Modeling To Assess Spatial Distributions and Population Numbers of Estuarine Species In the Lower Peace River and Charlotte Harbor, Florida

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Research was conducted to determine the influence of changes in salinity and other physicochemical factors on spatial distributions and population abundances of aquatic species in the Lower Peace River and Charlotte Harbor, Florida. Using GIS, habitats were mapped for temperature, salinity, dissolved oxygen, depth, and bottom type. Catch-Per-Unit-Effort (CPUEs) were computed from Fisheries-Independent Monitoring data collected from 1996-2013. Habitat suitability modeling (HSM) based on delta-gamma generalized additive models were applied to 8 fish and invertebrate species life-stages (32 life-stages by four seasons) with affinities for low salinities. Seasonal HSM maps based on natural breaks were created for early-juvenile, juvenile and adult life-stages. Seasonal dissolved oxygen, annual depth and annual bottom type grids were held constant in the HSM. Seasonal salinity and temperature grids derived from hydrological modeling from 2007-2013 differed between Baseline (BL) and Minimum Flow (MF) conditions. Since, other factors were held constant, this allowed the assessment of seasonal impacts of water withdrawals on species life-stages using HSM. Salinity was the most significant factor in the HSMs of most species-life stages. The seasonal HSM maps were very similar between BL and MF for each species life-stage. The percentage areas of HSM zones had <2% differences between BL and MF conditions. Most seasonal population estimates for MF were less than BL estimates indicating an impact on population numbers due to water withdrawals. The differences in population numbers ranged from 1 to 21% with most being <15%. The spatial analyses provide a statistically reliable method for estimating population numbers that relate CPUEs to environmental conditions. In addition to helping set Minimum Flows and Levels, the methods can support Ecosystem-Based Fisheries Management.

INTRODUCTION

The Southwest Florida Water Management District (SWFWMD), by virtue of its responsibility to permit the consumptive use of water and a legislative mandate to protect water resources from "significant harm", has been directed to establish minimum flows and levels (MFLs) for rivers and streams within its boundaries (Section 373.042, Florida Statutes) (SWFWMD 2010). As currently defined by statute, "the minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or the ecology of the area."

The Lower Peace River, which flows into the northern part of Charlotte Harbor (**Figure 1**) does not have dams that impede the movement of fishes upstream and/or alter freshwater inflows. It was the first to receive MFLs and the first to be re-evaluated. The present report develops a framework which examines the influence of freshwater inflows on habitats and associated species life-stages in the river and in the estuary. It represents a new approach involving spatial modeling to quantify relationships between seasonal habitat conditions and population numbers derived from the models to support the creation of MFLs.

Fundamental to the approach used for development of MFLs is the realization that a freshwater flow regime is necessary to protect the ecology of both riverine and estuarine systems (SWFWMD 2010). The initial step in this process requires an understanding of historic and current flow conditions to assess the extent to which water withdrawals or other anthropogenic factors have affected flows. It has been demonstrated that flow declines in the Peace River can be ascribed to both climatic variation and anthropogenic effects (PBS&J 2007, SWFWMD 2010).

Based on hydrological modeling of flow conditions in the Lower Peace River and Shell Creek (Chen 2004), the ranges in flow rates presently being used for water withdrawals are presented associated with Baseline (BL) and Minimum Flow (MF) conditions (**Figure 2**). Since, the Lower Peace River has higher flows, the ranges selected there are higher than those being used in Shell Creek. The latter is a tributary river with lower flow rates.

To elucidate how aquatic species respond to changing environmental conditions in the tidal Lower Peace River and Charlotte Harbor, research and monitoring have been conducted to relate phytoplankton, zooplankton, macro-invertebrate species composition and abundance to freshwater inflow, salinity and temperature, as well as other water-quality and benthic habitat variables (Peebles et al. 2002, 2007; SWFWMD 2010).These data supplement Fisheries-Independent Monitoring (FIM) data collected by the Florida Fish and Wildlife Conservation Commission-Fish and Wildlife Research Institute (FWC-FWRI). The studies found that conditions vary seasonally and that fish and invertebrate species distributions vary along salinity gradients (Flannery et al. 2002; Peebles 2002; Greenwood et al. 2004; Idelberger and Greenwood 2005; Greenwood 2007; Peebles et al. 2007; Call et al. 2011, 2013; Peebles and Burghart 2013; Stevens et al. 2013).

A Delta-type generalized additive model (GAM) was recently developed by FWC-FWRI using R software to support the creation of seasonal habitat suitability model (HSM) maps in Tampa Bay (Rubec et al. 2016a). While various GIS-based HSM exist, the present models are more quantitative allowing the prediction of CPUEs across a matrix of grid cells. Habitat-grid data linked to delta-type GAMs derived from Fisheries Independent Monitoring (FIM) data were used to create raster grids containing predicted CPUEs for 87 species life-stages in Tampa Bay. The predicted CPUE-grids were then used to estimate population numbers. It also provided a means to spatially visualize the population abundance of species life-stages using HSM maps.

In the present study, we applied Delta-gamma GAMs to study the influence of salinity, temperature, dissolved oxygen, depth, and bottom type on spatial distributions and population abundances of selected estuarine species life-stages which show affinities for low-salinities. One of the main goals in the present study was to estimate population numbers for species life-stages from predicted CPUE-grids.

To determine the effect of seasonal water withdrawals on selected estuarine species, Delta gamma GAMs were conducted for each species life stage under Baseline (BL) conditions without withdrawals, and again for each species life-stage under Minimum Flow (MF) conditions involving different water withdrawals during each season. The Delta gamma GAM models were run using seasonal temperature and salinity data derived from hydrologic modeling conducted by Chen (2003a, 2003b, 2004, 2007, 2011) from 2007 to 2013.

METHODS

Sampling

Fisheries Independent Monitoring has been conducted by FWC-FWRI in Charlotte Harbor since 1989. In the present study, we analyzed FIM data gathered from 1996 to 2013 in geographic segments A, B, C, and M of Charlotte Harbor and the Lower P segment in the Lower Peace River up to the I-75 bridge (about 10.5 km from the river mouth) (**Figure 3**). The segment north of the bridge (Upper P) did not receive long-term FIM sampling. Since the latter segment is important for the present study, we obtained temperature, salinity and dissolved oxygen data collected in Upper P associated with two special studies conducted from April 1997 to March 1998 (Greenwood et al. 2004) and July 2007 to June 2010 (Call et al. 2011).

Seasons

The seasons chosen in the present study correspond to four, three-month periods with generally different river flow patterns in the region which differ from the range of months for normal seasons (PBS&J 1999, Flannery al. 2002). The fall (Oct-Dec) and spring (April-June) typically correspond to dry periods with low flows in the rivers entering Charlotte Harbor, though flows can be high in early October and tend to increase in mid-June. A minor seasonal peak in flows often occurs in the late winter (Jan-March) due to rains associated with the passage of cold fronts. Summer (July-Sept) is the wet season associated with higher rainfall and higher flows in the Peace and Myakka Rivers.

Habitat Mapping

Data collected by FWC-FWRI and SWFWMD were utilized to support habitat mapping for dissolved oxygen, depth, and bottom type in Charlotte Harbor including lower portions of the Myakka and Peace Rivers (**Figure 4**).

Bottom Type Mapping

Seagrass coverages in Charlotte Harbor were created by SWFWMD from data collected using aerial photography about every two years since 2002. Seagrass mapping from Tarpon Springs to Boca Grande was conducted during 2012 (Photo Science Inc. and Kaufman 2013). FWC-FWRI reviewed submerged aquatic vegetation (SAV) shapefiles for Charlotte Harbor obtained from SWFWMD. We chose the 2012 SAV coverage as being most representative for use with a new benthic habitat map for Charlotte Harbor.

Mud polygons were created from a bottom type dataset created by NOAA Sea Division (Bathymetric Fishing Charts 1989). The mud and SAV polygons were merged in ArcGIS 10.2.2. Areas within the study area that were not mud or SAV were coded as "sand". This vector dataset was converted to a 15m raster in ArcGIS. A bottom type map, a categorized bottom type grid and metadata were created.

Bathymetry Mapping

Bathymetry data collected by Wang (2012) of the University of South Florida were obtained from SWFWMD for the Lower Peace River, Shell Creek, Upper Charlotte Harbor, Middle Charlotte, and Myakka River. Point data from the bathymetry dataset were merged into a single point feature class. Additional data for Gasparilla Sound were obtained from NOAA in areas where data were not present in the SWFWMD dataset. This included data from hydrographic surveys H08192 and H08193 collected in 1955 and 1956. The NOAA data and SWFWMD data were merged into a single point feature class.

Empirical Baysian kriging (Krivoruchka 2012) was used to interpolate bathymetry data in different sections of Charlotte Harbor with the ArcGIS Geostatistical Analyst 10.3 extension (ESRI 2014). The interpolated layer was exported to a raster with 15m x 15m cell size. The output raster grid was clipped to the water area within the study area. Large backwaters and canals with no bathymetry surveys were removed, but some smaller backwaters were included. A bathymetry map, bathymetry grid categorized to 1m intervals, and metadata were created.

Dissolved Oxygen Mapping

The SAS program used to extract dissolved oxygen data from the FIM database averaged surface and bottom readings at each sampling station. Repeated samples in the same location within a season were also averaged.

Point data were interpolated using Empirical Baysian kriging to create seasonal dissolved oxygen grids with 15m X 15m grid cells. The output raster grids were clipped to the water extent within the Charlotte Harbor study area. The same spatial extent as the bathymetry data and bottom type data was used; except for small portions of Lemon Bay and upstream Myakka River where we did not have dissolved oxygen data. These areas were excluded from the final grids. Grids for dissolved oxygen, depth and bottom type were created, as well as categorized maps, and GIS metadata.

Hydrodynamic Modeling Of Temperature and Salinity

We used seasonal temperature and salinity outputs derived from hydrodynamic modeling conducted by Dr. Xinjian Chen (SWFWMD) for each year from 2007 to 2013. There are no water withdrawals associated with Baseline (BL) scenarios and there are seasonal water withdrawals associated with the Minimum Flow (MF) scenarios for the Lower Peace River and Charlotte Harbor.

Dr. Chen provided depth averaged salinity and temperature values for the BL and MF scenarios using the UnLESS hydrodynamic model for each year from 2007 to 2013 (Chen 2011). UnLESS is a dynamic coupling of UnLESS3D and LAMFE (Chen 2007). LAMFE is a laterally averaged

(2DV), z-level hydrodynamic model (Chen 2003a, 2003b), and UnLESS3D is a three-dimensional, unstructured Cartesian grid, cut-cell, z-level hydrodynamic model (Chen 2004).

The predicted point locations have the same latitudes and longitudes for each year. This allowed FWRI to average the point data across years within each season (2007-2013). Then, the point data were interpolated to create seasonal temperature grids and seasonal salinity grids with the same spatial extent as the depth, bottom type and dissolved oxygen grids. All raster grids created have the same 15m X 15m cell size.

Estuarine Species Modeled

Eight species were selected based on the criterion that they exhibit preferences for low (oligohaline) or moderate (mesohaline) salinities and have been found to be abundant in the Lower Peace River. The first 6 species exhibited affinities for low salinity in a previous HSM study in Charlotte Harbor (Rubec et al. 2016b). The species were seasonally analyzed by early-juvenile (EJ), juvenile (J) or adult (A) life-stages. Hogchoker and Blue Crab were added based on studies by Peebles (2002) and Greenwood et al. (2004). For Hogchoker and Blue Crab, respectively, juvenile and adult life-stages (JA) were analyzed together. Size ranges selected for fish were based on standard length (SL). Size ranges for Blue Crab were based on carapace width (CW).

a) J-Bay Anchovy (*Anchoa mitchilli*) (15-29 mm SL).
b) A-Bay Anchovy (*Anchoa mitchilli*) (30-60 mm SL)
c) EJ-Southern Kingfish (*Menticirrhus americanus*) ((10-119 mm SL)
d) EJ-Red Drum (*Sciaenops ocellatus*) (10-299 mm SL)
e) EJ-Spot (*Leiostomus xanthurus*) (10-149 mm SL)
f) J-Sand Seatrout (*Cynoscion arenarius*) (10-149 mm SL)
g) JA-Hogchoker (*Trinectes maculatus*) (10-100 mm SL)
h) JA-Blue Crab (*Callinectes sapidus*) (10-150 mm CW)

The reports by Peebles (2002) and Greenwood et al. (2004) recognized estuarine residents, which reproduce in the estuary and remain there during all life-stages. Other species, termed estuarine transients, leave the estuary to spawn in the Gulf of Mexico (Stevens et al. 2013). Some of the species determined to spawn in or very near the tidal Peace River, based on the presence of eggs or early larval stages, included Hogchoker, Sand Seatrout, Southern Kingfish, and Bay Anchovy (Peebles 2002). Blue Crab may also be estuarine-residents, although no eggs or larvae were collected in the Lower Peace River. These species spend most of their life in the estuary (Idelberger and Greenwood 2005, Stevens et al. 2013). For the present study, estuarine-residents refers to species life-stages that were abundant in the Lower Peace River during most seasons of the year.

Habitat Suitability Modeling

The steps used to analyze FIM datasets with an excess of zero catches are as follows. First, environmental data values obtained from FIM sampling or from hydrodynamic modeling are interpolated using GIS to create habitat grids. Second, environmental data associated with central data points from 15m X 15m grid cells are exported. Third, the R program is used to associate CPUEs derived from FIM data (about 2,000 to 3,000 samples per season across years) with spatially corresponding environmental values in an HSM. Fourth, the model developed is used to predict gear-corrected (GC) CPUEs from the environmental data associated with the habitat grids (about 1.9 million records for Charlotte Harbor). Then, the predicted GC-CPUEs are imported into a GIS to create a predicted GC-CPUE-grid across the estuary. The predicted GC-CPUE-grid is partitioned into four HSM zones to create seasonal HSM maps. Histograms of observed mean GC-CPUEs across HSM zones are used to spatially verify the reliability of the predicted HSM maps.

The FIM program uses five gear types for sampling fish and invertebrates in the study area including a 21.3-m circular bag seine (gear 20), a 21.3-m boat bag seine (23), a 183-m haul seine (160), a 61-m haul seine used in the river (180) and a 6.1-m otter trawl (300) (**Figure 5**). The CPUEs associated with the gear types are standardized within the Delta-GAM R program used for HSM (Rubec et al. 2016a). Mean GC-CPUEs for each gear type are adjusted to the gear type with the highest mean CPUE using gear-correction (GC) ratios. Depending on selectivity for the size of the species analyzed, not all gear types were used in each HSM analysis.

A program was developed running in statistical R software to support the creation of seasonal HSM maps. The statistical approach taken involves the creation of Delta-type GAMs, which separately fit non-linear splines to +CPUEs and to probability of zero occurrence (P=0) data across environmental gradients. The +CPUE component is based on either gamma (ZAGA) or beta (BEINF0) statistical distributions. The statistics and methodology were described in detail by Rubec et al. (2016a).

The HSM are built using statistical functions that choose the best combination of environmental variables based on the lowest Akaike Information Criterion (AIC) (Rubec et al. 2016a). The program first chooses the best Full model. The analyst can then choose from three spline-fitting methods based on Owen's residual plots and lowest AIC. After the best HSM model is created from FIM sampling data; it creates predicted CPUEs (no/m^2) for 15m X 15m cells across the estuary. Various graphical outputs are created that help the analyst determine goodness-of-fit. Statistical tables for the Full model and the Reduced Model show which factors are most significant. The results presented herein are derived from the Reduced Model.

Log-transformed splines were separately fit to +CPUE data (MU) and to probability of zero occurrence data (NU) across environmental gradients. Then the spline data were back-transformed and the two components multiplied (MU X NU) to derive back-transformed GC-CPUE splines across gradients for water temperature, salinity, dissolved oxygen and depth. Splines were created for both the Full and Reduced models. Seasonal graphs showing back-transformed splines for GC-CPUEs versus salinity, temperature, dissolved oxygen, and depth were created for each species life-stage. Histograms with mean GC-CPUEs by bottom type, gear type, and year respectively were also created with the R program

Model Input GIS Data

Using ArcGIS for Desktop version 10.3, raster data were converted to vector point data at grid centroids (ESRI 2014). Using ArcGIS Spatial Analyst "Extract Multi Values to Points", attributes representing depth, bottom type, temperature, salinity and dissolved oxygen were added to seasonal point files. FIM point data for each species life-stage by season were spatially joined to the seasonal point files with habitat data. Each FIM data point was joined to the closest habitat point within 50 meters. These data were converted to CSV format for use in the model.

Model Output GIS Data

Gear-corrected (GC) CPUE data were used to create continuous raster datasets for each species life-stage by season. Using ArcGIS for Desktop version 10.3, model output CSV files were converted to 15m cell size raster data, with the same cell alignment as the grids created for Tasks 1 and 2. Using ArcGIS Spatial Analyst "Slice" tool, continuous raster data were assigned to one of 4 habitat suitability zones using the natural breaks method: 1-Low, 2-Moderate, 3-High, or 4-Optimum. The natural breaks method "specifies that the classes will be based on natural groupings inherent in the data. Break points are identified by choosing the class breaks that best group similar values and that maximize the differences between classes. The cell values are divided into classes whose boundaries are set when there are relatively big jumps in the data values."

Partitioning CPUE-Grids

Using the ArcGIS Spatial Analyst, continuous raster data were assigned to four HSM zones using natural breaks. The natural breaks method "specifies that the classes will be based on natural groupings inherent in the data. Break points are identified by choosing class breaks that best group similar CPUE values which maximize the differences between classes. The cell CPUEs are divided into classes, whose boundaries are set where there are relatively big jumps in the data values."

Natural breaks in the CPUEs were determined using an algorithm associated with ARC-GIS. After ordering the CPUE data from low to high, the program determines intervals with the most similar CPUEs and produces a graph that predicts the break points in the CPUEs. This provided us with an objective means of partitioning seasonal CPUE grids into four HSM zones for each species life-stage.

Creation of HSM Maps

Seasonal HSM maps were created for each species life-stage associated with BF conditions and again with MF conditions. Each HSM map created has four habitat suitability zones: L-Low, M-Moderate, H-High, and O-Optimum representing increasing mean GC-CPUEs across the zones.

