FINAL REPORT

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Everglades Restoration Impacts On Biscayne Bay's Shallowest Habitats: Linking Seasonal Patterns In Benthic Community Structure With Salinity and Temperature Patterns

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Introduction

The hydrology of South Florida has been drastically modified over the last 70 years by the construction of the Central and Southern Florida Project. This water management system comprises an extensive network of levees, canals, water control structures and pump stations that have altered the natural timing, quantity and quality of freshwater flow across the landscape and caused significant modifications in the structure and function of upland and coastal habitats (Browder and Ogden, 1999). A recent example of the ecological changes attributed to the altered hydrology was the mass mortality of seagrasses within Florida Bay, where over 4000 ha of *Thalassia testudinum* beds were lost starting in 1987 (Zieman et al., 1989, 1999; Robblee et al., 1991; Durako, 1994). Although the exact causes of this demise are still being debated, many of the potential causal factors (e.g., changes in salinity, reduced dissolved oxygen, sulfide toxicity, disease) have been linked to the modification in freshwater inputs and salinity fields within the coastal lagoons of South Florida as a consequence of the water management system now in place (Fourqurean and Robblee, 1999). Similarly, hypersalinity and reduced water levels have been correlated with a decline in catches of pink shrimp (*Farfantepenaeus duorarum*) catches (Browder, 1985; Browder et al., 1999). Finally, changes in freshwater deliveries have been related to the mortality of obligate marine organisms like sponges that are highly susceptible to wide fluctuations in salinity, which are commonly recorded in the vicinity of canals that release large volumes of freshwater into the nearshore environment over a short period of time (Knight and Fell, 1987; Fell et al., 1989).

In response to these signs of environmental degradation, the recently approved Comprehensive Everglades Restoration Plan (CERP) has been charged with the restoration, preservation and protection of the South Florida ecosystem. The components of this plan have been designed to restore historical hydrologic conditions and increase water storage and supply for the natural system as well as for urban and agricultural use. One of the goals of CERP is to increase freshwater inputs into coastal bays from upland sources to recover the estuarine conditions that once prevailed along nearshore environments (Davis and Ogden, 1994; Browder and Wanless, 2001). Considering the potential future impacts of these activities on South Florida's coastal lagoons, it is crucial to establish a comprehensive baseline to document present-day patterns in species composition, distribution, diversity, abundance, and condition of benthic communities that occupy these nearshore habitats (< 500 m from shore).

The nearshore habitats of Biscayne Bay, a shallow lagoon adjacent to the city of Miami, are influenced by salinity fluctuations caused by freshwater discharges from canals. The benthic communities in these littoral habitats have been under-represented in existing monitoring programs due to the difficulties associated with boat access into these shallow (< 1 m) environments. The location of Biscayne Bay along a highly populated, rapidly growing urban center and directly downstream of CERP activities on the watershed makes what has been described as a "national treasure" especially vulnerable to human disturbances and changes in water quality and flow (Serafy et al., 2001; Lirman et al., 2002; Lirman and Cropper, 2003).

Salinity fields within Biscayne Bay are determined by precipitation, freshwater inputs from land, canal and groundwater sources, and tidal influx of oceanic water (Alleman, 1995; Wang et al., 2003). The spatio-temporal distribution of these influences delineates salinity fields with distinct characteristics. Areas with low, variable salinity are found along the Bay's western margin due to freshwater discharges from canals (12 canals discharge into Biscayne Bay), groundwater and surface runoff, while higher, more stable salinities are found along the eastern margin where oceanic influences prevail (Wang et al., 1978, 2003; Serafy et al., 2003).

One of the most profound changes anticipated to occur with the implementation of CERP is the alteration of salinities within western Biscayne Bay. The areas most sensitive to the changes are shallow areas (i.e., less than one-meter deep) along the mainland shoreline, which account for about 10 percent of southern Biscayne Bay. These areas are critical nursery habitats for pink shrimp (Diaz, 2001) and economically-valuable fishes such as gray snapper, spotted seatrout and pinfish (Campos, 1985; Serafy et al., 1997; Ault et al., 1999a, b). Planned CERP activities will likely modify freshwater deliveries into western Biscayne Bay with unknown ecological effects on benthic and epibenthic organisms. Some of the CERP activities that could potentially influence freshwater deliveries and water quality of Biscayne Bay include the Biscayne Bay Coastal Wetlands Project, the C-111N Spreader Canal Project, the Levee-31 N Seepage Management Project, the Lake Belt Project, the West and South Miami-Dade Water Reuse Project, and the Water Conservation Decomparmentalization Project (Alleman et al., 2002).

Impacts of CERP to the benthic communities of Biscayne Bay are expected primarily in nearshore habitats where increased freshwater inflows through the tidal creeks and marshes of the South Dade Wetlands are expected to lower salinity at the mouths of creeks and expand areas of mesohaline conditions. In fact, one of the main underlying hypotheses of CERP is that the restoration of favorable flow and salinity regimes will expand the range of *Halodule* seaward into the near-shore environment of Biscayne Bay, reduce the region of *Thalassia* dominance, and increase both *Halodule* and *Ruppia* cover. However, limited information is available to date to determine whether present-day seagrass abundance and distribution patterns are influenced by salinity patterns in Biscayne Bay. The data collected in this project can be used, with continuing monitoring, to address this important CERP hypothesis and provide a much-needed baseline against which the effects of future watershed restoration activities may be discerned.

Research Activities

Our research program integrated two distinct efforts to: (1) conduct video surveys of the nearshore environment of Biscayne Bay between Turkey Point and Rickenbacker Causeway using an innovative benthic survey technology, the Shallow Water Positioning System (SWaPS) developed by scientists from NOAA's National Geodetic Survey; and (2) document salinity and temperature patterns of this nearshore environment by deploying arrays of miniature sensor/loggers that collect high-resolution data from these habitats that are positioned to allow CERP-related effects to be detected. The information collected provided: (1) a spatially-explicit baseline database on the seasonal a species composition, distribution, diversity, and abundance of benthic organisms that constitute the nearshore seagrass, macroalgal, and hardbottom communities; and (2) detailed, high resolution environmental data that are essential to relate the current status and future changes of benthic communities to these physical parameters at a scale commensurate with the benthic surveys conducted.

Benthic Surveys

The Shallow Water Positioning System

The shallow-water positioning system (SWaPS), developed by scientists from the National Oceanographic and Atmospheric Administration's National Geodetic Survey, uses a Global Positioning System (GPS) receiver attached to a video camera and a high-resolution digital SLR camera (7.0 megapixels) installed in a shallow-draft boat (14-ft Carolina skiff) (Lirman et al., 2006) (Figure 1). The GPS receiver is centered over a gimballed digital video camera that is suspended over a glass enclosure that provides a looking view of the bottom. A static GPS base station is established in the vicinity of the SWaPS operations and this base station tracks the visible GPS satellites in synchrony with the mobile GPS receiver onboard the SWaPS survey skiff. Both receivers record the GPS L1 and L2 carrier phases and code ranges every second during operations. After each survey period, both data files are post-processed using the software program KINPOS as described in Mader (1996). The position of the base station is accurately determined using OPUS, a GPS processing service created by the National Geodetic Survey (http://www.ngs.noaa.gov\OPUS). The code ranges are used in differential mode to locate the position of the SWaPS platform. The data collected by the base station is relayed via radio modem to the SWaPS survey platform where the data can be processed in real-time as described above. Each video frame recorded is stamped with time, date, depth, heading, and pitch and roll (Figure 1). The time code is used to retrieve the precise location of each frame based on the location of the boat with respect to the base station. The video surveys conducted with SWaPS provide a continuous digital video track of the bottom. The data are archived in video format and by "grabbing" non-overlapping frames at a rate of one frame per second and storing these as digital still images that were analyzed to determine percent cover and spatial distribution of seagrasses, macroalgae, and hardbottom organisms. A geospatial information system (GIS) is used subsequently to link the geospatial (locations) and thematic (descriptive) data to their respective image.

In 2005, spatially precise video surveys were conducted in the dry season (March-April) and the wet season (July-August) using a stratified random sampling design to document benthic community patterns along latitudinal and inshore-offshore gradients (Figure 1). A total of 249 sites were surveyed each sampling interval using the Shallow-Water Positioning System (SWaPS). The same sites were surveyed both seasons to provide a precise intra-annual comparison. The sampling scheme and site selection for this project followed a stratified random sampling design based on the US EPA's EMAP sampling protocol. This modified protocol consisted of the following steps: (1) A shoreline map of the study region was extracted from FDEP's 3-m Digital Ortho-Quarter Quad photography; (2) a shoreline vector was delineated and five 100-meter buffers (contours) were created; (3) buffers were divided into equal-size cells using the fishnet function in Xtools (ArcGIS extension); and (4) one survey point was generated within each subdivision of the buffer at random using Hawth's Tools (ArcGIS extension). The GPS coordinates for each point were obtained with the ArcGIS Field Calculator and this information exported to a Garmin GPS for navigation in the field. The location of the 100-m buffers and the sites surveyed in 2005 are shown in Figure 2.

For each survey location (i.e., a transect < 25 m along the survey track), 10 non-overlapping georeferenced images were chosen at random from the image library. This approach was chosen to be consistent with the methods used by existing long-term SAV monitoring programs in the region were multiple sites are sampled visually using 0.25 m^2-quadrats (Fourqurean et al., 2002). For each georeferenced digital image (i.e., the sample unit for that site), community type, species list, and abundance (percent cover) were recorded from a computer monitor. The contrast and brightness of each image were adjusted to improve classification. Percent cover was determined as the fraction of each frame occupied by each taxon and the values recorded for each frame were averaged by site (n = 10 frames per site). The benthic coverage data obtained were averaged for each site and used to develop percent cover surface contours using ArcView's Spatial Analyst using an Inverse Distance Weighted interpolation procedure. The mean cover of each taxon was compared between season using t-tests and among buffers and between seasons using a 2-way Analysis of Variance with season and buffer as main factors. Coverage data were arcsin-transformed to conform to the normality assumption of the statistical tests employed (Sokal and Rohlf, 1981).

In addition to the random surveys, we conducted detailed surveys in the immediate vicinity of Mowry Canal, Military Canal, and Black Creek. These areas were sampled in a regular grid pattern following parallel tracks centered around the canal structures. Survey tracks were separated by a distance of 75 m (150 m for Black Creek) and sites along each track were surveyed at 75-m intervals (150 m for Black Creek) using pre-loaded GPS tracks. For each survey location (i.e., a transect of 15-20 m along the survey track), 10 non-overlapping frames were chosen at random from the image library and analyzed using the methods previously described. The benthic coverage data obtained were averaged for each site and used to develop percent cover surface contours using ArcView's Spatial Analyst using an Inverse Distance Weighted interpolation procedure. The distance between each survey point and the discharge point of each canal (i.e., the point at which the canal structure enters the bay) was used to test the hypothesis that distance to canals influences the abundance and distribution of seagrasses using regression analysis.

One of the long-term goals of this project is to evaluate the potential links between the abundance, diversity, and distribution of SAV and the abundance and distribution of shoreline fishes and macroinvertebrates. As an initial step towards this goal, the abundance and distribution of pink shrimp and goldspotted killifish, two species potentially infleunced by salinity patterns, were overlaid over the abundance and distribution contours obtained for seagrasses in 2005 to assess the potential for spatial correlations between the different data layers. Abundance of pink shrimp was documented using throw-trap data collected by J. Browder's research team during the 2005 Dry Season. Abundance of killifish represent 5-year averages of fish abundance collected from visual transects placed along the mangrove habitats of western Biscayne Bay by J. Serafy's research team.

Calibration Between SWaPS and Visual Surveys

Because other benthic research programs in the region use visual surveys performed by divers to estimate abundance and distribution of benthic organisms (Fourqurean et al., 2002), it is important to compare the values obtained using SWaPS with those obtained by trained observers at the same sites. To provide this calibration, a subset of sites (n = 22) with different characteristics (e.g., seagrass-dominated, algal-dominated, mixed communities) were surveyed using both methods, and benthic attributes and time-effort estimates were compared. Trained observers followed the methods outlined by Fourqurean et al. (2002) to estimate the percent cover of benthic organisms from 10 haphazardly placed PVC quadrats (0.25 m^2) along a 20-25 m transect. The same area was surveyed using SWaPS and the data were analyzed as described above. The estimates of the mean percent cover for each seagrass species and macroalgal group were compared between survey methods for each site individually as well as among all sites (i.e., pooled data) using a Wilcoxon test due to non-conformity with the normality assumption required for parametric tests.

<u>Sensor Deployment</u>

In March 2005, we acquired 26 miniature (15 x 46 mm) salinity and temperature logger devices from Star Oddi (www.star-oddi.com). These sensors, commonly used in fish tagging studies, are ideal for deployment in extreme shallow habitats (< 20 cm of depth). In April 2005, these loggers were deployed between Black Point and Turkey Point at < 50 m from the mangrove shoreline at locations chosen to expand the spatial coverage of sensors deployed by Biscayne National Park and the Army Corps of Engineers into in the extreme shallows of Biscayne Bay. Two sensors with different conductivity ranges were deployed per site to capture the full range of salinity variation expected. The data collected by these sensors at 30-min intervals were retrieved every 4-6 weeks until December 2005.

To relate salinity patterns recorded by the loggers with precipitation and canal discharge patterns, the amount of freshwater discharged through Military and Mowry Canals as well as the precipitation values in the vicinity of these canals were obtained from historical records from the South Florida Water Management District (http://www.sfwmd.org). The daily canal discharge (cubic feet sec^{-1}) and precipitation values were added to obtain monthly values and monthly values were averaged for the period of 1995-2004, providing a 10-year mean. Monthly values for precipitation and canal flows were also obtained for the period March-September 2005.

Results

Benthic Surveys

The skiff used by the Shallow Water Positioning System performed well in the shallow environment of western Biscayne Bay and approximately 35 km of littoral habitats at depths < 75 cm were easily surveyed. Moreover, the shallow draft of the survey boat allowed us to survey efficiently even the shallowest habitats (< 40 cm) that are hard to access using other platforms. Depending on the depth of the habitats, survey speeds of < 1 knot provided the best image quality during continuous surveys. The average time required to collect georeferenced video along a 25-m transect is 2-3 min and, depending on the spacing of the survey locations, a large number of sites can be easily surveyed in a short period of time. In applications such as the canal surveys where sites are closely spaced, up to 100 sites can be surveyed in a day.

Three main benthic community types were documented in western Biscayne Bay: (1) seagrass communities composed of one or more of four seagrass species (*Thalassia testudinum*, *Halodule wrightii*, *Syringodium filiforme*, *Ruppia maritima*); (2) macroalgal communities with attached and/or drift components; and (3) hardbottom communities composed of sponges, soft corals, and hard corals. While these were the three main categories, mixed benthic communities composed of organisms from two or more of these broad categories were commonly observed.

Dry Season

Seagrass are the dominant component of the SAV communities of nearshore western Biscayne Bay (Tables 1,2; Figure 3). The most abundant seagrass species, *T. testudinum* (68 % of sites; mean % cover (S.D.) = 19.9 (28.0)), was found throughout the study domain with highest abundance levels in the Chicken Key area and north of Black Point (Table 1). The lowest abundance of this species was recorded in the northernmost section of the study area (Coconut Grove to the Rickenbacker Cswy), south of Black Point, and directly opposite Military and

Mowry canals (Figure 3). In contrast to the wide distribution of *Thalassia*, *H. wrightii* (38 % of sites; mean % cover = 4.2 (9.8)), *S. filiforme* (15 % of sites; mean % cover = 1.4 (8.3), and *R. maritima* (4 % of sites; mean % cover = 0.03 (0.2), had lower overall abundance and restricted spatial distribution (Figures 5-7). *H. wrightii* had high abundance foci in the areas in the immediate vicinity of canals throughout the study domain (Figure 8), *S. filiforme* was restricted to the northern section of the survey area (Figure 9), and *R. maritima* was restricted to the southern region in areas directly influenced by freshwater inflows from canals (Figure 10).

Attached and drift macroalgae are important components of the benthic communities of western Biscayne Bay and were found throughout the study region at 64 % and 69 % of sites respectively (Tables 1,2; Figures 11-14). The main components of the attached macroalgal group included *Halimeda* spp., *Caulerpa* spp., *Penicillus* spp., *Batophora* spp., *Acetabularia* sp., while *Laurencia* spp., *Chondria* spp*.,* and *Dictyota* spp. were the most abundant components of the drift macroalgal group. Finally, 17 % of sites were completely devoid of submerged aquatic vegetation. These sites were found mainly in the northern section of the study region (N of Shoal Point) in areas where dredging activities have taken place. Sponge-dominated hardbottom communities were only found at 5 % of sites, all N of Black Point.

Wet Season

Patterns of change in the abundance and distribution of SAV between the dry and wet seasons were highly taxon-specific and showed marked spatial patterns for most taxa (Table 1,2; Figures 15-22). The overall abundance and distribution of *T. testudinum* remained consistent between seasons (Table 2) with general increases in percent cover N of the Cutler Canal and comparable decreases in the region S of this canal (Figure 16). In contrast, both *H. wrigthii* and *S. filiforme* experienced significant increases in percent cover in the wet season (Table 2) and an expansion in the number of sites where these species were documented (Table 1). *R. maritima* cover showed a non-significant decrease in cover between seasons (Table 2; Figure 19). The spatial patterns of changes in percent cover of *H. wrightii* were the direct opposite of those documented for *T. testudinum*; the mean cover of *H. wrightii* generally increased in the area S of the Cutler Canal and decreased in the area N of this canal (Figures 16,17).

The macroalgal components of the SAV of western Biscayne Bay showed the largest difference between seasons (Table 2). While the percent cover of drift macroalgae decreased significantly (from 12.5 % to 4.4 %), the cover of attached macroalgae increased significantly (from 4% to 29 %). Similarly, while drift macroalgae experienced decreases in percent cover throughout the study domain, attached macroalgae experienced decreases in cover in the area N of the Cutler Canal and increases in the region S of this canal (Figures 21,22). The large increase in biomass and percent cover documented for attached macroalgae in the southern section of the study domain was caused by the bloom of *Chara* and *Batophora* in areas influenced by canals (Figure 21).

Seagrass communities within nearshore habitats (< 500 m from shore) showed significant patterns in percent cover with respect to distance to shore (Table 3). The cover of *T. testudinum* increased significantly with increasing distance from shore, while *S. filiforme* reached its highest value at the 300-m buffer. Decreases in the mean cover of *H wrightii* and *R. maritima* were documented with increasing distance from shore, but the low and variable cover of these species reduced the power to detect statistically different patterns (power < 0.3). The abundance of attached and drift macroalgae were significantly influenced by both season and distance to shore (Table 3). Peaks in percent cover of attached macroalgae were recorded close to shore (100-m buffer) in the wet season due to the bloom of species like *Batophora* and *Chara* (Figure 21).

