Collado-Vides, S. Bellmund, and J. Serafy. 2014. SAV communities of western Biscayne Bay, Miami, Florida, USA: Human and natural drivers of seagrass and macroalgae abundance and distribution along a continuous shoreline. Estuaries and Coasts 37:1243-1255.

Lirman, D., S. Bellmund, J. Browder, J. Serafy. 2013. IBBEAM—Integrated Biscayne Bay Ecological Assessment and Monitoring. 1st Annual Report to the U.S. Army Corps of Engineers and the

Restoration Coordination and VERification Group of the Comprehensive Everglades Restoration Plan (CERP) by the University of Miami Rosenstiel School of Marine and Atmospheric Science, National Park Service, and National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service.

Lirman, D., S. Bellmund, J. Browder, J. Serafy. 2015. IBBEAM—Integrated Biscayne Bay Ecological Assessment and Monitoring. 3rd Annual Report to the U.S. Army Corps of Engineers and the Restoration Coordination and VERification (RECOVER) Group of the Comprehensive Everglades Restoration Plan (CERP) by the University of Miami Rosenstiel School of Marine and Atmospheric Science, National Park Service, and National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NOAA-NMFS-SEFSC-PRBD-2013-06).

Lirman, D., S. Bellmund, J. Browder, J. Serafy. 2016. IBBEAM—Integrated Biscayne Bay Ecological Assessment and Monitoring. 4th Annual Report to the U.S. Army Corps of Engineers and the Restoration Coordination and VERification Group of the Comprehensive Everglades Restoration Plan (CERP) by the University of Miami Rosenstiel School of Marine and Atmospheric Science, National Park Service, and National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NOAA-NMFS-SEFSC-PRBD-2016-15).

Macias, E. B. 2012. Faunistic analysis of the caridean shrimps inhabiting seagrasses along the NW coast of the Gulf of Mexico and Caribbean Sea. Revista de Biologia Tropical 60(3) ISSN 0034-774.

McManus, L. C., S. Yurek, P. B. Teare, T. E. Dolan and J. E. Serafy. 2014. Killifish habitat suitability as a measure of coastal restoration performance: Integrating field data, behavioral trials and simulation. Ecological Indicators 44:173-181.

McCarthy, L. C., W. F. Loftus, and J. S. Rehage. 2012. Segregation of palaemonid shrimp along an Everglades estuarine gradient: Do multiple species have similar trophic function? Bulletin of Marine Science 88:843-861.

Nelson, J. S., E. J. Crossman, H. Espinoza-Perez, L. T. Findley, C. R. Gilbert, R. N. Lea, and J. D. Williams. 2004. Common and Scientific Names of Fishes from the United States, Canada, and Mexico, Sixth Edition. American Fisheries Society Special Publication 29. Bethesda, Maryland. 386 pp.

Neter, J., M. Kutner, C. Nachtsheim, and W. Wasserman. 1996. Applied Linear Statistical Models. McGraw-Hill Companies, Inc., NY.

Pitts, P., S. Bellmund, J. Browder, H. Jobert, J. Serafy, and L. Wingard. 2017. Historical salinity conditions of southwestern nearshore Biscayne Bay. Technical Report of a voluntary sub-team of the Southern Coastal Systems Region of the Comprehensive Everglades Restoration Plan's Restoration, Coordination, Verification (RECOVER) Program.

Robins, C. R. and G. C. Ray. 1986. A Field Guide to Atlantic Coast Fishes North America. Houghton Mifflin, New York. 354 pp.

Serafy, J. E., C. H. Faunce, and J. J. Lorenz. 2003. Mangrove shoreline fishes of Biscayne Bay, Florida. Bulletin of Marine Science 72, 161-180.

Serafy, J. E., M. Valle, C.H. Faunce, and J. Luo. 2007. Species-specific pattern of fish abundance and size along a subtropical mangrove shoreline: An application of the Delta Approach. Bulletin of Marine Science 80 (3), 609-624.

Serafy, J.E., D. Johnson, and B. Teare. 2011. Shoreline Fish Community Visual Assessment. CERP Monitoring and Assessment Plan Component 3.2.3.6 . 92pp.

Serrano, X, M. Grosell and J. E. Serafy. 2010. Salinity selection and preference of the gray snapper, *Lutjanus griseus*: Field and laboratory observations. Journal of Fish Biology 76, 1592–1608.

Stabenau E., A. Renshaw, J. Luo, E. Kearns and J. D. Wang. 2015. Improved coastal hydrodynamic model offers insight into surface and groundwater flow and restoration objectives in Biscayne Bay, Florida, USA. Bulletin of Marine Science 91: 433-454.

Table 1: IBBEAM sampling sites.

Water Quality Site	Latitude (Dec)	Longitude (Dec)	Biotic Site	Latitude (Dec)	Longitude (Dec)
D6	25.62097	-80.29736	**1**	25.62922	-80.28854
			2	25.62392	-80.29930
D2	25.61678	-80.30128	**3**	25.61749	-80.30163
			4	25.61583	-80.30276
62	25.61225	-80.30583	**5**	25.61372	-80.30617
			6	25.60936	-80.30747
C8	25.58897	-80.30697	**7**	25.59440	-80.30791
			8	25.57974	-80.30502
C6	25.57425	-80.30264	**9**	25.57414	-80.30340
56	25.56444	-80.30531	**10**	25.56941	-80.30255
			11	25.56853	-80.30327
			12	25.56173	-80.30756
C4	25.55506	-80.30878	**13**	25.55792	-80.30760
			14	25.55160	-80.31017
C2	25.54586	-80.31372	**15**	25.54500	-80.31229
B8	25.53853	-80.31783	**16**	25.54029	-80.31282
			17	25.53757	-80.31336
B6	25.52728	-80.32986	**18**	25.53200	-80.32874
			19	25.52529	-80.33122
			20	25.51834	-80.33099
B4	25.51011	-80.33531	**21**	25.51682	-80.33369
			22	25.51553	-80.33411
			23	25.51430	-80.33483
			24	25.51232	-80.33514
			25	25.50960	-80.33577
			26	25.50554	-80.33361
40	25.50533	-80.33577	**27**	25.50402	-80.33258
			28	25.50507	-80.33668
			29	25.50455	-80.33788
28	25.49844	-80.33875	**30**	25.49734	-80.33933
22	25.49242	-80.33911	**31**	25.49314	-80.33833
			32	25.49030	-80.34032
			33	25.48680	-80.33996
			34	25.48532	-80.33964
A8	25.48128	-80.33967	**35**	25.48022	-80.34032
			36	25.47977	-80.34034
14	25.47361	-80.34003	**37**	25.47707	-80.34036
			38	25.46934	-80.34016
			39	25.46579	-80.33761
A6	25.45211	-80.33133	**40**	25.45878	-80.33721
			41	25.45537	-80.33617
			42	25.45039	-80.33062
			43	25.44463	-80.33092
			44	25.44296	-80.33012
NONE			**45**	25.43778	-80.32408
			46	25.43767	-80.32155
			47	25.43728	-80.31927

Table 2: Overview of selected indicator species and parameters.

	Water quality	SAV	Epifauna	Mangrove Fish
Species	--	*Thalassia* *Halodule*	Goldspotted killifish Gulf pipefish Pink shrimp *Palaemonetes* spp.	Goldspotted killifish Yellowfin mojarra Gray snapper
Specific Focus	Mesohaline Index Oligohaline Index Oligo-Mesohaline index Hyperhaline Index Variability Index Salinity Regime Suitability Index Mesohaline Duration Index Oligohaline Duration Index Oligo-Mesohaline Duration Index Hyperhaline Duration Index	Percent Cover Canopy Height Spatial Extent	Occurrence Density	Occurrence Density

Table 3: Simplified color scheme for salinity indices.

	Red		
Mesohaline Index	Min = Lowest value in matrix	50%	Max = Mean seasonal value at DJ*
Hypersaline Index	Max = Highest value in matrix	50%	Min = Mean seasonal value at DJ*
Variability Index	Max = Highest value in matrix	50%	Min = Mean seasonal value at DJ*
SRSI	Min = Lowest value in matrix	50%	Max = Mean seasonal value at DJ*

Red = Not Suitable
Yellow = Adequate
Green = Optimal

**DJ =Downstream Joe Bay, 25.21665 N and -80.55563W, chosen reference site, data provided by J. Lorenz (The Coastal Wetlands Monitoring and Assessment Project, Florida Audubon Tavernier Science Center, unpublished data)*

Table 4: Temporal overview and descriptions of ‘extreme’ events occurring in Biscayne Bay, Florida, 2004-2018. We considered a given season as hypersaline if its average (i.e., across all operating YSI stations) hypersalinity index value exceeded 0.08. This 0.08 index threshold value corresponds to salinity conditions > 40 psu occurring for a two weeks of the 6-month season.

Year	Season	Description
2004	Wet	Hypersalinity
2010	Dry	Cold Snap
2011	Wet	Hypersalinity
2013	Wet	Algae Bloom
2015	Wet	Hypersalinity
2017	Wet	Hurricane Irma

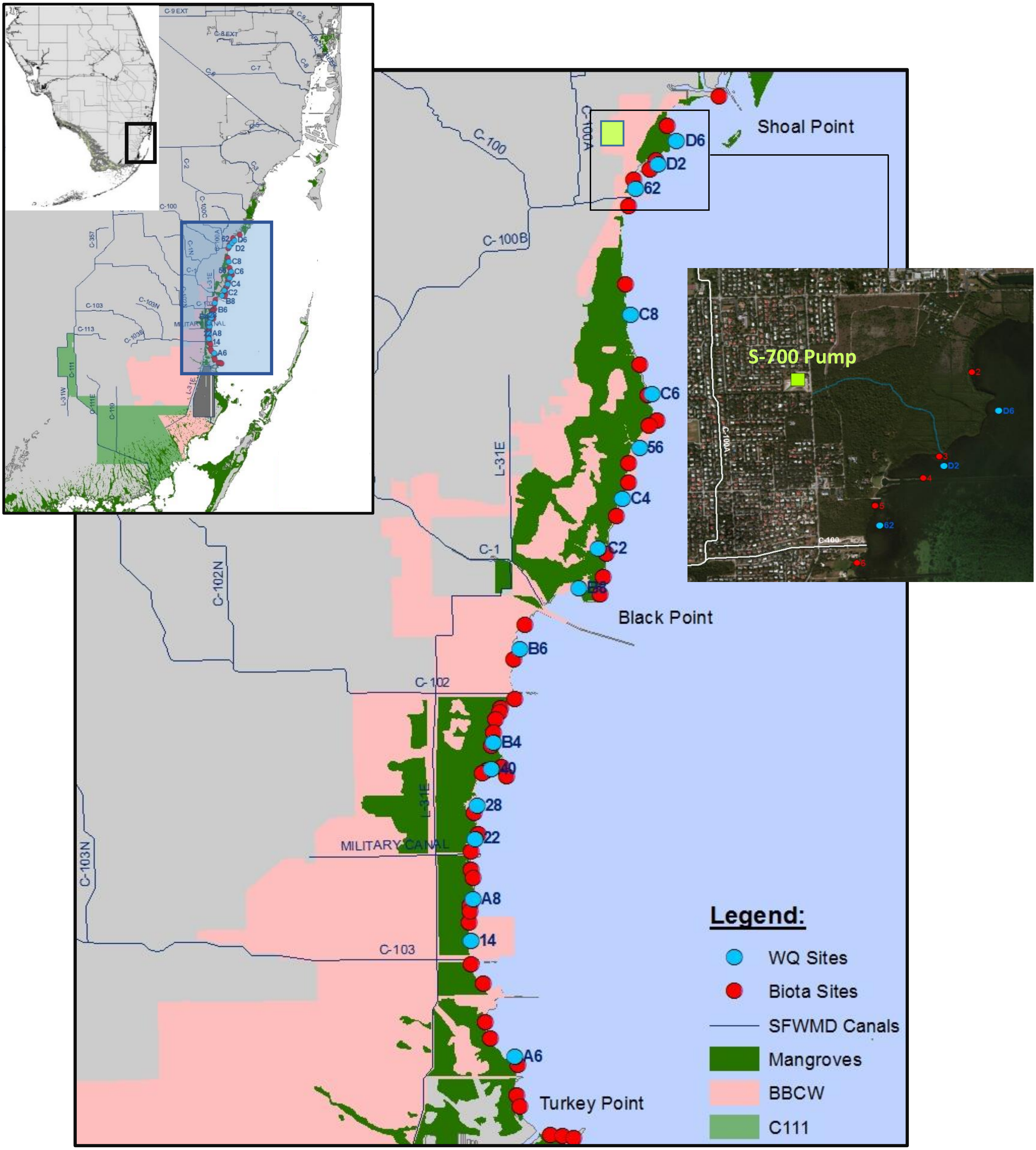


Figure 1: IBBEAM sampling area. **Site labels and locations provided in Table 1.** *Circles present sampling areas (red-Biota site sampled semiannual; blue-Water quality site sampled all year around).