Estimating Zonal Areas and Population Numbers

Tables were created in Excel for each species life-stage respectively for BL and for MF conditions, that present mean GC-CPUEs (no/sq m) and zonal areas (sq m) for each HSM zone. Also presented are percents (%) of the total area for each HSM zone. By multiplying mean GC-CPUEs by the zonal areas, population estimates by HSM zones were derived. Total population estimates in the study area were then estimated by summing the zonal population estimates.

Population Tables

Seasonal population numbers were estimated from GC-CPUEs for each species life-stage in the study area. Computations determined that there were 1,906,683 15m X 15m cells with a total area of 429,003,675 m^2. Tables were created that computed zonal percentages of the total area associated with the seasonal HSM zones derived using natural breaks for each species life-stage.

Zonal population estimates were derived by multiplying mean GC-CPUEs (no/m^2) by the areas (m^2) associated with the HSM zones.

Verification Graphs

Using ArcGIS, FIM point data for each species life-stage, within each season, were spatially joined to the zonal grid data to create verification datasets. We verified each model by overlaying the observed data onto predicted HSM zones to create verification graphs. Increasing trends across the zones indicate spatial agreement between observed mean GC-CPUEs and predicted mean GC-CPUEs within HSM zones.

RESULTS

Habitat Maps

Examples of the habitat maps derived from FIM data for temperature, salinity and dissolved oxygen during summer and annual maps for depth and bottom type are presented (**Figure 4**). Salinity is of special interest due to the direct relationship between freshwater inflow and salinity and the need to set MFLs to manage freshwater withdrawals from the Lower Peace River (SWFWMD 2010). We used the annual grids for bottom type and depth, and seasonal grids for dissolved oxygen in the present HSM analyses.

Seasonal datasets for salinity and for temperature used in the present study were derived from hydrodynamic modeling by SWFWMD. Habitat maps for salinity created by FWC-FWRI are presented for each season for BL (**Figure 6a**) and for MF (**Figure 6b**) conditions. The BF and MF salinity maps appear to be very similar within each season.

Habitat maps for temperature created by FWC-FWRI are presented for each season for BL (**Figure 7a**) and for MF (**Figure 7b**). While there are large differences in temperatures in the study area between seasons, the BL and MF temperature maps within each season appear to be very similar.

Statistical Table Reduced Model.

Table 1 presents the statistical significance of the GC-CPUEs for the eight-species analyzed using Delta gamma GAMs by season associated with BF and with MF conditions. Only one statistical table is presented; since the FIM data used as input were the same for both the BF and the MF analyses.

Within **Table 1**, there are two sub-tables appended together. The first represents the MU side and the second represents the NU side of the Delta-gamma GAM. The statistical predictions are derived from CPUE relationships associated with the environmental variables presented. The Reduced model used the lowest AIC to select the best combination of environmental variables. Non-significant variables listed in the table were included in the models. Blank spaces in the table indicate factors that were not included in final models. For the sake of brevity, the significance of different gear types, and years are not presented in the table.

Salinity was highly significant within both the MU and NU sub-tables for most of the species life-stages analyzed (**Table 1**). For both J-Bay Anchovy and A-Bay Anchovy salinity was highly significant during spring (SP), summer (SM), and fall (FL) for the MU side of the model. But, considering the significance of both NU and MU sides of the models, all four seasons were significant for both juvenile and adult Bay Anchovy. Temperature, depth and/or dissolved oxygen were significant during several seasons and submerged aquatic vegetation (SAV) was significant during the spring. The JA-Blue Crab and JA-Hogchoker exhibited highly significant affinities for salinity during all seasons. Temperature was significant during FL, SP, and SM seasons. Salinity was significant for EJ-Red Drum during summer (SM) and winter (WN). Salinity was highly significant during most seasons for EJ-Southern Kingfish, EJ-Spot, and J-Sand Seatrout.

Fitted Splines and Histograms From HSM

The example presented is for JA-Hogfish in the Spring based on the Full Delta Gamma GAM model (**Figure 8**). The dashed lines associated with each plot are 95% confidence limits.

CPUE By Salinity Splines

To determine optimum salinities that contributed to significant CPUEs, the plots for CPUE by salinity were aggregated for each species life-stage by season (**Figure 9**). The JA-Hogchoker exhibited high CPUEs at salinities <5 ‰ for all four seasons. The CPUE splines for J-Sand Seatrout peaked near 7 ‰ during all four seasons. The CPUEs for JA-Blue Crab peaked at about 10 ‰ in FL and WN, at 8 ‰ in SP and <5 ‰ in SM. The CPUE splines for EJ-Southern Kingfish peaked at 15 ‰ in FL, and near 18 ‰ during WN, SP and SM. The splines for J-Bay Anchovy and A-Bay Anchovy are similar during all four seasons with peaks for the fitted CPUEs near 18 ‰. EJ-Red Drum CPUEs peaked near 20 ‰ in FL, < 10‰ in WN and <5 ‰ in SP and SM. The splines for EJ-Spot peak at >30 ‰ in FL, at 8 ‰ in WN and < 5 ‰ in SP. The EJ-Spot spline for SM shows a declining CPUE relationship at low salinities (< 5 ‰) and increasing CPUEs at high salinities (>30 ‰).

JA-Hogchoker were found at the lowest range of salinities during all four seasons. J-Sand Seatrout were also found at low salinities in Upper P and Lower P segments at somewhat higher salinity ranges than the JA-Hogchoker. J-Sand Seatrout were also abundant in the Lower P segment of the river. Each species appears to select different salinity ranges proceeding downstream. The species order from low to higher salinities is JA-Hogchoker<J-Sand Seatrout <JA-Blue Crab <EJ-Kingfish<J-Bay Anchovy<A-Bay Anchovy<EJ-Red Drum<EJ-Spot.

HSM Maps

Seasonal HSM maps were created from zonal grids created respectively for 32 species life-stages. The Optimum zone represents the area with the highest abundance. In most cases, predicted Optimum zones were found to occur in the Lower Peace River.

JA-Hogchoker

The seasonal HSM maps for JA-Hogchoker (**Figures 10a, 10b**) show Optimum zones of abundance in the Upper P segment for all four seasons. The Optimum zones for JA-Hogchoker extended further up the Lower Peace River in Upper P during all four seasons than the Optimum zones for J-Sand Seatrout and JA-Blue Crab. This is consistent with the CPUE by salinity splines by season for JA-Hogchoker which show their highest abundance at < 5 ‰ (**Figure 9**). The HSM maps for BL and MF conditions are very similar during each season. The Optimum zones expand during SM for both BL and MF scenarios. But, close examination of the Optimum zones for both BL and MF shows that the Optimum zone for MF contracts slightly associated with water withdrawals during SM.

J-Sand Seatrout

The seasonal HSM maps for J-Sand Seatrout for both BL and MF conditions (**Figures 11a, 11b**) show them occurring in both the Upper P and Lower P segments of the Lower Peace River. Faint traces of the Optimum zone are present in Upper P during WN. Then, they are very abundant throughout the Upper P and Lower P segments during SP, suggesting they recruit to the river during that season. During SM, they are less abundant with the Lower Peace River and upper portion of Charlotte Harbor having High abundance. But, there is also a small patch near the mouth of the estuary, suggesting they leave Charlotte Harbor during SM. There are still traces of the Optimum zone in the Lower Peace in the Upper P and Lower P segments during FL. This might indicate that some adults remain in the river where they spawn in SP producing the surge in abundance shown in both the BL and MF maps. The seasonal HSM maps are very similar between BL and MF conditions, making it difficult to visually discern from the maps whether there is an effect of water withdrawals.

JA-Blue Crab

The Optimum zones for JA-Blue Crab in the Lower Peace River are prevalent in the Upper P and Lower P segments during WN for both BL and MF scenarios (**Figures 12a, 12b**) suggesting that they recruit at that time of year. In SP, they are still abundant, but the Optimum zones contract for unexplained reasons, possibly due to fishing pressure. The Optimum zones expand again in SM. The Optimum zone in FL contracts being present in the Lower P segment. The HSM maps are very similar between BL and MF scenarios, making it difficult to visually discern an effect of water withdrawals from the seasonal MF maps (**Figure 12b**).

EJ-Southern Kingfish

The HSM maps for EJ-Southern Kingfish indicate they were abundant in the Lower Peace River during all four seasons (**Figures 13a, 13b**). The Optimum zones were mostly situated in the Lower P segment. The Optimum zone expands during WN with High abundance in the upper portion of Charlotte Harbor. There is a contraction of the ranges for both BL and MF maps in SP. During SM, the Optimum and High zones expand again possibly in relation to higher freshwater inflows during the wet season.

J-Bay Anchovy

Seasonal HSM maps are presented for J-Bay Anchovy (**Figures 14a, 14b**). The Optimum zones are present in the Lower Peace River and in the Myakka River during the FL, WN, and SP seasons. These seasons have reduced rainfall and lower inflows to the estuary. During SM, the Optimum zones expanded from the rivers into northern Charlotte Harbor in shallow water areas (<2 m) occupied by SAV. The HSM maps are very similar for each season between BL and MF conditions.

A-Bay Anchovy

The seasonal HSM maps for A-Bay Anchovy (**Figures 15a, 15b**) are similar for J-Bay Anchovy (**Figures 14a, 14b**) with both BL and MF conditions**.** There is an expansion of Optimum zones during SM for both juvenile and adult Bay Anchovy. Summer is the wet season associated with higher rainfall and increased freshwater inflows from the rivers into the estuary. Hence, juvenile and adult Bay Anchovy responded in a similar manner to seasonal increases in freshwater inflow.

Unpublished analyses by Rubec et al. (2017) indicates that the salinity preferences demonstrated by the seasonal salinity splines (**Figure 9**) stay about the same during all four seasons. But, the ranges of abundance represented by GC-CPUEs for species life-stages can expand when there are increasing inflows during SM. This appears to be the case with both J-Bay Anchovy and A-Bay Anchovy.

EJ-Red Drum

Based on Optimal zones for EJ-Red Drum in seasonal HSM maps (**Figure 16a, 16b**), they were most abundant over SAV in Charlotte Harbor in FL. During WN, they were most abundant in the Upper P segment of the Lower Peace River. The Optimum zones indicate they moved downriver into Lower P and into northern Charlotte Harbor in SP, being most abundant in shallow water over SAV. The HSM map for SM shows them being abundant (High zone) in deeper water situated in the northern part of Charlotte Harbor. Some were still present in the Lower P segment of the river in SM.

EJ-Spot

The HSM maps for EJ-Spot (**Figure 17a, 17b**) show they were abundant in the Upper P segment during WN and SP. After that, they were only found in small areas near the mouth of Charlotte Harbor during SM and FL. This indicates that they leave the estuary after spending about six months in the river. The movement out of Charlotte Harbor during SM was unexpected. As with the other species life-stages, the HSM maps for EJ-Spot were very similar within each season between BL and MF conditions.

Example for Estimating Zonal Areas and Population Numbers

Zonal areas and population estimates were derived for A-Bay Anchovy in SP respectively for BL and for MF conditions (**Table 2**). The total area of Charlotte Harbor, the Lower Peace River and Myakka River is 429,003,675 sq m. Total population numbers for BL and for MF were estimated by multiplying mean GC-CPUEs by zonal areas and then summing across the HSM zones. The total population numbers estimated for A-Bay Anchovy in SP for BL is 2,098,463,644 and for MF is 1,995,985,434. Similar computations were done with the other species life-stages for each season.

Changes in Percentage Zonal Areas Between BL and MF

By subtracting the percentages within seasons for MF from BL, changes in the percentages of the zonal areas were computed (**Table 3**). The percentages derived are positive when the MF percentages were less than the BF percentages of the total area in the estuary. Some percentages have a negative sign indicating that the MF percentages were greater than the corresponding BF percentages. Since all the percentages tie to the total area of the estuary, a decline in one zonal percentage will result in an increase in the percentage(s) associated with the other zonal areas within each seasonal HSM map. The results shown confirm that the changes in percentage areas by zones were generally $\leq$2%. Since the changes in percentage areas by zones were small, it explains why it was difficult to visually discern zonal changes between the seasonal BL HSM maps and MF HSM maps for each species life-stage.

Population Estimates

Baseline

The JA-Hogchoker BL population numbers were about 701 thousand in FL, 553 thousand in WN, 126 thousand in SP and 125 thousand in SM (**Table 4**). J-Sand Seatrout BL numbers were 4.5 million in SP, 3 million in SM, 980 thousand in FL and 17 thousand in WN. JA-Blue Crab numbers were 337 thousand in FL, 5.5 million in WN, 204 thousand in SP, and about 94 thousand in SM. EJ-Southern Kingfish estimates were 480 thousand in FL, 289 thousand in WN, 290 thousand in SP and 177 thousand in SM. The population numbers for J-Bay Anchovy were estimated at about 411 million in FL, 1.3 billion in WN, 2 billion in SP, and 301 million during SM. A-Bay Anchovy were estimated to be about 409 million in FL, 1.1 billion in WN, 2 billion in SP, and 275 million in SM. The EJ-Red Drum estimates range from 12.6 million in FL, 2.7 million in WN, 363 thousand in SP, and 265 thousand in SM. EJ-Spot population numbers were 108 thousand in WN, 783 thousand in SP, 58 thousand in SM and 6 thousand in FL.

Minimum Flow

Similar, but somewhat lower population numbers were estimated for these species-life stages associated with MF (**Table 4**). The percentage changes in population numbers between BL and MF indicate that population numbers declined between 1% and 21%. Most population numbers decreased by <15%. Higher reductions in population numbers were found for JA-Hogchoker in SP (19.04%), J-Sand Seatrout in SM (20.99%) and EJ-Southern Kingfish in SM (17.46%). In a few cases, such as A-Bay Anchovy in SM, population numbers increased by 1.1% for MF. In the case of EJ-Spot their population numbers increased by 4.8% in SM and by 7.8% in FL. But, these are the seasons when Spot left the estuary and population numbers were low. This may help to explain why EJ-Spot population numbers increased during SM and FL.

Verification Graphs

Graphs were created for observed mean GC-CPUEs by HSM zones. Increasing mean CPUE relationships across HSM zones were scored by season for each species life-stage (**Table 5**). The total verification scores by season range from 7.0-8.0. An example for A-Bay Anchovy in fall is presented (**Figure 18**).

DISCUSSION

The statistical analyses in the present report indicate that salinity was highly significant during most seasons for the species life-stages analyzed (**Table 1**). The CPUE by salinity graphs show the peak salinity and approximate ranges of salinity where each species life-stage was most abundant (**Figure 9**). Most of the seasonal graphs are similar for each species life-stage tending to indicate that most species have a preferred salinity range, which does not change between seasons. This was verified by overlaying Optimum CPUE zones onto the salinity grids and extracting the salinity ranges by season (Rubec et al. MS 2017).

Based on plankton sample data, over 20 taxa of fish and invertebrates displayed significant distributional responses to freshwater inflow (Peebles and Burghart 2013). While all the taxa moved downstream in response to increased inflow, the distribution of different taxa in the river was staggered and some were located farther upstream than others. Based on seine and trawl data, Greenwood et al. (2004) similarly found that various life-stages of 14 taxa had distributional responses in relation to freshwater inflow.

The seasonal HSM maps for JA-Hogchoker (**Figures 10 a,b**) show optimum zones of abundance in the Upper P segment for all four seasons. This is consistent with the CPUE by salinity splines by season which show their highest abundance at < 5 ‰ (**Figure 9**). The seasonal splines for JA-Hogchoker, J-Sand Seatrout, JA-Blue Crab, EJ-Southern Kingfish, J-Bay Anchovy and A-Bay Anchovy are similar within each species across seasons. These are the species which Peebles (2002) considered to be estuarine residents based on the presence of their eggs and/or larval life-stages in plankton surveys conducted in the Lower Peace River. The CPUE by salinity graphs tend to agree with the Optimum zones of abundance depicted in the HSM maps that were derived from zonal grids. Each species tends to occupy a different range of salinity progressing downstream in the Lower Peace River (**Figures 10a, b; 11a, b; 12a, b; 13a, b; 14a, b; 15a, b)**. There is good statistical evidence that the main factor influencing their spatial distributions and Optimum abundances is the salinity gradient (**Table 1**).

Most of the seasonal HSM maps for the species mentioned in the previous paragraph show an expansion of their spatial distributions in the Lower Peace River during SM associated with higher freshwater inflows. The fact that there were no corresponding changes in the fitted CPUE splines for these species (**Figure 9**) is explicable. Preferred salinity ranges for each species stay about the same, while the salinity zones expanded in area in SM as freshwater inflows increased. In most cases, Optimum zones of abundance depicted in the HSM maps expanded. But, the salinity ranges associated with the Optimum zones in the HSM maps did not change to any great degree (Rubec et al. MS 2017). The largest expansions of Optimum zones occurred with J-Bay Anchovy in SM (**Figures 14a, b**) and A-Bay Anchovy in SM (**Figure 15a, b**).

Papers reviewed by Doering and Wan (2017) have noted positive correlations between inflows from rivers and landings for a number of commercially and recreationally important species of estuarine fish and shellfish. Reductions in freshwater inflow from droughts and the construction of dams were associated with reduced landings. Doering and Wan (2017) noted that fishery data was ideal for establishing a minimum flow target associated with a legislative mandate such as the MFL regulations in Florida. Annual CPUEs, computed from Blue Crab landings and effort data obtained from the Calhoosatchee Estuary were found to be significantly correlated with rainfall, freshwater inflow and the Multivariate ENSO Index during the previous year's dry season.

Studies reviewed by Patillo et al. (1997) indicated that Sand Seatrout, Spot and Red Drum spawn in the Gulf of Mexico, after which early life-stages move into the estuary. Most spawning of Sand Seatrout was reported to occur in the Gulf of Mexico primarily in waters between 7 m and 15 m in depth, but could occur in depths up to 91 m and as far as 175 km from shore (Cowan and Shaw 1988). Analyses of Sand Seatrout (≤ 100 mm SL) from Apalachicola Bay, Suwannee River estuary, Tampa Bay and Charlotte Harbor indicate they recruited into these estuaries from May through October (Purtlebaugh and Rogers 2007). They were abundant over unvegetated mud bottoms, in mesohaline salinities, near salt march vegetation. Their highest abundance occurred in small rivers, tidal creeks and areas adjacent to the mouths of large rivers.