Canal Surveys

Only three seagrass species, *T. testudinum*, *H. wrightii*, and *R. maritima,* were found in the vicinity of Black Creek, Military and Mowry Canals in July-August 2005 (Table 4). The benthic habitats in the vicinity of Military and Mowry Canals were dominated by seagrasses, with *H. wrightii* being the most abundant at both locations (Table 4). At Black Point, *T. testudinum* was the most abundant taxon (mean % cover = 12.8 (± 21.6)), followed by *H. wrightii* (9.9 (± 9.6)). Macroalgae were abundant only in the vicinity of Black Point (12.1 %) and Mowry Canal (3.4 %). The dominant components of the macroalgal community at these locations were members of the attached group commonly associated with low salinity such as *Batophora* (all three areas) and *Chara* (Black Point only). The low abundance (< 3 % maximum cover) and distribution (present at only 21 % of sites) of *R. maritima* precluded meaningful statistical analyses. At

Military Canal, the abundance of both *H. wrightii* and *T. testudinum* was significantly influenced by distance to the canal discharge point (linear regression, $p < 0.01$). The abundance of *H. wrightii* decreased with distance to the canal discharge point and the opposite pattern was documented for *T. testudinum* (Figure 23). At Mowry Canal, only the abundance *T. testudinum* decreased significantly with proximity to the canal ($p < 0.01$), while no significant spatial patterns with respect to canal influences were observed for *H. wrightii* (Figure 24). Only 6 stations (12.5 %) were completely devoid of seagrass in the vicinity of Mowry Canal, 2 stations (4.2 %) had no seagrass biomass in the Black Point area, while no stations devoid of seagrass biomass were observed in the vicinity of Military canal. At Black Point, no significant patterns were observed with distance to shore (linear regression, $p > 0.05$). In contrast, significant spatial patterns were observed with respect to the rocky jetty (t test, $p < 0.05$). Benthic communities in the area N of the jetty were dominated by *T. testudinum* and habitats S of the jetty were dominated by *H. wrightii* (Figure 25), highlighting the role of the jetty as a physical barrier to the freshwater discharge from Black Creek..

Links Between SAV and Mobile Fish and Epibenthic Macrofauna

The correlation analyses performed using the percent cover of all seagrasses and the abundance of pink shrimp (Figure 26) and goldspotted killifish (Figure 27) showed no significant relationships between the data layers. However, it must be noted that the benthic and macrofauna surveys were not synchronized and the three programs were developed using independent sampling designs. Future efforts are planned to improve the temporal and spatial overlap in data collection that will allow for more robust statistical analyses of these data.

Calibration

A total of 22 sites were surveyed visually by trained observers *in situ* as well as using SWaPS. The time it took a trained observer to collect percent cover data from ten 0.25-m^2 quadrats in the field ranged from 10 to 20 minutes, depending on the composition of the benthic community. Using SWaPS, the average time required to collect georeferenced video along a 25-m transect is 2-3 min and, depending on the spacing of the survey locations, a large number of sites can be easily surveyed in a short period of time. In applications such as the canal surveys where sites are closely spaced, up to 100 sites can be surveyed in a day. The time required to score on a computer monitor the 10 digital frames chosen from each site ranged from 5 to 12 minutes.

When data were pooled among all sites, no significant differences in the percent cover of *T. testudinum*, *H. wrightii*, *S. filiforme*, *R. maritima*, drift macroalgae, and attached macroalgae were found between survey methods (Wilcoxon test, $p > 0.05$). When data were analyzed for each site separately, no significant differences in the percent cover of *T. testudinum* were found for any of the sites. For the other species or groups, no significant differences were found for *H. wrightii* at 18 sites (82 % of sites), *S. filiforme* at 86 % of sites, *R. maritima* at 77 % of sites, drift macroalgae at 77 % of sites, and attached macroalgae at 73 % of sites. These results indicate that SWaPS can be used effectively to document patterns of abundance and distribution of SAV in shallow environments and that the results obtained using SWaPS are fully comparable to the data collected by other regional SAV monitoring programs.

Sensor Deployment

Salinity and Temperature Patterns

The data loggers deployed at 13 locations between Black Point and Turkey Point (Figure 28) experienced software and hardware failures at different points during the deployment. The loggers have been returned to the manufacturer for data retrieval and continuous records are presently available for only a limited number of sites (Figures 29,30). Nevertheless, the information collected by the loggers at these locations clearly reveal the influence of precipitation and canal outflow on the salinity patterns of western Biscayne Bay as well as the wide fluctuation in salinity that can result from precipitation and canal releases. During the dry season (March-May), mean salinity was higher at all three sites compared to the values obtained during the wet season (June-September) (Figure 29A). Moreover, the areas in the vicinity of Military and Mowry Canals had consistently lower mean monthly salinity compared to the Turkey Point area where no canal discharge is present (Figure 29A). Similarly, the variability in salinity (expressed as the coefficient of variation, CV) increased with decreasing salinity in the wet season, and canal-influenced areas had a higher degree of variability compared to non-canal influenced areas (with the exception of September when a higher CV was obtained for the Turkey Point area compared to the Military Canal area) (Figure 29B). These patterns were accentuated in the wet season when both precipitation and canal discharges increase (Figure 29C,D). While both canal-influenced areas had lower salinity than the non-canal influenced area, mean salinity in the vicinity of Mowry Canal was consistently lower than the mean salinity recorded in the vicinity of Military Canal (with the exception of May when this pattern was reversed). Finally, the high-resolution data collected in the immediate vicinity of canals show that these areas can experience drastic fluctuations in salinity, especially during South Florida's wet season when mean daily salinity can drop by as much as 35 psu over a 2-day period and remain < 5 psu for > 7 days (Figure 30).

The salinity patterns documented can be explained by the canal-specific and seasonal differences in freshwater flow. Canal discharge rates were higher in the wet, rainy season than in the dry season. Moreover, discharge values were considerably higher for Mowry Canal compared to Military Canal throughout the year. The only time when canal flow values were higher at Mowry Canal in 2005 was in May (Mowry Canal = 67 cubic feet sec^{-1}, Military Canal = 32 cubic feet sec^{-1}), which corresponds with the period when monthly mean salinity was lower in the vicinity of Mowry Canal (Figure 29C). Finally, the 10-year record of precipitation correlates with the observed salinity patterns, with a marked increase in precipitation in June at the onset of the rainy season that is captured in the drop in salinity at all three sites at this time (Figure 29D). The precipitation values recorded for 2005 were within the 95 % confidence interval recorded for the 10-year precipitation mean (Figure 29D). Finally, extreme nearshore environments (< 50 m from shore) experience wide daily fluctuations in temperature of up to 6° C that are directly associated with air temperature and not directly influenced by probe location in relation to canal discharges (Figure 30)

Summary

1. The abundance and distribution of seagrasses in nearshore (< 500 m from shore) habitats of western Biscayne Bay are clearly influenced at present by the inflow of freshwater from canals. Populations of *Halodule* and *Ruppia* exhibit the highest levels of benthic cover only in areas close to canals. *Thalassia* is a dominant component of the seagrass community throughout the

region but its abundance increases locally with increasing distance from shore and the mouths of canals. Abundant populations of *Syringodium* are only found in the northern section of our study domain in areas with open oceanic exchange (i.e., across from the Safety Valve).

2. While canal outflow was shown to influence seagrass and macroalgal distribution, areas in the immediate vicinity of canals still support productive benthic communities. The occurrence of "dead zones" devoid of SAV appears to be restricted to a 50 -100 m buffer at the mouth of canals and in dredged areas in the region between Shoal Point and the Rickenbacker Cswy.

3. The overall abundance and distribution of *T. testudinum* remained consistent between seasons with general increases in percent cover north of the Cutler Canal and comparable decreases in the region south of this canal. In contrast, both *H. wrigthii* and *S. filiforme* experienced significant increases in percent cover in the wet season and an expansion in the number of sites where these species were documented.

4. Nearshore habitats support extensive and productive macroalgal communities. A shift in the composition of macroalgal communities was detected at the onset of the wet season in areas in the vicinity of canals (e.g., Black Creek, Princeton Canal) were *Chara* and *Batophora*, two species commonly associated with freshwater, became dominant components.

5. No statistically significant relationships were found between the abundance of seagrasses and the abundance and distribution of pink shrimp and goldspotted killifish. However, it must be noted that the spatial and temporal scales at which the different data layers were obtained may have limited our ability to document potential correlations. Extended benthic surveys that are synchronized with macrofauna surveys are needed in the future to elucidate potential inter-relationships between SAV and fishes and macroinvertebrates in western Biscayne Bay.

6. Salinity patterns of nearshore habitats are influenced significantly by the outflow of freshwater from canal structures. Freshwater releases at these locations result in lowered and more variable salinity patterns that locally influence the abundance and distribution of seagrasses. Areas with low and variable salinity in the vicinity of canals are commonly dominated by *Halodule wrightii*.

7. Extreme nearshore environments (< 50 m from shore) experience wide daily fluctuations in temperature of up to 6° C that are directly associated with air temperature and not directly influenced by canal discharges. The areas where the loggers were deployed were dominated by seagrass throughout the year, showing limited impacts of temperature fluctuations on seagrass distribution, however, potential impacts on other biota warrant further study.

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Conclusions

The present research project, funded by the CESI program, performed the first comprehensive, seasonally and spatially resolved survey of the benthic organisms occupying nearshore habitats of western Biscayne Bay. The SWaPS methodology used in these surveys proved to be a rapid and effective tool to assess the abundance and distribution of SAV and hardbottom organisms. Moreover, the data and the visual permanent record in these surveys (i.e., photographs and video footage) provide the baseline information needed to assess long-term status and change in these important habitats.

One of the most profound changes anticipated to occur with the implementation of CERP is the alteration of salinities along western Biscayne Bay with unknown ecological effects on benthic organisms. Present-day abundance and distribution patterns of seagrass and macroalgae show statistically significant patterns with respect to the inflow of freshwater from water management canals in the study domain. The initial relationships between abundance and distribution of SAV and salinity patterns established in this study indicate that these organisms could be used effectively as long-term indicators of changes in salinity patterns as proposed in CERP. However, before the abundance and distribution of SAV can be used as performance measures in CERP, continued monitoring of nearshore benthic habitats is needed to evaluate the inter-annual variability in these potential indicators of changes in salinity patterns.

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Season	Dry	Wet
no SAV	17	15
T. testudinum	68	63
S. filiforme	15	21
H. wrightii	38	50
R. maritima	4	5
Attached Algae	64	66
Drift Algae	69	43
Seagrass	78	80
Macroalgae	77	74
Sponges	5	2

Table 1. Percentage of sites (n = 249 sites each season) where different benthic organisms were found in western Biscayne Bay in the Dry (March-April) and Wet (July-August) seasons of 2005.

Season	Dry	Wet	p values
T. testudinum	19.9 (28.0)	19.2 (28.3)	ns
H. wrightii	4.2 (9.8)	5.2 (12.2)	< 0.05
S. filiforme	1.4 (8.3)	4.0 (13.2)	< 0.01
R. maritima	0.03 (0.2)	0.01 (0.1)	ns
Attached Algae	4.0 (10.4)	29.0 (33.4)	< 0.01
Drift Algae	12.5 (18.7)	4.4 (10.4)	< 0.01
Seagrass	25.5 (30.1)	28.4 (30.8)	ns
Macroalgae	16.5 (20.8)	33.4 (35.5)	< 0.01
Sponges	0.03 (0.3)	0.02 (0.2)	ns

Table 2. Percent cover (S.D.) of benthic organisms in western Biscayne Bay in the Dry (March-April) and Wet (July-August) seasons of 2005. The mean cover of each taxon was compared between the dry and wet seasons using a t-test. ns = no significant differences between seasons.

Buffer	100 m		200 m		300 m		400 m		500 m		p values		
Season	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Season	Buffer	Interaction
T. testudinum	14.1 (25.5)	12.6 (25.2)	11.8 (17.1)	19.9 (28.3)	28.3 (33.4)	21.5 (27.0)	23.2 (24.0)	26.8 (31.3)	31.3 (36.2)	27.0 (32.1)	ns	< 0.05	ns
H. wrightii	3.5 (7.9)	7.5 (10.2)	4.1 (3.9)	7.0 (8.2)	5.7 (16.2)	2.5 (23.7)	6.7 (5.1)	2.2 (13.9)	1.9 (0.6)	1.5 (7.6)	ns	ns	ns
S. filiforme	1.0 (8.3)	2.2 (15.1)	0.9 (8.6)	2.1 (14.9)	4.6 (15.9)	10.6 (5.1)	0.9 (10.6)	6.2 (5.5)	0.1 (3.8)	2.8 (3.3)	< 0.05	< 0.05	ns
R. maritima	0.05 (0.3)	0.02 (0.1)	0.06 (0.4)	0.01 (0.04)	0	0	0	0	0	0.01 (0.04)	ns	ns	ns
Attached Algae	3.4 (20.4)	39.4 (7.7)	3.5 (21.0)	22.0 (8.4)	2.5 (16.2)	24.4 (12.4)	7.4 (14.4)	20.4 (14.6)	3.6 (18.1)	23.7 (10.5)	< 0.05	< 0.05	< 0.05
Drift Algae	11.5 (8.4)	2.1 (38.2)	14.7 (8.9)	3.2 (28.7)	12.1 (5.3)	5.6 (30.5)	9.6 (18.4)	8.3 (27.3)	15.0 (7.9)	7.9 (27.9)	< 0.05	< 0.05	ns
Seagrass	18.7 (26.9)	22.3 (29.7)	16.9 (21.1)	29.1 (30.8)	38.6 (34.1)	34.5 (29.3)	30.8 (29.1)	35.2 (32.9)	33.3 (36.4)	31.1 (31.2)	ns	< 0.05	ns
Macroalgae	14.9 (22.0)	41.5 (38.3)	18.3 (22.2)	25.1 (31.7)	14.7 (18.0)	30.0 (34.3)	17.0 (21.4)	28.6 (33.4)	18.7 (19.3)	31.6 (33.4)	< 0.05	ns	ns

Table 3. Percent cover (S.D.) of benthic organisms in western Biscayne Bay in the Dry (March-April) and Wet (July-August) seasons of 2005. Survey sites were distributed among 100-m buffers at increasing distance from shore. The mean cover of each taxon was compared among buffers and between the dry and wet seasons using a 2-way Analysis of Variance with season and buffer as main factors. ns = no significant differences between seasons.

	Black Creek	Military Canal	Mowry Canal
T. testudinum	8.7 (15.4)	28.2 (26.5)	12.8 (21.6)
H. wrightii	31.8 (27.5)	31.8 (24.2)	9.9 (9.6)
S. filiforme	0	0	0
R. maritima	0.3 (2.2)	0.3 (0.6)	0.3 (0.6)
Attached Algae	2.6 (3.8)	0.8 (1.3)	6.1 (8.1)
Drift Algae	0.8 (3.0)	0.1 (0.4)	6.0 (12.5)
Seagrass	40.8 (29.0)	60.3 (18.1)	22.9 (21.7)
Macroalgae	3.4 (4.7)	0.9 (1.5)	12.1 (16.2)

Table 4. Percent cover (S.D.) of benthic organisms in the vicinity of water management canals that release freshwater into western Biscayne Bay. N = 48 sites from each canal area.

Figure Legends

Figure 1. Photographs of the SWaPS survey skiff and a sample video frame containing location, depth, and pitch and roll information.

Figure 2. A) Map of the study area and the location of the study sites (n = 249 sites surveyed each season). The location of survey sites was determined based on a stratified random sampling design using the following steps: B) Shoreline vector obtained from Florida Department of Environmental Protection 3 meter Digital Ortho-Quarter Quad photography, C) Five 100-m buffers were created at increasing distance from shore and each buffer was divided into equal-length sections, D,E) Sites were located randomly within each sub-section of the five buffers.

Figures 3-7. Seasonal abundance and distribution contours for seagrasses in western Biscayne Bay. The benthic coverage data obtained were averaged for each site and used to develop percent cover surface contours using ArcView's Spatial Analyst using an Inverse Distance Weighted interpolation procedure.

Figures 8-10. Seasonal relative abundance of seagrasses in western Biscayne Bay. In these figures, the color scheme represents the minimum-maximum percent cover of each taxon. Taxa with a full range of percent cover values (0 – 100%) were thus excluded. These contours are intended to highlight the spatial patterns of distribution of taxa that are not observable when displayed when using the full scale (Figures 3-7).

Figures 11-12. Seasonal abundance and distribution contours for macroalgae in western Biscayne Bay. The benthic coverage data obtained were averaged for each site and used to develop percent cover surface contours using ArcView's Spatial Analyst using an Inverse Distance Weighted interpolation procedure.

Figures 13-14. Seasonal relative abundance of macroalgae in western Biscayne Bay. In these figures, the color scheme represents the minimum-maximum percent cover of each taxon. These contours are intended to highlight the spatial patterns of distribution of taxa that are not observable when displayed when using the full scale (Figures 11-12).

Figures 15-22. Seasonal change in the abundance and distribution of SAV in western Biscayne Bay. The amount of change in percent cover for each site was obtained for each taxon by calculating the percent change with respect to the Dry Season value (% change = (% cover wet season - % cover dry season) / (% cover dry season). The % change for each site was used to obtained abundance and distribution contours using ArcView's Spatial Analyst using an Inverse Distance Weighted interpolation procedure. Figure 20 shows photographs of the two species of rhizophytic macroalgae (*Chara* and *Batophora*) that experienced significant increases in abundance during the wet season.

Figures 23-25. Abundance and distribution of *Thalassia testudinum* and *Halodule wrightii* in the vicinity of the water management canals that release freshwater into western Biscayne Bay. These areas were sampled in a regular grid pattern following parallel tracks centered around the canal structures. Survey tracks were separated by a distance of 75 m (150 m for Black Creek) and sites along each track were surveyed at 75-m (150 m for Black Creek) intervals using pre-loaded GPS tracks. The benthic coverage data obtained were averaged for each site and used to develop percent cover surface contours using ArcView's Spatial Analyst using an Inverse Distance Weighted interpolation procedure.

Figures 26-27. Abundance of pink shrimp and killifish along nearshore habitats of western Biscayne Bay in relationship to the abundance and distribution of seagrasses documented during the 2005 Dry Season. Abundance of pink shrimp was calculated using throw-trap data collected by J. Browder's research team during the 2005 Dry Season. Abundance of goldspotted killifish represent 5-year averages of fish abundance collected from visual transects placed along the mangrove habitats of western Biscayne Bay by J. Serafy' research team.

Figure 28. Location of the salinity probes deployed in this study (stars) and salinity probes deployed by BNP and the ACoE (dots). The inset shows the miniature (4 cm) loggers used in this study.

Figure 29. Salinity and temperature patterns from a canal-influenced site (Mowry Canal) and a site further away from canal influences (Turkey Point) in western Biscayne Bay. Loggers were deployed at < 50 m from shore and data retrieved at monthly intervals.

Figure 30. Salinity patterns, canal discharge rates, and precipitation patterns for selected locations in western Biscayne Bay. A) mean monthly salinity values (± 1 S.D), B) salinity variability (coefficient of variation, CV). Data for A and B were collected using loggers deployed in 2005. Values were collected at 30-min intervals and used to calculate daily and then monthly averages. Monthly SD and CV were calculated using daily averages. C) Mean monthly canal discharge patterns (± 1 S.D), D) Mean monthly precipitation values (± 1 S.D). Data for C and D were obtained from the South Florida Water Management District. Daily discharge and precipitation data were added to obtain a monthly total and these values were averaged for the period between 1995-2004 to obtain 10-year means. The diamonds in D show monthly precipitation values for 2005.