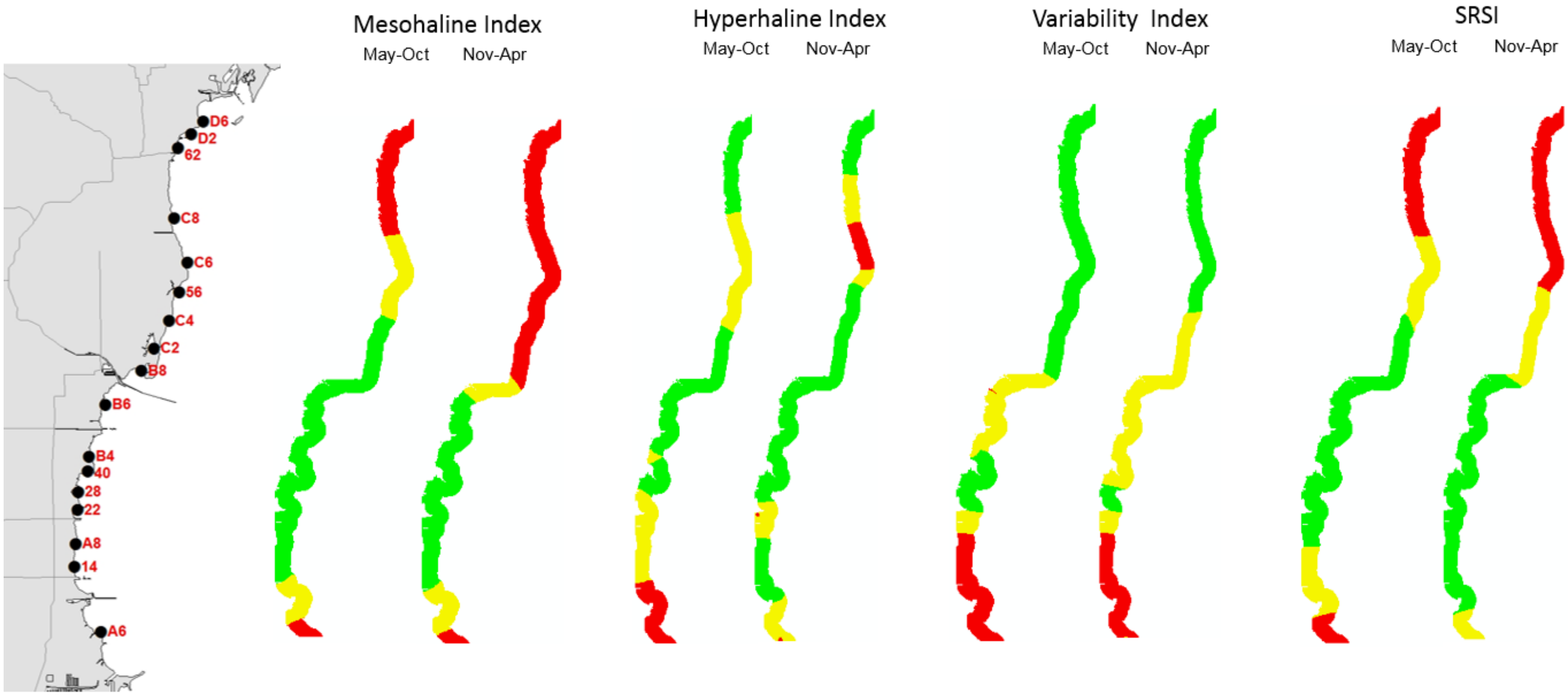


Figure 2: Salinity indices, November-April (dry season, D) and May to October (wet season, W). Averaged from CYR 2004-2018. **Color scheme shown in Table 3**

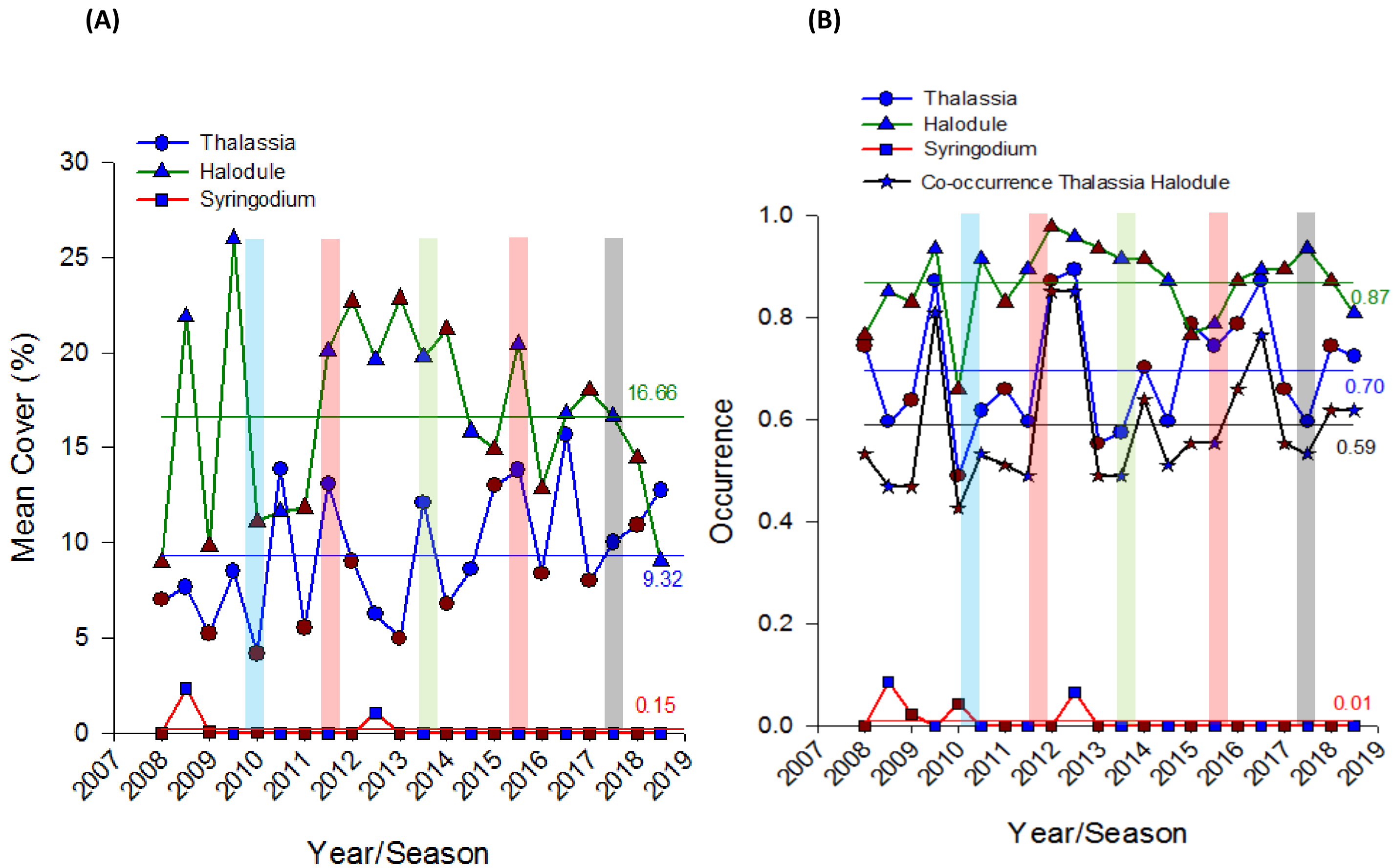
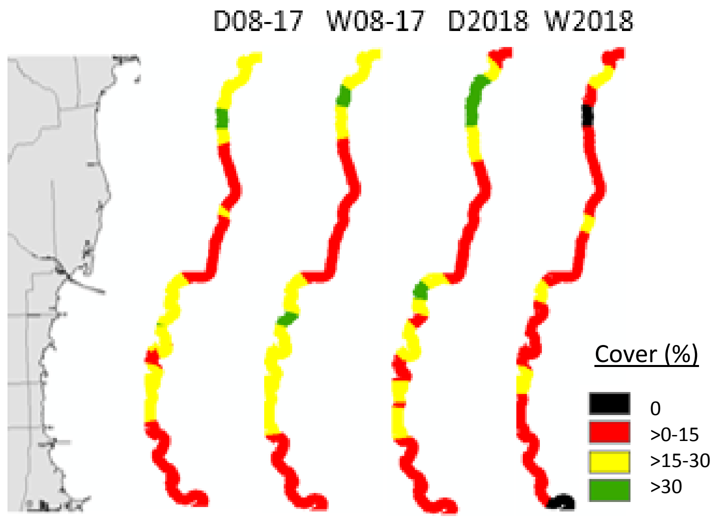


Figure 3: Mean Cover (A) and Occurrence (B) of Halodule, Thalassia and Syringodium by year and season (blue colored symbol indicates wet season) 2008-2018 from the 47 nearshore IBBEAM sites. Co-occurrence values represent the proportion of sites where both seagrass species were documented each year.

*****vertical bars represent various ‘extreme’ events: red = hypersalinity, blue = cold snap, green = algae bloom, grey = Hurricane (***details see Table 4***)*

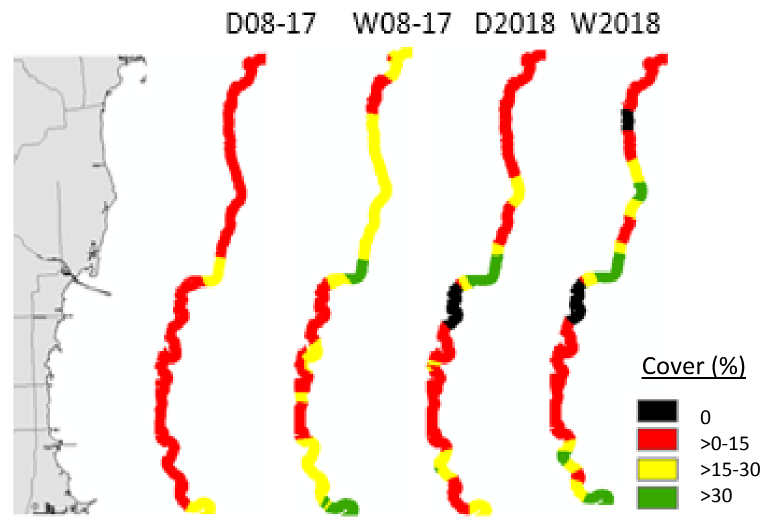
Figure 4: Pictures of the brown macroalga *Sargassum* along the mangrove shoreline and on the bottom.

(A)



Cover (%)	D08-17	W08-17	D2018	W2018
0				8.72
>0 -15	52.48	47.59	58.45	74.54
>15 -30	41.73	46.07	21.43	16.74
>30	5.79	6.34	20.12	

(B)



Cover (%)	D08-17	W08-17	D2018	W2018
0			9.17	11.02
>0 -15	88.78	34.66	68.33	59.75
>15 -30	11.22	53.02	16.18	12.89
>30		12.32	6.32	16.34

Figure 5: Spatial analysis of (A) Halodule cover (%) and (B) Thalassia cover (%).(D=dry season, W=wet season, Calendar-year 2008-2018). Table shows proportional cover values of interpolated areas.

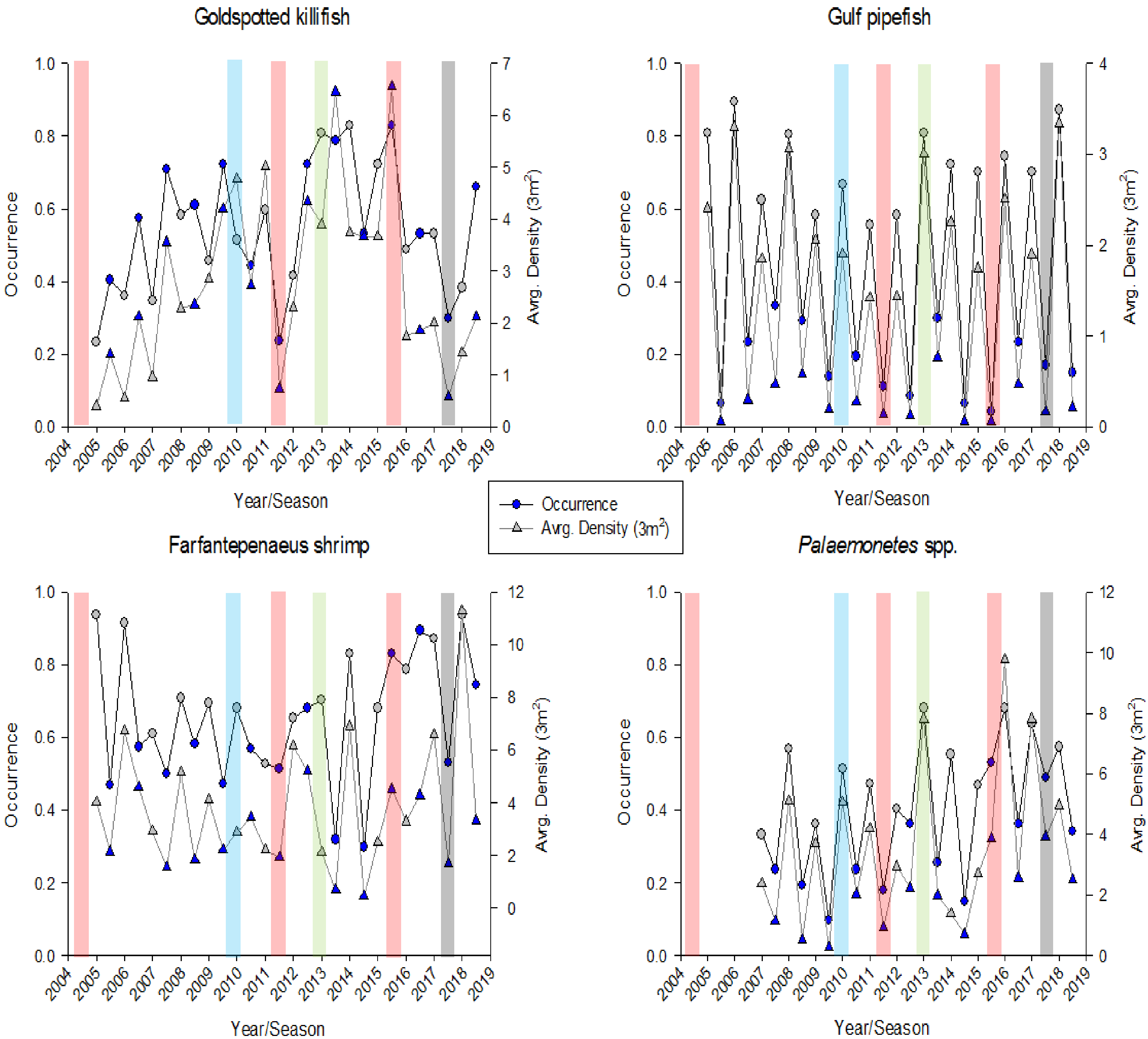


Figure 6: Occurrence (circle) and mean density (triangle) of epifaunal (SAV-associated) (A) goldspotted killifish, (B) gulf pipefish, (C) Farfantepenaeus shrimp and (D) Palaemonetes spp. by year and season (open symbols indicate dry season).Density is number per 3m^2.

vertical bars represent various 'extreme' events: red = hypersalinity, blue = cold snap, green = algae bloom (details see Table 4**)*