Knapp and Purtlebaugh (2008) examined the abundance and distributions of Sand Seatrout (> 100 mm SL) in relation to environmental conditions and river discharge in Tampa Bay and Charlotte Harbor. Smaller Sand Seatrout (145-175 mm SL) were found in low salinity areas near river mouths, while larger Sand Seatrout >175 mm SL were found in high salinity areas in the lower portion of the estuaries. They found a negative relationship between relative abundance and mean river discharge in both estuaries and a positive relationship between relative abundance and 2-yr lagged river discharge in Tampa Bay. They found isolated catches of large Sand Seatrout in the seaward portions of Tampa Bay and Charlotte Harbor in winter, suggesting it was plausible that Sand Seatrout remained in the estuaries during cold months. A passive acoustic survey detected drumming sounds indicative of spawning aggregations of Sand Seatrout in Tampa Bay during 2004, and again in 2005 when red tide blooms occurred (Walters et al. 2013). Spawning sites for Sand Seatrout were located in central areas of Tampa Bay, increasing the adult vulnerability to a red tide and, ultimately, their mortality from it during 2005. The distribution of Sand Seatrout spawning aggregations along the central, high current areas of the bay would tend to facilitate transport of larvae to juvenile riverine habitats through selective tidal-stream transport. Sand Seatrout mature at a small size and age (Shlossman and Chittenden 1981). Sand Seatrout hatched early in the spawning season could become mature adults and spawn within the same season (Walters et al. 2013). Larvae, produced before the appearance of the 2005 red tide, halfway through the spawning period, could have moved into low-salinity freshwater river systems and matured to become first-time spawning adults. Since, the present HSM analyses indicates (**Figures 11 a,b**) that Sand Seatrout left Charlotte Harbor in the SM and FL, it is possible that some of the population spawns in the Gulf of Mexico while others spawn within Charlotte Harbor.

Flaherty and Guenther (2011) summarized literature for Blue Crab in Florida. In the northern part of their U.S. range, they take up to 2 years to mature. But, in Florida, they reach maturity in 12 months. Spawning generally begins in March through May and ends in August through October, but in west-central Florida waters some spawning occurs in the winter. The larvae develop offshore before recruiting to the estuaries as megalopae. FIM data collected in Tampa Bay using seines and trawls from 1996-2004 were analyzed. Peaks in the monthly abundance of recruits (≤ 20 mm CW), juveniles (21-80 mm CW) and adults by sex (> 80 mm CW) were analyzed. Highs in abundance were apparent for recruits in January and February, in February through March for juveniles, and in May for adults. A second peak in abundance was found for recruits in September and September-October for juveniles. Salinity had a significant influence on the distribution of juvenile and adult Blue Crabs. Juvenile and adult male Blue Crab were most abundant up rivers in areas of low salinity (0-5 ‰). Maps show that most of the adult male and female Blue Crab were in tributary rivers. The sequential appearance of recruits, juveniles and adults from January through to May data suggests that Blue Crab spawn in Tampa Bay.

According to published literature, Red Drum spawn in the Gulf of Mexico during September near the mouths of estuaries (Peters and McMichael, Jr. 1987; Patillo et al. 1997). Fitted CPUE splines for EJ-Red Drum during WN, SP, and SM indicate they were most abundant at salinities < 10 ‰ (**Figure 9**). Based on Optimum zones in our seasonal HSM maps (**Figures 16 a,b**), EJ-

Red Drum were most abundant over SAV in Charlotte Harbor during FL. In WN, they moved into the Upper P segment of the Lower Peace River. The Optimum zones in the HSM maps during SP indicate they moved downriver into Lower P and into northern Charlotte Harbor, being most abundant in shallow water over SAV. In SM, the Optimum zones for BL and MF indicated they were most abundant in the Lower P segment of the river. But, High zones (shown in green) in the HSM maps indicate they also were prevalent in deeper water in upper Charlotte Harbor. The literature indicates that juvenile Red Drum remain in the estuary for about 3 years before spawning in the Gulf of Mexico (Patillo et al. 1997).

The scientific literature for EJ-Spot states that they move up into low salinity headwater areas and may ascend brackish to freshwater during SP and SM (Hildebrand and Cable 1930, Patillo et al. 1997). Killam et al. (1992) found that the spawning season in the Gulf of Mexico near Tampa Bay was during FL and WN. The HSM map for EJ-Spot in WN (**Figures 17 a,b**) indicates that they were most abundant in the Lower Peace River in Upper P and Lower P segments. The Optimum zones for BL and MF indicate they were also abundant in shoreline areas of Charlotte Harbor associated with SAV. In SP, the Optimum zones shift upstream to the Upper P segment, with High abundance further downstream in the river and in Charlotte Harbor in Gasparilla Sound near the mouth of the estuary. In SM, the HSM maps for BL and MF show an expansion of the Optimum zones and High zones near the mouth of the Charlotte Harbor. Some of the population of EJ-Spot is still present in the Upper P segment in SM. In FL, most EJ-Spot have left the Lower Peace River and some remnants are present in Gasparilla Sound near the mouth of Charlotte Harbor. This indicates that most EJ-Spot left Charlotte Harbor in SM and in FL starting at an age of about 6 months.

The fitted CPUE splines by salinity for EJ-Spot (**Figure 9**) are of interest. During WN, the CPUE spline peaks at about 7 ‰ accounting for their Optimum abundance in the Lower Peace River. But, the fitted spline is quite broad and can also account for their High abundance in Charlotte Harbor. In SP, the spline agrees with the HSM map (**Figures 17a, b**) in showing Optimum abundance in the Upper P segment of the river. In SM, the CPUE spline declines from 0 to 10‰, then increases from 20 to 35 ‰. This is consistent with the HSM map in indicating some EJ-Spot were present in the river in SM at low salinities, with the rest of the population present near the mouth of the estuary where high salinities are found. In FL, the spline shows a marked affinity for salinities >30 ‰, which is consistent with the interpretation that Spot move out of the estuary to spawn (Patillo et al. 1997). Spot mature at 1 or 2 years of age. Monthly length frequencies of EJ-Spot caught in Tampa Bay during 1958 indicted spawning occurred from January through March (Springer and Woodburn 1960). The present findings indicate that Spot left Charlotte Harbor starting in SM. This is earlier than other studies which found Spot leave estuaries in the Gulf of Mexico in FL and WN (LeBlanc et al. 1991, Patillo et al. 1997). Based on data from Cedar Key and Tampa Bay, Springer and Woodburn (1960) stated that most Spot in our area probably migrate offshore in late SM.

Some notable studies using delta-type GAMs are the following. Jensen et al. (2005) used delta-lognormal GAMs to model the distributions and map the abundance of female Blue Crabs during the winter in Chesapeake Bay on an annual basis for 13 years (1990–2002). Grüss et al. (2014) developed quasi-Poisson GAMs and binomial GAMs to support the creation of CPUE-based distribution maps of adult Pink Shrimp in the northern Gulf of Mexico. However, we are not aware of any published studies (other than Rubec et al. 2016a) that have derived population estimates from the predicted CPUE-grids used to create HSM maps.

The present study employed Delta-gamma GAMs to relate the abundance (GC-CPUEs) of species life-stages to environmental variables in the Lower Peace River and Charlotte Harbor. The back-transformed GC-CPUE splines **(Figure 9**) show affinities of each resident species for low to moderate salinities. Likewise, the statistical table (**Table 1**) derived from the Reduced Delta-gamma GAMs shows that salinity is highly significant for the species life-stages analyzed during most seasons of the year.

By linking the models derived from FIM data with interpolated habitat grids, we created predicted GC-CPUE grids and predicted HSM grids for 32-species life-stages. The HSM maps created by partitioning the continuous grid using natural breaks in the GIS show the resident species analyzed were abundant in the Lower Peace River during most seasons.

The population estimates derived from the GC-CPUE grids (**Table 4**) represent the long-term average abundances from 1996 to 2013. This is a new approach to support the management of estuaries and management of fish and invertebrate species based on habitat suitability modeling.

Analyses using delta GAMSs can provide information concerning the habitat requirements of estuarine species for various life-stages and seasons. They can be used to help determine essential fish habitat (EFH) (Rubec et al. 1998, 1999, 2016a; Le Pape et al. 2003; Trimoreau et al. 2013) and habitat areas of particular concern (HAPC) for fisheries management (Rosenberg et al. 2000), to support ecosystem-based fisheries management (EPAP 1999; Carocci et al. 2009), to support inclusion of fish habitat information in fisheries ecosystem plans by U.S. fishery management councils (GMFMC 2005), to determine critical habitats for threatened and endangered species (Scott et al. 2006), to support oil spill response and natural resources damage assessment of areas impacted by chemical spills (French-McCay 2009), and to support coastal zone planning and management. The main products presented on a CD-ROM accompanying this report are a predicted CPUE-grid with CPUEs computed in numbers per square meter, an HSM map created within the GIS, and tabular estimates of population abundance.

While salinity is correlated with the abundance of estuarine residents in the Lower Peace River during all four seasons, it is not clear why the estuarine transients (EJ-Red Drum, EJ-Spot) are attracted to the Lower Peace River during WN and SP. It is likely that freshwater inflows to the river introduce nutrients that enhance the production of phytoplankton and zooplankton which are exploited by early life-stages of estuarine fish and invertebrates (Peebles 2002, Flannery et al. 2002). Monitoring of nutrient concentrations, water quality and plankton densities have been conducted in the Lower Peace River and other rivers in southwest Florida which supports this assertion. In other words, salinity is an indicator of the inflow of nutrients to the river which enhance primary and secondary production.

Inter-annual trends in abundance of Blue Crab were analyzed (Flaherty and Guenther 2011). Immature and adult Blue Crab indices of abundance and commercial landings were high in Tampa Bay in 1998 in association with increased rainfall during the 1997-1998 El Nino. This was followed by lower-than-average river inflows from late 1998 through to the beginning of

2002, which corresponds to a reduction in the abundance of immature Blue Crabs in 2002. They noted that reduced rainfall and freshwater diversions had the potential to adversely affect recruitment and survival of young crabs in the estuary. From 2003 to 2004, however, there was a dramatic increase in Blue Crab recruitment and a steady rise in adult abundance and commercial landings that may be linked to increases in river inflows above historic means.

Stevens et al. (2013) compared fish species assemblage composition and relative abundances in the oligohaline segment (salinity 0.5-5 ‰) to those of the lower river mouth segment (Lower P) of the Lower Peace River. The abundance of Sand Seatrout, Red Drum and Spot were similar between the two segments. During a dry period, the oligohaline fish assemblage became more similar to the assemblage of the lower river mouth. Reductions in the abundance in the oligohaline segment were offset by increases in the abundance of Bay Anchovy in the lower river mouth segment. The study provided insight into how the oligohaline segment functions as fish habitat, and determined changes in fish assemblages that occurred during low freshwater inflow conditions.

In the Lower Peace River, water managers have focused on the oligohaline segment as their MFL management target (Flannery et al. 2002, SWFWMD 2010). The minimum flows and levels in the Peace River are set to allow no more than a 15% decrease in the volume of low salinity water. Maintenance of low salinity water is considered biologically meaningful. Hydrodynamic model runs found that maintaining the area of low salinity water in the Lower Peace River was more conservative than using higher salinities as a metric.

Salinity and temperature conditions from 2007 to 2013 were predicted by SWFWMD in the present study using hydrodynamic modeling during each season for BL and MF conditions. Delta-gamma GAMs were applied by FWC-FWRI to predict the potential impacts of water withdrawals during each season on the spatial distributions and relative abundance of eight estuarine fish and invertebrate species life-stages. Population number estimates were derived for BL and MF conditions (**Table 4**). The research indicates that the goals set for the study were met to help support water management by SWFWMD in setting MFLs in the Lower Peace River and Charlotte Harbor. The general conclusion is that present water withdrawals are not harmful to the species which were analyzed.

Future HSM research should focus on years with reduced freshwater inflows. The reductions may be related more to reductions in rainfall rather than to water withdrawals (SWFWMD 2010). The role played by climatic variation needs further study. Inter-annual fluctuations in CPUEs determined in the present study needs to be analyzed further. Nutrient inputs to the Lower Peace River need analyses to explain how they support food webs that support fish production.

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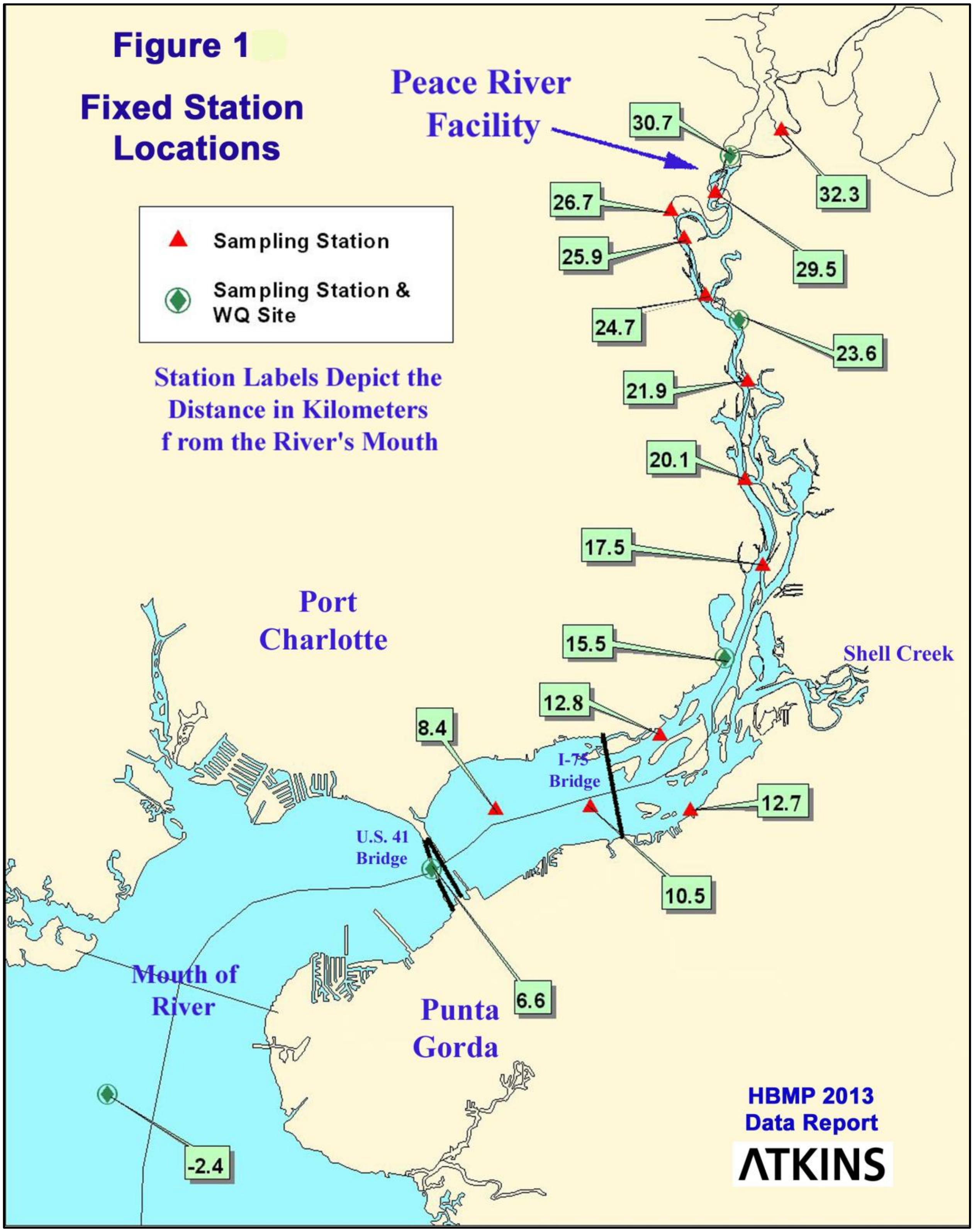

Figure 1. Station locations for data recorders (red triangles) based on distance from the mouth of the Lower Peace River. Water withdrawals are conducted at the Peace River Facility.

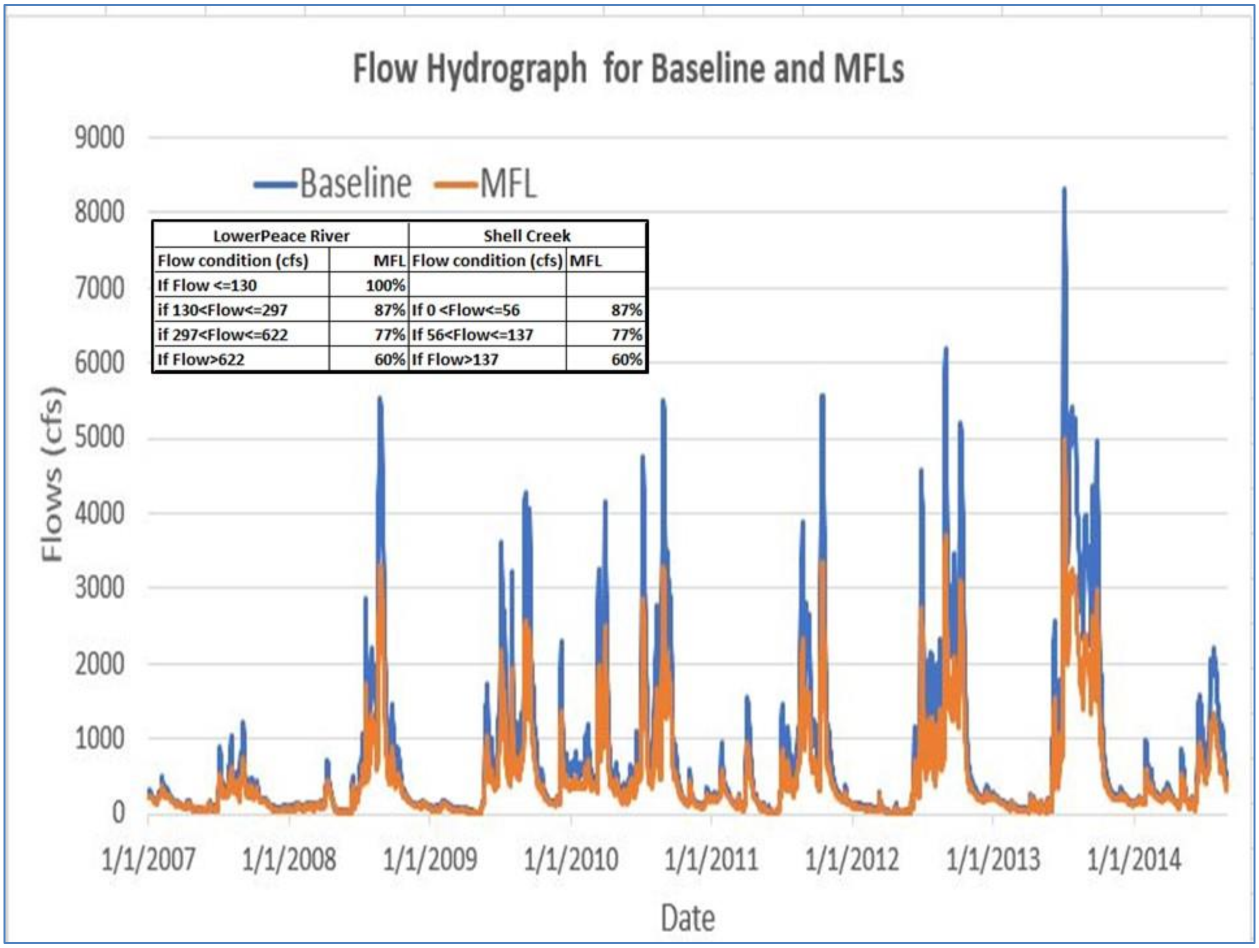

Figure 2. Flow hydrograph for Baseline (BL) and Minimum Flow (MF) conditions in the Lower Peace River. Ranges of flow conditions being used for water withdrawals are presented for the Lower Peace River and for Shell Creek.