SWaPS SURVEY PLATFORM

SAMPLE VIDEO FRAME

Fig. 1

2005 BENTHIC SURVEYS:
SAMPLING DESIGN AND SAMPLING SITES

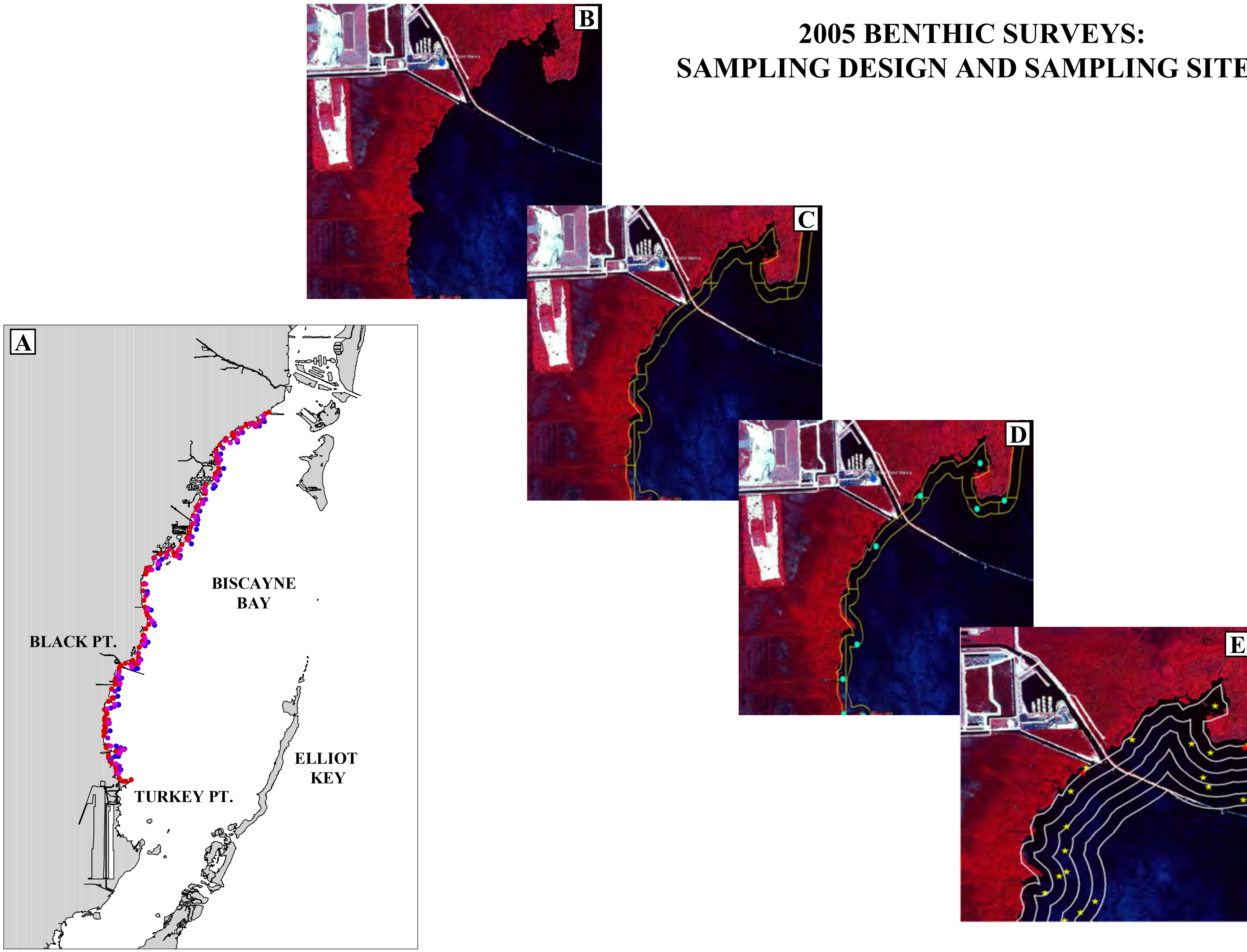


Fig. 2

Abundance of All Seagrasses Combined

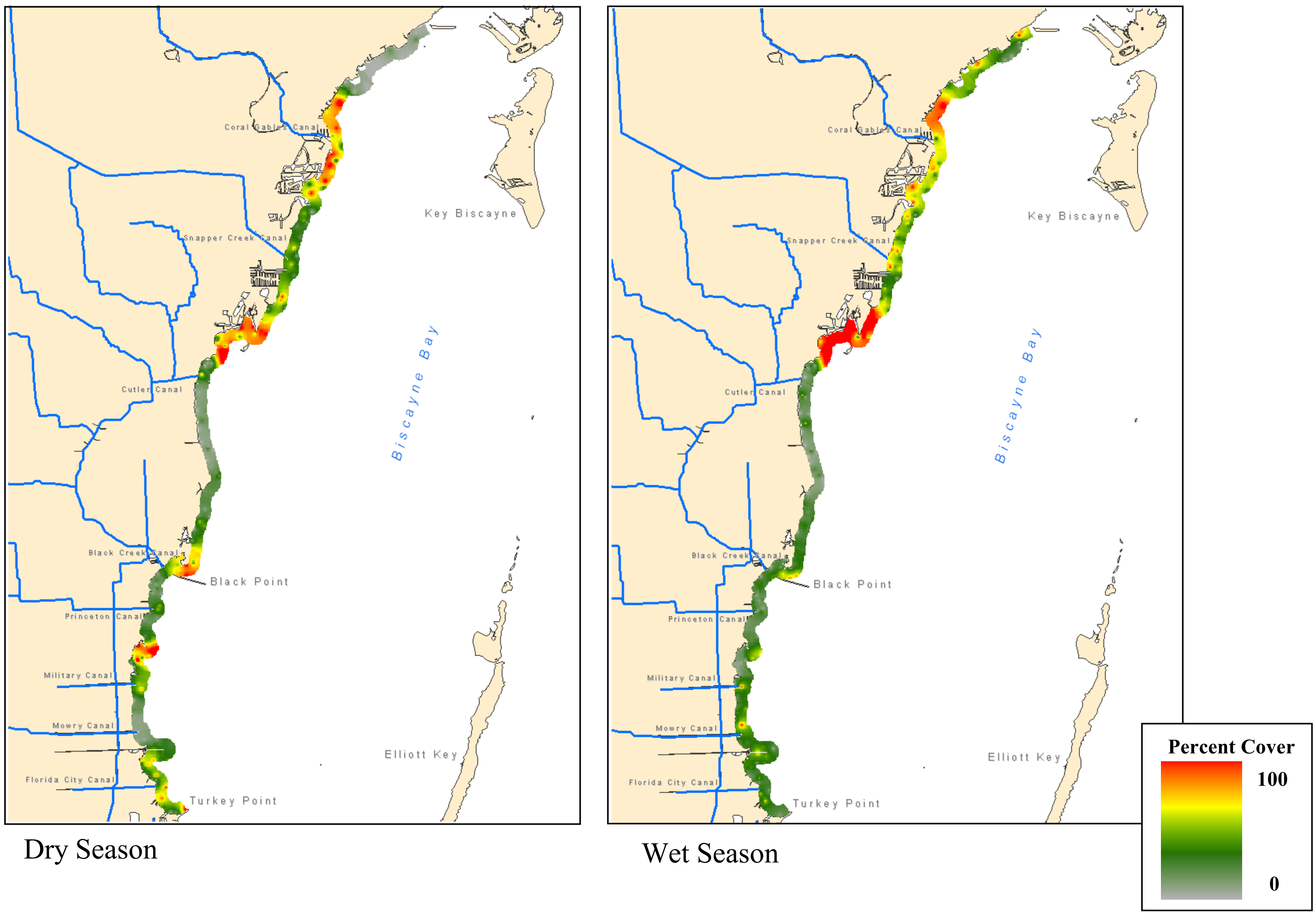


Fig. 3

Abundance of *Thalassia testudinum*

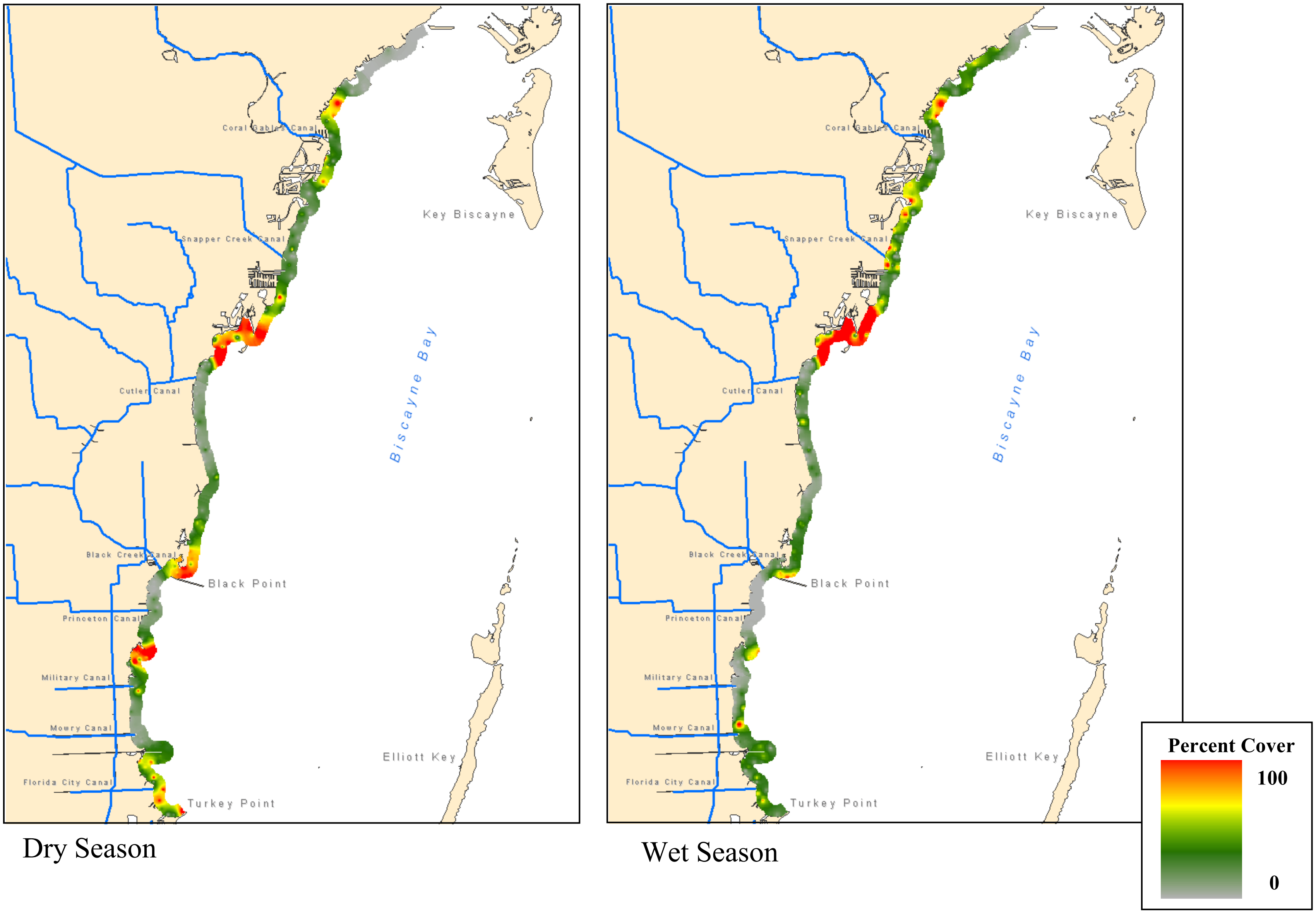


Fig. 4

Abundance of *Halodule wrightii*

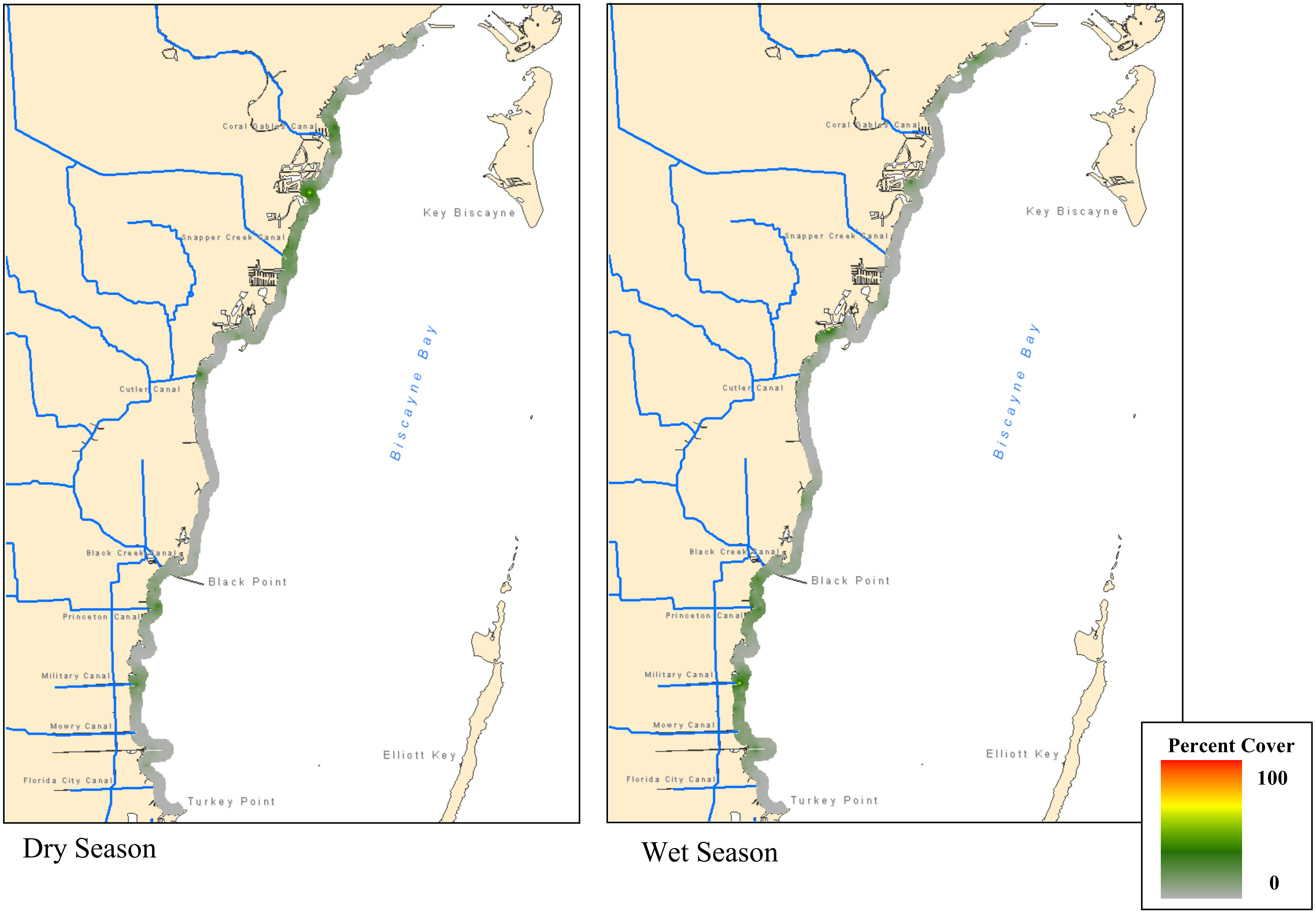


Fig. 5

Abundance of *Syringodium filiforme*

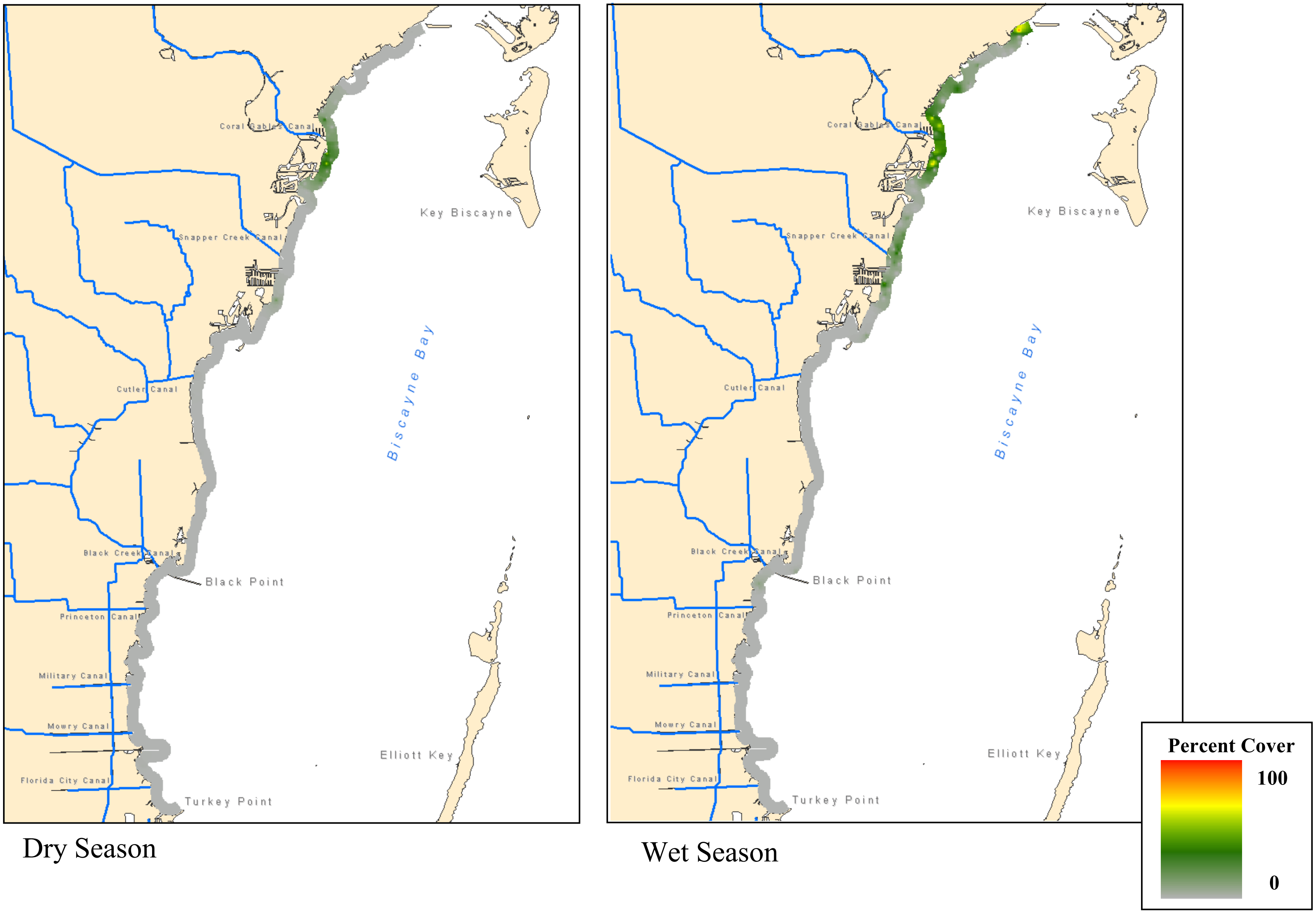


Fig. 6

Abundance of *Ruppia maritima*