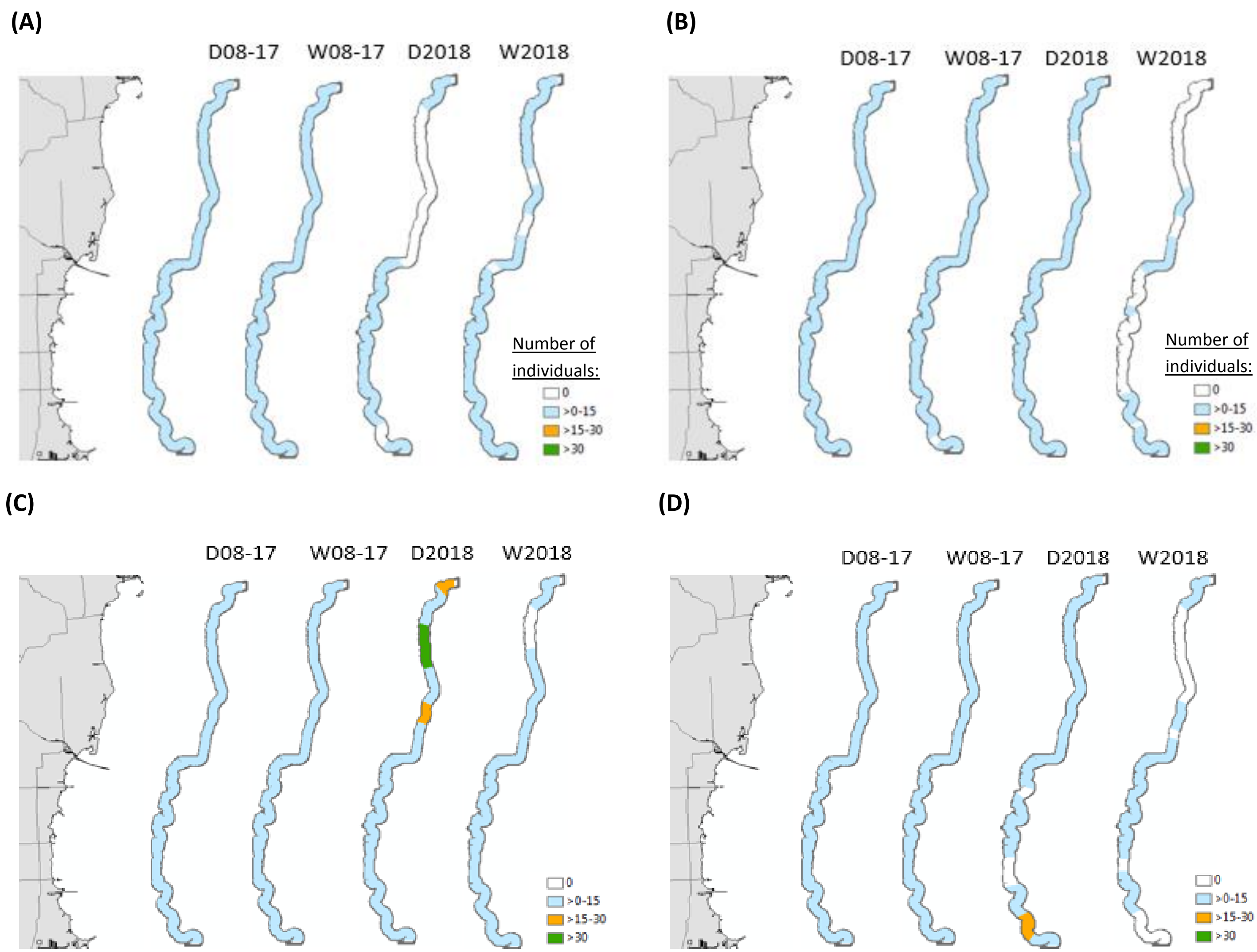


Figure 7: Spatial analysis of epifaunal (SAV-associated) (A) goldspotted killifish, (B) gulf pipefish, (C) Farfantepenaeus shrimp and (D) Palaemonetes spp abundance. *(D=dry season, W=wet season, Calendar-year 2008-2018). Density per 3m^2.*

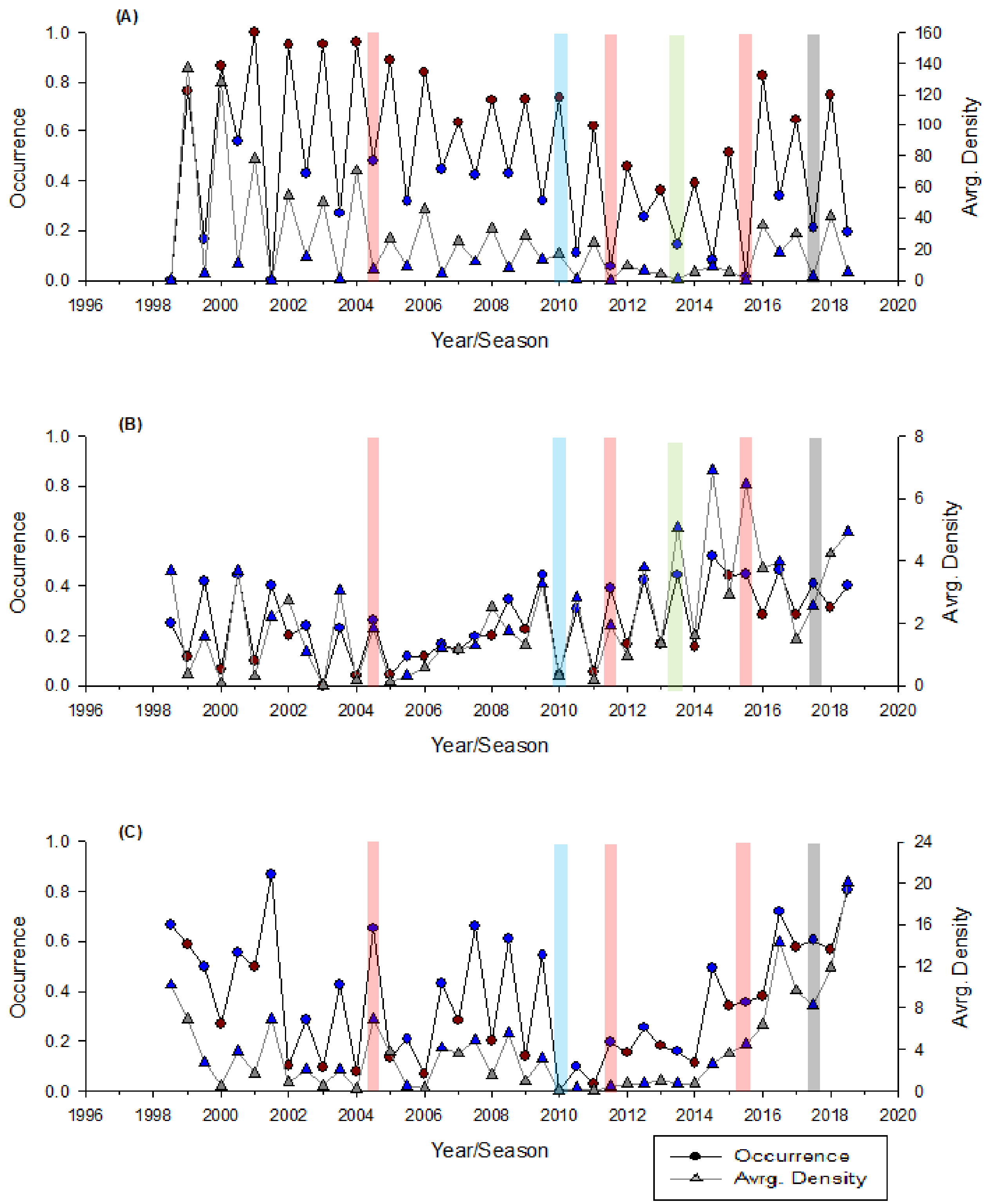


Figure 8: Occurrence and mean density of mangrove-associated (A) goldspotted killifish, (B) gray snapper, and (C) yellowfin mojarra by season and year. (blue colored symbol indicates wet season). Density per 30m^2.

vertical bars represent various 'extreme' events: red = hypersalinity, blue = cold snap, green = algae bloom (details see Table 4**)*

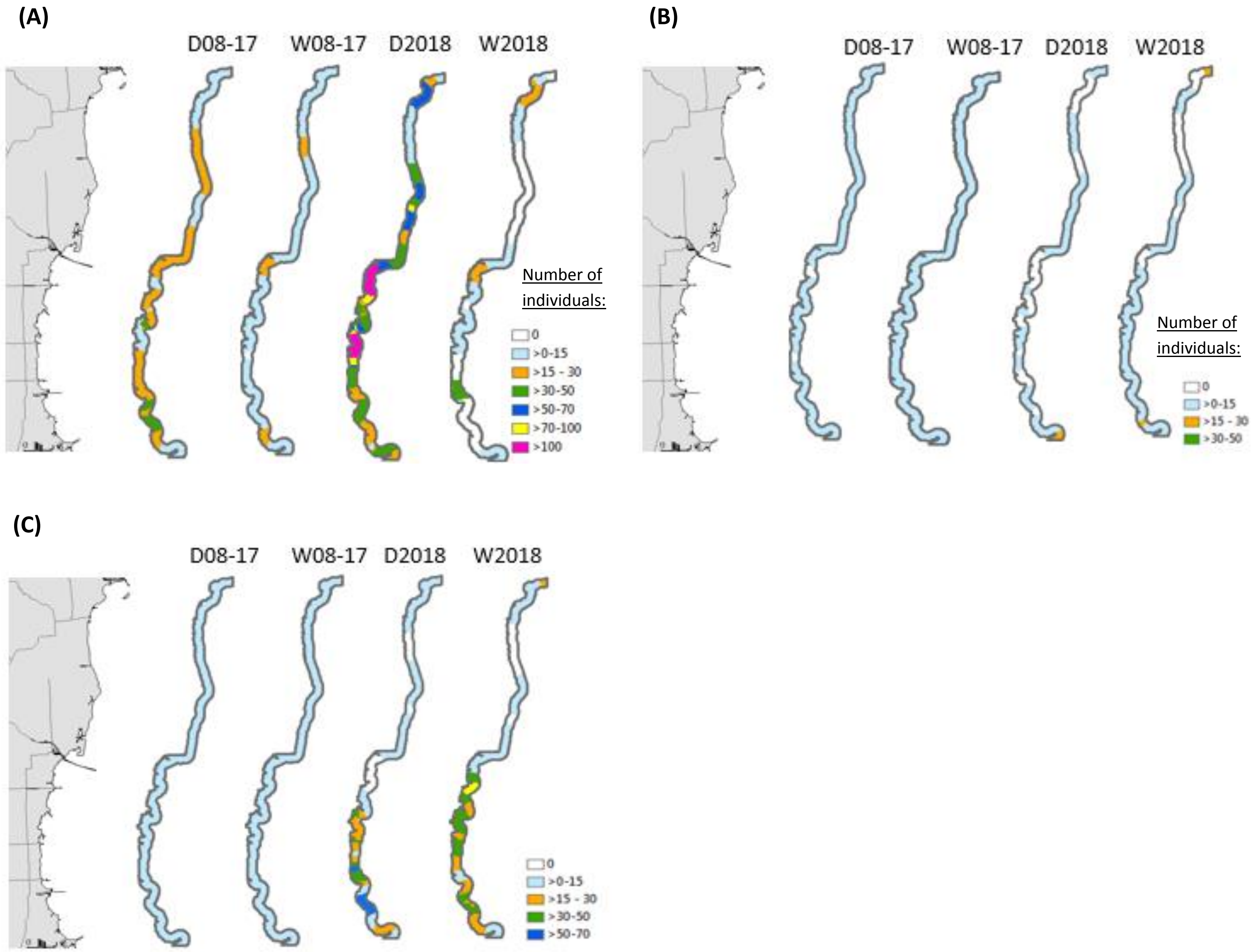
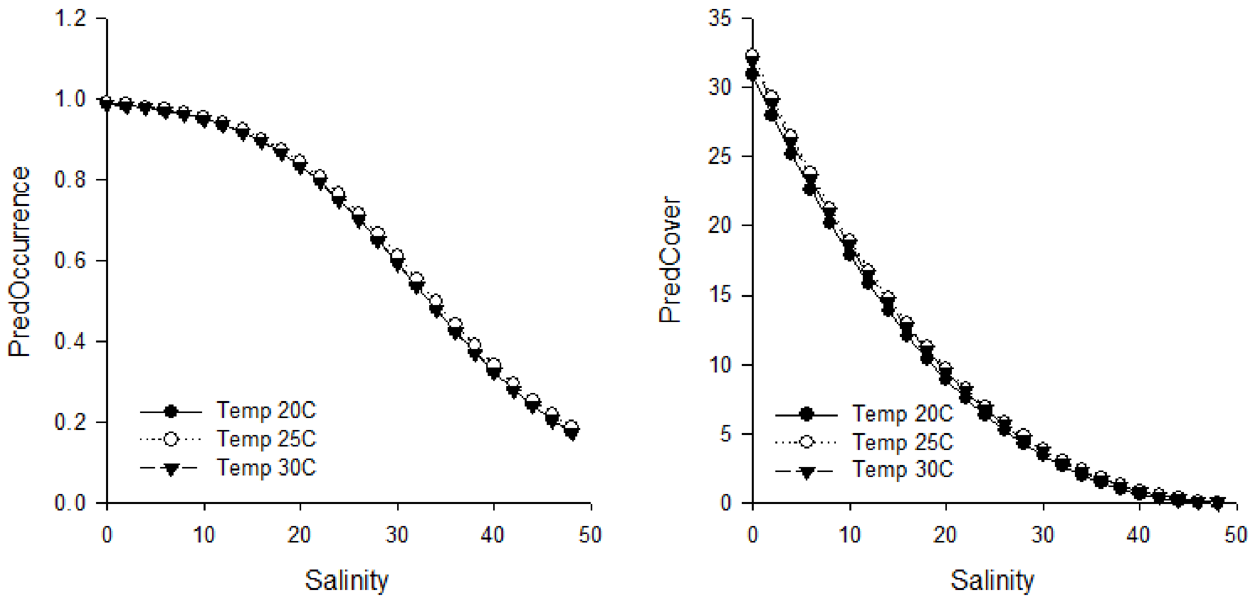


Figure 9: Spatial analysis of mangrove-associated (A) goldspotted killifish, (B) gray snapper and (C) yellowfin mojarra abundance. (D=dry season, W=wet season, Calendar-year 2008-2018). Density per $30m^2$.

(A)



(B)

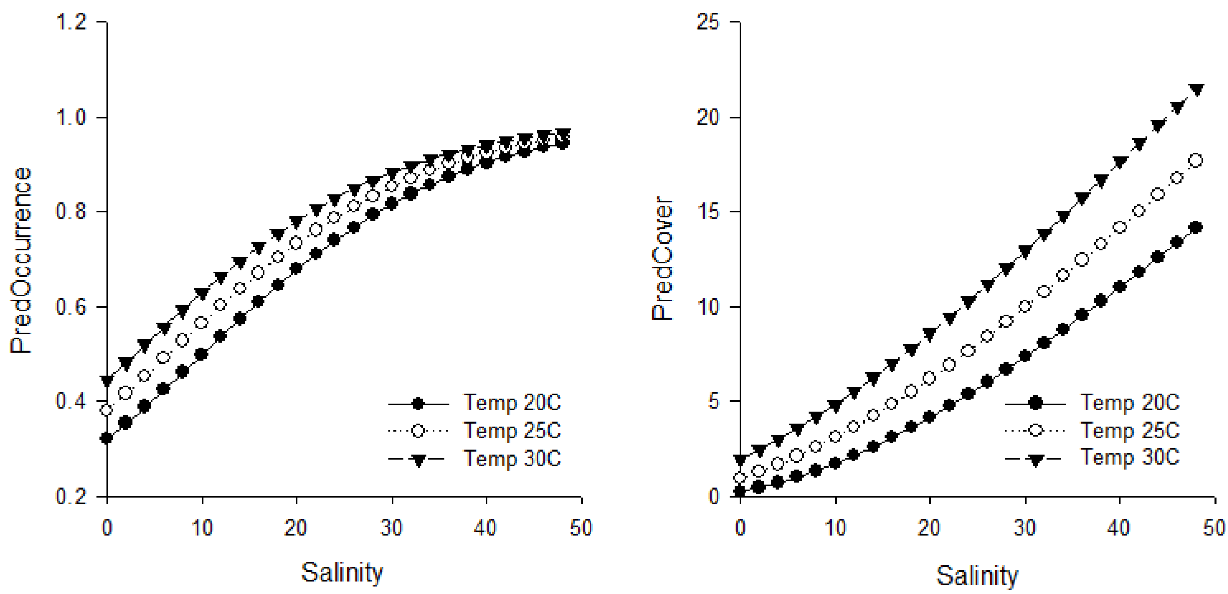


Figure 10: Regression model predictions of occurrence and cover of Halodule (A) and Thalassia (B).Models are statistically significant at $p<0.05$ (see Appendix B Table 1).