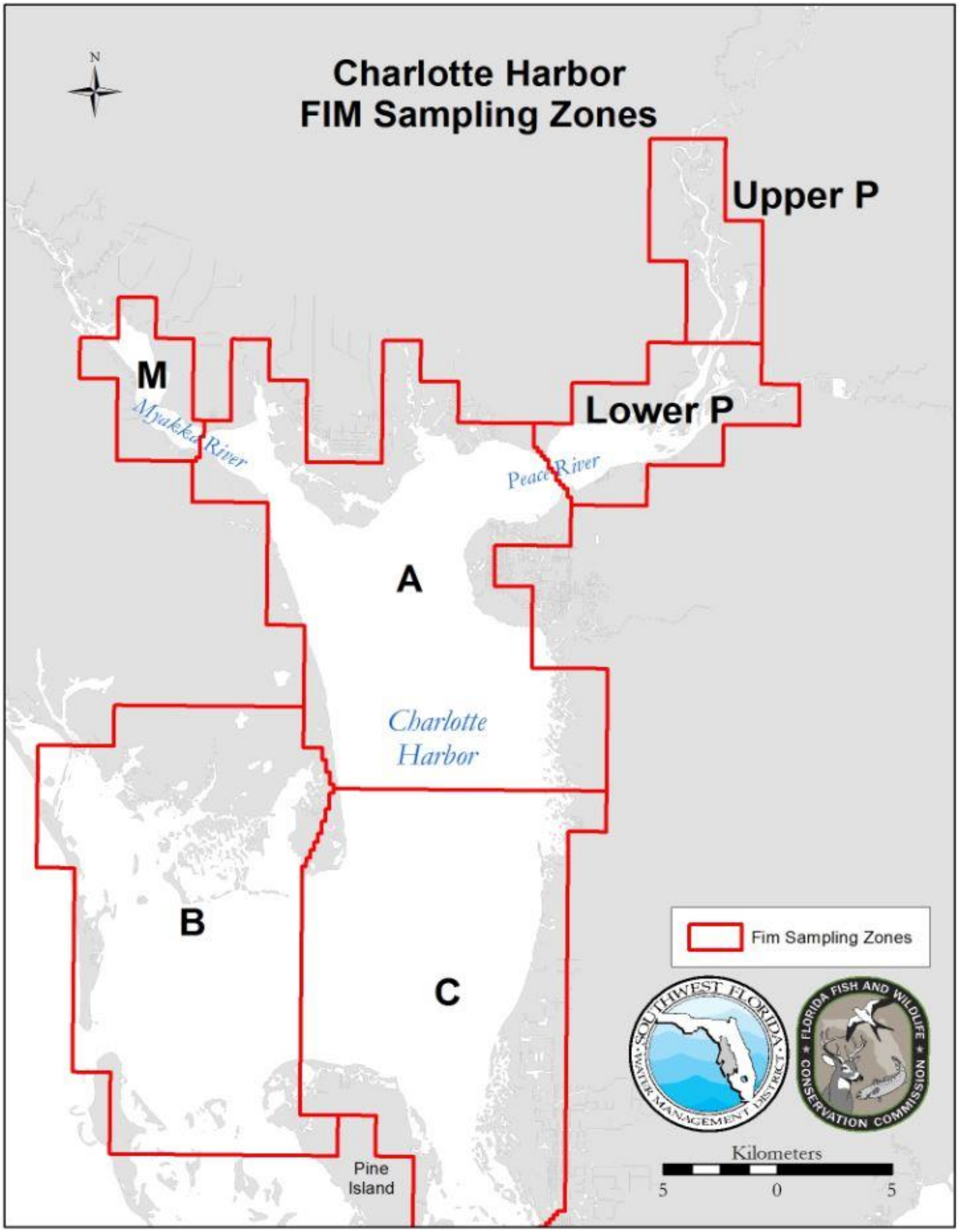

Figure 3. FIM sampling segments in Charlotte Harbor and Lower Peace River. The segment designated Upper P is the area associated with special FIM studies.

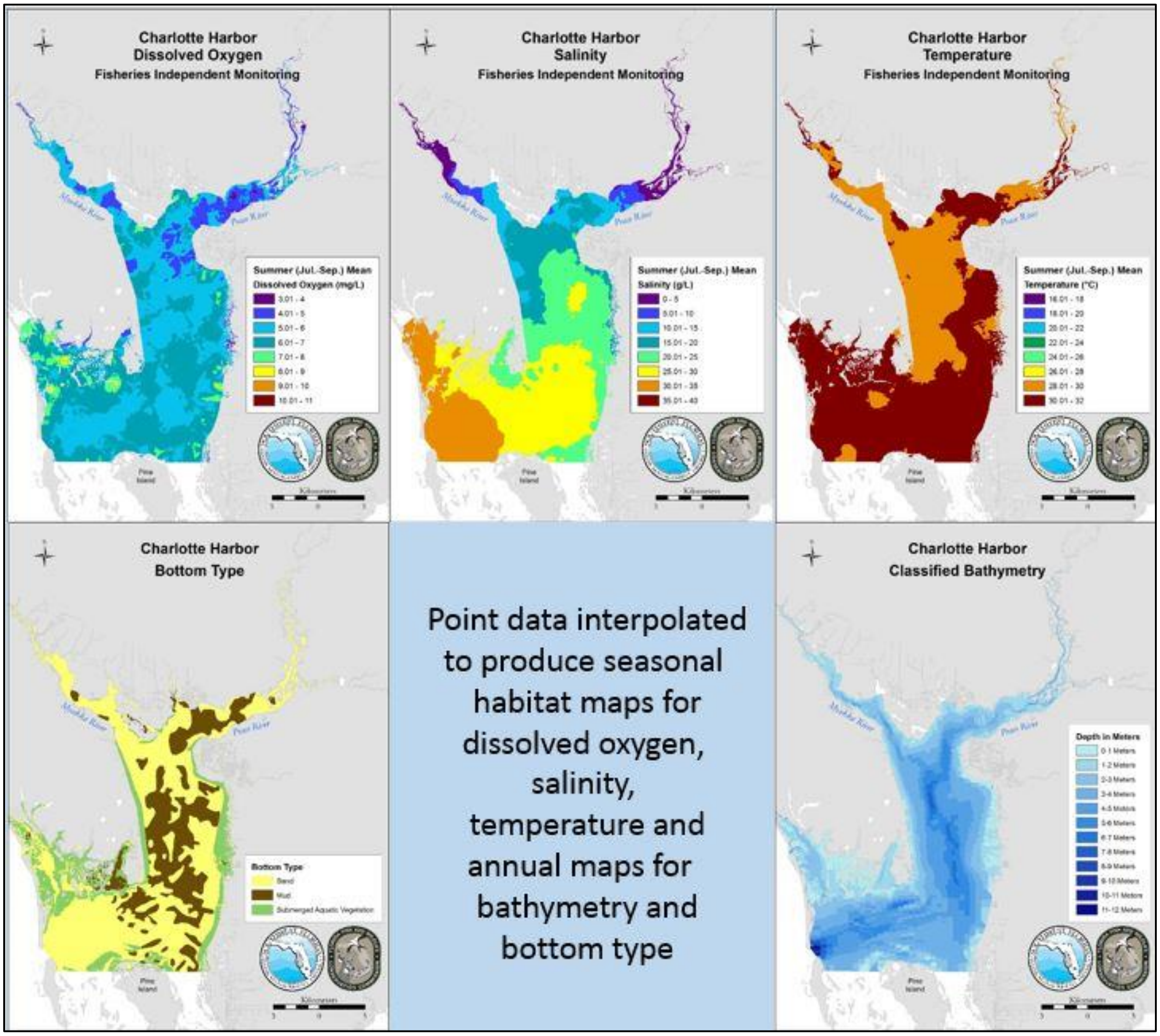

Figure 4. Seasonal maps for dissolved oxygen, salinity, temperature derived from FIM sampling data and annual maps for bottom type and bathymetry created using NOAA data for bottom sediments and SWFWMD data for submerged aquatic vegetation (SAV) and depths derived from an acoustic survey by USF.

Figure 5. Staff from FWC-FWRI Fisheries Independent Monitoring program sampling fish and invertebrates using seines and trawls.

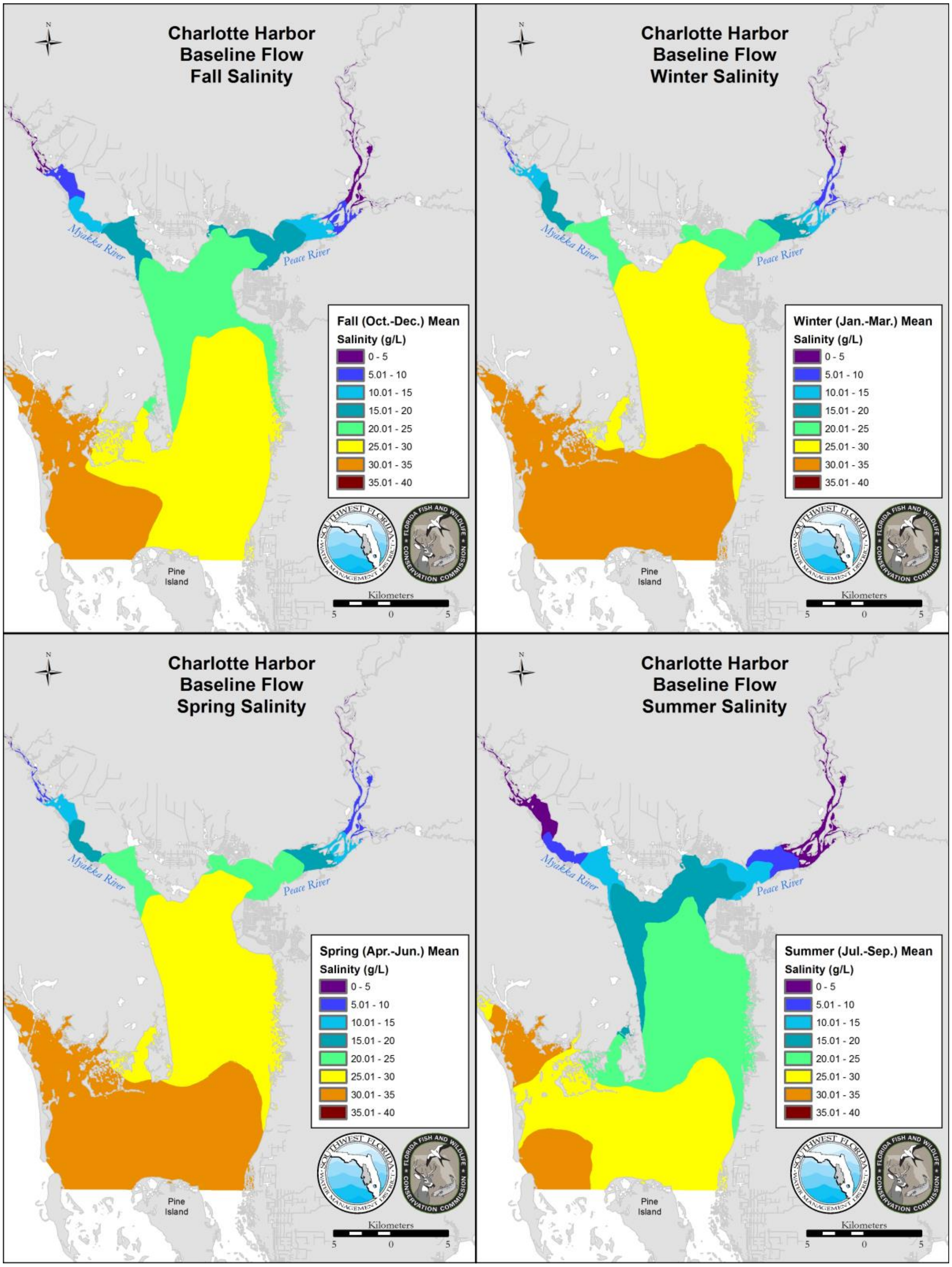

Figure 6a. Seasonal maps for salinity derived from BF data created from hydrodynamic modeling.

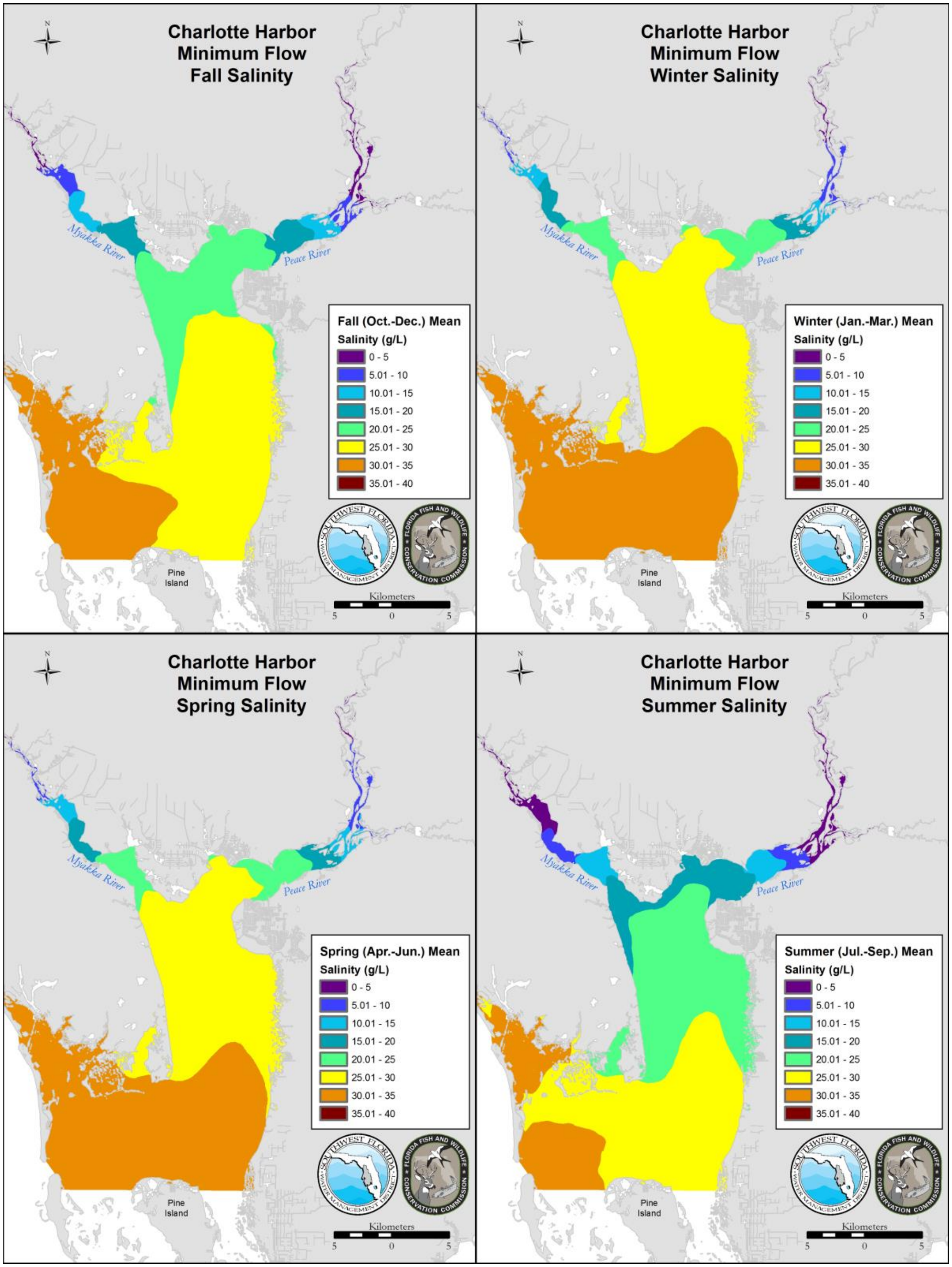

Figure 6b. Seasonal maps for salinity derived from MF data created from hydrodynamic modeling.