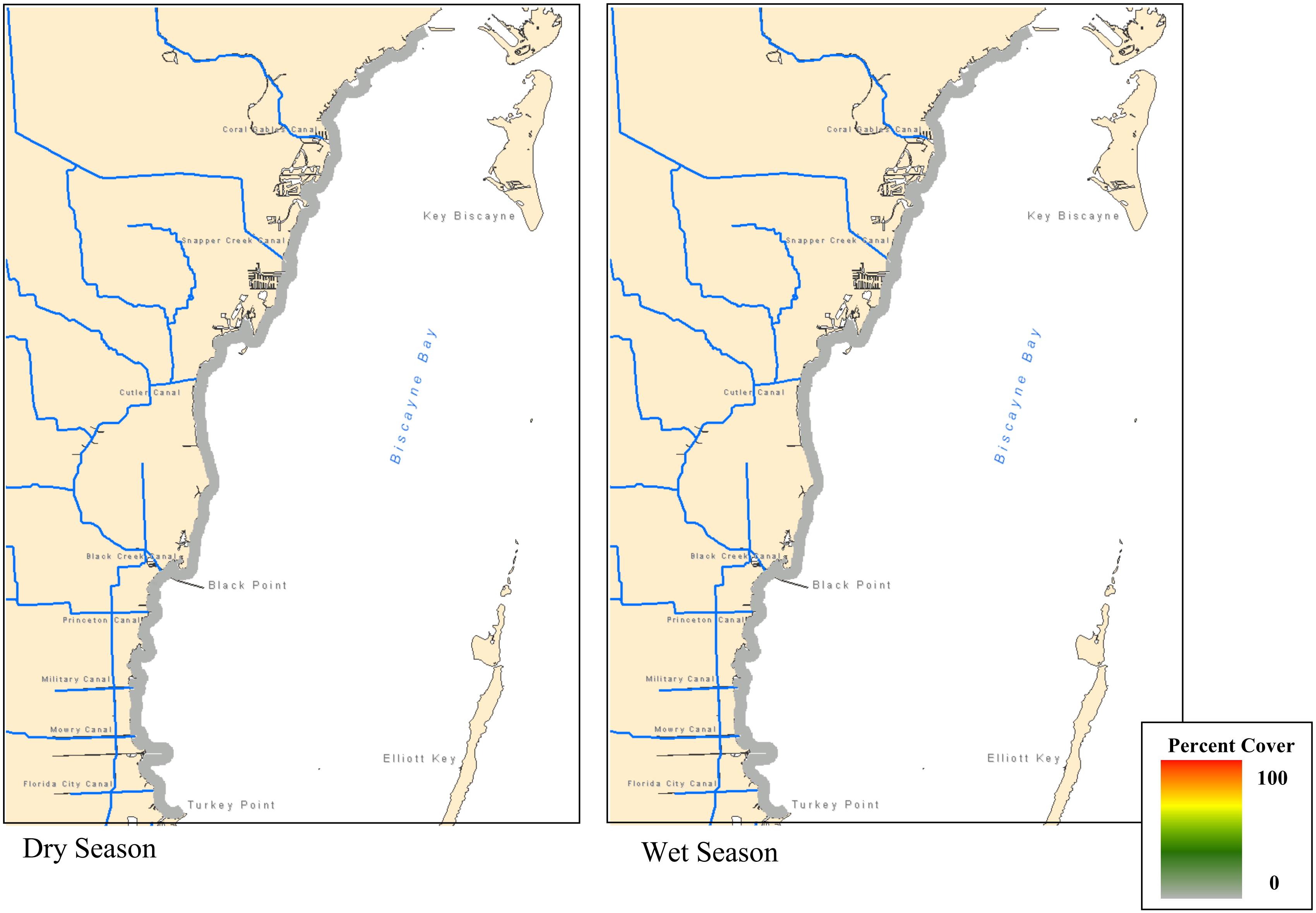


Fig. 7

Relative Abundance of *Halodule wrightii*

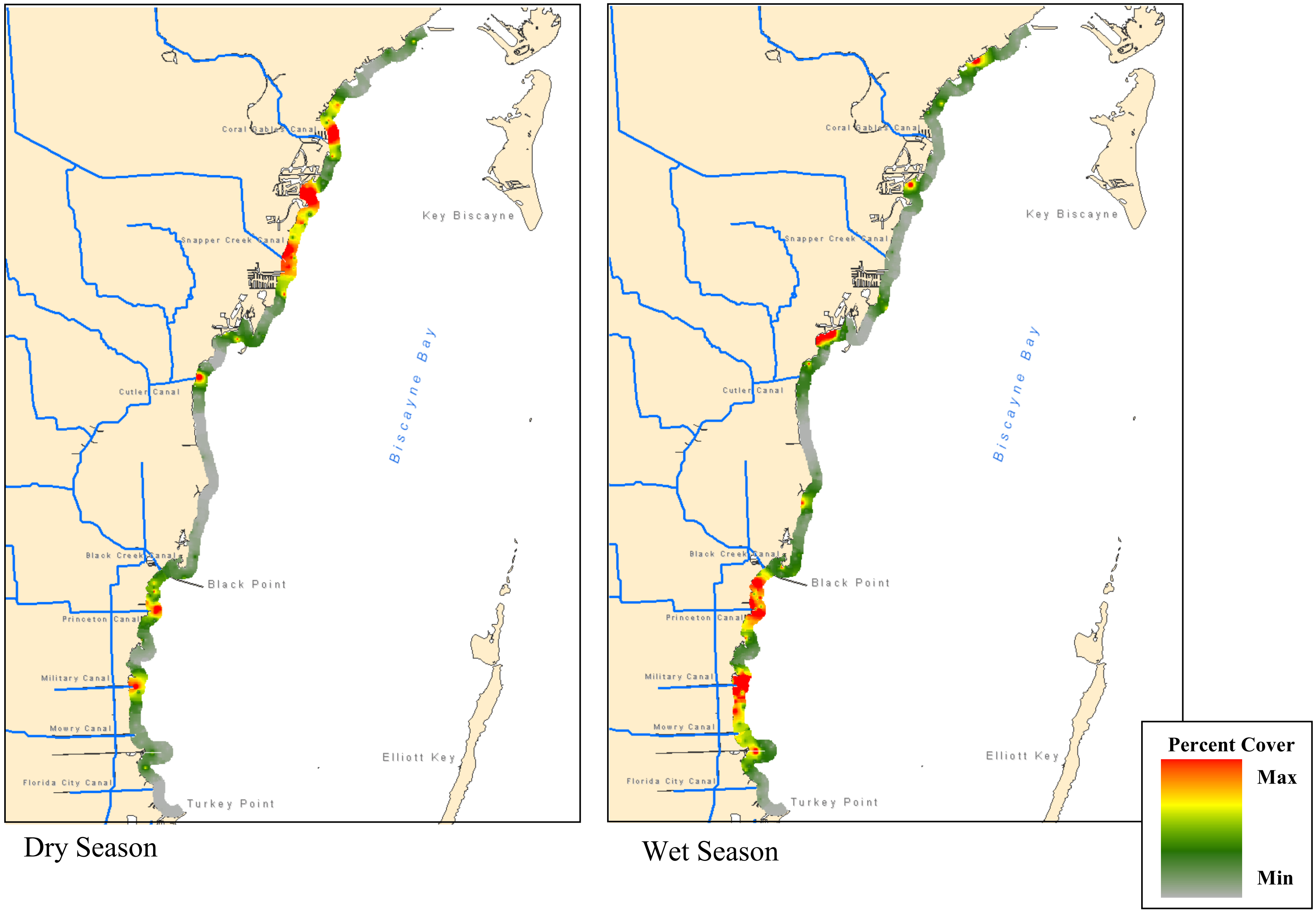


Fig. 8

Relative Abundance of *Syringodium filiforme*

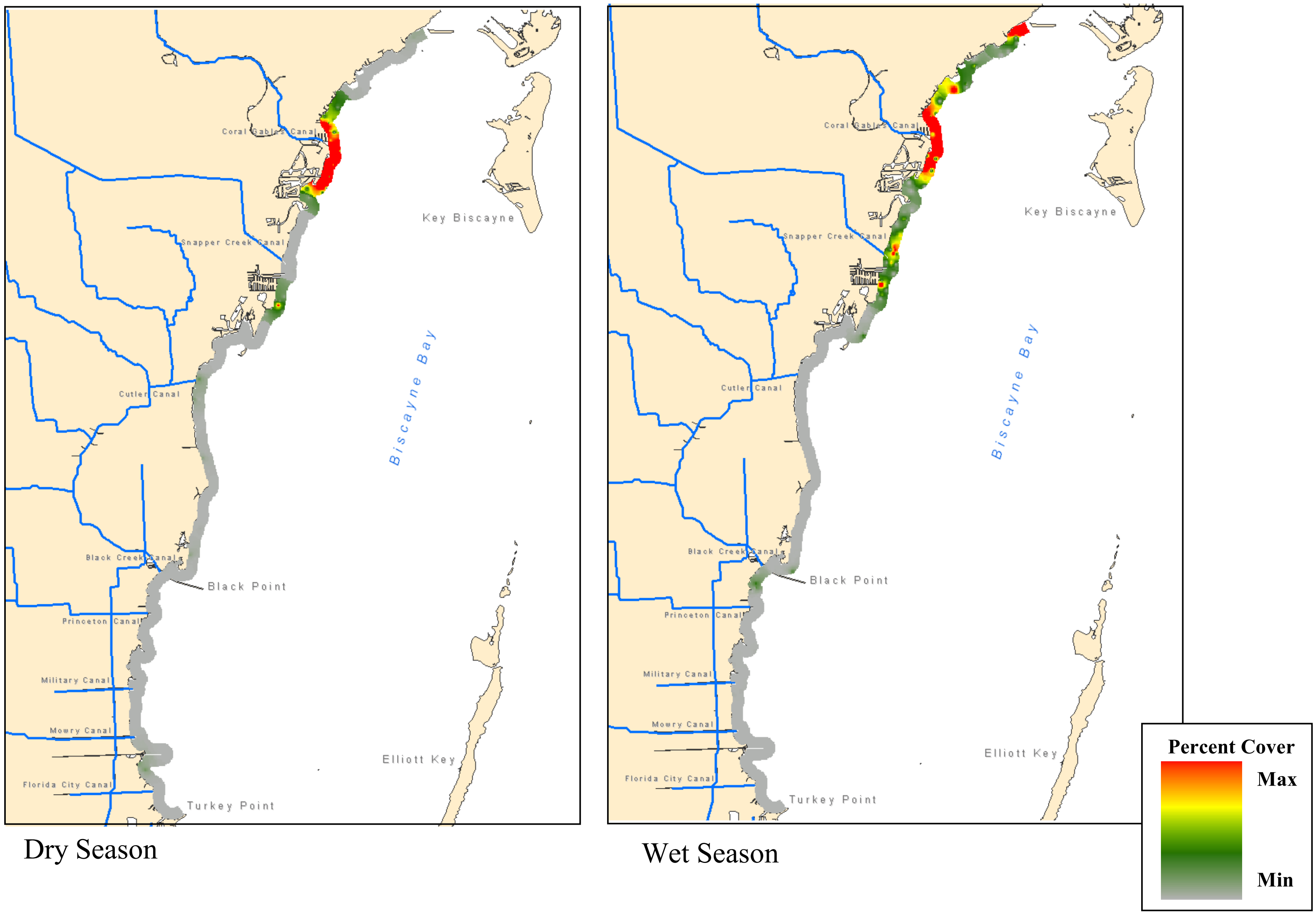


Fig. 9

Relative Abundance of *Ruppia maritima*

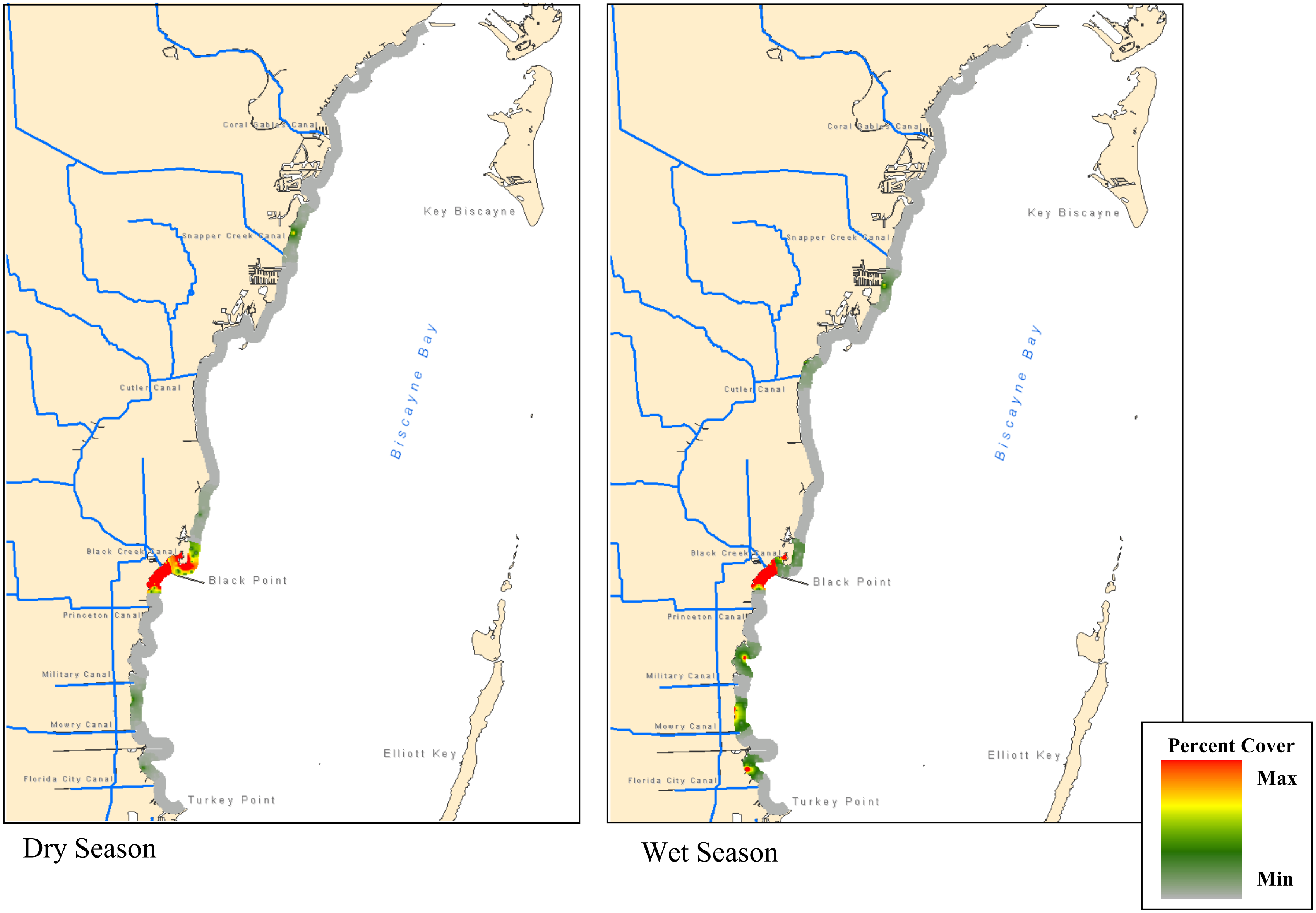


Fig. 10

Abundance of Attached Macroalgae

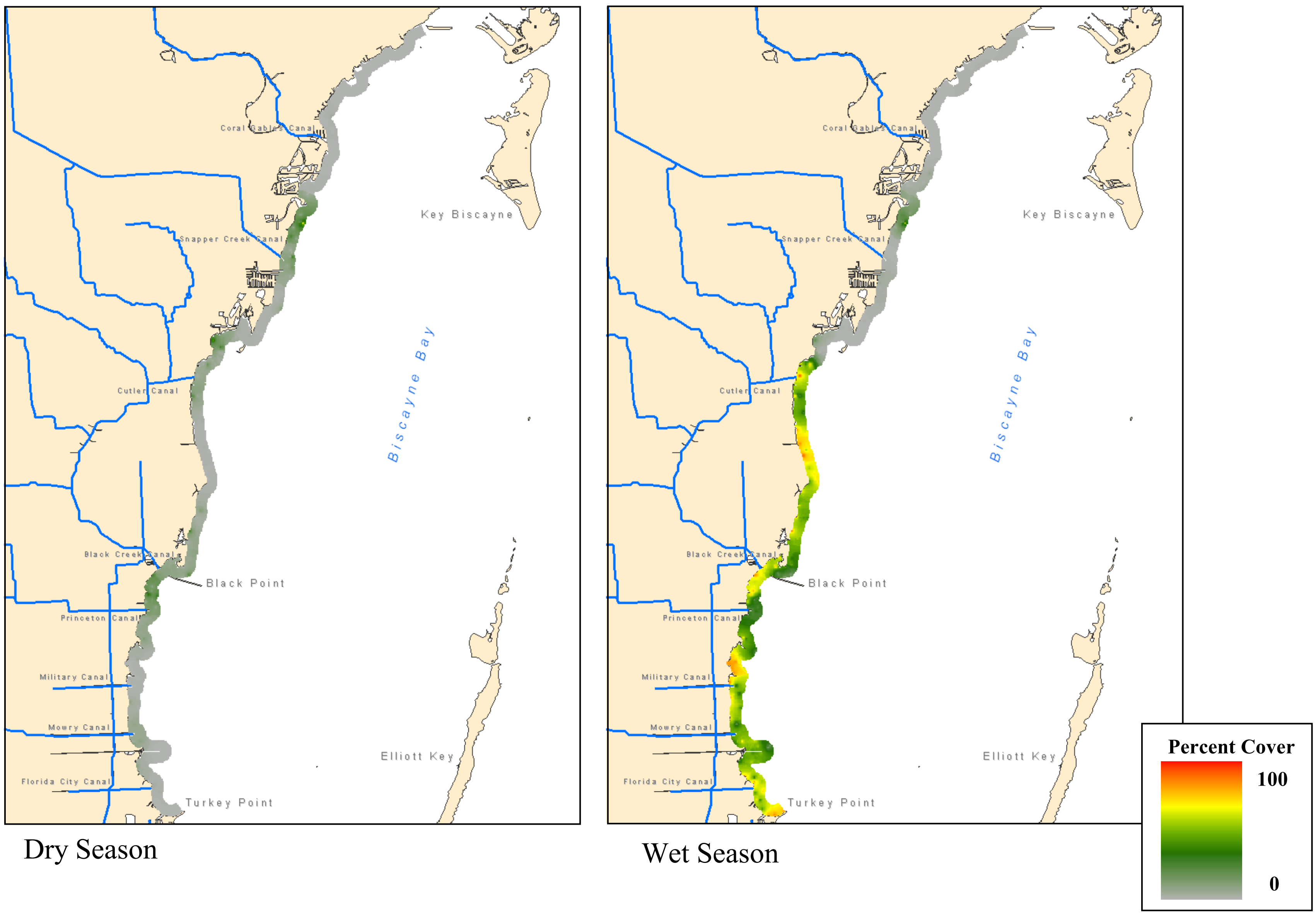


Fig. 11

Abundance of Drift Macroalgae

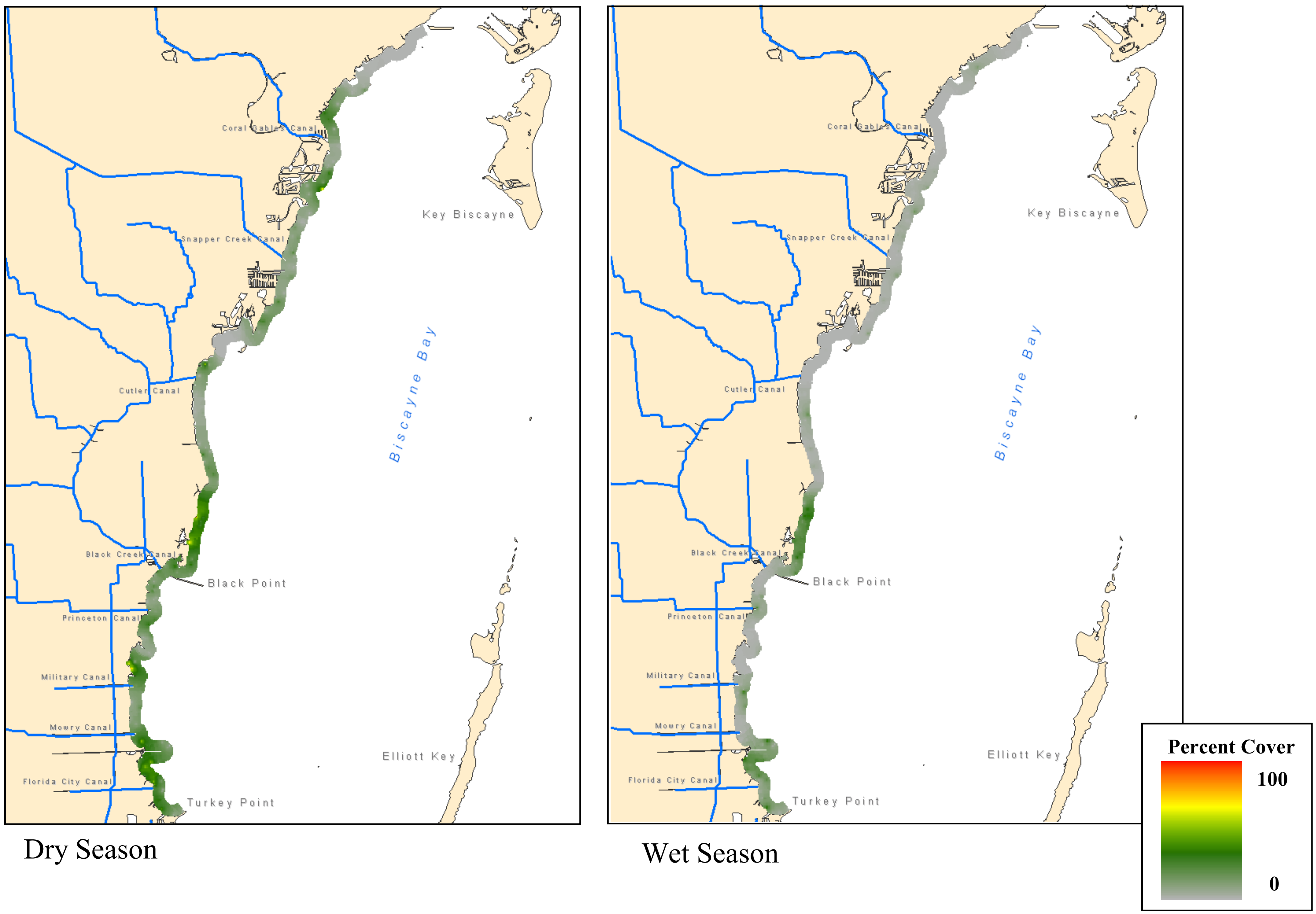
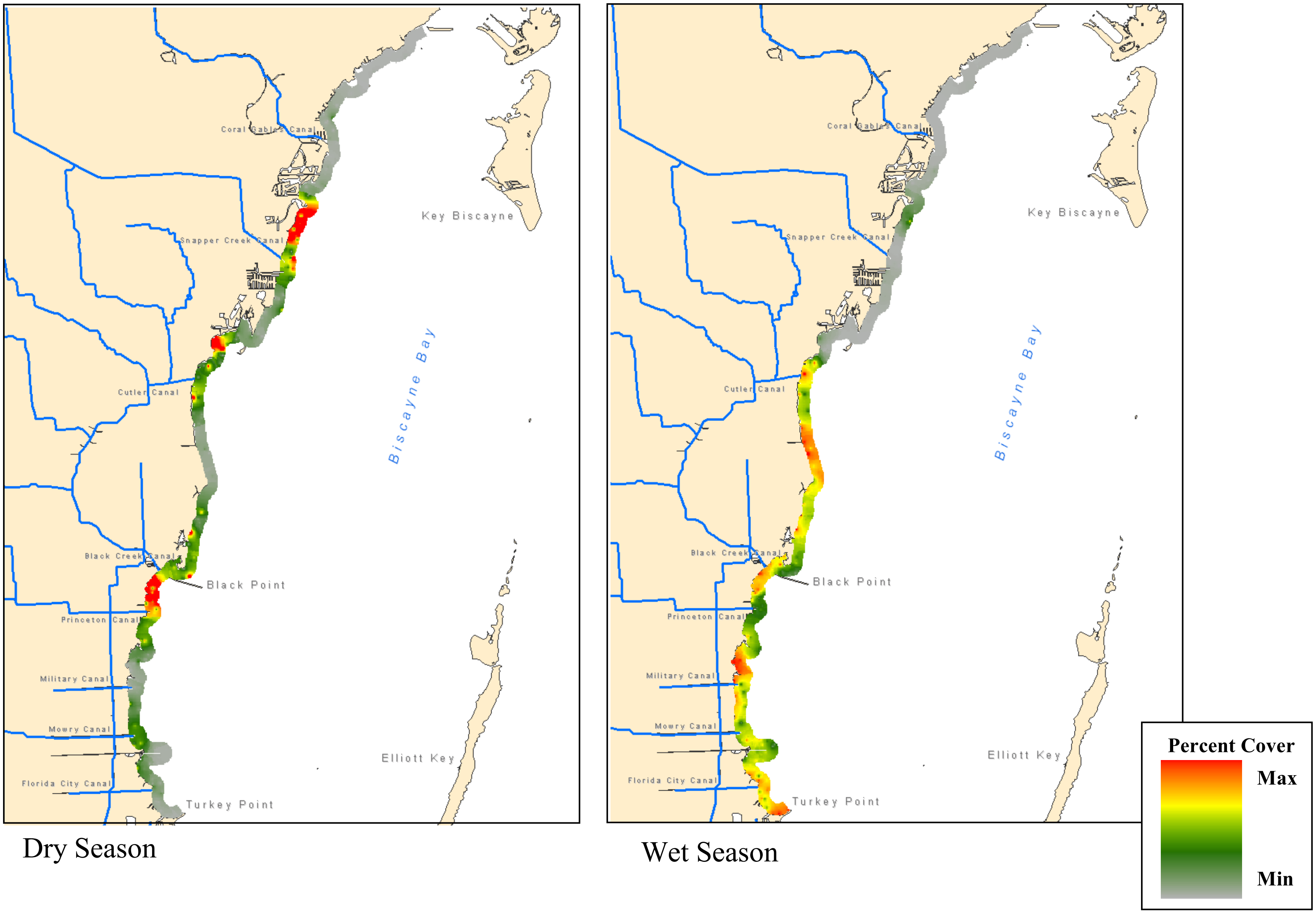


Fig. 12

Relative Abundance of Attached Macroalga