(A)

(B)

(C)

(D)

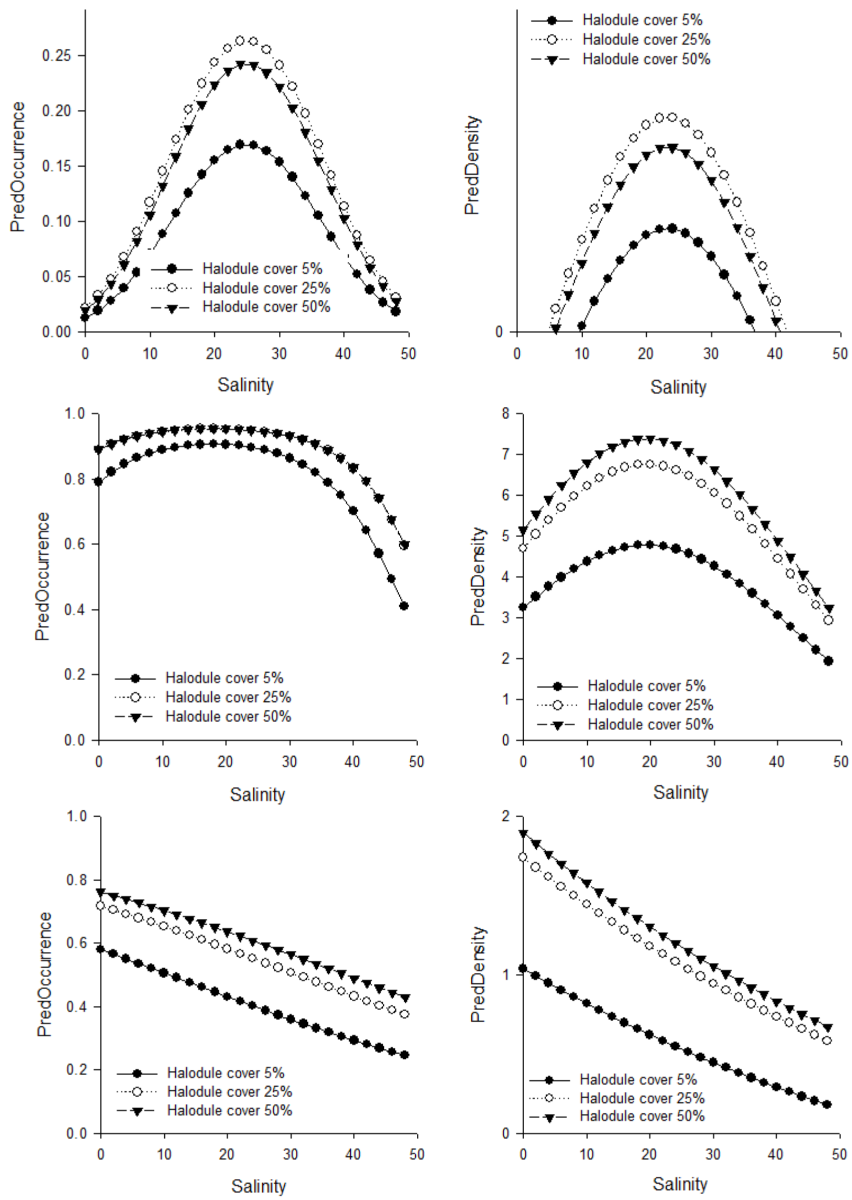
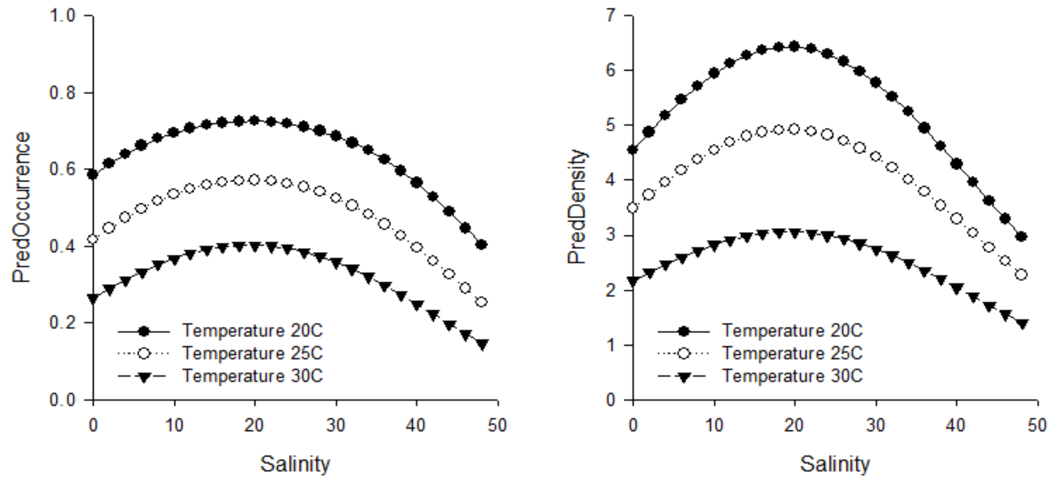
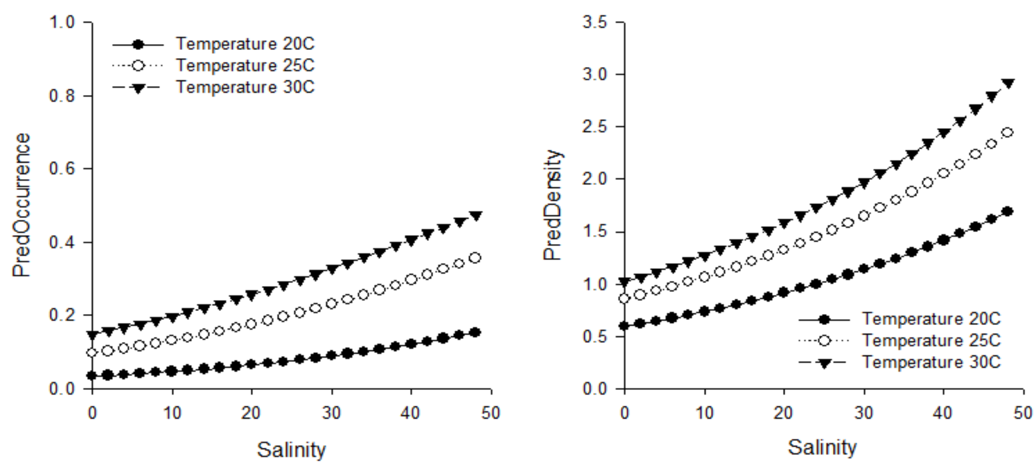


Figure 11: Regression model predictions of occurrence and density of epifaunal (A) goldspotted killifish, (B) gulf pipefish, (C) Farfantepenaeus shrimp and (D) Palaemonetes shrimp. Models are statistically significant at $p<0.05$ (see Appendix B Table 1).

(A)



(B)



(C)

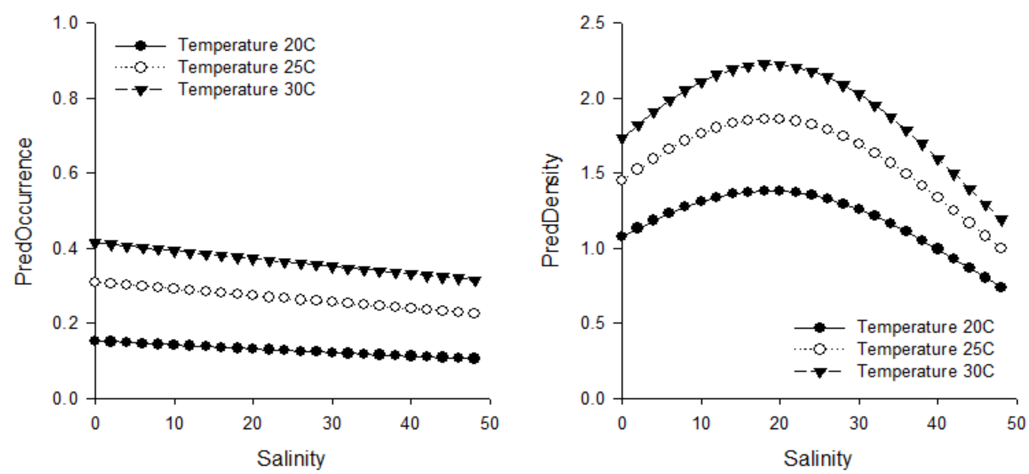


Figure 12: Regression model predictions of occurrence and density of mangrove (A) goldspotted killifish, (B) gray snapper, and (C) yellowfin mojarra. Models are statistically significant at $p<0.05$ (see Appendix B Table 1).

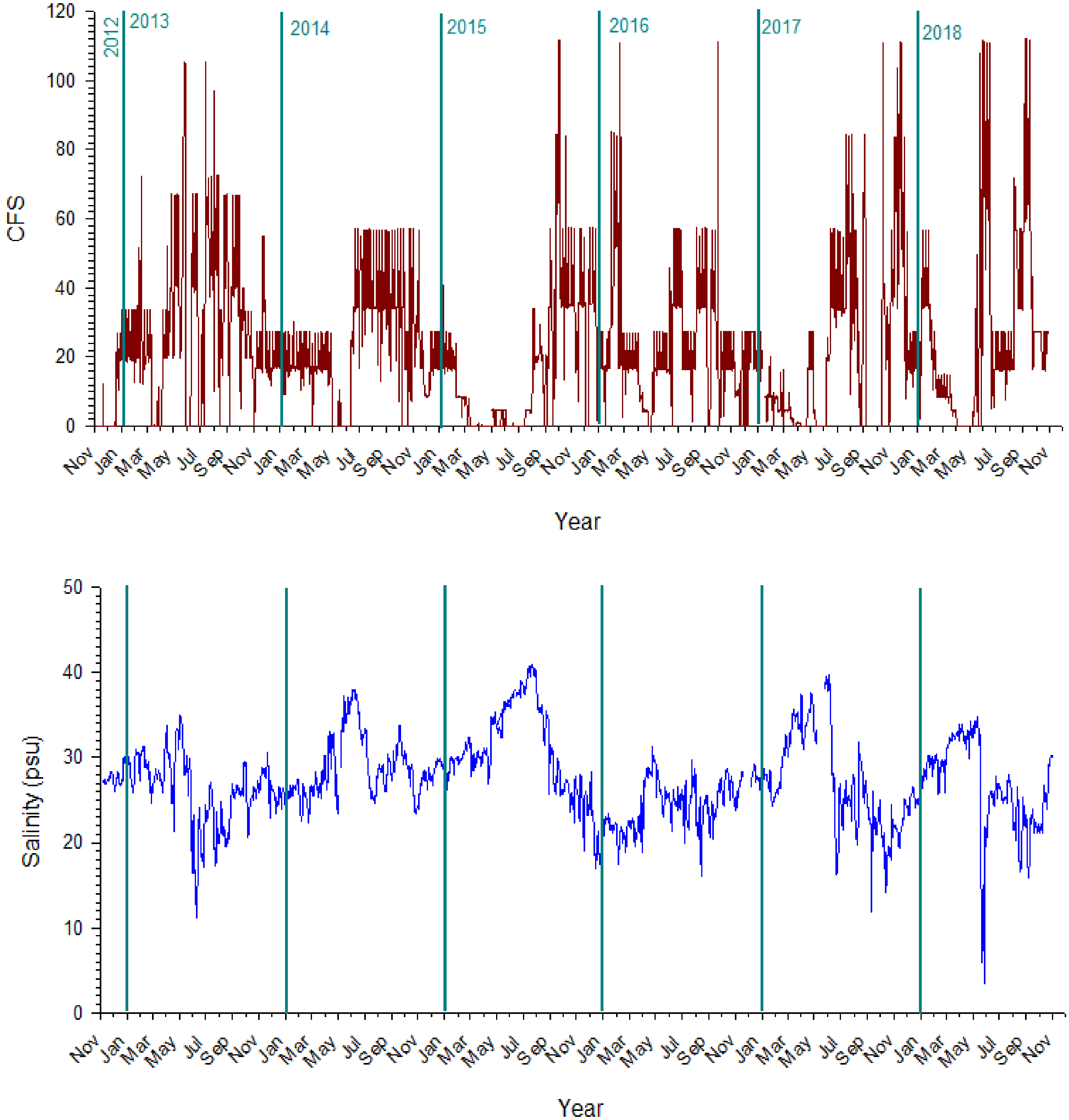


Figure 13: Comparison of (A) flow (cfs) from S-700 (DBkey AI615) with (B) salinity data from site D2. November 2012 to October 2018.

Flow data source:*http:/my.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu*.