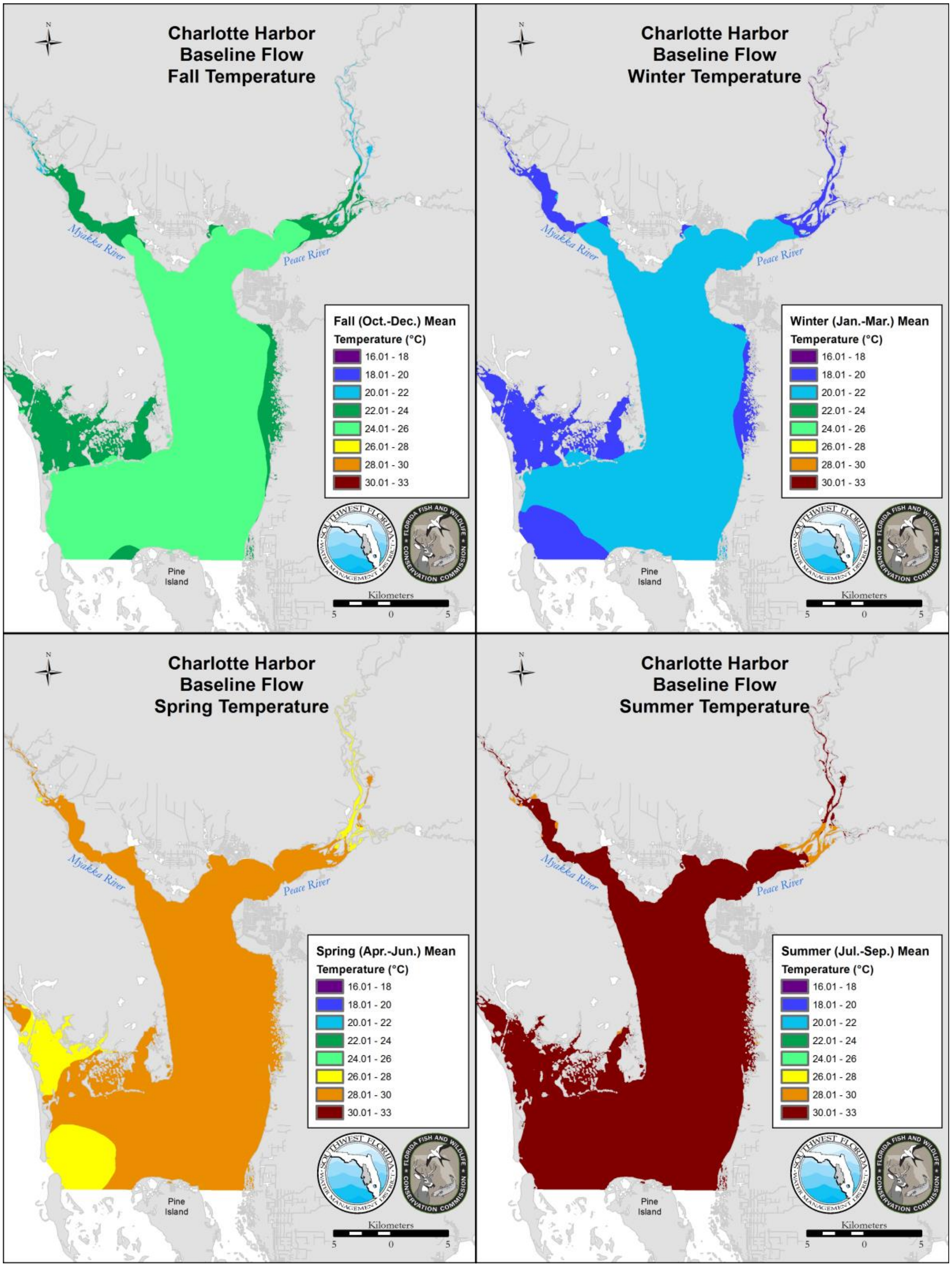

Figure 7a. Seasonal maps for temperature derived from BF data created from hydrodynamic modeling.

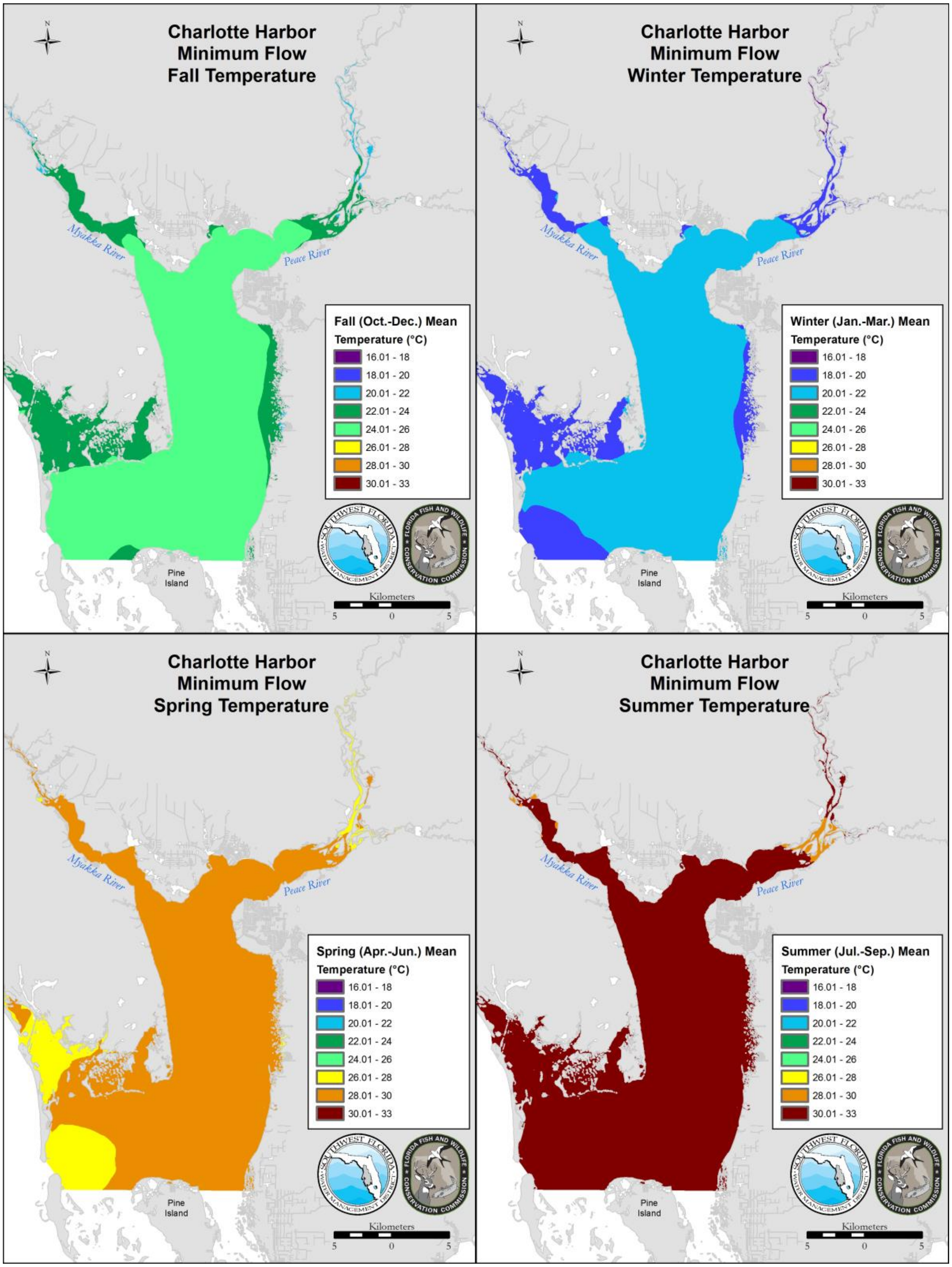

Figure 7b. Seasonal maps for temperature derived from MF data created from hydrodynamic modeling.

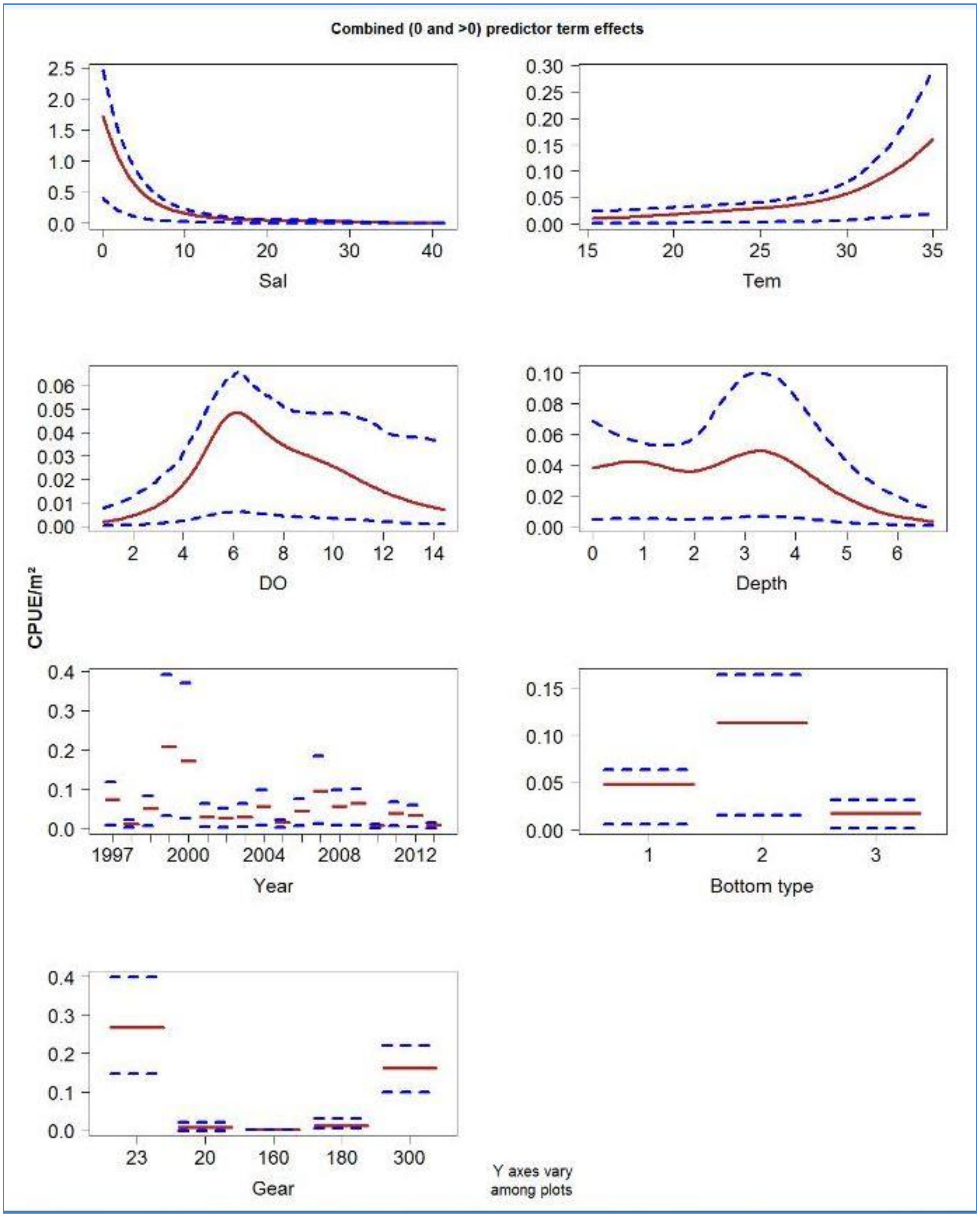

Figure 8. Back-transformed splines and histograms for Juvenile-Adult Hogchoker in the Spring.

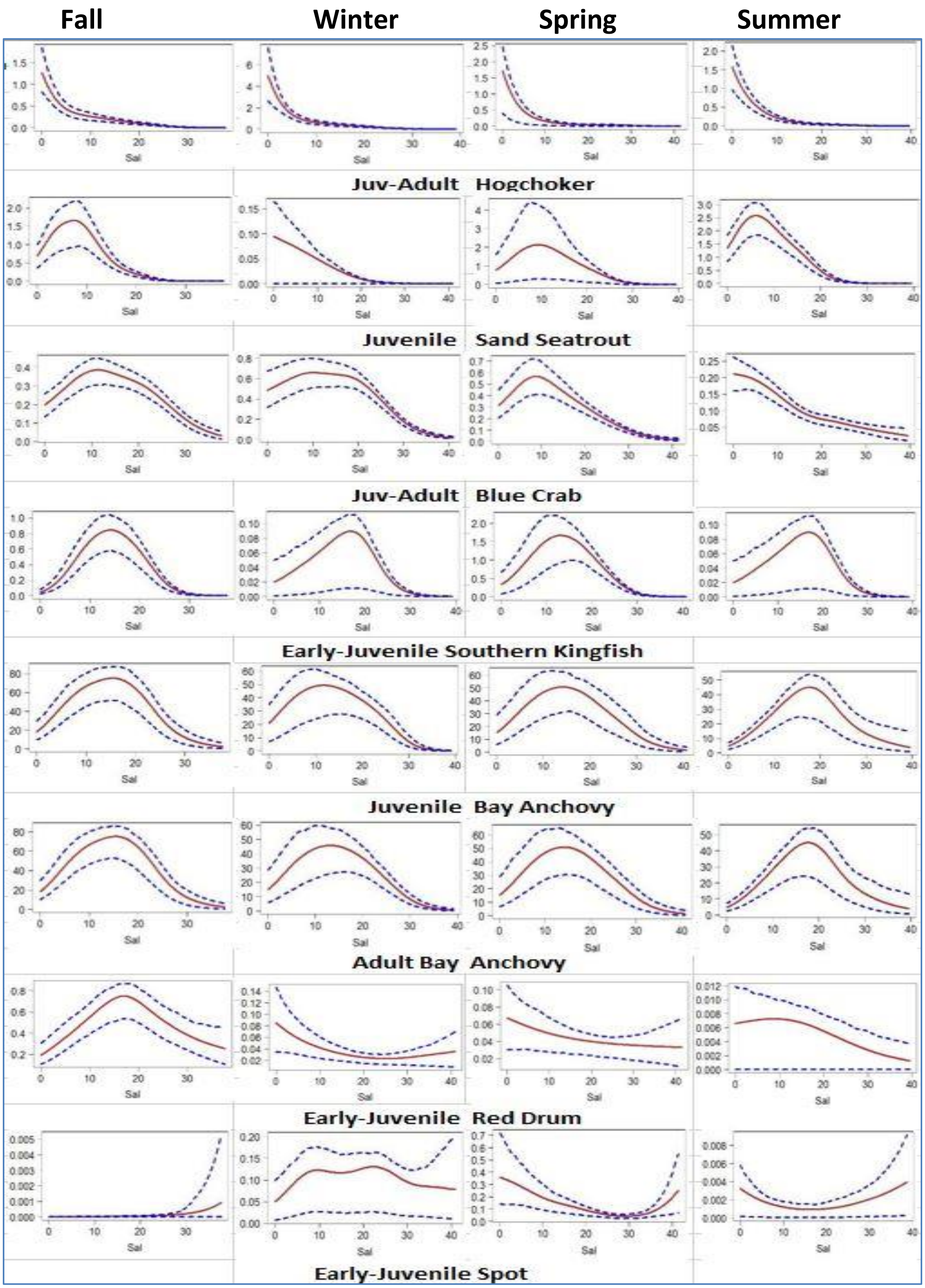

Figure 9. Seasonal fitted splines for back-transformed GC-CPUEs by salinity for species life-stages. Dashed lines represent 95% confidence limits.

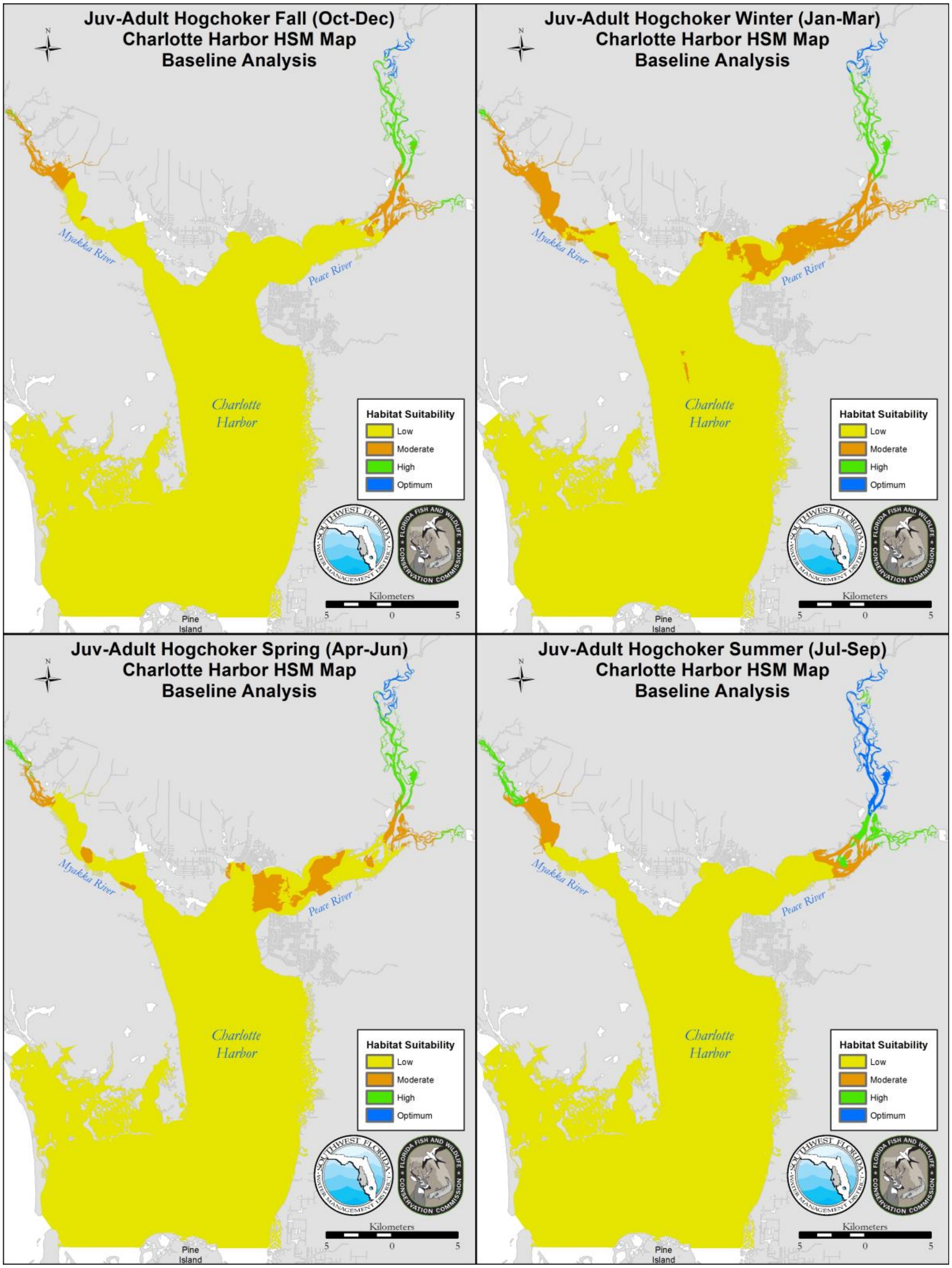

Figure 10a. HSM maps for juvenile-adult Hogfish depicting changes in Optimum zones between seasons for BF scenario.