Dry Season

Wet Season

Fig. 13

Relative Abundance of Drift Macroalgae

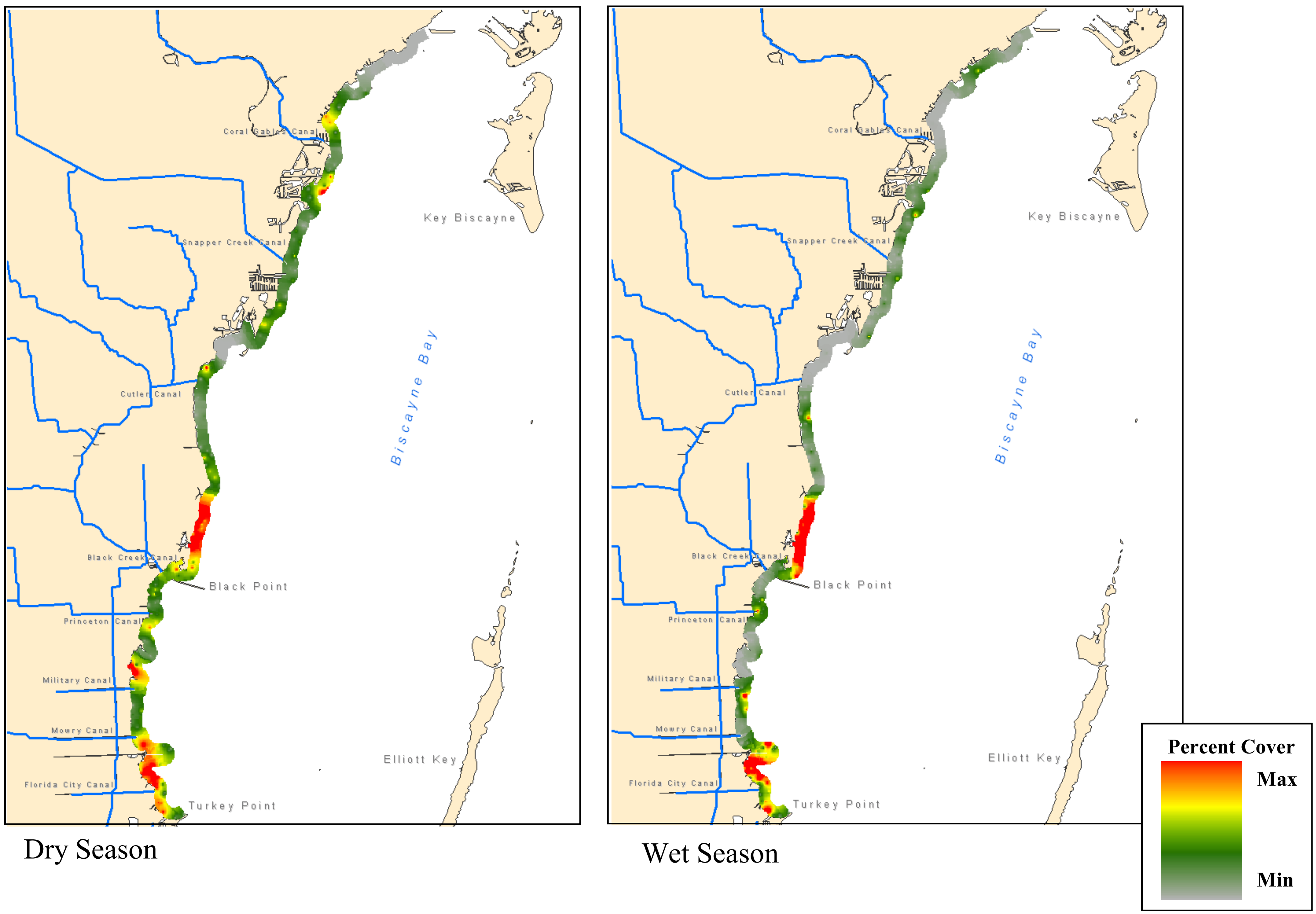
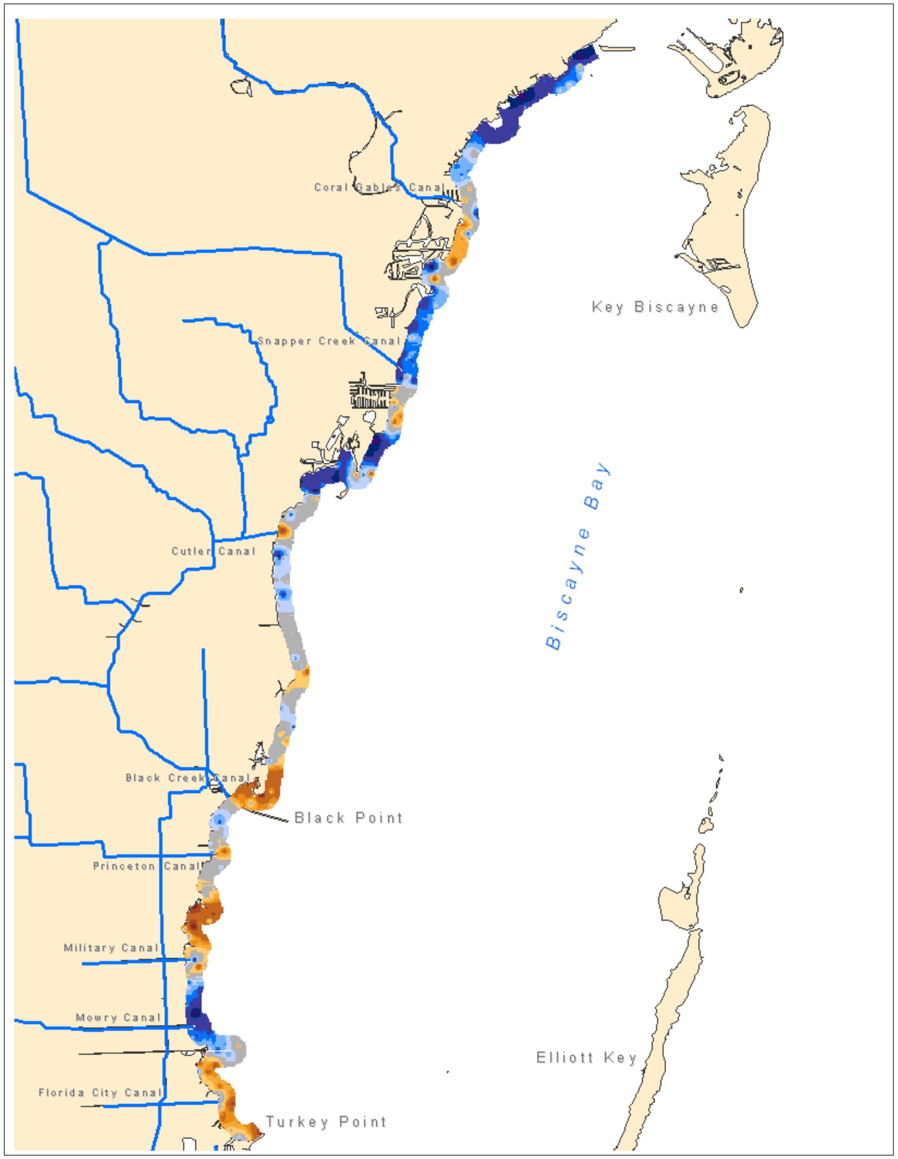


Fig. 14

Seasonal Change in Abundance of All Seagrasses Combined



$$\% \text{ Change} = \frac{(\text{Wet Season} - \text{Dry Season})}{\text{Dry Season}}$$

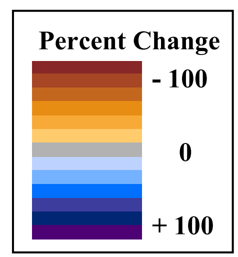
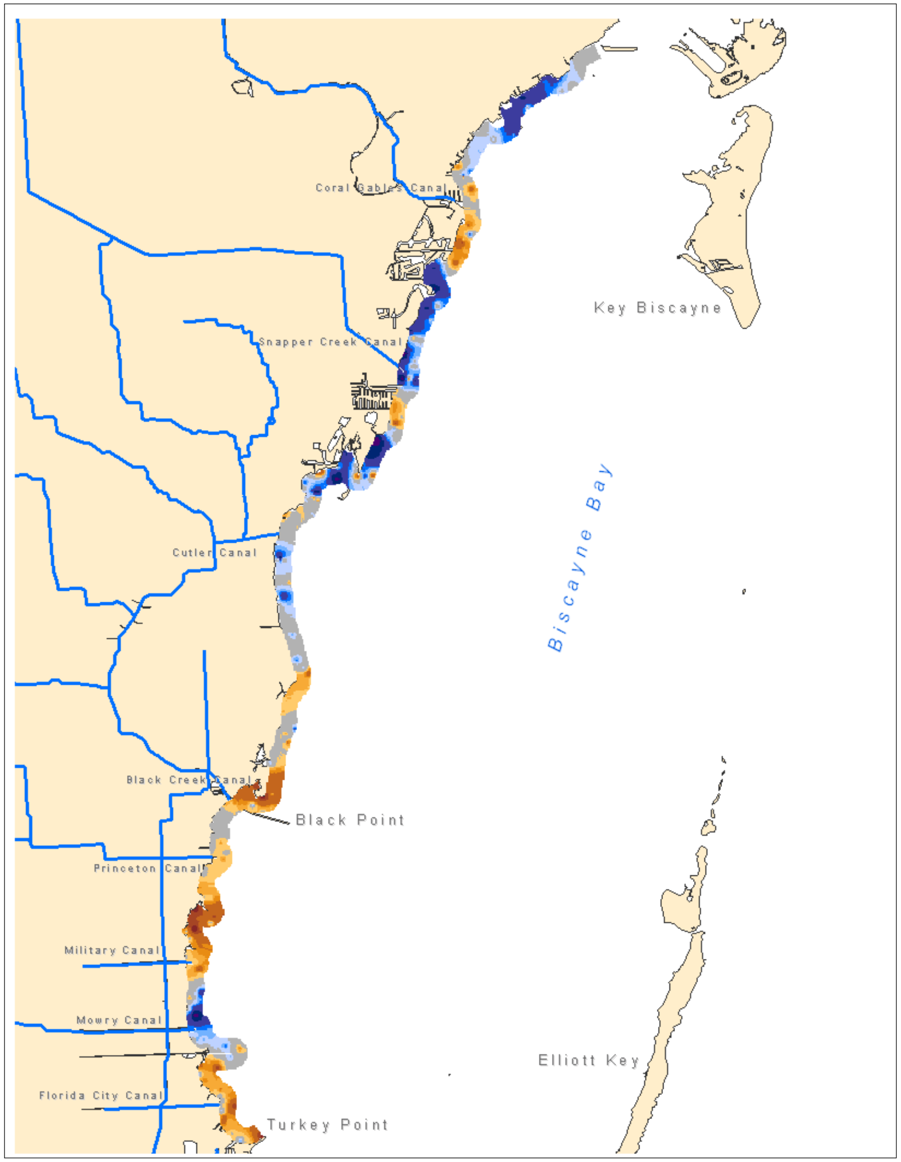


Fig. 15

Seasonal Change in Abundance of *T. testudinum*



$$\% \text{ Change} = \frac{(\text{Wet Season} - \text{Dry Season})}{\text{Dry Season}}$$