(A)

(B)

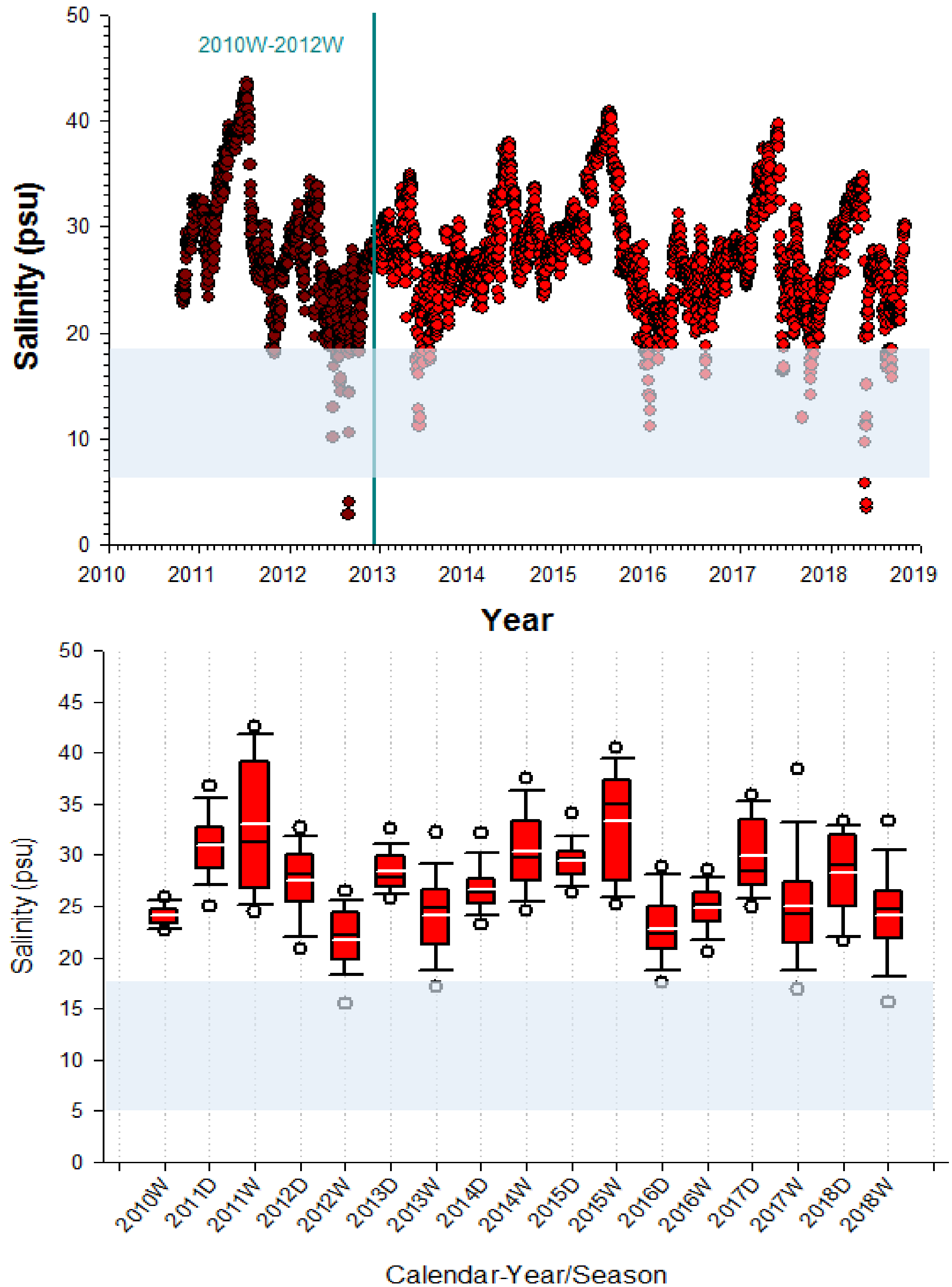


Figure 14: Site D2 (A) daily average salinity data and (B) boxplot of 15min salinity data before (2010W-2012W) and after (2013D – 2018W) Deering Estate flow-way implementation. (White line = Mean, black horizontal line = Median, black circles = 5th/95th percentile, red box = 25th/7th percentile, black vertical lines = minimum/maximum. Horizontal blue band represents mesohaline range ≥5 and <18psu defined by Venice system).

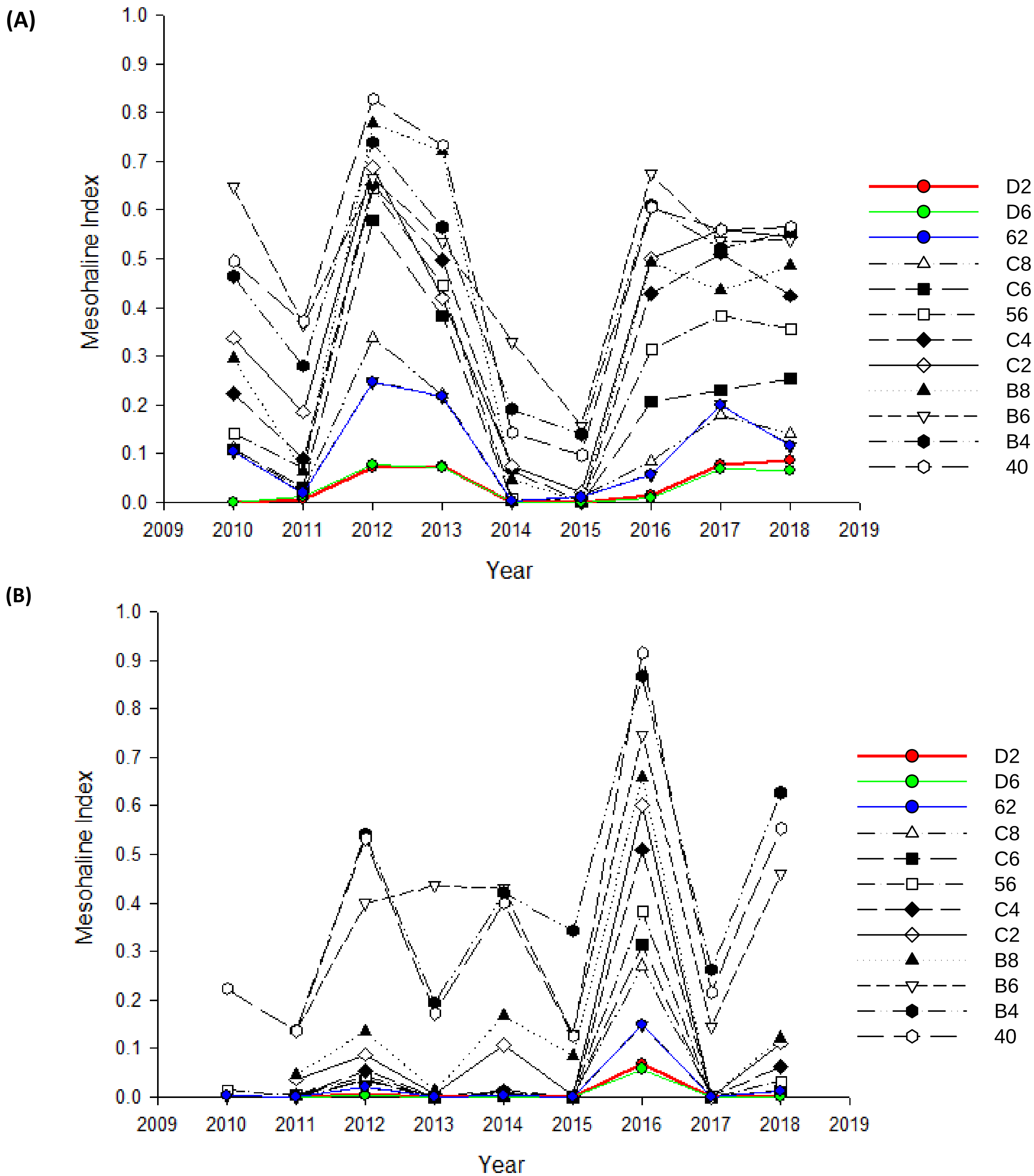


Figure 15: Mesohaline Index value, during (A) wet season and (B) dry season, 2010 to 2017, for all sites from Deering Estate to Black Point (D2 to B4), and one site south of Black Point (Site 40). Colored lines present data from sites near Deering Estate.

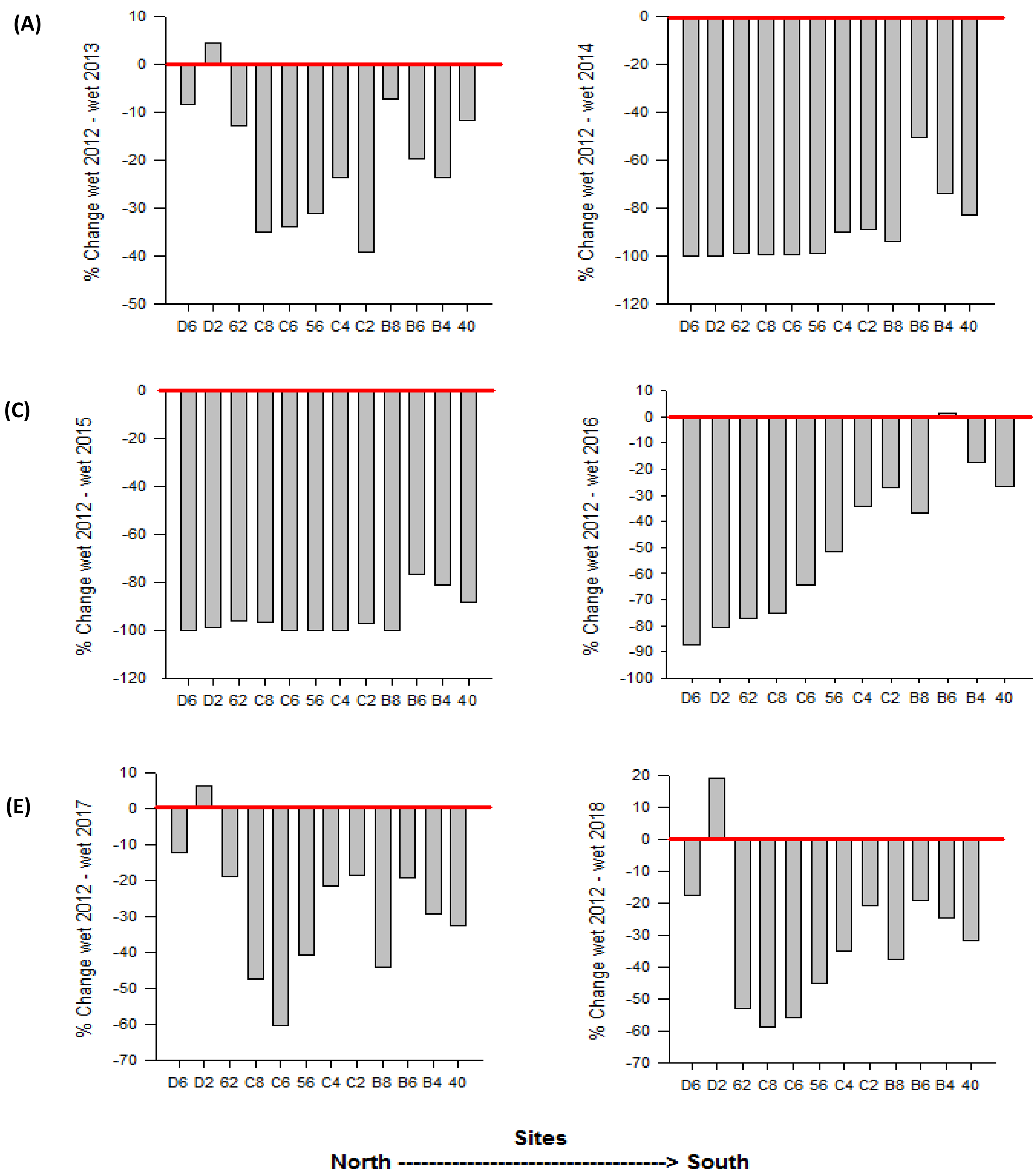


Figure 16: Percent change of mesohaline index value from (A) wet 2012 to wet 2013, (B) wet 2012 to wet 2014, (C) wet 2012 to wet 2015, (D) wet 2012 to wet 2016, (E) wet 2012 to wet 2017 and (F) wet 2012 to wet 2018 at WQ sites from Deering Estate southward to Black Point and site 40 south of Black Point.

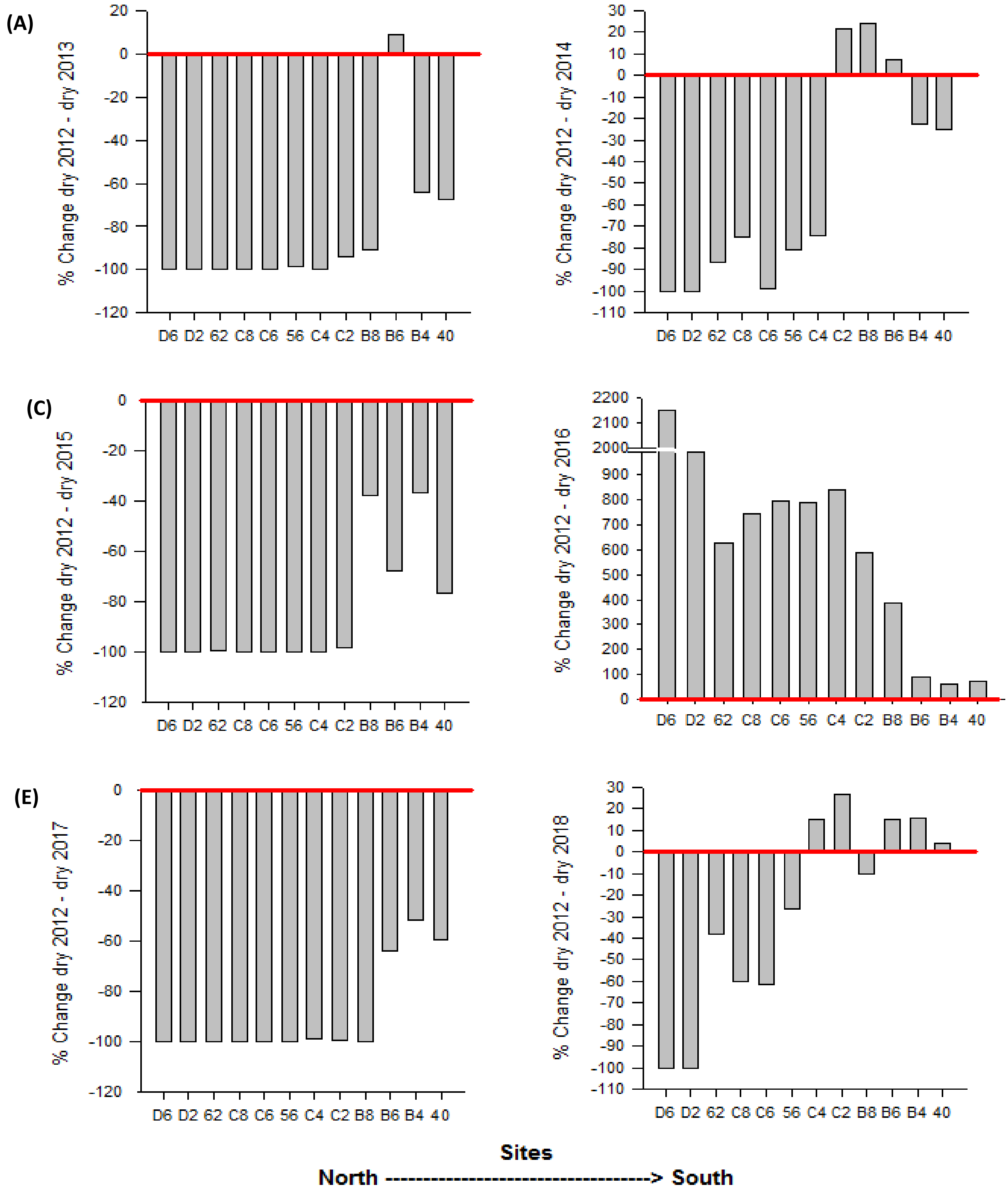


Figure 17: Percent change of mesohaline index value from (A) dry 2012 to dry 2013, (B) dry 2012 to dry 2014, (C) dry 2012 to dry 2015, (D) dry 2012 to dry 2016, (E) dry 2012 to dry 2017 and (F) dry 2012 to dry 2018 at WQ sites from Deering Estate southward to Black Point and site 40 south of Black Point.