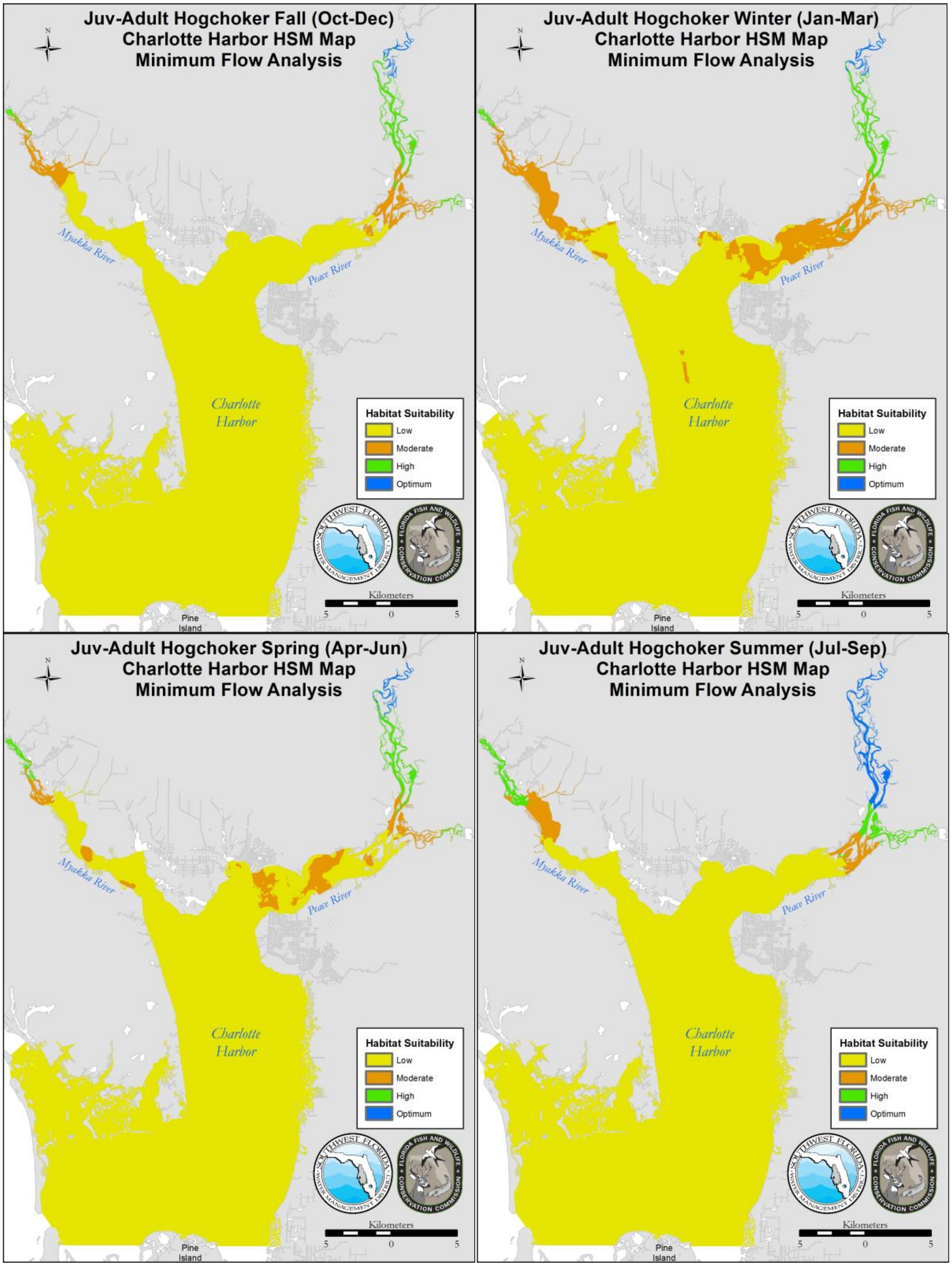

Figure 10b. HSM maps for juvenile-adult Hogfish depicting changes in Optimum zones between seasons for MF scenario.

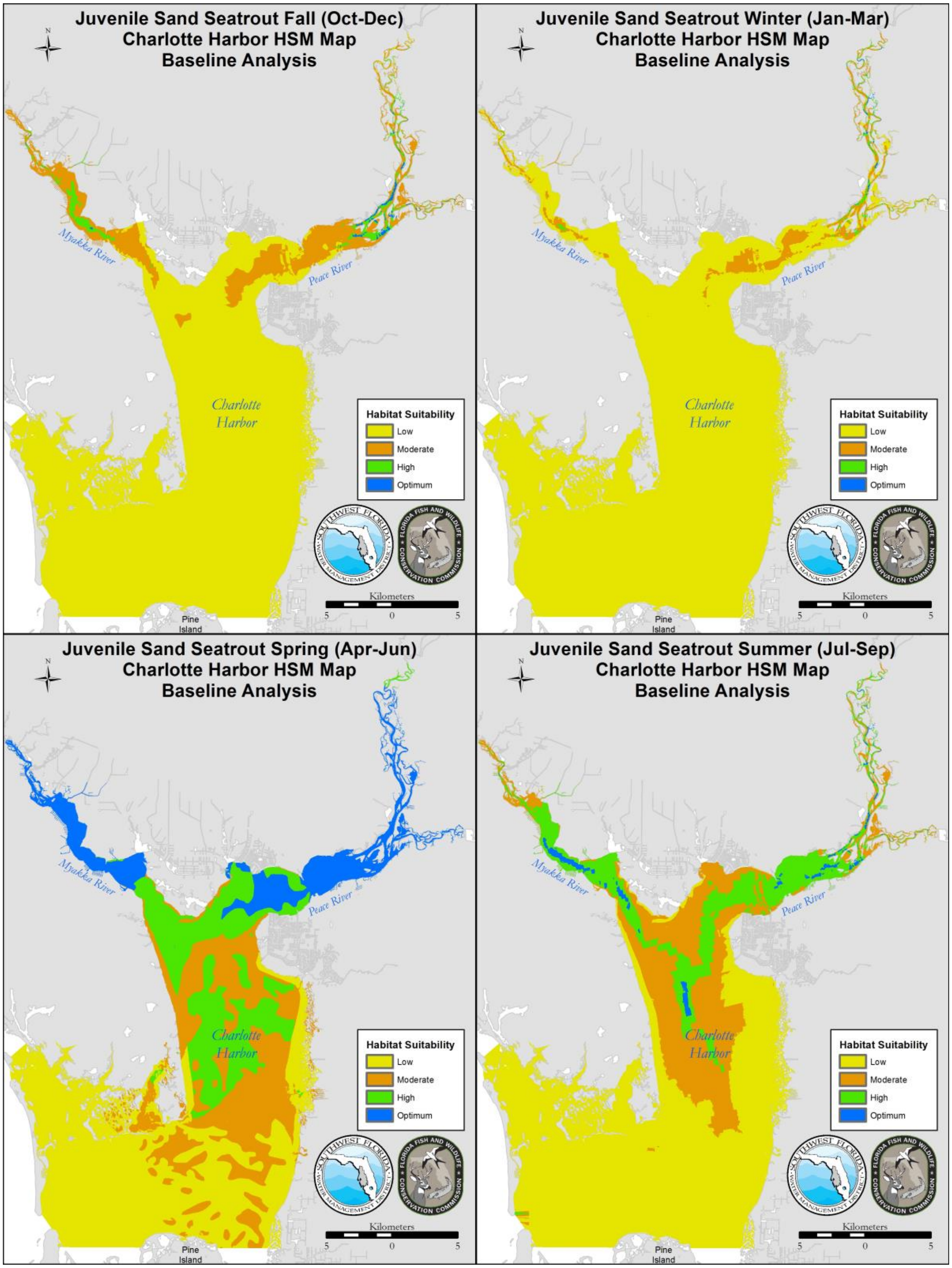

Figure 11a. HSM maps for juvenile Sand Seatrout depicting changes in Optimum zones between seasons for BF scenario.

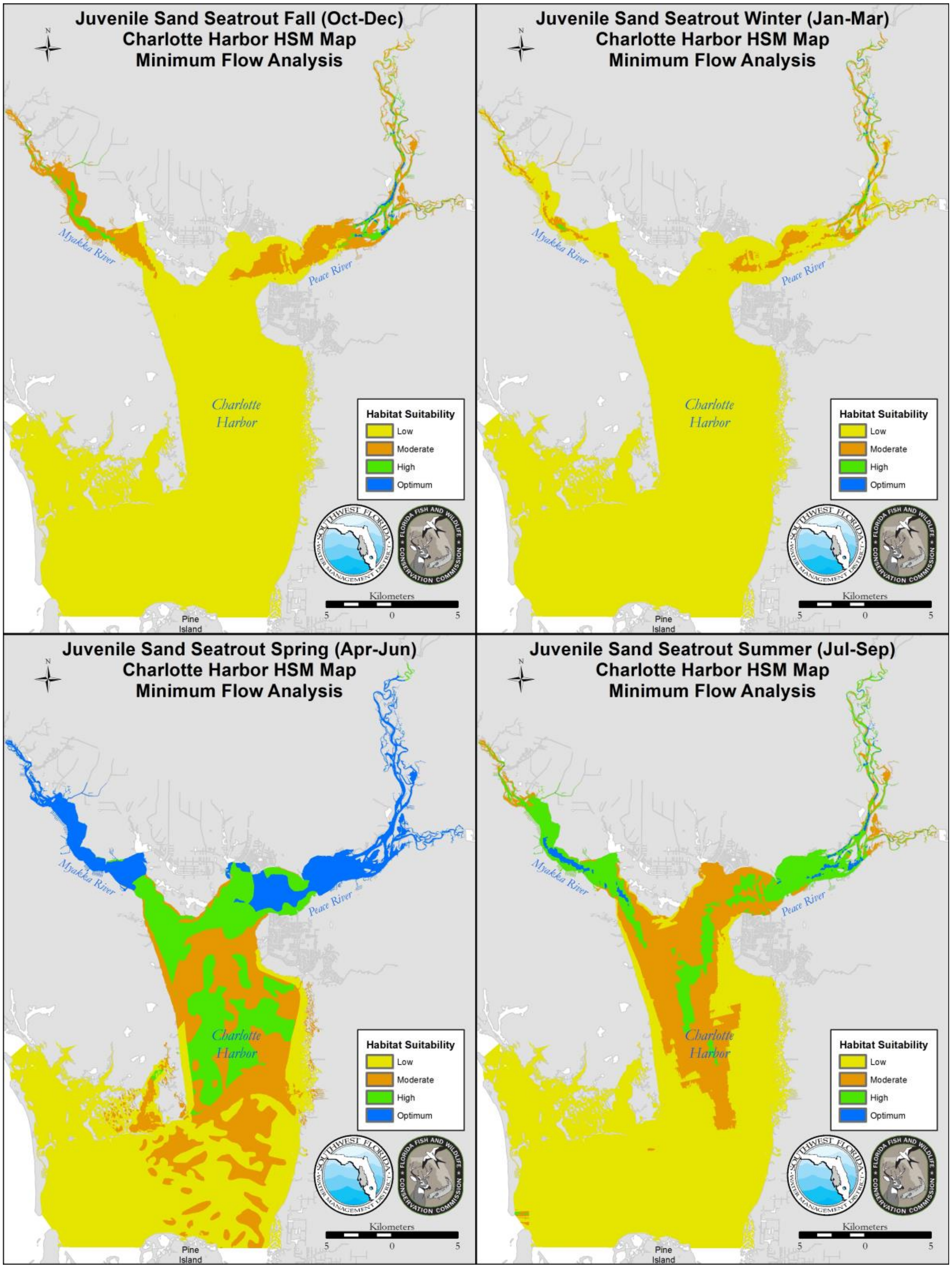

Figure 11b. HSM maps for juvenile Sand Seatrout depicting changes in Optimum zones between seasons for MF scenario.

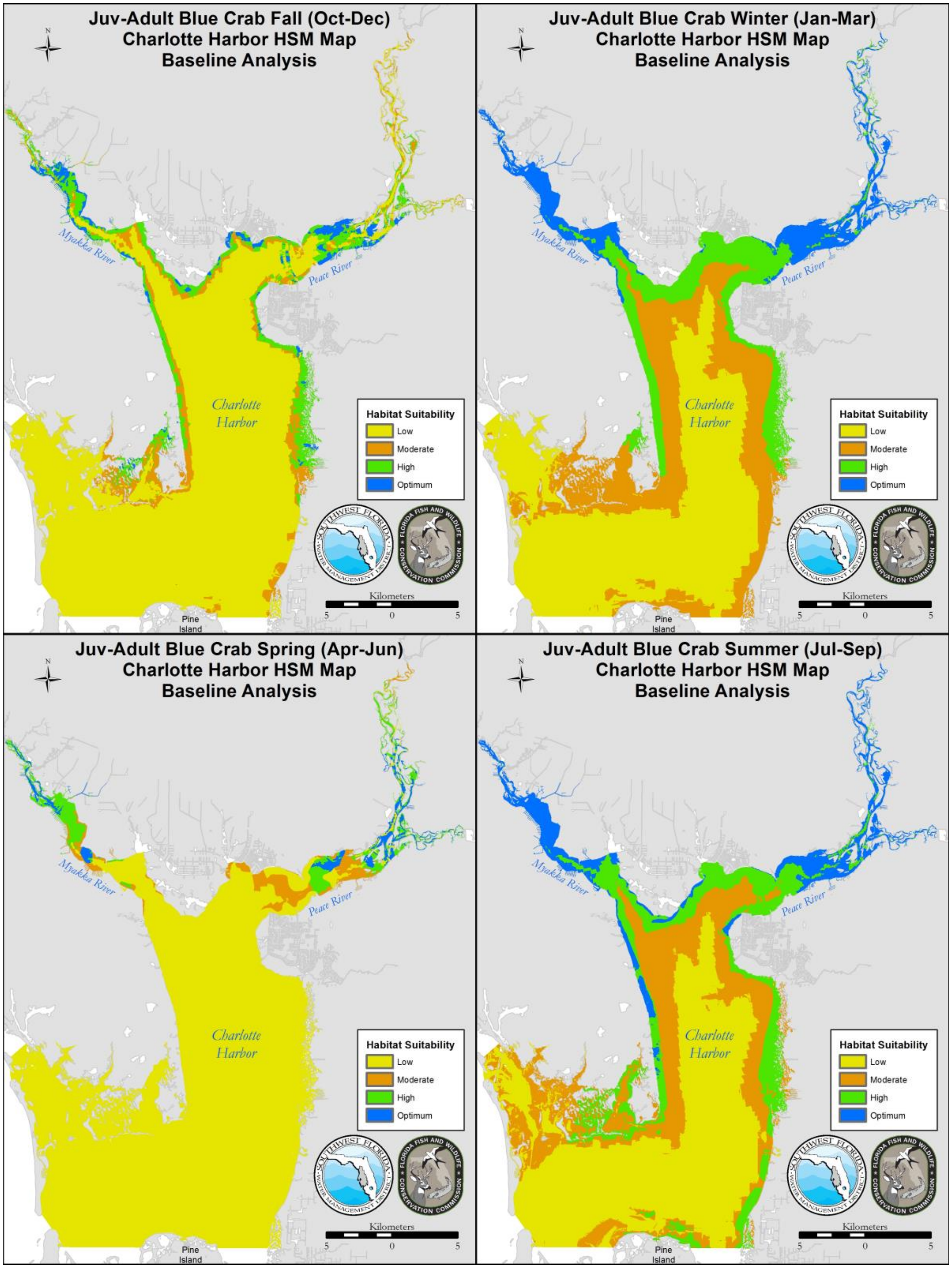

Figure 12a. HSM maps for juvenile-adult Blue Crab depicting changes in Optimum zones between seasons for BF scenario.

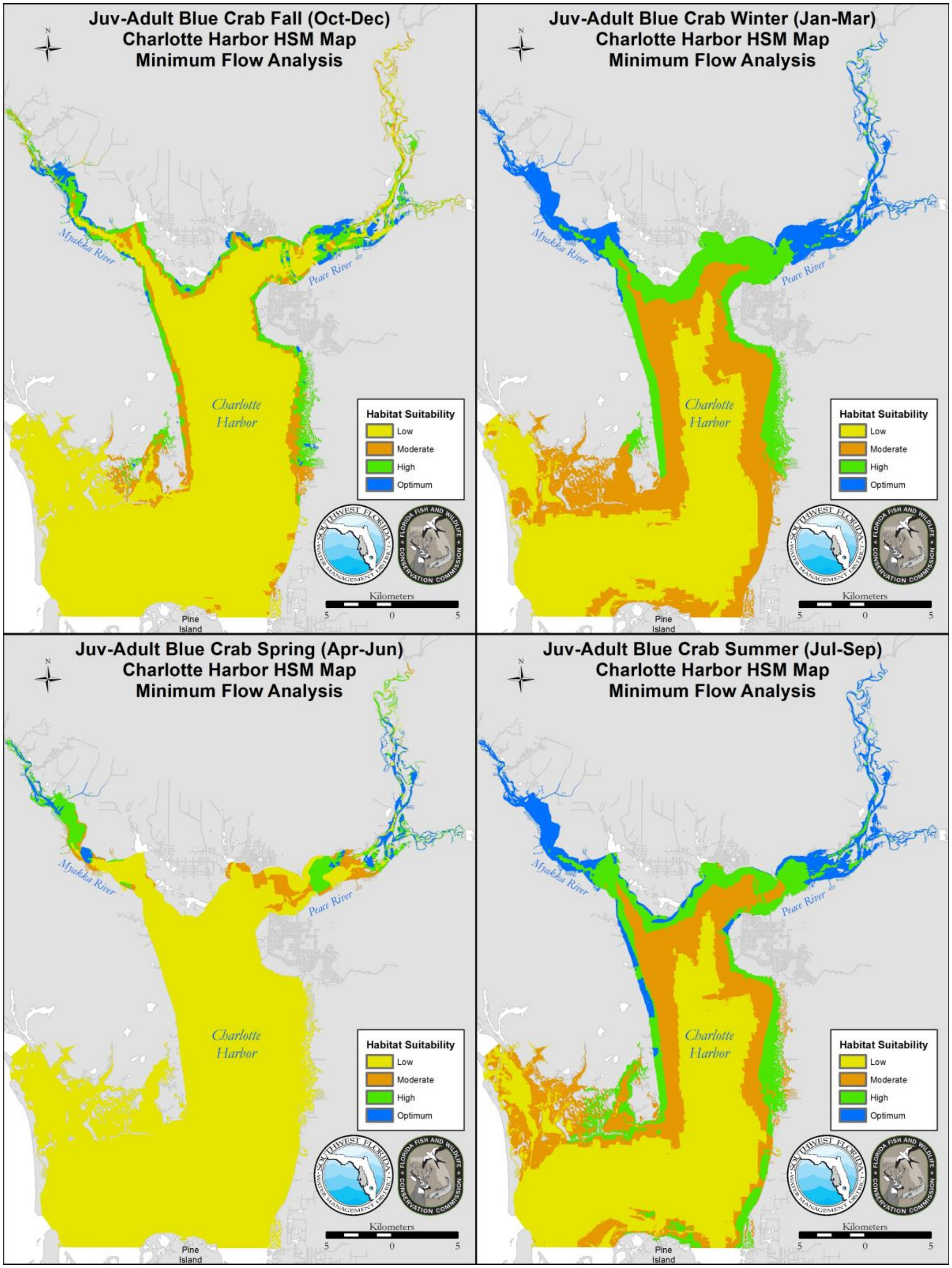

Figure 12b. HSM maps for juvenile-adult Blue Crab depicting changes in Optimum zones between seasons for MF scenario.