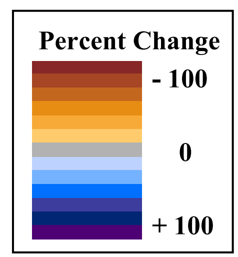
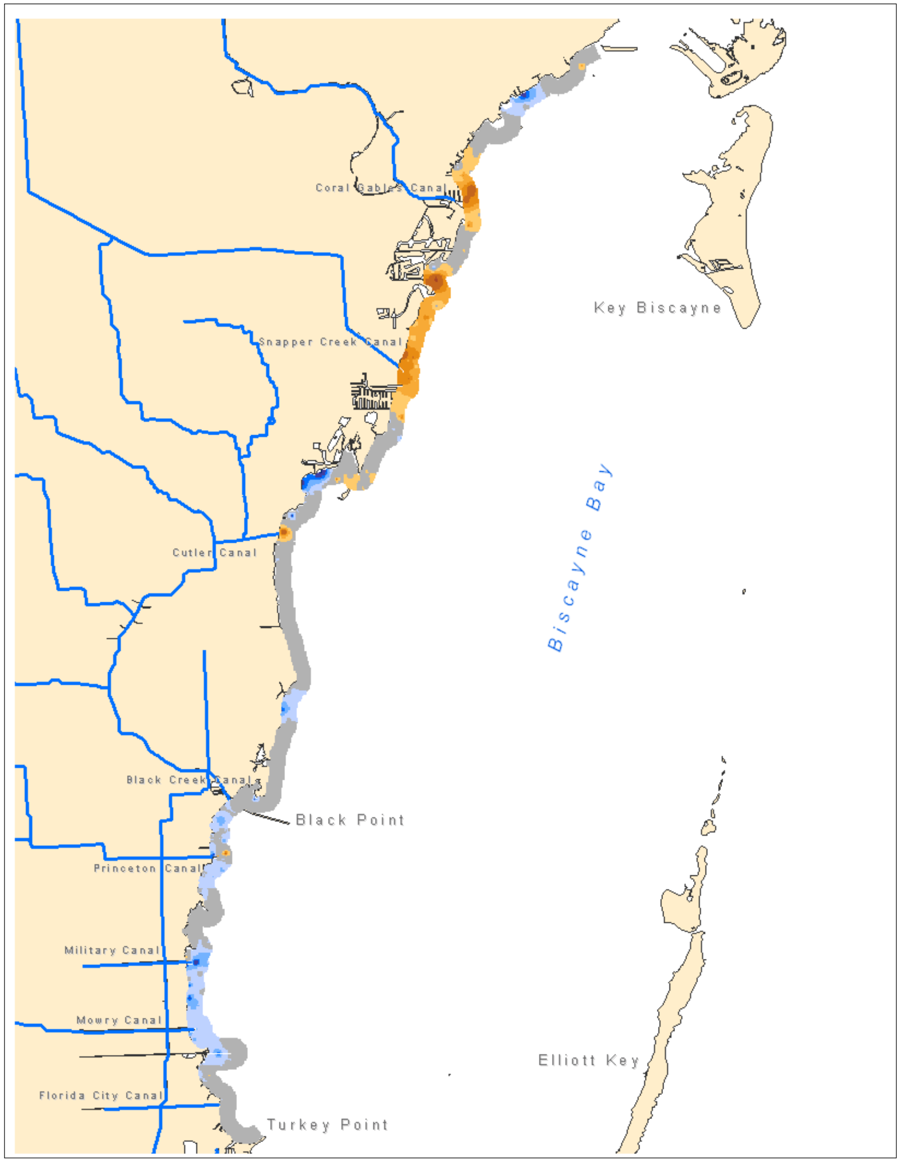


Fig. 16

Seasonal Change in Abundance of *H. wrightii*



$$\% \text{ Change} = \frac{(\text{Wet Season} - \text{Dry Season})}{\text{Dry Season}}$$

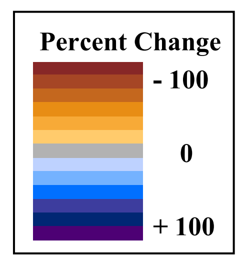
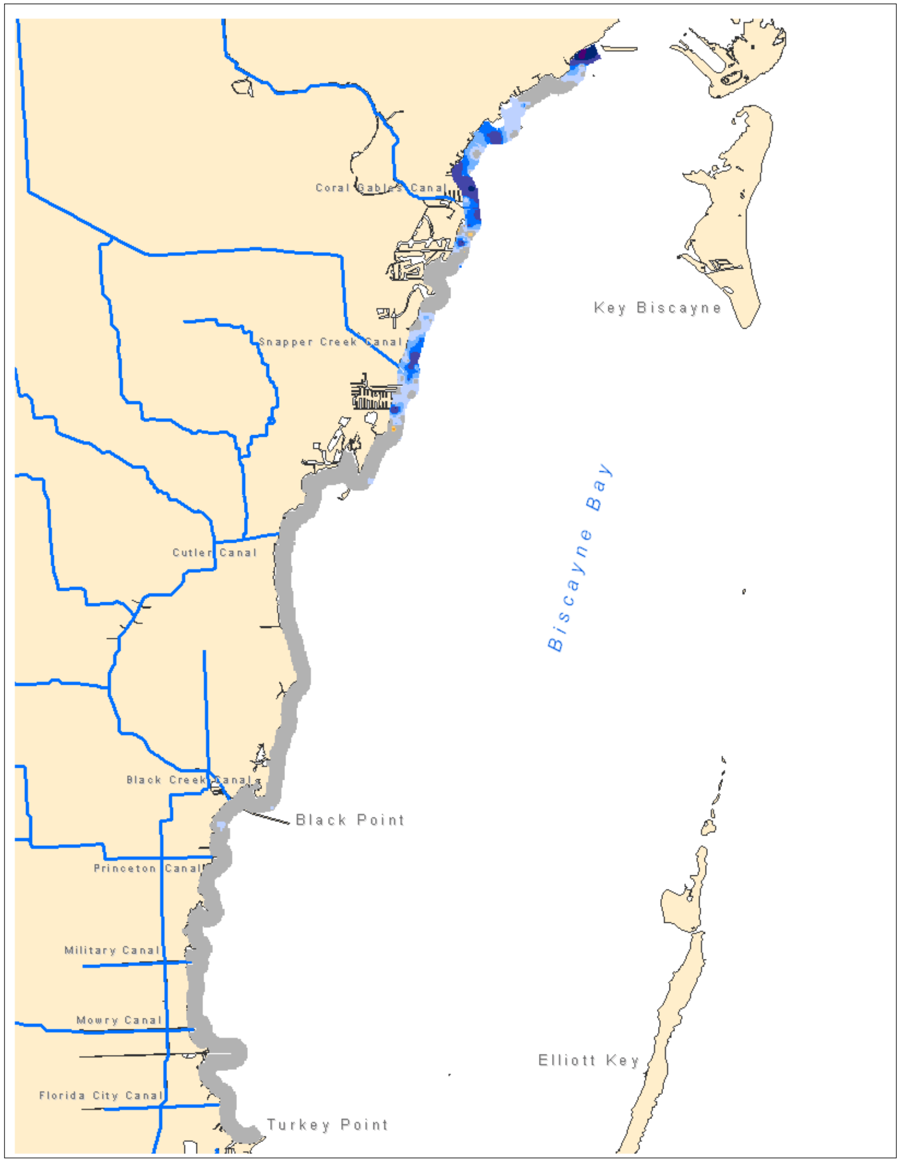


Fig. 17

Seasonal Change in Abundance of *S. filiforme*



$$\% \text{ Change} = \frac{(\text{Wet Season} - \text{Dry Season})}{\text{Dry Season}}$$

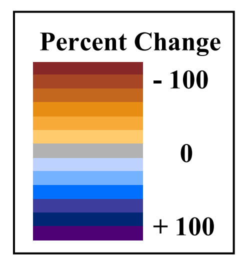
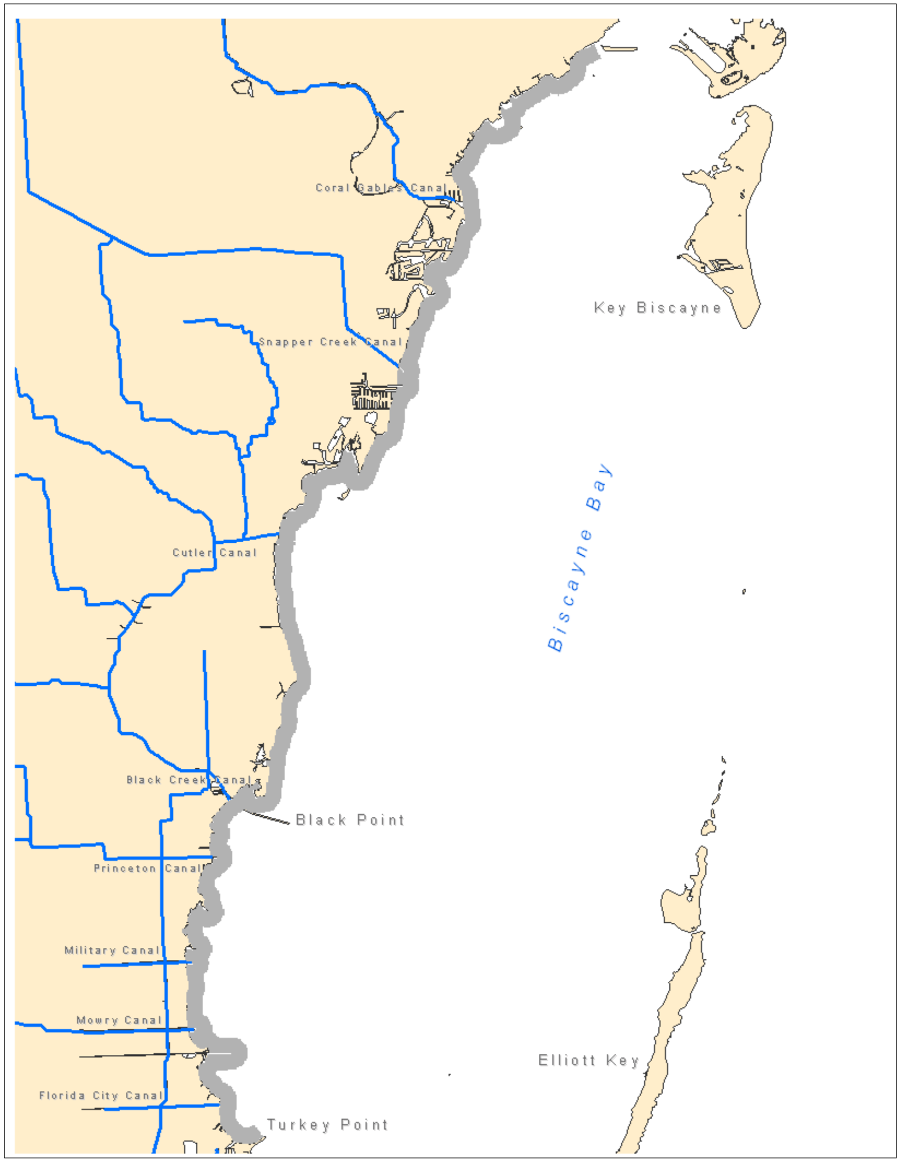


Fig. 18

Seasonal Change in Abundance of *R. maritima*



$$\% \text{ Change} = \frac{\text{(Wet Season – Dry Season)}}{\text{Dry Season}}$$

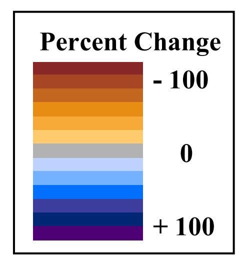
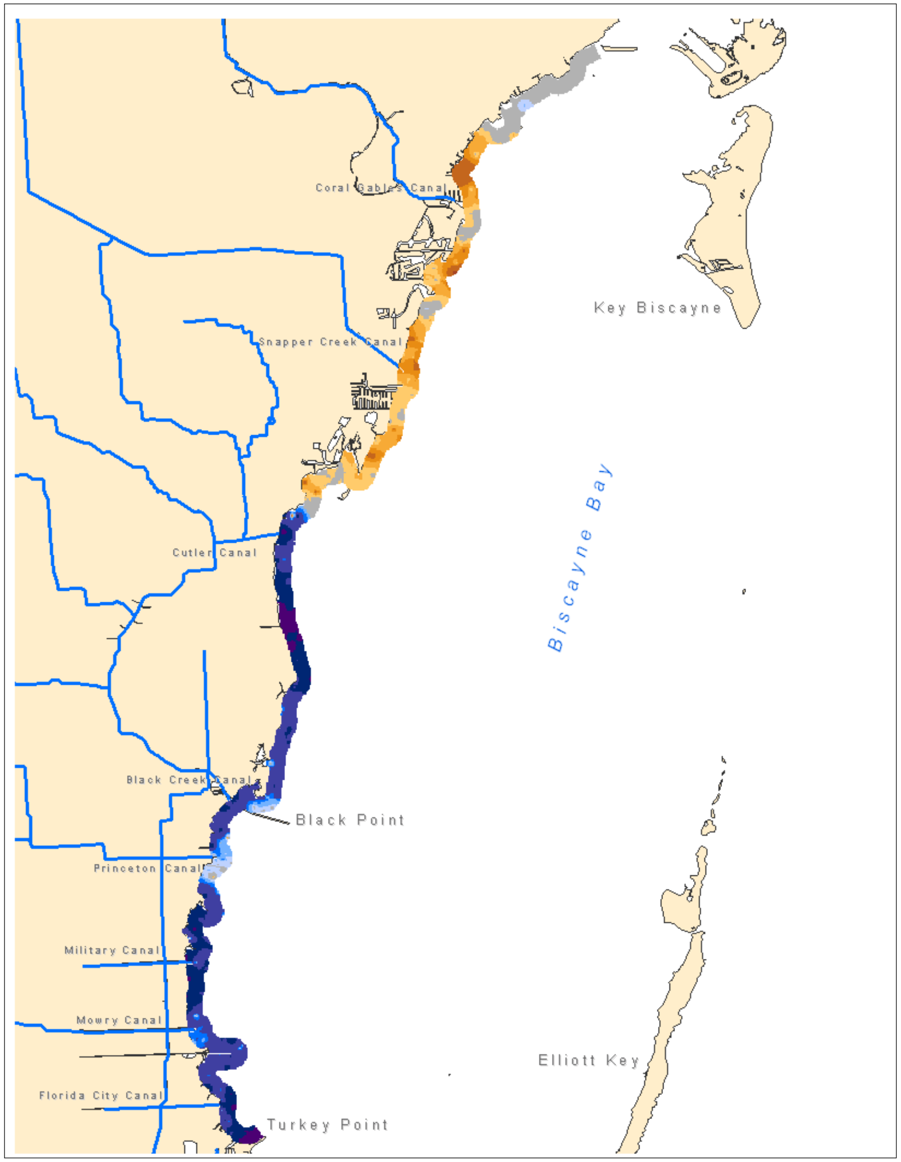


Fig. 19

Seasonal Change in Abundance of all Macroalgae Combined



$$\% \text{ Change} = \frac{(\text{Wet Season} - \text{Dry Season})}{\text{Dry Season}}$$

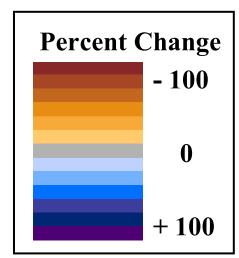
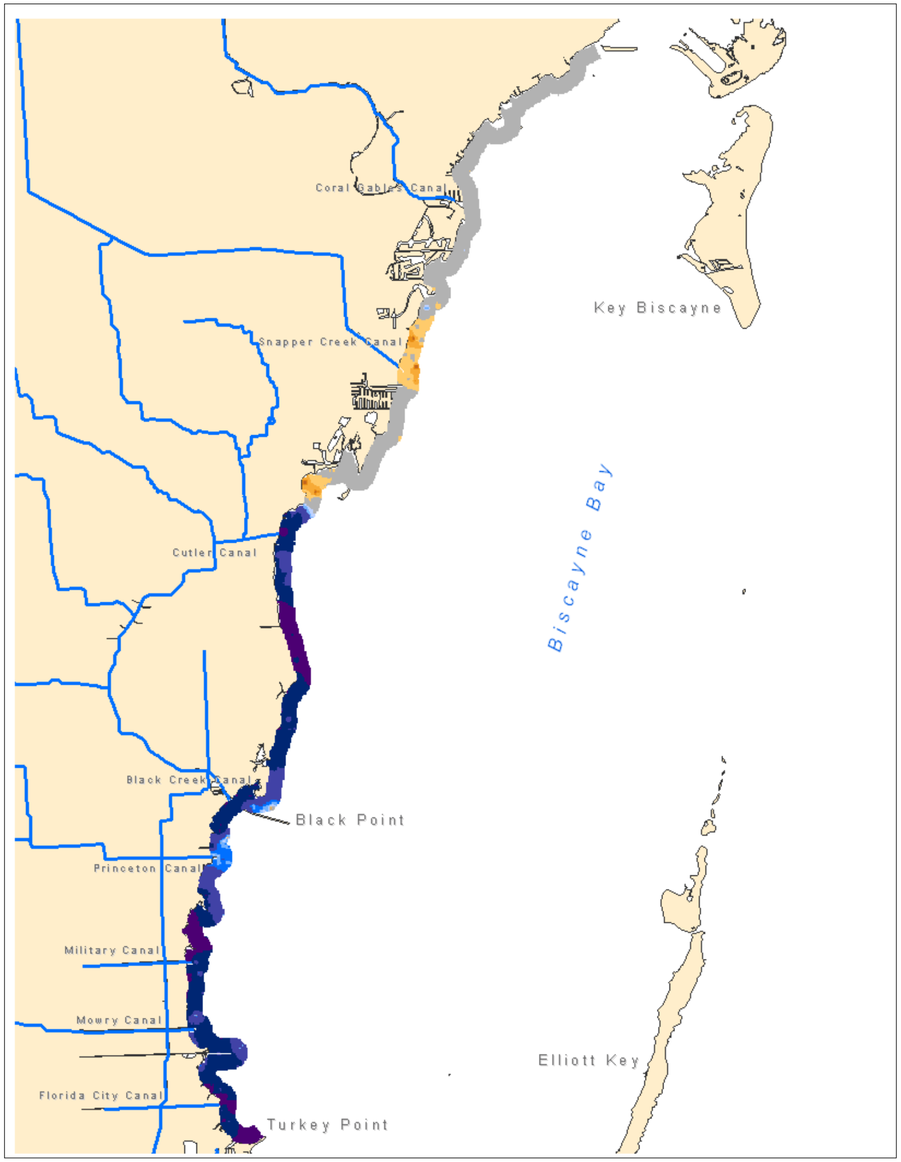


Fig. 20

Seasonal Change in Abundance of Attached Macroalgae



$$\% \text{ Change} = \frac{(\text{Wet Season} - \text{Dry Season})}{\text{Dry Season}}$$