APPENDIX A

Appendix A Table 1: Mesohaline Index by water-year (WYR), calendar-year (CYR) and season (Wet=May-Oct; Dry=Nov-Apr). (MI=proportion of salinity observations ≥5-<18). **Color scheme see Table 3. (For 2004-2009 see IBBEAM 3rd Annual Report).**

WYR	2010		2011		2012		2013		2014		2015		2016		2017		2018		2019		Mean	
CYR	2009	2010	2010	2011	2011	2012	2012	2013	2013	2014	2014	2015	2015	2016	2016	2017	2017	2018	2018			
Month	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct		May-Oct	Nov-Apr
Season	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet		Wet	Dry
D6			0.00	0.00	0.01	0.00	0.08	0.00	0.07	0.00	0.00	0.00	0.00	0.06	0.01	0.00	0.07	0.00	0.06		0.04	0.01
D2			0.00	0.00	0.01	0.01	0.07	0.00	0.07	0.00	0.00	0.00	0.00	0.07	0.01	0.00	0.08	0.00	0.09		0.04	0.01
62	0.01	0.00	0.10	0.00	0.02	0.02	0.25	0.00	0.22	0.00	0.00	0.00	0.01	0.15	0.06	0.00	0.20	0.01	0.12		0.11	0.02
C8			0.11	0.00	0.02	0.03	0.34	0.00	0.22	0.01	0.00	0.00	0.01	0.27	0.08	0.00	0.18	0.01	0.14		0.12	0.04
C6			0.11	0.00	0.03	0.04	0.58	0.00	0.38	0.00	0.00	0.00	0.00	0.31	0.21	0.00	0.23	0.01	0.25		0.21	0.05
56	0.05	0.01	0.14	0.00	0.07	0.04	0.65	0.00	0.45	0.01	0.01	0.00	0.00	0.38	0.31	0.00	0.38	0.03	0.36		0.28	0.06
C4			0.22	0.00	0.09	0.05	0.65	0.00	0.50	0.01	0.07	0.00	0.00	0.51	0.43	0.00	0.51	0.06	0.42		0.33	0.08
C2			0.34	0.04	0.19	0.09	0.69	0.01	0.42	0.11	0.08	0.00	0.02	0.60	0.50	0.00	0.56	0.11	0.54		0.37	0.12
B8			0.29	0.05	0.06	0.14	0.78	0.01	0.72	0.17	0.05	0.08	0.00	0.66	0.49	0.00	0.43	0.12	0.49		0.38	0.15
B6			0.65	0.14	0.37	0.40	0.67	0.44	0.53	0.43	0.33	0.13	0.16	0.74	0.67	0.14	0.54	0.46	0.54		0.48	0.36
B4			0.46	0.14	0.28	0.54	0.74	0.19	0.56	0.42	0.19	0.34	0.14	0.87	0.61	0.26	0.52	0.63	0.56		0.45	0.42
40	0.29	0.22	0.49	0.14	0.37	0.53	0.83	0.17	0.73	0.40	0.14	0.12	0.10	0.91	0.61	0.22	0.56	0.55	0.56		0.49	0.38
28	0.16	0.17	0.52	0.11	0.23	0.43	0.78	0.11	0.59	0.33	0.11	0.13	0.07	0.88	0.46	0.15	0.46	0.55	0.49		0.40	0.34
22	0.24	0.16	0.60	0.12	0.25	0.45	0.72	0.11	0.60	0.29	0.11	0.07	0.05	0.84	0.46	0.16	0.42	0.51	0.47		0.38	0.32
A8			0.44	0.12	0.19	0.42	0.60	0.14	0.51	0.24	0.09	0.14	0.07	0.70	0.42	0.18	0.42	0.43	0.49		0.35	0.30
14	0.24	0.23	0.44	0.13	0.21	0.57	0.57	0.22	0.53	0.13	0.11	0.18	0.09	0.68	0.46	0.25	0.48	0.44	0.51		0.37	0.32
A6			0.09	0.04	0.06	0.18	0.22	0.01	0.09	0.03	0.02	0.01	0.04	0.30	0.06	0.03	0.16	0.16	0.08		0.09	0.09
DJ		0.82	0.30	0.56	0.22																0.26	0.69

*** Cells not color coded (i.e., white) represent absent or incomplete (gray values) datasets*

Appendix A Table 2: Oligohaline Index by water-year (WYR), calendar-year (CYR), and season (Wet=May-Oct; Dry=Nov-Apr). (MI=proportion of salinity observations < 5). Mean is calculated from WYR 2004-2018. **Color scheme see Table 3. (For 2004-2009 see IBBEAM 3rd Annual Report).**

WYR	2010		2011		2012		2013		2014		2015		2016		2017		2018		2019	Mean	
CYR	2009	2010	2010	2011	2011	2012	2012	2013	2013	2014	2014	2015	2015	2016	2016	2017	2017	2018	2018		
Month	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	May-Oct	Nov-Apr
Season	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Wet	Dry
D6			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
D2			0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
62	0.01	0.01	0.01	0.00	0.01	0.01	0.06	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.04	0.02	0.00
C8			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C6			0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
56	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C4			0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
C2			0.00	0.00	0.00	0.00	0.04	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00
B8			0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00
B6			0.09	0.00	0.00	0.00	0.28	0.00	0.31	0.01	0.02	0.00	0.00	0.17	0.10	0.00	0.16	0.01	0.27	0.14	0.02
B4			0.00	0.00	0.00	0.00	0.16	0.00	0.22	0.01	0.00	0.00	0.00	0.08	0.06	0.00	0.11	0.00	0.11	0.08	0.01
40	0.00	0.00	0.02	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.00	0.04	0.02	0.00
28	0.00	0.00	0.02	0.00	0.00	0.00	0.04	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.01	0.00
22	0.00	0.00	0.01	0.00	0.01	0.00	0.04	0.00	0.03	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.02	0.00
A8			0.02	0.00	0.00	0.00	0.04	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.03	0.00	0.03	0.01	0.00
14	0.00	0.00	0.05	0.01	0.01	0.01	0.12	0.00	0.08	0.00	0.00	0.00	0.00	0.06	0.02	0.00	0.04	0.00	0.03	0.04	0.01
A6			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DJ		0.15	0.25	0.13	0.03															0.14	0.14

*** Cells not color coded (i.e., white) represent absent or incomplete (gray values) datasets*

Appendix A Table 3: Oligo-mesohaline Index by water-year (WYR), calendar-year (CYR), and season (Wet=May-Oct; Dry=Nov-Apr). (MI=proportion of salinity observations < 18). Mean is calculated from WYR 2004-2018. **Color scheme see Table 3. (For 2004-2009 see IBBEAM 3rd Annual Report).**

WYR	2010		2011		2012		2013		2014		2015		2016		2017		2018		2019	Mean	
CYR	2009	2010	2010	2011	2011	2012	2012	2013	2013	2014	2014	2015	2015	2016	2016	2017	2017	2018	2018		
Month	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	May-Oct	Nov-Apr
Season	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Wet	Dry
D6			0.00	0.00	0.01	0.00	0.08	0.00	0.07	0.00	0.00	0.00	0.00	0.06	0.01	0.00	0.07	0.00	0.07	0.04	0.01
D2			0.00	0.00	0.01	0.01	0.08	0.00	0.08	0.00	0.00	0.00	0.00	0.07	0.01	0.00	0.08	0.00	0.10	0.04	0.01
62	0.02	0.01	0.11	0.00	0.03	0.03	0.31	0.00	0.26	0.00	0.00	0.00	0.01	0.15	0.06	0.00	0.22	0.01	0.16	0.13	0.03
C8			0.11	0.00	0.02	0.03	0.34	0.00	0.22	0.01	0.00	0.00	0.01	0.27	0.08	0.00	0.18	0.01	0.14	0.12	0.04
C6			0.11	0.00	0.03	0.04	0.59	0.00	0.38	0.00	0.00	0.00	0.00	0.31	0.21	0.00	0.23	0.01	0.25	0.21	0.05
56	0.05	0.01	0.14	0.00	0.07	0.04	0.67	0.00	0.45	0.01	0.01	0.00	0.00	0.38	0.31	0.00	0.39	0.03	0.36	0.28	0.06
C4			0.22	0.00	0.09	0.05	0.68	0.00	0.50	0.01	0.07	0.00	0.00	0.51	0.43	0.00	0.51	0.06	0.43	0.34	0.08
C2			0.34	0.04	0.19	0.09	0.72	0.01	0.43	0.11	0.08	0.00	0.02	0.60	0.50	0.00	0.56	0.11	0.55	0.38	0.12
B8			0.29	0.05	0.06	0.14	0.80	0.01	0.72	0.17	0.05	0.08	0.00	0.68	0.49	0.00	0.43	0.12	0.50	0.38	0.16
B6			0.74	0.14	0.37	0.40	0.95	0.44	0.84	0.44	0.35	0.13	0.16	0.92	0.77	0.14	0.70	0.47	0.81	0.62	0.38
B4			0.46	0.14	0.28	0.54	0.90	0.19	0.78	0.43	0.19	0.34	0.14	0.95	0.67	0.26	0.63	0.63	0.67	0.53	0.43
40	0.29	0.22	0.52	0.14	0.37	0.53	0.90	0.17	0.74	0.40	0.14	0.12	0.10	0.91	0.62	0.22	0.59	0.55	0.61	0.51	0.38
28	0.16	0.17	0.54	0.11	0.23	0.43	0.81	0.11	0.60	0.33	0.11	0.13	0.07	0.88	0.46	0.15	0.47	0.55	0.52	0.41	0.34
22	0.24	0.16	0.60	0.12	0.25	0.45	0.77	0.11	0.63	0.29	0.11	0.09	0.05	0.84	0.46	0.16	0.43	0.51	0.50	0.40	0.32
A8			0.46	0.12	0.19	0.42	0.64	0.14	0.53	0.24	0.09	0.14	0.07	0.71	0.42	0.18	0.45	0.43	0.52	0.36	0.30
14	0.24	0.23	0.49	0.15	0.23	0.58	0.68	0.22	0.61	0.13	0.11	0.18	0.09	0.74	0.48	0.25	0.52	0.44	0.54	0.41	0.34
A6			0.09	0.04	0.06	0.18	0.22	0.01	0.09	0.03	0.02	0.01	0.04	0.30	0.06	0.03	0.16	0.16	0.08	0.09	0.09
DJ		0.97	0.55	0.70	0.26															0.40	0.83

*** Cells not color coded (i.e., white) represent absent or incomplete (gray values) datasets*

Appendix A Table 4: Hyperhaline Index by water-year (WYR), calendar-year (CYR), and season (Wet=May-Oct; Dry=Nov-Apr). (HI=proportion of salinity observations >40). Mean is calculated from WYR 2004-2018. **Color scheme see Table 3. (For 2004-2009 see IBBEAM 3rd Annual Report).**

WYR	2010		2011		2012		2013		2014		2015		2016		2017		2018		2019	Mean	
CYR	2009	2010	2010	2011	2011	2012	2012	2013	2013	2014	2014	2015	2015	2016	2016	2017	2017	2018	2018		
Month	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	May-Oct	Nov-Apr
Season	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Wet	Dry
D6			0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
D2			0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
62	0.03	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
C8			0.00	0.02	0.14	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00
C6			0.00	0.03	0.13	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.18	0.00	0.00	0.00	0.01	0.00	0.00	0.06	0.00
56	0.09	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00
C4			0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00
C2			0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
B8			0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
B6			0.00	0.01	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
B4			0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00
40	0.10	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
28	0.05	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.03	0.00	0.00	0.05	0.00
22	0.05	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00
A8			0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.15	0.00	0.00	0.00	0.02	0.00	0.00	0.05	0.00
14	0.07	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.16	0.00	0.00	0.00	0.06	0.00	0.00	0.07	0.00
A6			0.00	0.02	0.36	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.34	0.00	0.00	0.00	0.13	0.00	0.00	0.12	0.00
DJ		0.00	0.00	0.00	0.06															0.03	0.00

*** Cells not color coded (i.e., white) represent absent or incomplete (gray values) datasets*

Appendix A Table 5: Variablity Index by water-year (WYR), calendar-year (CYR), and season (Wet=May-Oct; Dry=Nov-Apr). (Variability proportion of observations where daily salinity range >5). Mean is calculated from WYR 2004-2018. **Color scheme see Table 3. (For 2004-2009 see IBBEAM 3rd Annual Report).**

WYR	2010		2011		2012		2013		2014		2015		2016		2017		2018		2019		Mean	
CYR	2009	2010	2010	2011	2011	2012	2012	2013	2013	2014	2014	2015	2015	2016	2016	2017	2017	2018	2018			
Month	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct		May-Oct	Nov-Apr
Season	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet		Wet	Dry
D6			0.00	0.01	0.04	0.06	0.16	0.07	0.10	0.03	0.00	0.00	0.04	0.03	0.02	0.00	0.04	0.00	0.05		0.06	0.03
D2			0.00	0.01	0.03	0.05	0.12	0.03	0.06	0.08	0.04	0.01	0.01	0.03	0.04	0.01	0.11	0.02	0.12		0.07	0.03
62	0.23	0.13	0.41	0.18	0.13	0.08	0.36	0.03	0.19	0.04	0.09	0.03	0.13	0.08	0.09	0.01	0.28	0.02	0.10		0.17	0.06
C8			0.12	0.00	0.05	0.09	0.17	0.01	0.09	0.02	0.01	0.00	0.02	0.08	0.09	0.00	0.10	0.01	0.07		0.07	0.03
C6			0.14	0.08	0.10	0.07	0.38	0.02	0.18	0.06	0.04	0.01	0.01	0.10	0.15	0.00	0.22	0.01	0.12		0.15	0.04
56	0.02	0.07	0.16	0.06	0.13	0.07	0.24	0.03	0.10	0.12	0.07	0.02	0.07	0.10	0.04	0.07	0.20	0.05	0.13		0.12	0.06
C4			0.07	0.00	0.09	0.04	0.08	0.01	0.03	0.03	0.05	0.02	0.04	0.13	0.02	0.05	0.07	0.02	0.04		0.05	0.04
C2			0.53	0.19	0.40	0.25	0.43	0.13	0.26	0.18	0.32	0.13	0.28	0.36	0.19	0.09	0.14	0.07	0.32		0.29	0.18
B8			0.17	0.24	0.21	0.23	0.29	0.23	0.09	0.05	0.04	0.01	0.02	0.08	0.11	0.01	0.09	0.03	0.07		0.11	0.11
B6			0.29	0.03	0.24	0.17	0.35	0.07	0.32	0.14	0.40	0.08	0.23	0.24	0.39	0.10	0.36	0.38	0.27		0.32	0.15
B4			0.29	0.08	0.21	0.21	0.21	0.10	0.29	0.25	0.18	0.14	0.15	0.19	0.42	0.25	0.35	0.21	0.29		0.26	0.18
40	0.08	0.03	0.08	0.02	0.10	0.18	0.08	0.13	0.09	0.10	0.06	0.01	0.03	0.05	0.08	0.01	0.10	0.02	0.06		0.07	0.06
28	0.04	0.09	0.21	0.39	0.48	0.08	0.10	0.06	0.14	0.12	0.03	0.01	0.03	0.02	0.08	0.01	0.09	0.03	0.08		0.13	0.09
22	0.13	0.07	0.47	0.19	0.19	0.12	0.21	0.10	0.16	0.02	0.10	0.01	0.03	0.04	0.09	0.03	0.08	0.03	0.07		0.12	0.07
A8			0.27	0.07	0.23	0.21	0.30	0.18	0.28	0.18	0.28	0.14	0.29	0.28	0.37	0.22	0.41	0.31	0.49		0.33	0.20
14	0.47	0.44	0.57	0.23	0.41	0.41	0.62	0.56	0.59	0.38	0.48	0.29	0.31	0.55	0.52	0.45	0.60	0.59	0.65		0.52	0.43
A6			0.12	0.08	0.10	0.05	0.19	0.10	0.27	0.06	0.18	0.01	0.01	0.10	0.15	0.04	0.20	0.03	0.18		0.16	0.06
DJ		0.02	0.01	0.00	0.01																0.01	0.01