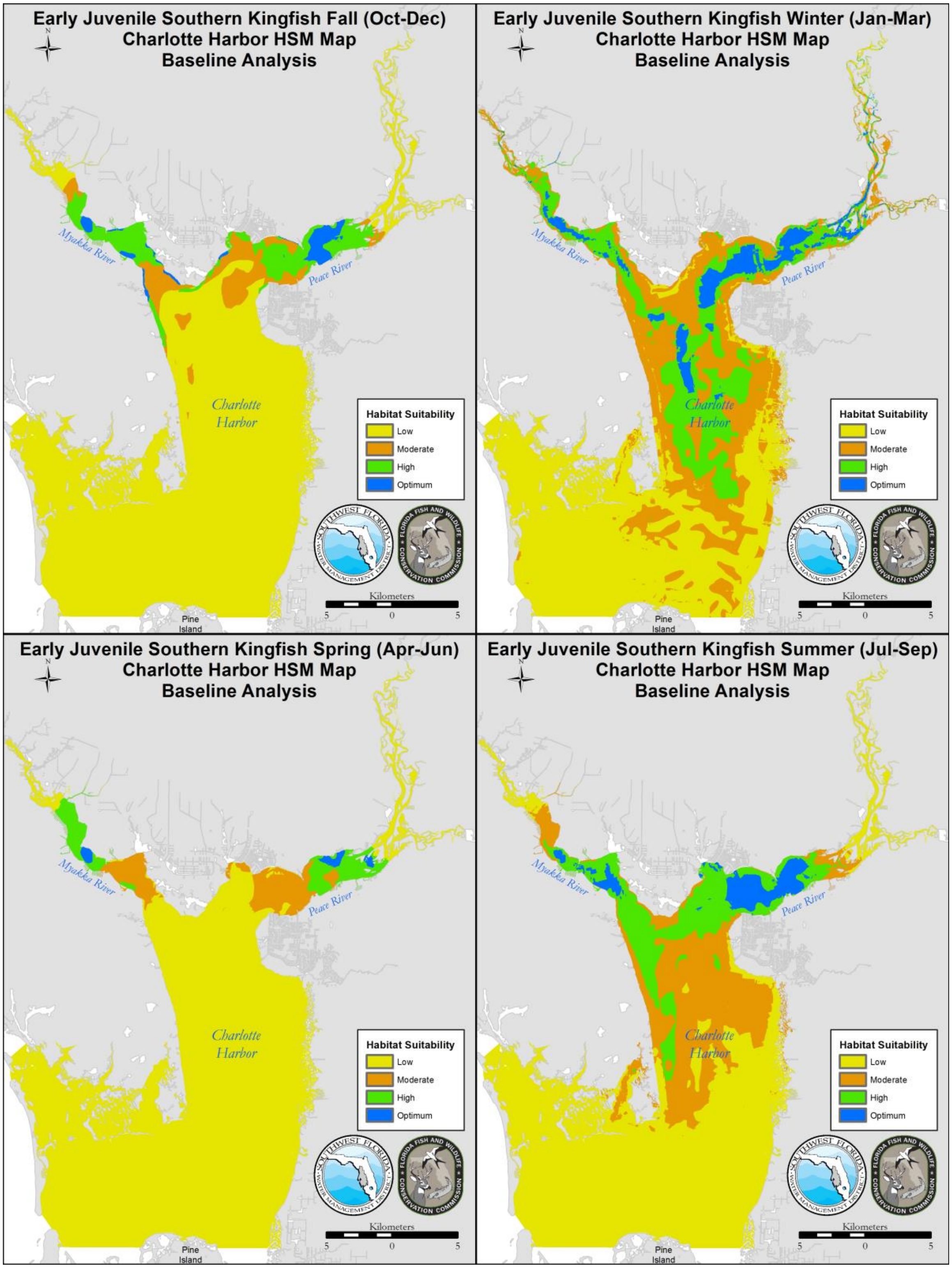

Figure 13a. HSM maps for early-juvenile Southern Kingfish depicting changes in Optimum zones between seasons for BF scenario.

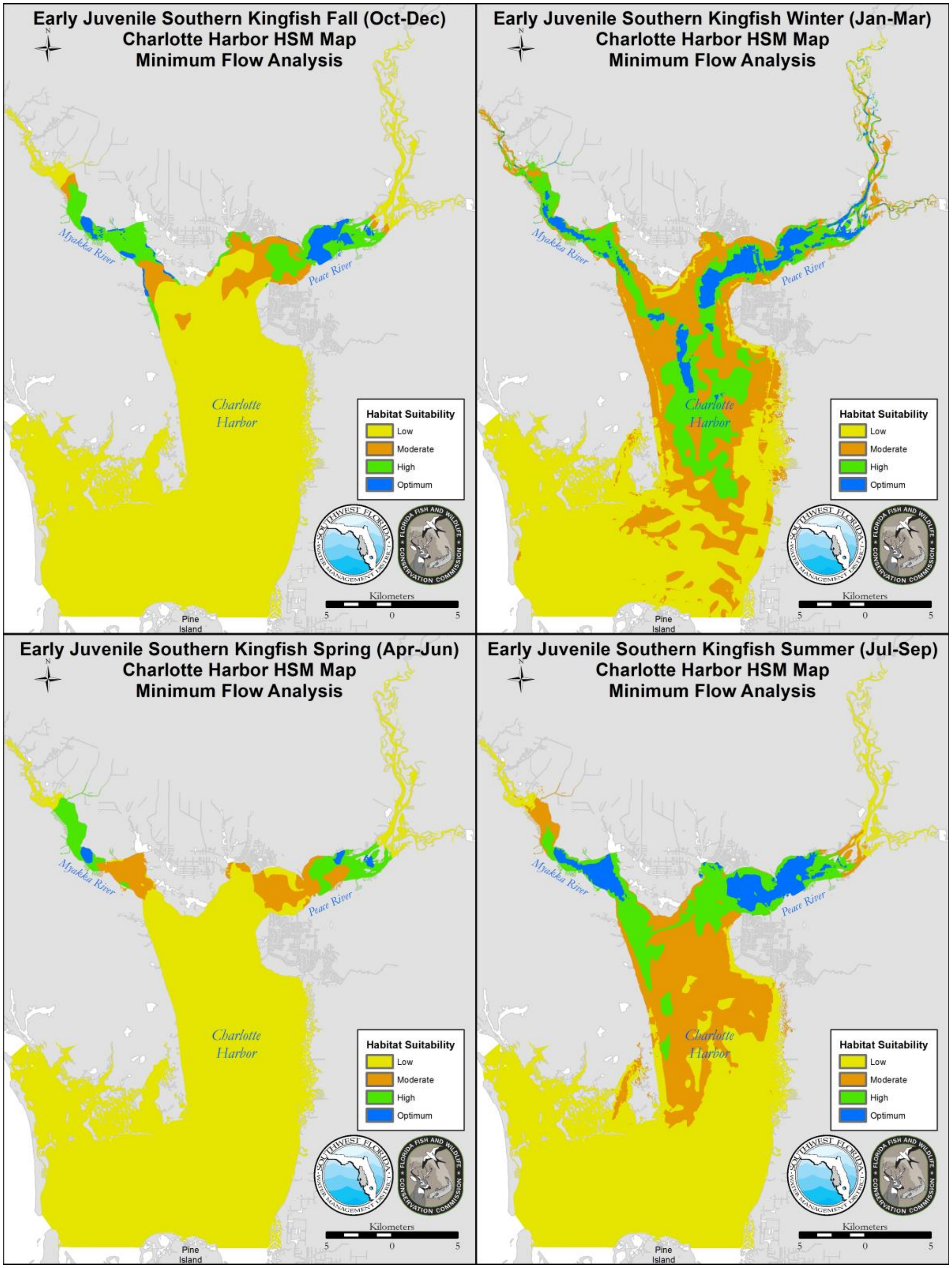

Figure 13b. HSM maps for early-juvenile Southern Kingfish depicting changes in Optimum zones between seasons for MF scenario.

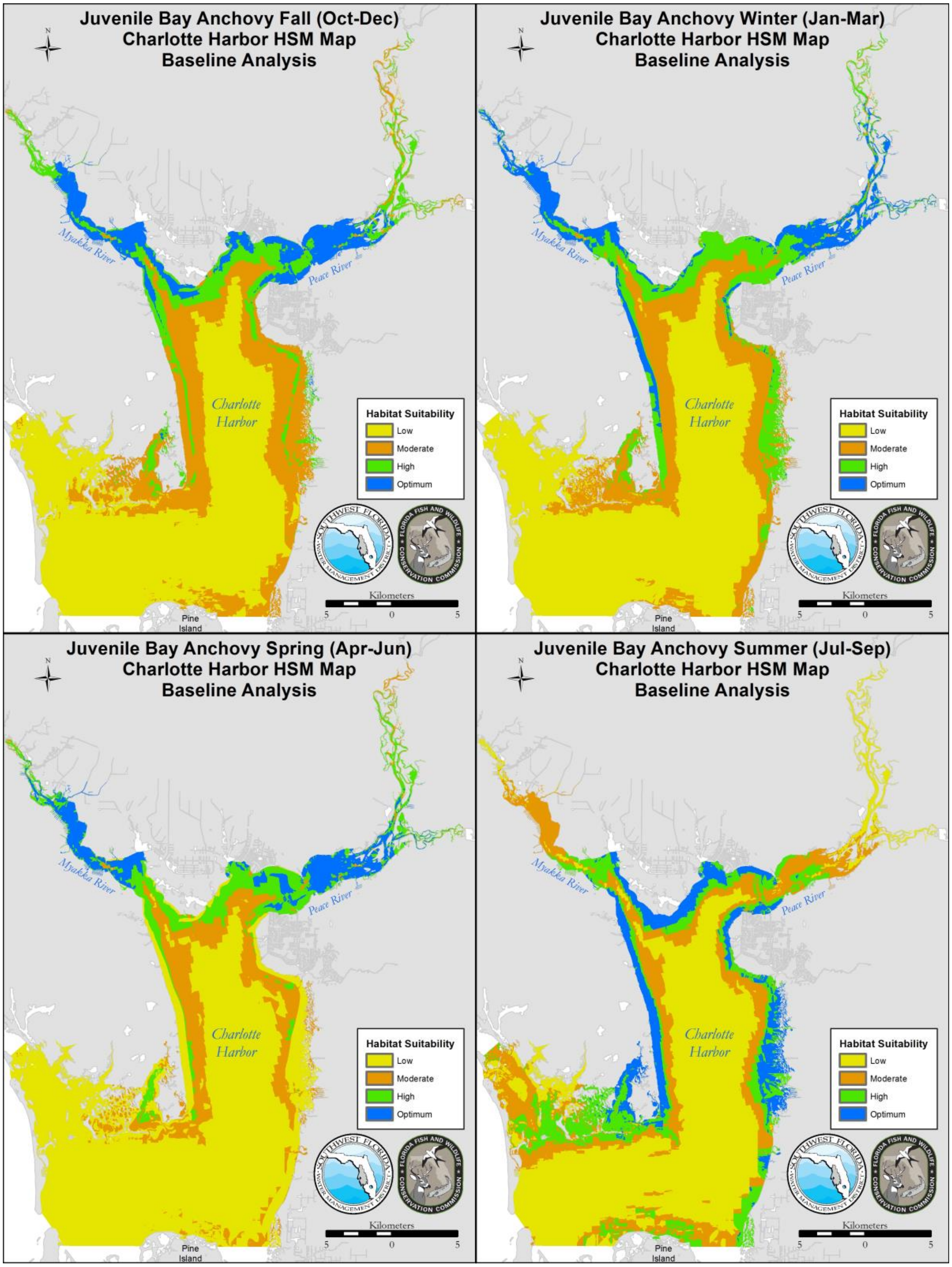

Figure 14a. HSM maps for juvenile Bay Anchovy depicting changes in Optimum zones between seasons for BF scenario.

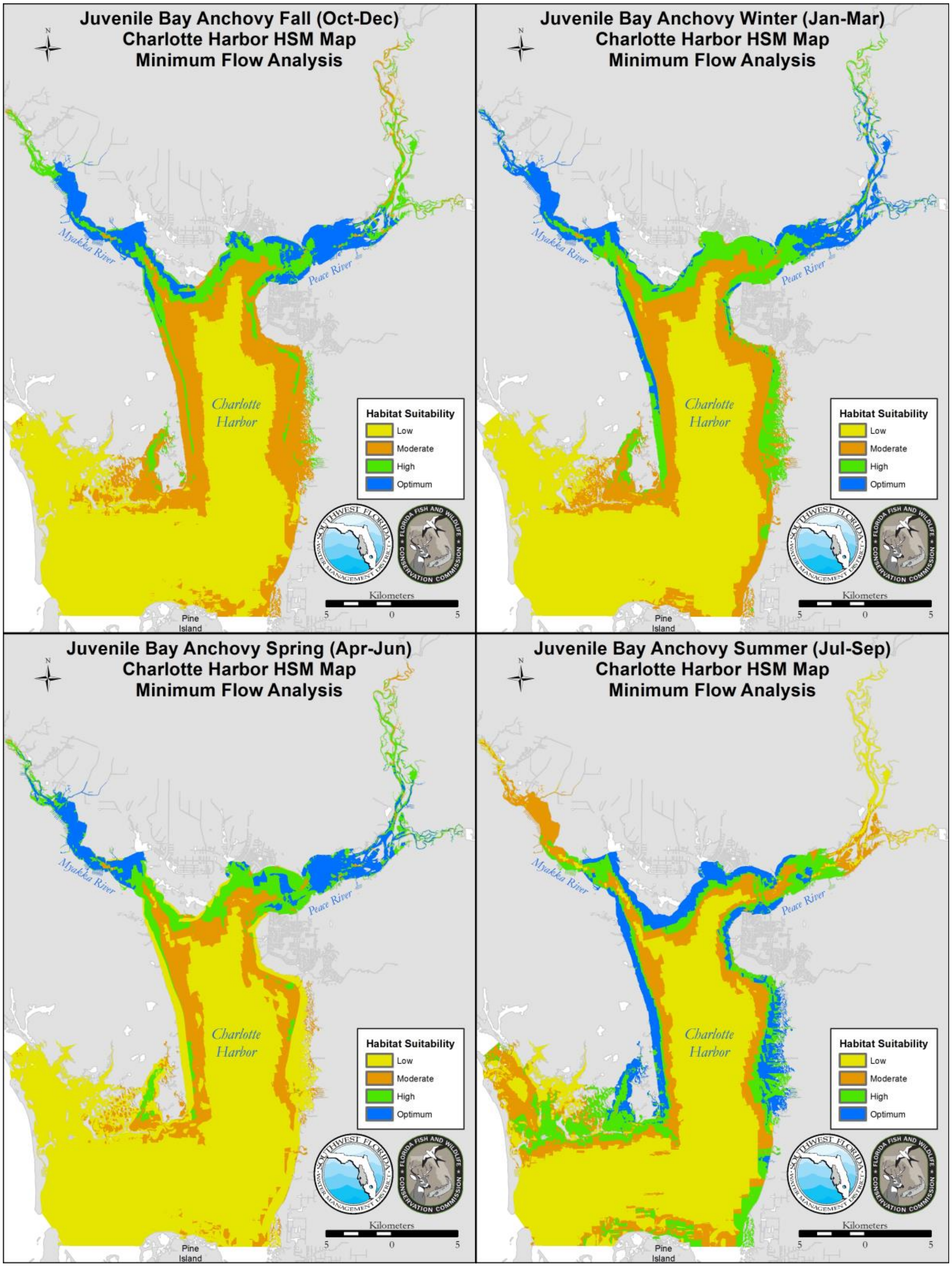

Figure 14b. HSM maps for juvenile Bay Anchovy depicting changes in Optimum zones between seasons for MF scenario.