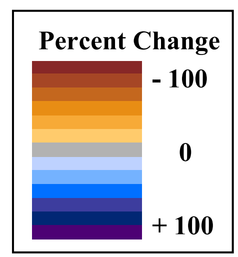
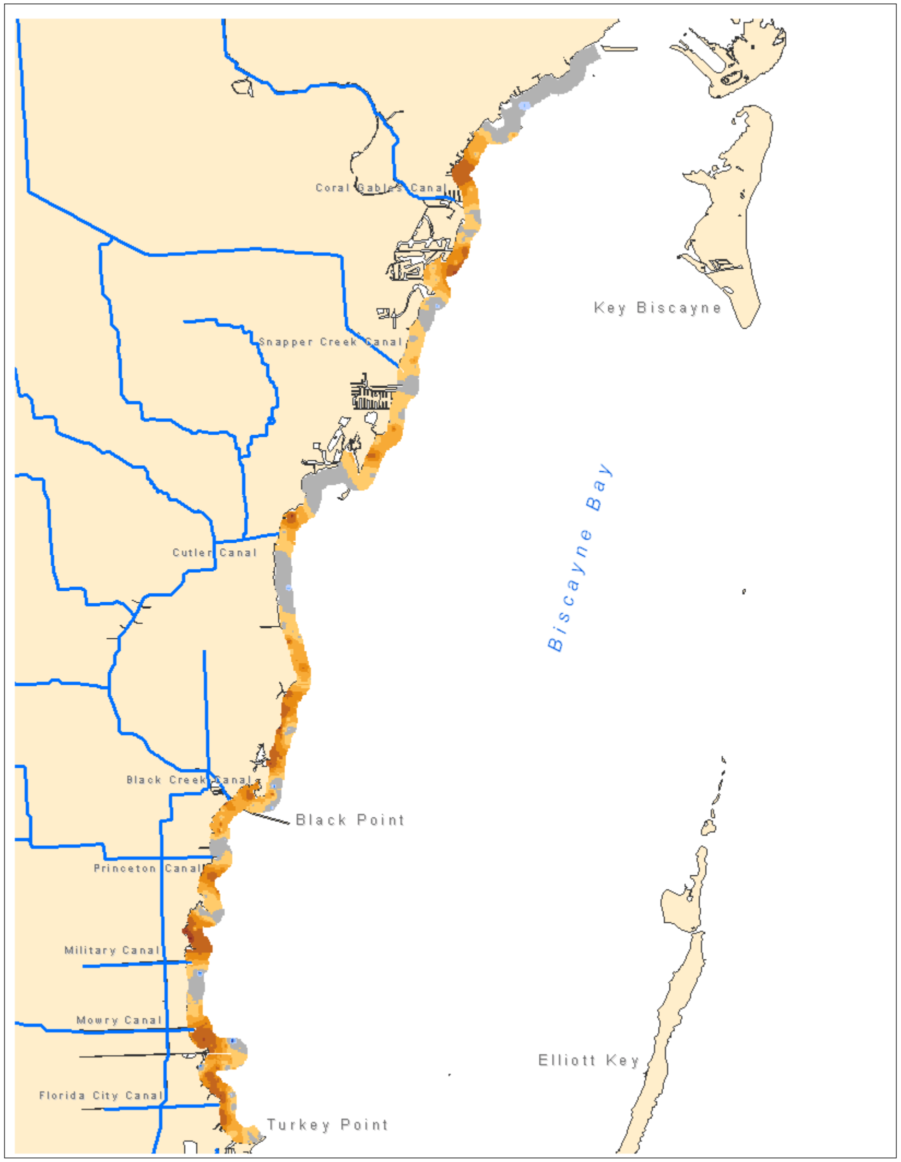


Fig. 21

Seasonal Change in Abundance of Drift Macroalgae



$$\% \text{ Change} = \frac{(\text{Wet Season} - \text{Dry Season})}{\text{Dry Season}}$$

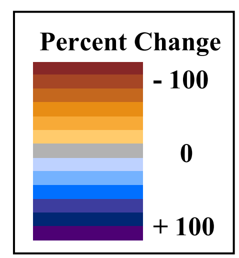
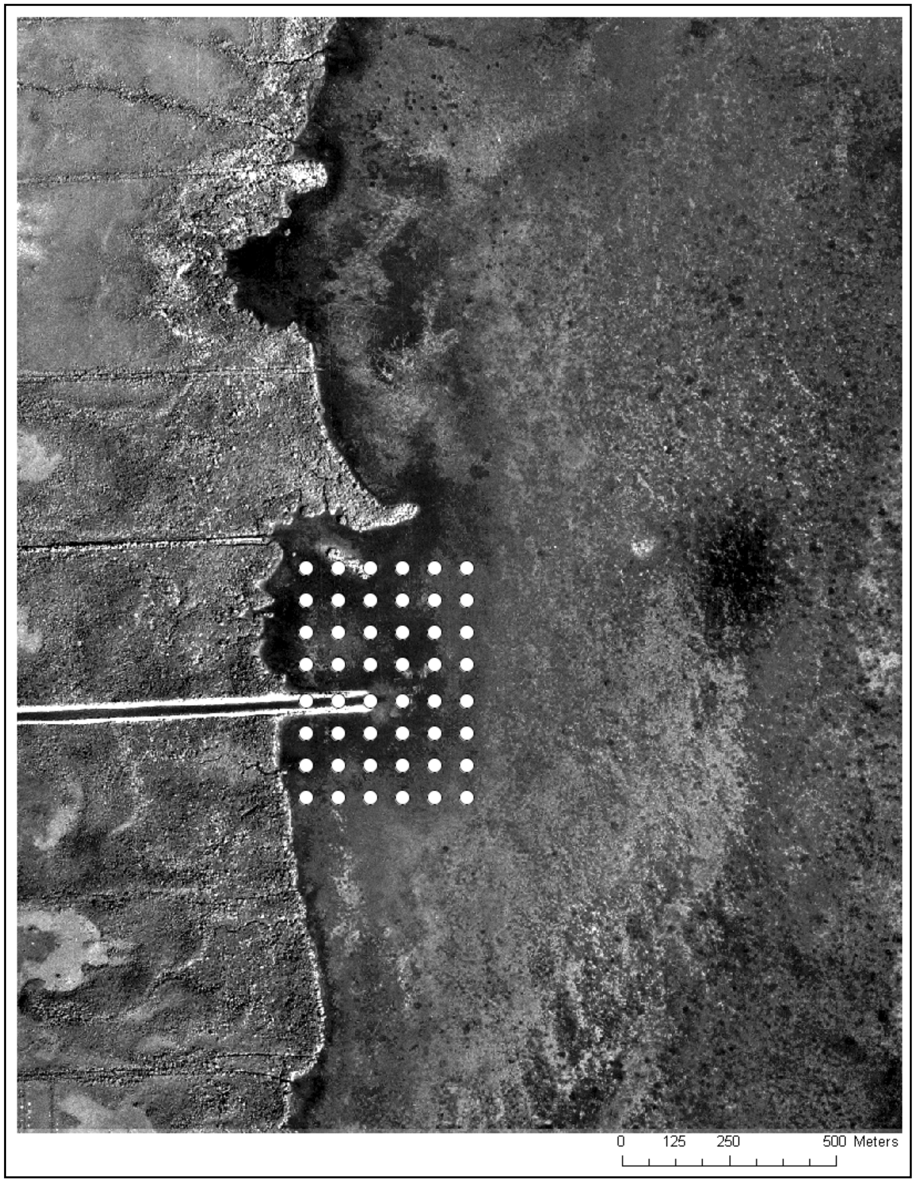


Fig. 22

Military Canal



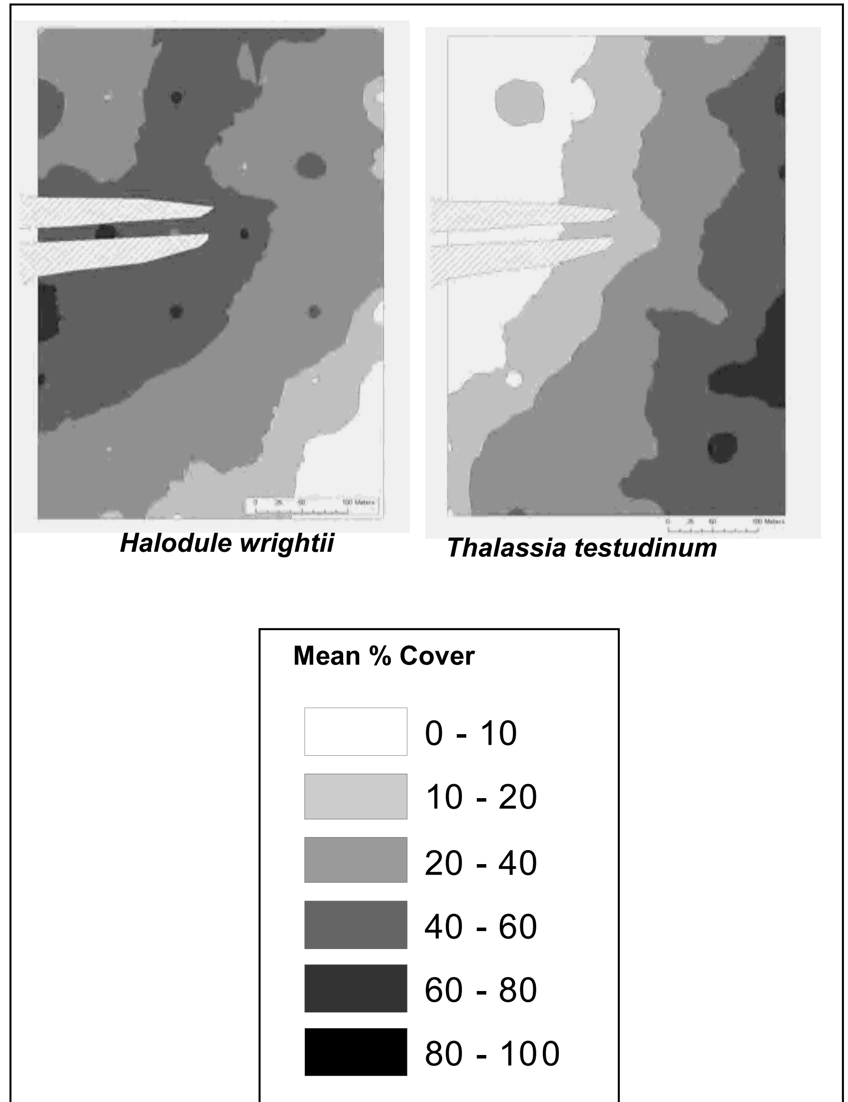


Fig. 23

Mowry Canal

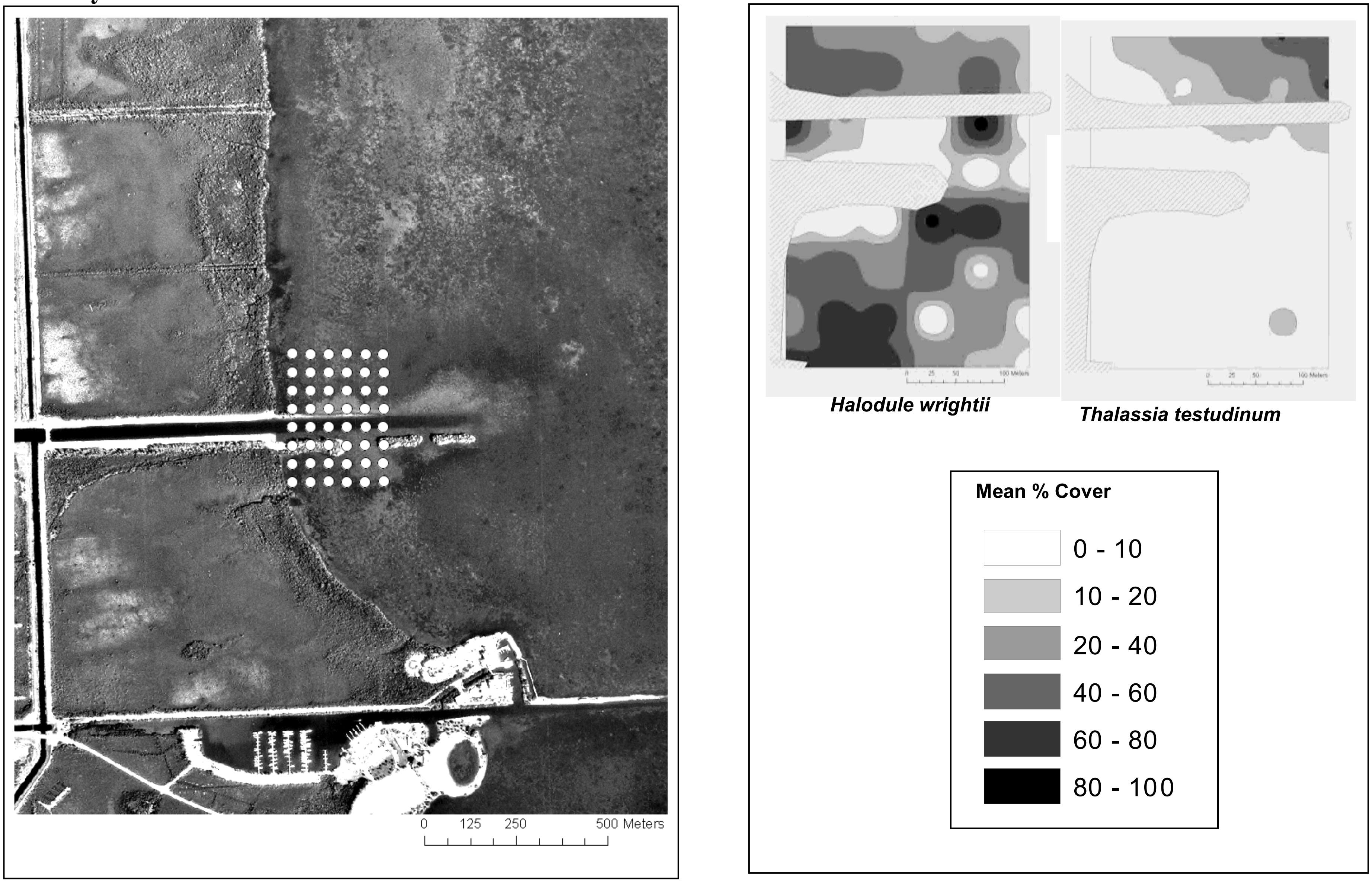
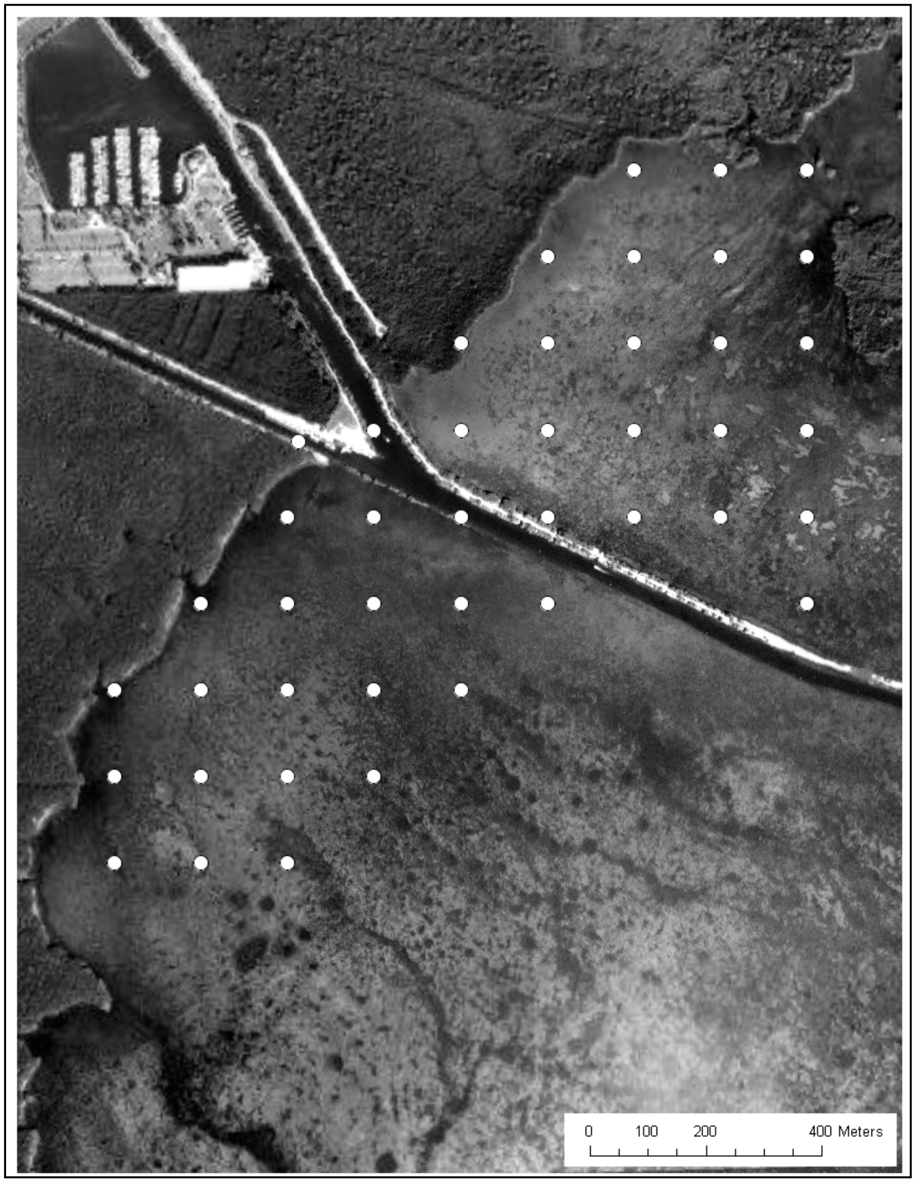