*** Cells not color coded (i.e., white) represent absent or incomplete (gray values) datasets*

Appendix A Table 6: Salinity Regime Suitability Index by water-year (WYR), calendar-year (CYR), and season (Wet=May-Oct; Dry=Nov-Apr). This index is a composite of the mesohaline, hypersaline and variability indices presented above. Mean is calculated from WYR 2004-2018. **Color scheme see Table 3. (For 2004-2009 see IBBEAM 3rd Annual Report).**

WYR	2010		2011		2012		2013		2014		2015		2016		2017		2018		2019	Mean	
CYR	2009	2010	2010	2011	2011	2012	2012	2013	2013	2014	2014	2015	2015	2016	2016	2017	2017	2018	2018		
Month	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	May-Oct	Nov-Apr
Season	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Wet	Dry
D6			0.00	0.00	0.23	0.13	0.40	0.00	0.40	0.00	0.00	0.00	0.00	0.38	0.21	0.00	0.40	0.00	0.39	0.25	0.06
D2			0.00	0.00	0.16	0.18	0.40	0.00	0.41	0.00	0.00	0.00	0.08	0.41	0.24	0.00	0.41	0.00	0.42	0.27	0.07
62	0.22	0.11	0.39	0.05	0.25	0.27	0.54	0.00	0.56	0.14	0.13	0.06	0.20	0.51	0.37	0.00	0.53	0.23	0.47	0.38	0.16
C8			0.46	0.00	0.27	0.31	0.65	0.00	0.59	0.20	0.12	0.00	0.22	0.63	0.42	0.00	0.54	0.23	0.51	0.41	0.17
C6			0.46	0.14	0.28	0.32	0.71	0.00	0.68	0.07	0.15	0.00	0.06	0.66	0.56	0.00	0.56	0.24	0.61	0.45	0.18
56	0.35	0.24	0.49	0.15	0.37	0.34	0.79	0.08	0.74	0.20	0.17	0.00	0.00	0.70	0.67	0.00	0.67	0.31	0.68	0.51	0.22
C4			0.59	0.13	0.42	0.37	0.84	0.00	0.78	0.24	0.39	0.00	0.00	0.76	0.75	0.08	0.78	0.39	0.74	0.59	0.25
C2			0.54	0.31	0.46	0.40	0.73	0.17	0.68	0.44	0.36	0.11	0.24	0.73	0.74	0.07	0.78	0.47	0.72	0.59	0.34
B8			0.63	0.33	0.35	0.47	0.82	0.21	0.87	0.54	0.35	0.44	0.11	0.85	0.76	0.00	0.73	0.49	0.77	0.60	0.42
B6			0.77	0.51	0.61	0.69	0.76	0.74	0.72	0.72	0.58	0.49	0.49	0.83	0.74	0.51	0.70	0.66	0.73	0.67	0.64
B4			0.69	0.50	0.54	0.75	0.84	0.56	0.74	0.68	0.54	0.67	0.48	0.89	0.71	0.58	0.70	0.79	0.73	0.66	0.68
40	0.62	0.60	0.77	0.51	0.66	0.76	0.91	0.53	0.87	0.71	0.51	0.50	0.44	0.95	0.82	0.60	0.80	0.82	0.81	0.73	0.67
28	0.52	0.54	0.74	0.40	0.45	0.73	0.89	0.47	0.80	0.67	0.48	0.50	0.38	0.95	0.75	0.52	0.74	0.81	0.77	0.66	0.63
22	0.58	0.53	0.68	0.45	0.53	0.74	0.83	0.46	0.79	0.66	0.47	0.41	0.34	0.93	0.75	0.53	0.73	0.79	0.76	0.65	0.62
A8			0.69	0.48	0.49	0.69	0.75	0.48	0.72	0.58	0.39	0.50	0.34	0.79	0.64	0.52	0.62	0.67	0.63	0.57	0.59
14	0.49	0.51	0.58	0.47	0.44	0.69	0.60	0.46	0.60	0.43	0.38	0.51	0.37	0.67	0.60	0.52	0.56	0.57	0.56	0.52	0.54
A6			0.43	0.32	0.33	0.55	0.56	0.19	0.40	0.30	0.24	0.23	0.29	0.65	0.38	0.31	0.49	0.54	0.40	0.38	0.39
DJ		0.93	0.67	0.83	0.59															0.63	0.88

*** Cells not color-coded (i.e., white) represent absent or incomplete (gray values) datasets*

Appendix A Table 7: Maximum duration of mesohaline salinity conditions (Number of consecutive days with salinity ≥5-<18) by water-year (WYR), calendar-year (CYR), and season (Wet=May-Oct; Dry=Nov-Apr). Mean is calculated from WYR 2004-2018. **Color scheme see Table 3. (For 2004-2009 see IBBEAM 3rd Annual Report.)**

WYR	2010		2011		2012		2013		2014		2015		2016		2017		2018		2019		Mean	
CYR	2009	2010	2010	2011	2011	2012	2012	2013	2013	2014	2014	2015	2015	2016	2016	2017	2017	2018	2018			
Month	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct		May-Oct	Nov-Apr
Season	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet		Wet	Dry
D6			0.00	0.00	0.78	0.33	2.81	0.00	7.27	0.00	0.00	0.00	0.00	2.80	1.27	0.00	6.26	0.00	6.48		3.11	0.39
D2			0.00	0.00	0.31	0.20	3.51	0.00	4.60	0.00	0.00	0.00	0.11	4.84	0.94	0.00	5.01	0.00	4.14		2.33	0.63
62	0.39	0.11	2.36	0.01	0.58	1.75	6.97	0.00	6.65	0.19	0.13	0.02	0.26	10.84	4.86	0.00	6.00	1.01	7.96		4.18	1.73
C8			3.30	0.00	1.50	2.35	12.65	0.00	9.86	1.08	0.32	0.00	1.64	8.36	5.10	0.00	10.77	1.72	8.01		6.23	1.69
C6			2.18	0.20	2.13	2.31	20.27	0.00	11.79	0.06	0.26	0.00	0.04	12.48	3.94	0.00	10.31	0.72	7.74		7.06	1.97
56	4.02	0.31	5.58	0.14	1.68	1.59	24.22	0.09	23.05	0.22	0.28	0.00	0.00	9.05	11.99	0.00	13.45	0.81	22.48		12.14	1.49
C4			7.75	0.21	6.54	3.41	33.21	0.00	42.33	1.56	4.43	0.00	0.00	25.63	17.55	0.02	19.31	3.89	32.51		19.49	4.34
C2			3.25	2.51	4.72	2.13	24.36	0.22	19.44	2.85	4.23	0.10	0.30	27.41	15.42	0.03	25.23	8.07	18.18		13.98	5.42
B8			11.73	7.61	3.08	3.14	38.90	0.71	41.34	7.64	2.91	10.80	0.10	47.40	13.54	0.00	25.47	10.09	20.30		18.21	10.92
B6			24.24	8.25	10.60	20.73	31.92	37.50	19.43	12.27	8.21	12.25	6.11	20.63	23.38	6.01	15.20	12.33	15.10		16.24	16.25
B4			12.32	4.06	7.67	26.14	14.47	10.51	11.65	22.45	7.84	13.34	15.38	33.47	16.27	10.36	13.11	29.99	16.15		12.82	18.79
40	13.94	10.59	11.91	9.52	17.25	45.35	39.71	10.59	22.65	26.41	7.86	9.77	5.05	65.96	31.15	9.04	17.51	31.29	15.95		19.64	25.99
28	10.05	7.83	14.76	9.51	16.75	31.91	24.97	6.07	17.45	24.39	7.20	6.41	2.95	64.01	30.89	8.26	17.43	34.86	13.23		16.36	23.18
22	10.00	9.13	12.89	10.03	12.20	33.22	16.73	3.56	19.36	24.95	7.13	4.84	4.07	53.96	12.60	5.08	16.40	18.32	23.98		14.06	19.25
A8			13.38	6.33	7.40	12.27	14.67	7.97	8.67	8.52	3.58	6.08	4.17	13.90	7.93	7.07	10.17	11.36	20.18		9.59	9.19
14	7.27	9.05	13.14	6.33	11.71	9.34	10.32	8.40	7.47	3.52	4.35	7.10	5.26	10.31	6.42	8.57	9.81	13.33	12.80		8.52	8.36
A6			4.90	2.96	3.53	5.05	11.59	1.17	4.39	3.17	1.45	0.49	5.28	7.15	2.57	2.53	15.70	9.28	9.21		6.71	3.97
DJ		91.96	32.79	64.87	35.71																34.25	78.42

*** Cells not color-coded (i.e., white) represent absent or incomplete (gray values) datasets*

Appendix A Table 8: Maximum duration of oligohaline salinity conditions (Number of consecutive days with salinity < 5) by water-year (WYR), calendar-year (CYR), and season (Wet=May-Oct; Dry=Nov-Apr). Mean is calculated from WYR 2004-2018. **Color scheme see Table 3. (For 2004-2009 see IBBEAM 3rd Annual Report).**

WYR	2010		2011		2012		2013		2014		2015		2016		2017		2018		2019		Mean	
CYR	2009	2010	2010	2011	2011	2012	2012	2013	2013	2014	2014	2015	2015	2016	2016	2017	2017	2018	2018			
Month	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct		May-Oct	Nov-Apr
Season	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet		Wet	Dry
D6			0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.86		0.14	0.00
D2			0.00	0.00	0.00	0.00	0.99	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.74		0.22	0.00
62	0.18	0.14	0.28	0.13	0.30	1.86	2.54	0.00	2.80	0.00	0.02	0.00	0.10	0.22	0.07	0.00	0.35	0.00	3.92		1.26	0.28
C8			0.00	0.00	0.00	0.00	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.05	0.00
C6			0.00	0.00	0.00	0.00	0.31	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06		0.07	0.00
56	0.00	0.00	0.00	0.00	0.00	0.00	2.06	0.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.31		0.35	0.00
C4			0.00	0.00	0.00	0.00	4.44	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.01		0.69	0.00
C2			0.18	0.00	0.25	0.03	3.19	0.00	0.33	0.03	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.38		0.52	0.01
B8			0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.01	0.00	0.00	0.00	2.39	0.00	0.00	0.00	0.00	1.91		0.49	0.30
B6			3.95	0.00	0.25	0.00	9.75	0.00	13.50	1.51	2.68	0.00	0.18	8.51	6.74	0.00	5.09	0.40	11.83		6.25	1.30
B4			0.00	0.00	0.04	0.00	7.10	0.00	5.50	0.57	0.00	0.00	0.00	5.76	5.04	0.00	4.27	0.00	7.32		3.66	0.79
40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00
28	0.00	0.00	2.27	0.00	0.00	0.00	2.86	0.00	1.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.75	0.00	3.69		1.29	0.00
22	0.00	0.00	0.98	0.00	0.94	0.00	2.75	0.00	4.13	0.00	0.00	4.39	0.00	0.29	0.00	0.00	1.48	0.00	3.95		1.65	0.58
A8			1.60	0.44	0.21	0.00	1.65	0.00	1.91	0.10	0.00	0.00	0.00	1.50	0.00	0.00	2.85	0.00	2.03		1.08	0.26
14	0.00	0.08	2.86	1.08	1.50	0.91	3.04	0.00	2.64	0.00	0.00	0.00	0.00	2.89	1.29	0.00	4.34	0.06	3.13		1.99	0.62
A6			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.00	0.00	0.00	0.00	0.00		0.00	0.05
DJ		21.75	45.29	16.08	1.79																23.54	18.92

*** Cells not color-coded (i.e., white) represent absent or incomplete (gray values) datasets*

Appendix A Table 9: Maximum duration of oligo-mesohaline salinity conditions (Number of consecutive days with salinity < 18) by water-year (WYR), calendar-year (CYR), and season (Wet=May-Oct; Dry=Nov-Apr).Mean is calculated from WYR 2004-2018. **Color scheme see Table 3. (For 2004-2009 see IBBEAM 3rd Annual Report).**

WYR	2010		2011		2012		2013		2014		2015		2016		2017		2018		2019	Mean	
CYR	2009	2010	2010	2011	2011	2012	2012	2013	2013	2014	2014	2015	2015	2016	2016	2017	2017	2018	2018		
Month	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	May-Oct	Nov-Apr
Season	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Wet	Dry
D6			0.00	0.00	0.78	0.33	5.16	0.00	7.27	0.00	0.00	0.00	0.00	2.80	1.27	0.00	6.26	0.00	8.86	3.70	0.39
D2			0.00	0.00	0.31	0.20	5.55	0.00	4.60	0.00	0.00	0.00	0.11	4.84	0.94	0.00	5.01	0.00	8.12	3.08	0.63
62	0.39	0.16	2.36	0.13	1.33	5.03	7.53	0.00	8.78	0.19	0.13	0.02	0.26	10.84	4.86	0.00	8.15	1.01	9.15	5.02	2.15
C8			3.30	0.00	1.50	2.35	12.65	0.00	9.86	1.08	0.32	0.00	1.64	8.36	5.10	0.00	10.77	1.72	8.01	6.23	1.69
C6			2.18	0.20	2.13	2.31	20.27	0.00	11.79	0.06	0.26	0.00	0.04	12.48	3.94	0.00	10.31	0.72	7.79	7.07	1.97
56	4.02	0.31	5.58	0.14	1.68	1.59	24.22	0.09	32.88	0.22	0.28	0.00	0.00	9.05	11.99	0.00	13.45	0.81	22.48	13.37	1.49
C4			7.75	0.21	6.54	3.41	33.21	0.00	42.33	1.56	4.43	0.00	0.00	25.63	17.55	0.02	19.31	3.89	32.51	19.49	4.34
C2			3.94	2.51	4.72	2.13	33.54	0.22	24.00	2.85	4.23	0.10	0.30	27.41	15.42	0.03	25.23	8.07	18.18	15.70	5.42
B8			11.73	7.61	3.08	3.14	38.90	0.71	41.34	7.64	2.91	10.80	0.10	47.40	27.07	0.00	25.47	10.09	20.30	19.90	10.92
B6			26.03	8.25	10.60	20.73	70.67	37.50	58.25	12.27	10.91	12.25	6.11	51.32	31.81	6.01	48.56	27.03	67.40	38.04	21.92
B4			12.32	4.06	9.80	26.14	35.80	10.51	35.70	26.16	7.84	13.34	15.38	33.47	23.48	10.36	31.59	48.47	25.88	23.18	21.56
40	13.94	10.59	24.11	9.52	17.25	45.35	42.76	10.59	22.65	26.41	7.86	9.77	5.05	65.96	31.15	9.04	32.52	50.03	26.16	23.17	28.33
28	10.05	7.83	23.65	9.51	16.75	31.91	43.34	6.07	17.45	24.39	7.20	6.41	2.95	64.01	30.89	8.26	31.50	48.94	24.71	21.85	24.94
22	10.00	9.13	22.98	10.03	16.88	33.22	29.88	3.56	19.36	24.95	7.13	4.84	4.07	53.96	12.60	5.08	31.47	32.81	23.98	18.17	21.06
A8			17.54	9.68	7.40	12.27	29.50	7.97	9.68	8.52	3.58	6.08	4.17	26.71	7.93	7.07	31.51	11.36	20.18	14.24	11.21
14	7.27	9.05	22.76	6.33	11.71	12.51	28.78	8.40	10.66	3.52	4.35	7.10	5.26	26.82	10.26	8.57	31.59	13.33	20.67	15.41	10.82
A6			4.90	2.96	3.53	5.05	11.59	1.17	4.39	3.17	1.45	0.49	5.28	7.15	2.57	2.53	15.70	9.28	9.21	6.71	3.97
DJ		115.50	78.08	142.96	44.71															61.40	129.23

*** Cells not color-coded (i.e., white) represent absent or incomplete (gray values) datasets*

Appendix A Table 10: Maximum duration of hypersalinity events (Number of days with salinity >40) by water-year (WYR), calendar-year (CYR), and season (Wet=May-Oct; Dry=Nov-Apr). Mean is calculated from WYR 2004-2018. **Color scheme see Table 3. (For 2004-2009 see IBBEAM 3rd Annual Report).**

WYR	2010		2011		2012		2013		2014		2015		2016		2017		2018		2019		Mean	
CYR	2009	2010	2010	2011	2011	2012	2012	2013	2013	2014	2014	2015	2015	2016	2016	2017	2017	2018	2018			
Month	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct		May-Oct	Nov-Apr
Season	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet		Wet	Dry
D6			0.00	0.22	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.59	0.00	0.00	0.00	0.39	0.00	0.00		1.91	0.03
D2			0.00	0.19	26.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.81	0.00	0.00	0.00	0.60	0.00	0.00		4.33	0.02
62	1.21	0.00	0.15	0.00	1.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.57	0.00	0.00	0.00	0.00	0.00	0.00		0.59	0.00
C8			0.00	3.15	6.35	0.00	0.00	0.00	0.00	0.00	5.90	0.00	9.43	0.00	0.00	0.00	0.43	0.00	0.00		2.76	0.39
C6			0.00	1.96	11.13	0.00	0.00	0.00	0.00	0.00	8.95	0.00	12.86	0.00	0.00	0.00	0.44	0.00	0.00		4.17	0.24
56	15.66	0.00	0.00	0.14	10.99	0.00	0.00	0.00	0.00	0.00	5.99	0.00	7.59	0.00	0.00	0.00	0.05	0.00	0.00		3.08	0.02
C4			0.00	0.36	3.27	0.00	0.00	0.00	0.00	0.00	5.53	0.00	6.47	0.00	0.00	0.00	0.00	0.00	0.00		1.91	0.05
C2			0.00	0.00	6.36	0.00	0.00	0.00	0.00	0.00	10.73	0.00	7.89	0.00	0.00	0.00	0.00	0.00	0.00		3.12	0.00
B8			0.00	0.05	5.15	0.00	0.00	0.00	0.00	0.00	1.04	0.00	2.56	0.00	0.00	0.00	0.00	0.00	0.00		1.09	0.01
B6			0.00	0.60	21.71	0.00	0.00	0.00	0.00	0.00	0.06	0.00	5.14	0.00	0.00	0.00	0.00	0.00	0.00		3.36	0.08
B4			0.00	0.00	32.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.27	0.00	0.00	0.00	0.00	0.00	0.00		5.37	0.00
40	6.00	0.00	0.00	0.00	11.27	0.00	0.00	0.00	0.00	0.00	3.32	0.00	14.53	0.00	0.00	0.00	0.00	0.00	0.00		3.64	0.00
28	8.59	0.00	0.00	0.00	1.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.79	0.00	0.00	0.00	3.16	0.00	0.00		2.98	0.00
22	5.69	0.00	0.00	0.00	39.29	0.00	0.00	0.00	0.00	0.00	0.00	2.07	14.34	0.00	0.00	0.00	0.19	0.00	0.00		6.73	0.26
A8			0.00	0.00	18.36	0.00	0.00	0.00	0.00	0.00	1.98	0.00	16.92	0.00	0.00	0.00	1.89	0.00	0.00		4.89	0.00
14	10.00	0.00	0.00	0.01	54.50	0.00	0.00	0.00	0.00	0.00	2.61	0.00	10.69	0.00	0.00	0.00	4.19	0.00	0.00		9.00	0.00
A6			0.00	2.64	36.75	0.00	0.00	0.25	0.00	0.06	5.08	0.00	32.65	0.00	0.00	0.00	20.42	0.00	0.00		11.86	0.37
DJ		0.00	0.00	0.00	11.54																5.77	0.00

*** Cells not color-coded (i.e., white) represent absent or incomplete (gray values) datasets*

APPENDIX B

Appendix B Table 1: Final model variables and estimates for Halodule (Halo) and Thalassia (Thal), for epifaunal goldspotted killifish (Gold), gulf pipefish (Gulf), Farfantepenaeus shrimp (Penaid) and Palaemonetes spp. (Palae) and for mangrove-associated goldspotted killifish (Flo car), gray snapper (Lut gri) and yellowfin mojarra (Ger cin) occurrence (A) and density (B). (S=Salinity; T=Temperature; D=Depth; Th=Thalassia; Ha=Halodule; Syr=Syringodium; C=Canopy height; X^2=Square terms. Only statistically significant ($P < 0.05$) model terms were included in final models. Occurrence relationships were determined with logistic regression, and model fit was judged with the "Concordance Index" (C-value), which ranges from 0.5 to 1.0. Density relationships were determined with linear regression, and model fit was judged with the Coefficient of Determination (Adjusted R^2), which ranges from 0 to 1.

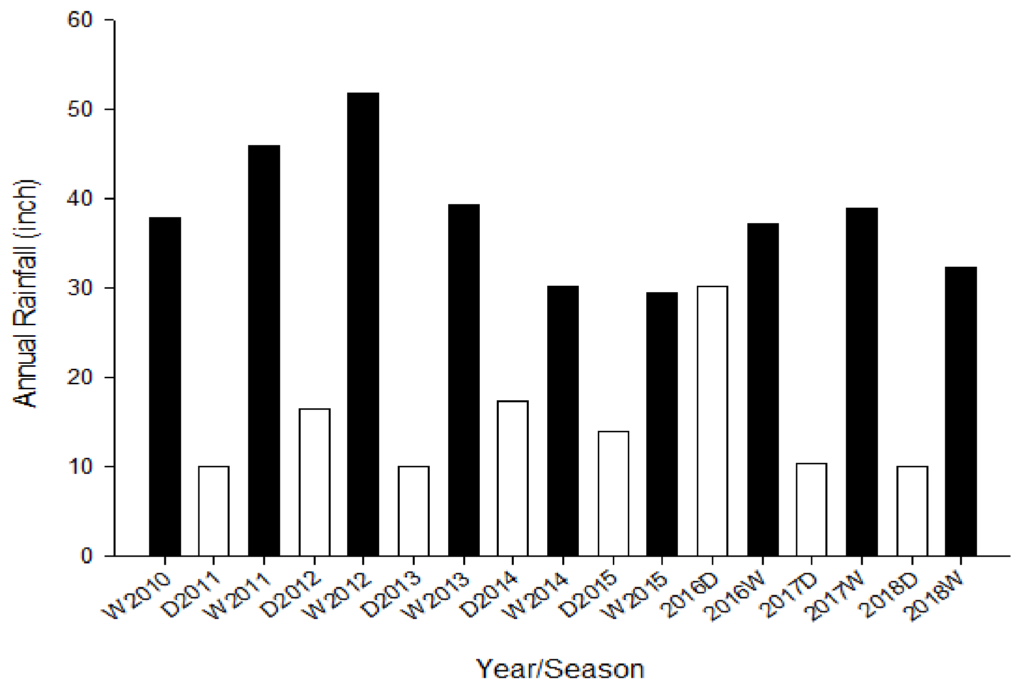
(A)

Taxon	Intercept	S	D	T	C	TH	HA	SYR	S2	D2	T2	C2	TH2	H2	SYR2	C-Value
Halo	3.141	-0.152	-0.891	0.145	N/A	N/A	N/A	N/A	0.001	0.018	-0.003	N/A	N/A	N/A	N/A	0.765
Thal	-1.984	0.075	0.343	0.053	N/A	N/A	N/A	N/A								0.701
Gold	0.916	-0.020	-0.009				0.055	0.037						-0.001		0.648
Gulf	-14.087	0.224		1.039	0.097		0.050		-0.005		-0.024	-0.003		-0.0007		0.787
Penaeid	0.853	0.105		-0.075	0.021	0.059	0.062		-0.003				-0.0008	-0.0008		0.67
Palae	2.960	-0.030		-0.114			0.045							-0.0005		0.67
Flo car	5.244	0.065	-0.044	-0.136	N/A	N/A	N/A	N/A	-0.002			N/A	N/A	N/A	N/A	0.761
Lut gri	-17.194	0.034	0.074	0.786	N/A	N/A	N/A	N/A		-0.0002	-0.013	N/A	N/A	N/A	N/A	0.661
Ger cin	-12.364	-0.009	0.069	0.588	N/A	N/A	N/A	N/A		-0.0004	-0.009	N/A	N/A	N/A	N/A	0.67

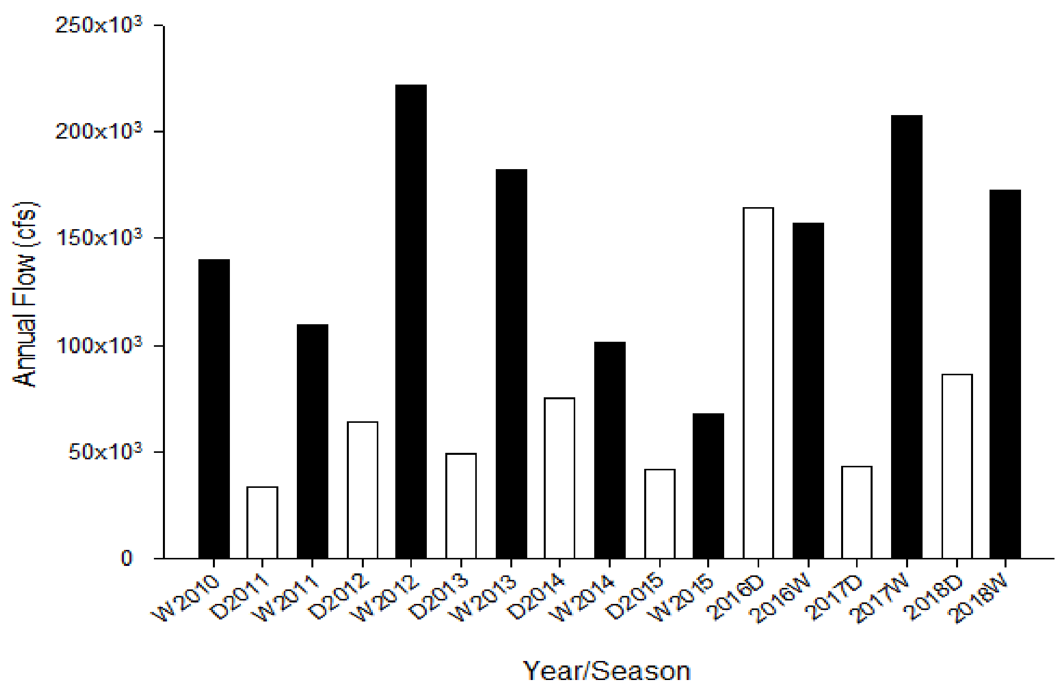
(B)

Taxon	Intercept	S	D	T	C	TH	HA	SYR	S2	D2	T2	C2	TH2	H2	SYR2	R^2-Value
Halo	0.381	-0.014	-0.076	0.017	N/A	N/A	N/A	N/A	5.5E-05	0.002	-0.0003	N/A	N/A	N/A	N/A	0.198
Thal	-0.155	0.008	0.060	0.009	N/A	N/A	N/A	N/A	-3E-05	-0.002		N/A	N/A	N/A	N/A	0.091
Gold	0.731	0.026	-0.004			0.013	0.026	0.021	-0.001				-0.0002	-0.0003		0.067
Gulf	-2.270	0.068		0.211	0.023	0.003	0.020		-0.001		-0.005	-0.0006		-0.0003		0.251
Penaeid	1.329	0.032		-0.039	0.010	0.024	0.022		-0.0008		-0.0003			-0.0003		0.068
Palae	1.997	-0.011		-0.055	0.029		0.023					-0.0006		-0.0003		0.084
Flo car	2.384	0.036	-0.047	0.134	N/A	N/A	N/A	N/A	-0.0009	0.0002	-0.004	N/A	N/A	N/A	N/A	0.173
Lut gri	-4.903	0.022	0.016	0.245	N/A	N/A	N/A	N/A		7.4E-05	-0.004	N/A	N/A	N/A	N/A	0.246
Ger cin	-3.245	0.027	0.026	0.165	N/A	N/A	N/A	N/A	-0.0007	-0.0001	-0.002	N/A	N/A	N/A	N/A	0.061

APPENDIX C



Appendix C Figure 1: Total annual rainfall data (average of S20G, S20G, S21A, S21, S123) from wet season CYR 2010 to wet season CYR 2018. Data source: http://www.sfwmd.gov/



Appendix C Figure 2: Total annual flow data (sum of S20G, S20G, S21A, S21, S123) from wet season CYR 2010 to wet season CYR 2018. Data source: http://www.sfwmd.gov/