Fig. 24

Black Creek



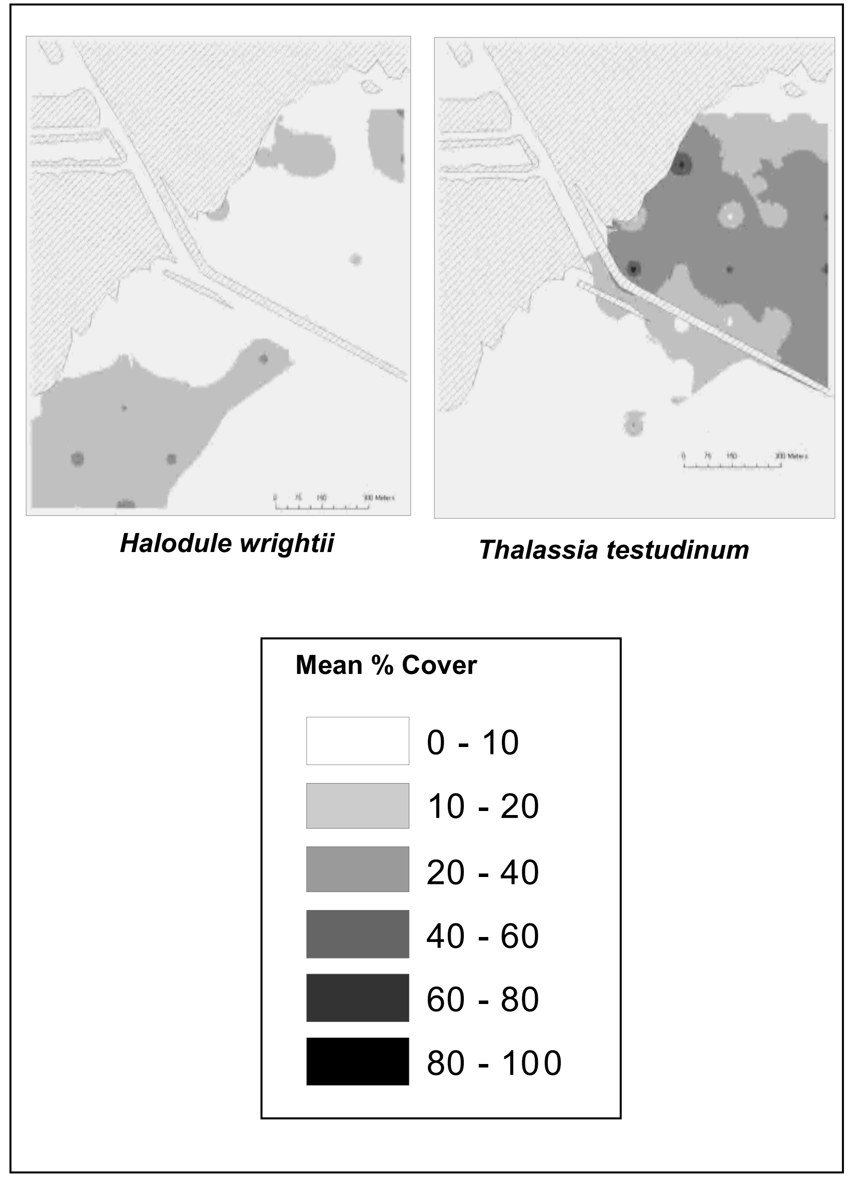
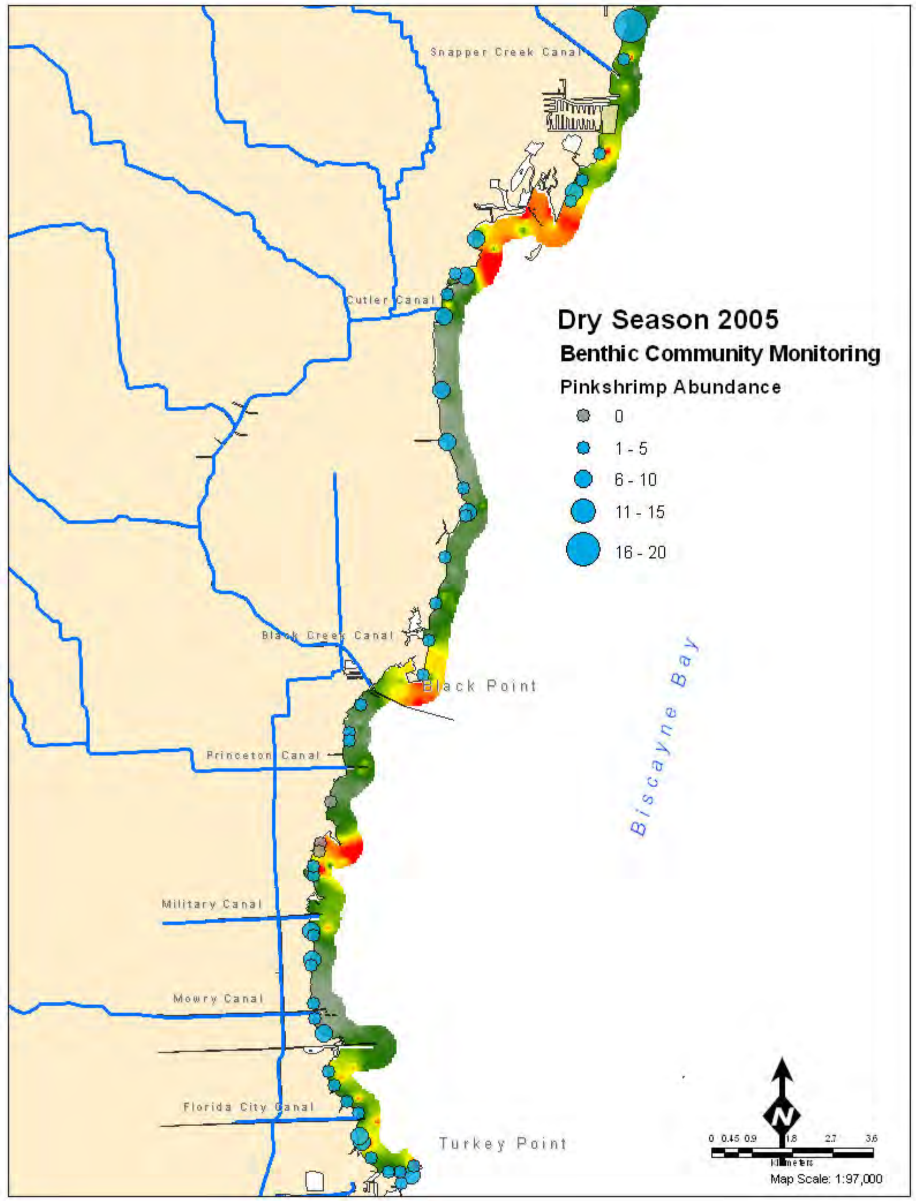


Fig. 25

ABUNDANCE OF PINK SHRIMP

Data provided by J. Browder (NOAA)



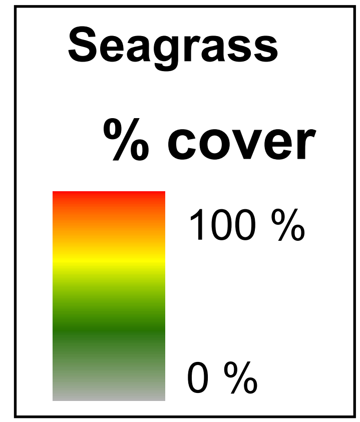


Fig. 26

ABUNDANCE OF KILLIFISH

Data provided by J. Serafy (NOAA)

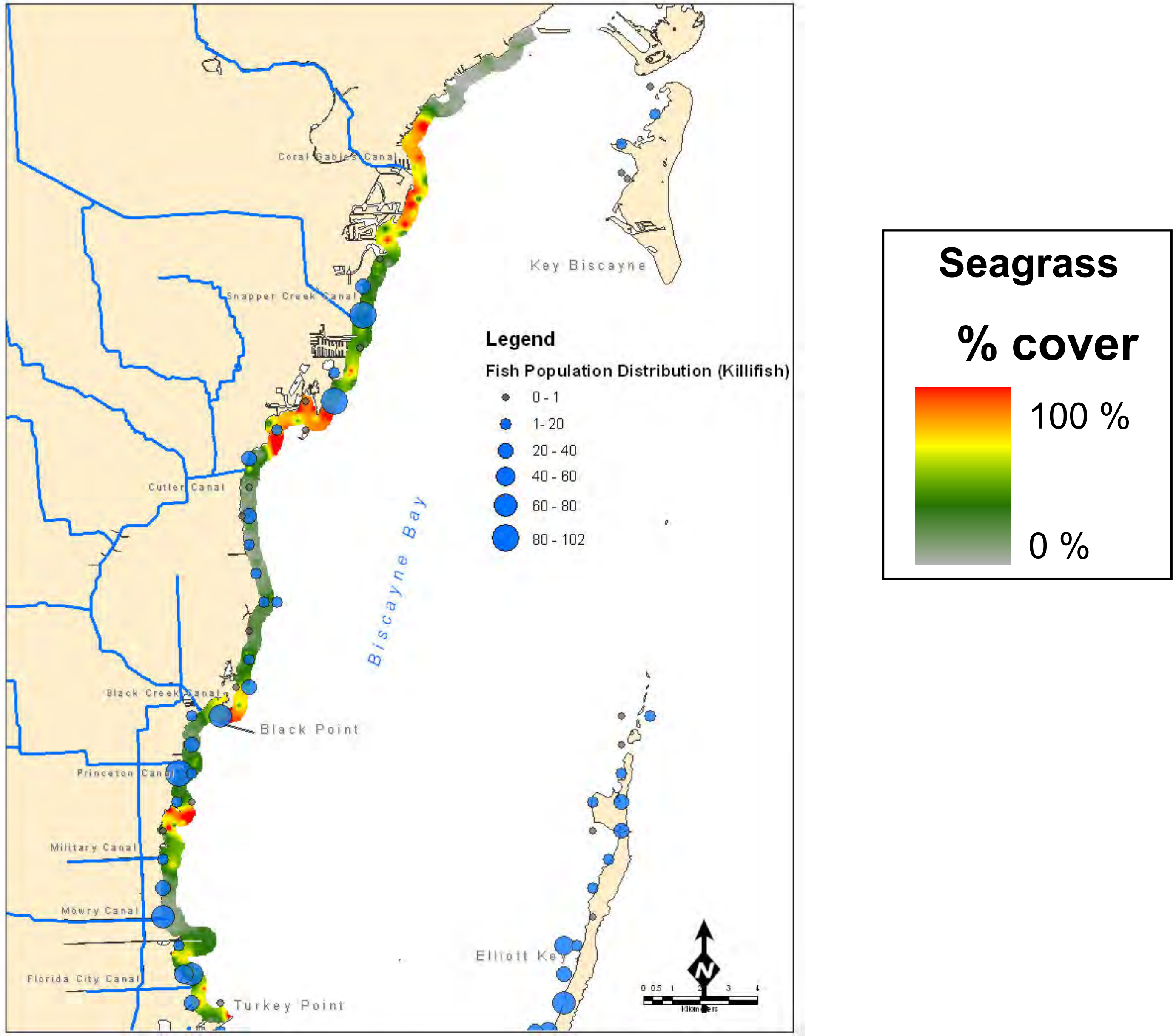
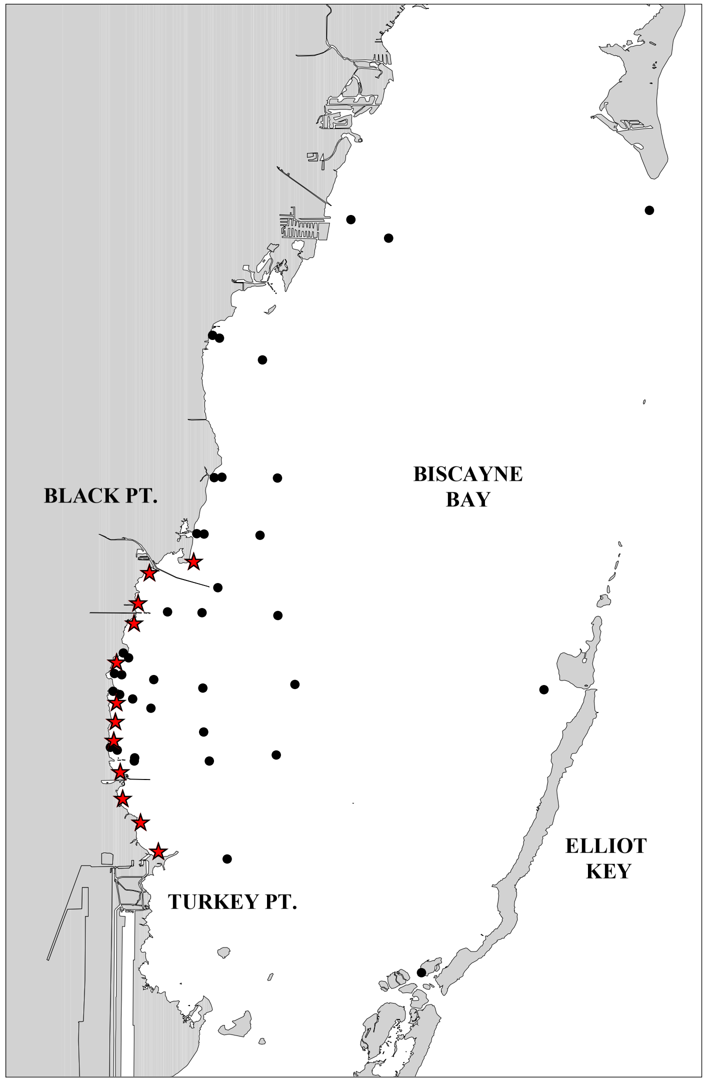


Fig. 27

SALINITY/TEMPERATURE LOGGERS DEPLOYED IN BISCAYNE BAY



Salinity/Temperature Probes

- ★ This study
- ● BNP and ACoE

Fig. 28

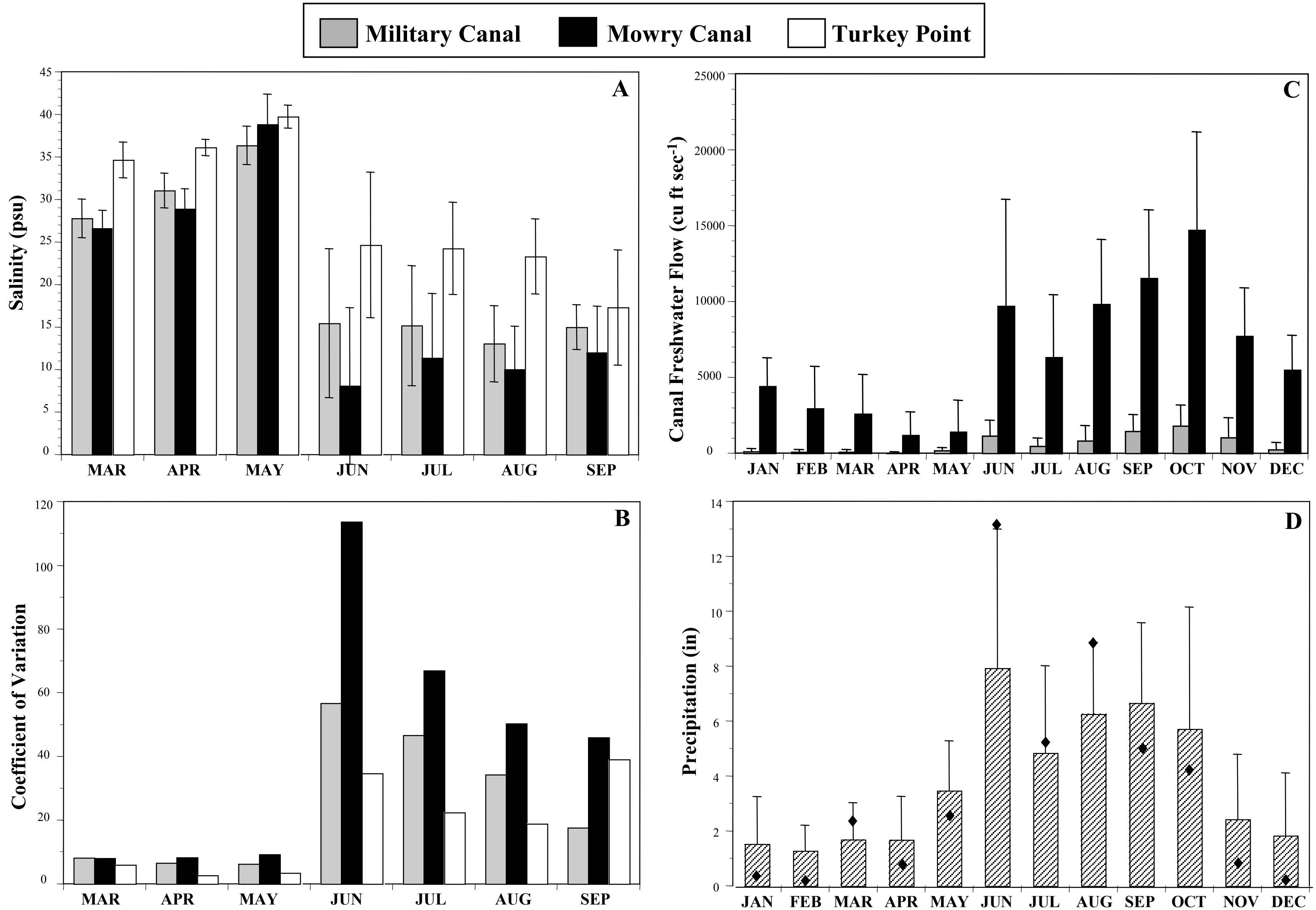

Military Canal
Mowry Canal
Turkey Point
A
Salinity (psu)
0
5
10
15
20
25
30
35
40
45
MAR
APR
MAY
JUN
JUL
AUG
SEP
B
Coefficient of Variation
0
20
40
60
80
100
120
MAR
APR
MAY
JUN
JUL
AUG
SEP
C
Canal Freshwater Flow (cu ft sec-1)
0
5000
10000
15000
20000
25000
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
D
Precipitation (in)
0
2
4
6
8
10
12
14
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

Fig. 29

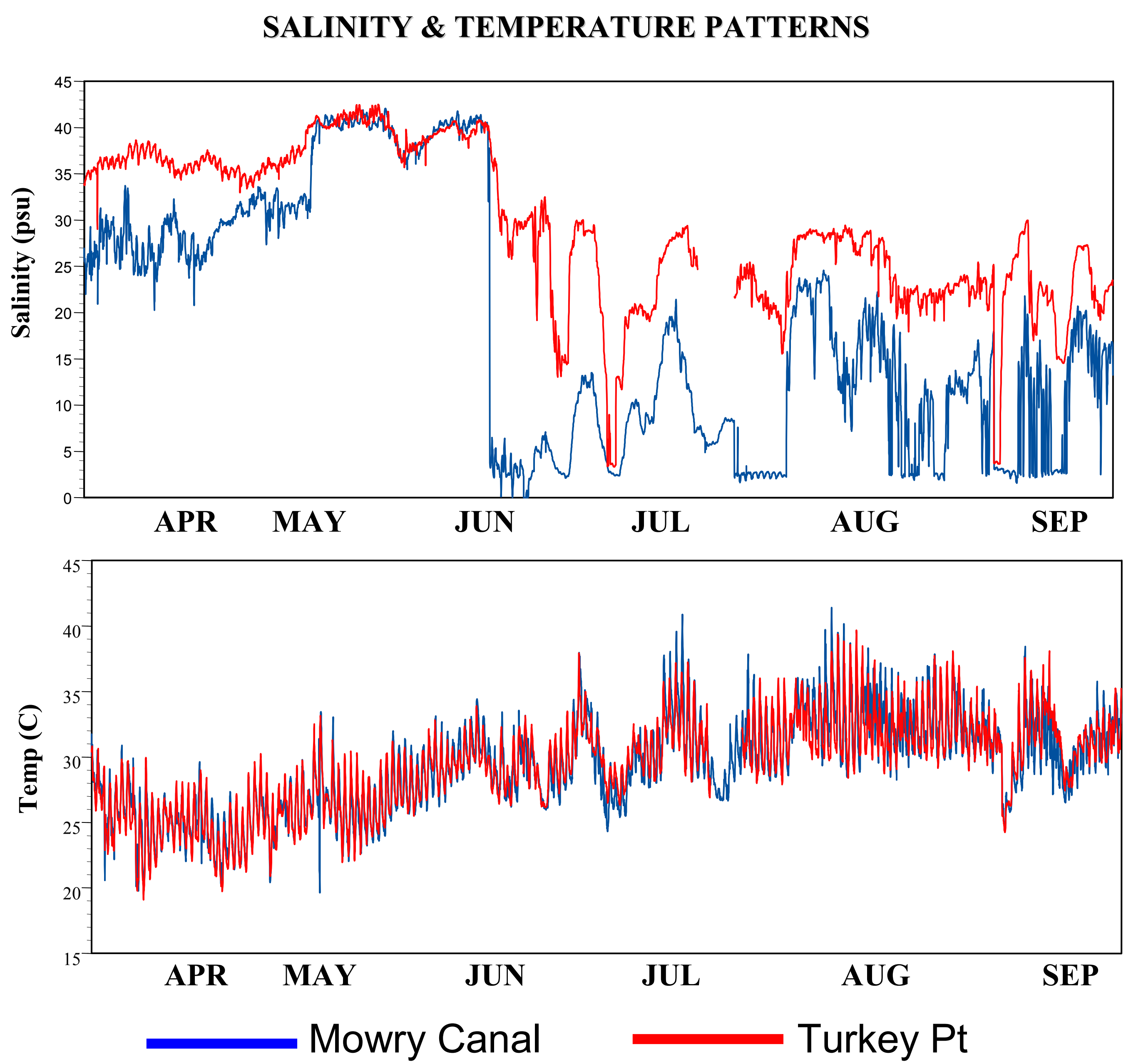

SALINITY & TEMPERATURE PATTERNS
Salinity (psu)
45
40
35
30
25
20
15
10
5
0
APR
MAY
JUN
JUL
AUG
SEP
Temp (C)
45
40
35
30
25
20
15
APR
MAY
JUN
JUL
AUG
SEP
Mowry Canal
Turkey Pt

Fig. 30