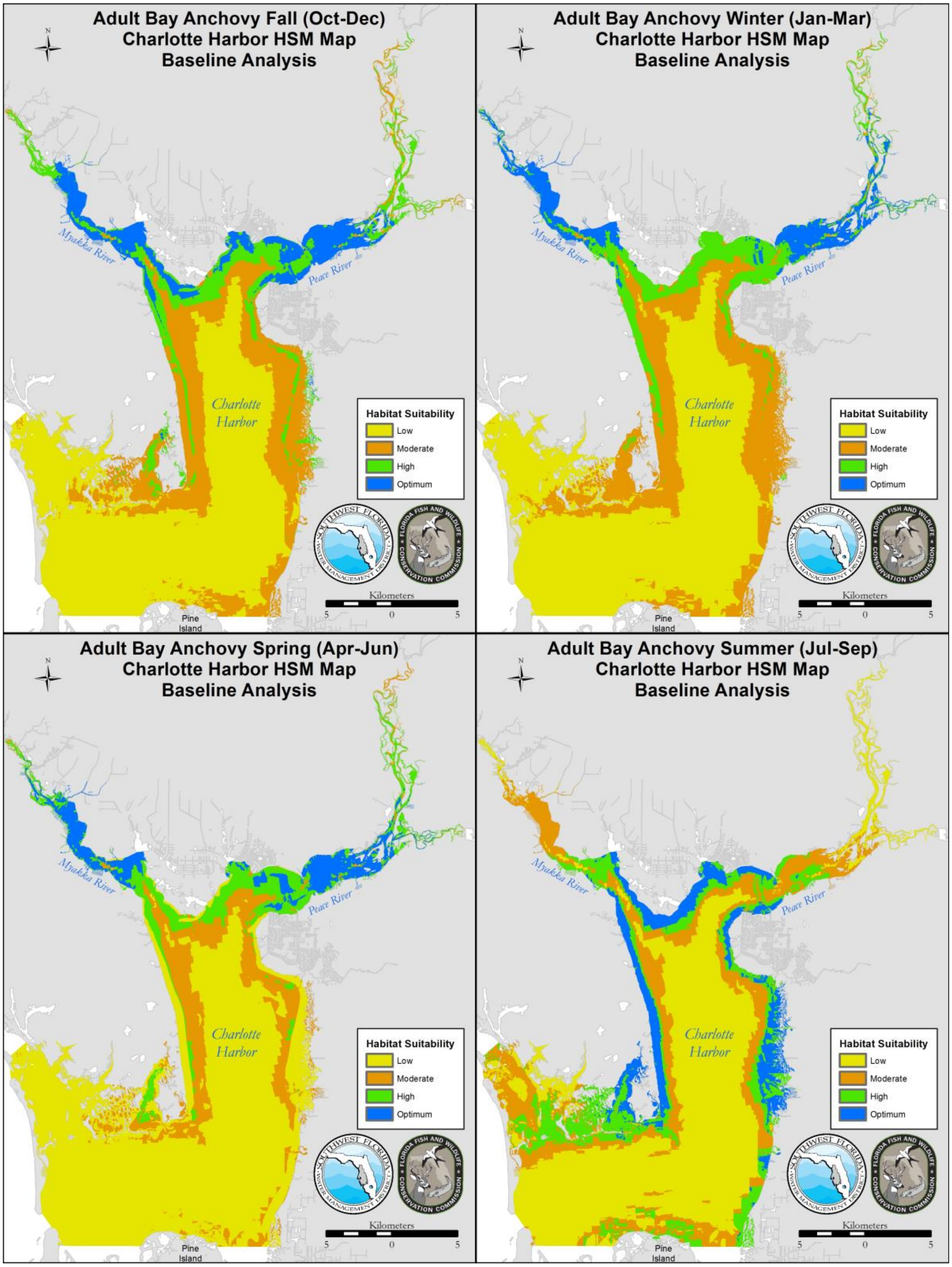

Figure 15a. HSM maps for adult Bay Anchovy depicting changes in Optimum zones between seasons for BF scenario.

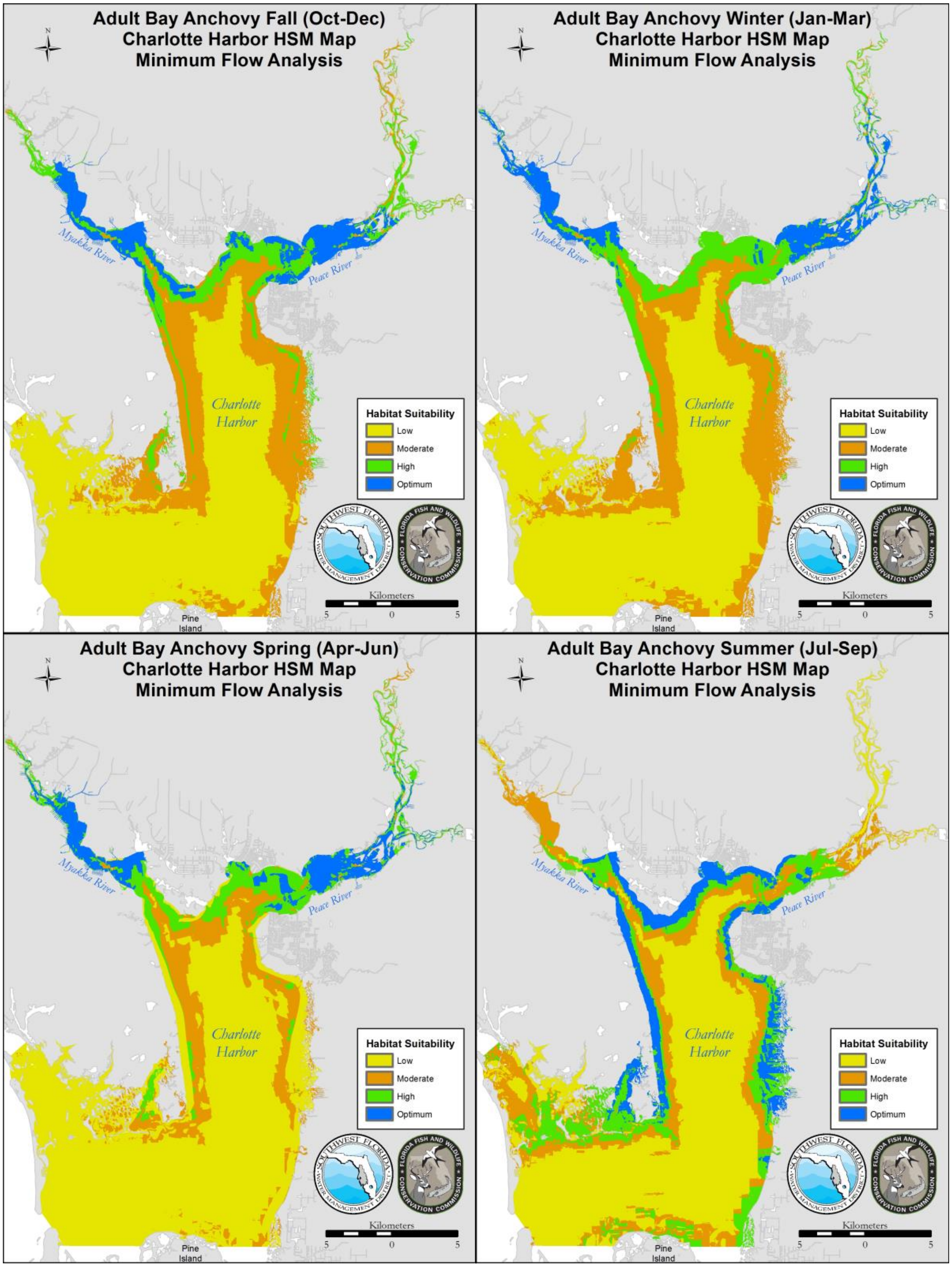

Figure 15b. HSM maps for adult Bay Anchovy depicting changes in Optimum zones between seasons for MF scenario.

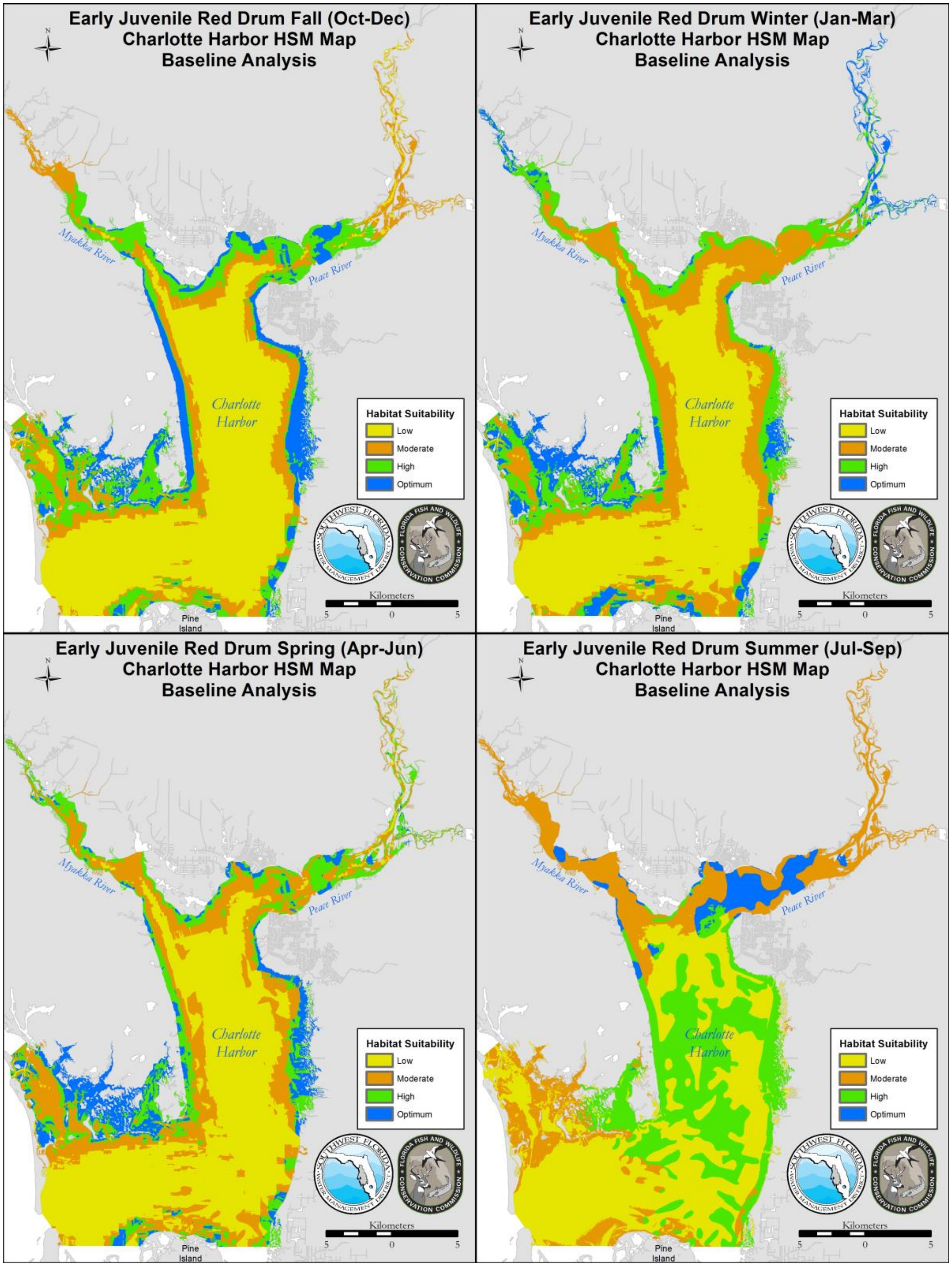

Figure 16a. HSM maps for early-juvenile Red Drum depicting changes in Optimum zones between seasons for BF scenario.

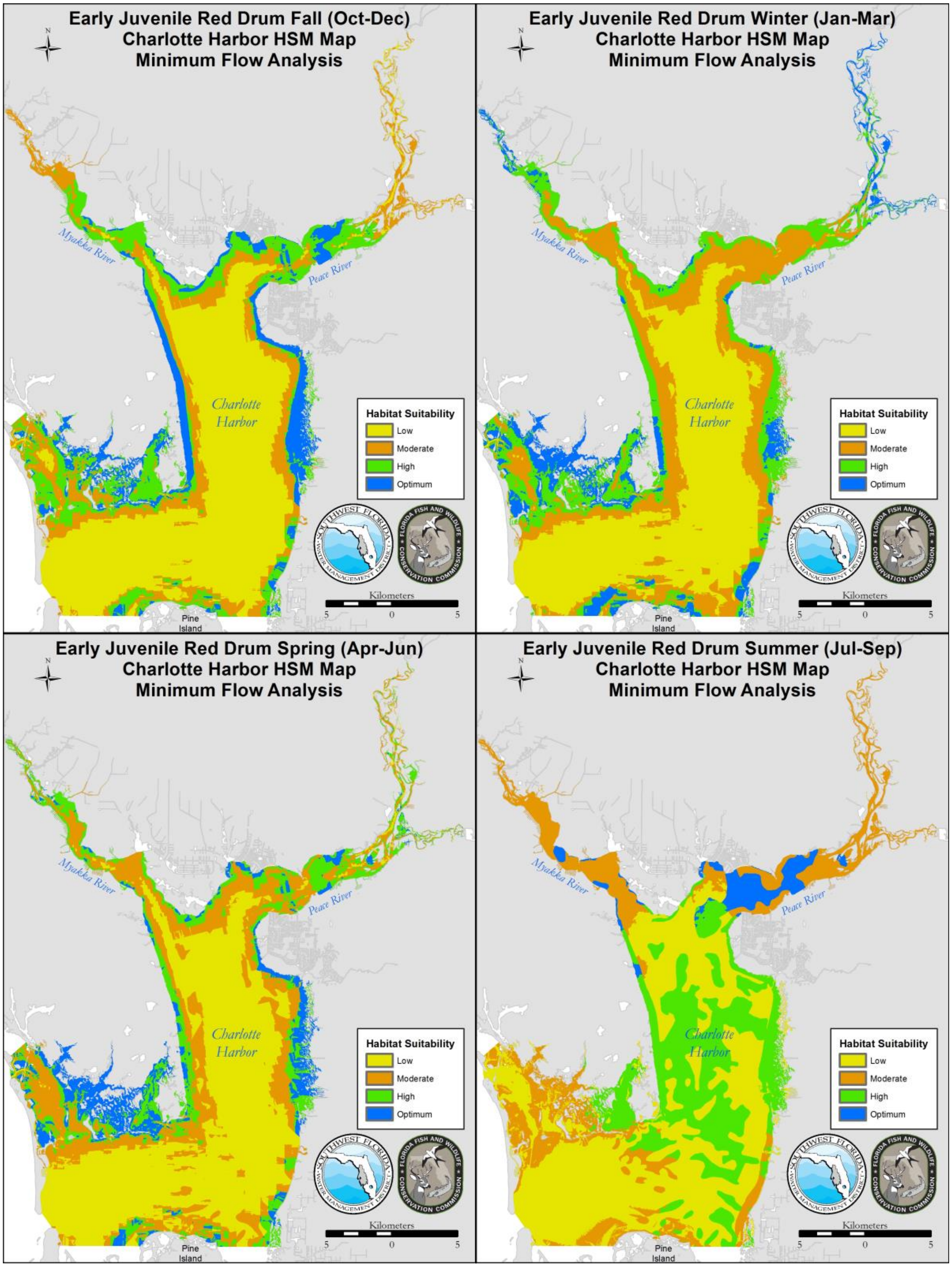

Figure 16b. HSM maps for early-juvenile Red Drum depicting changes in Optimum zones between seasons for MF scenario.

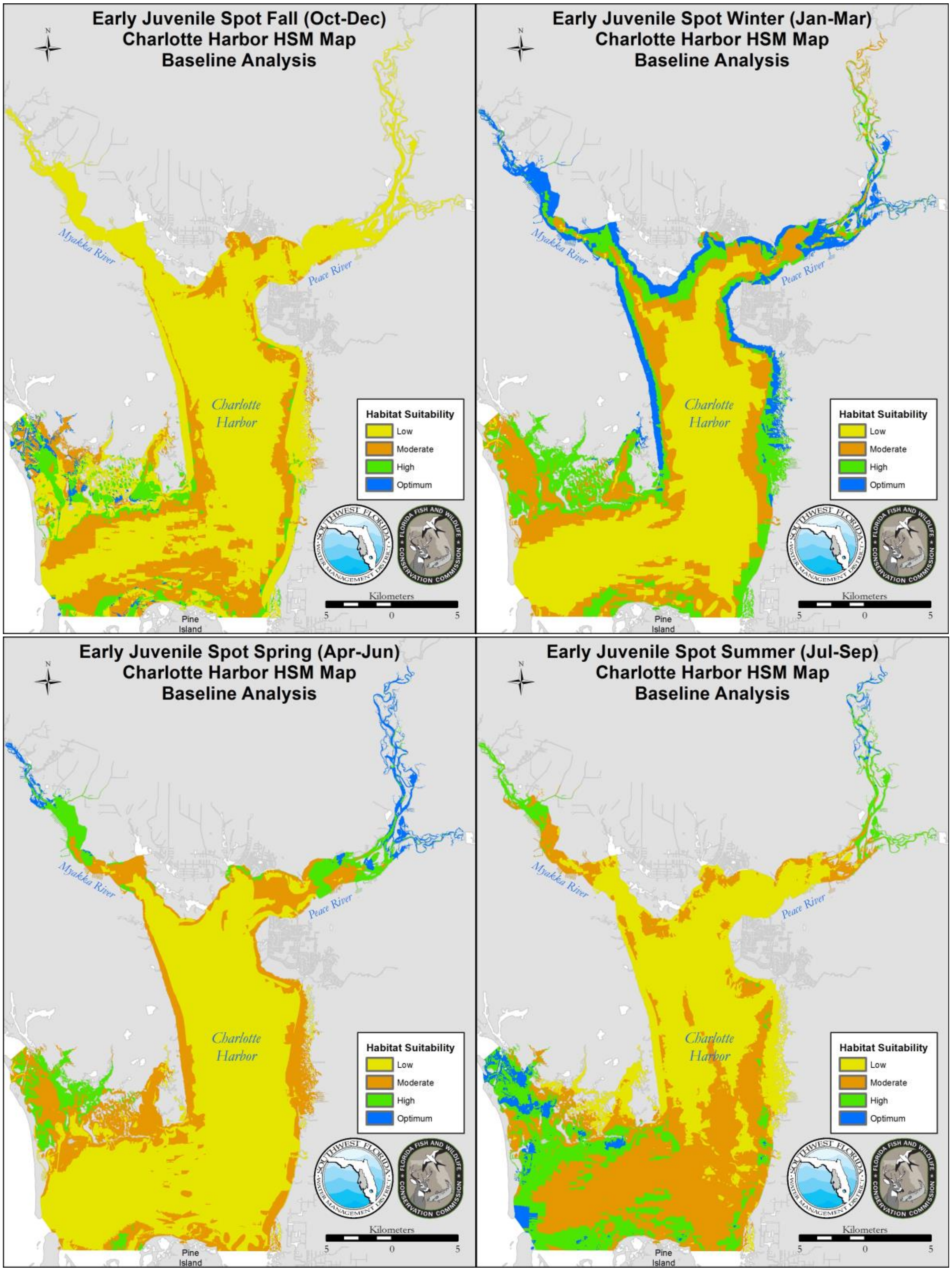

Figure 17a. HSM maps for early-juvenile Spot depicting changes in Optimum zones between seasons for BF scenario.

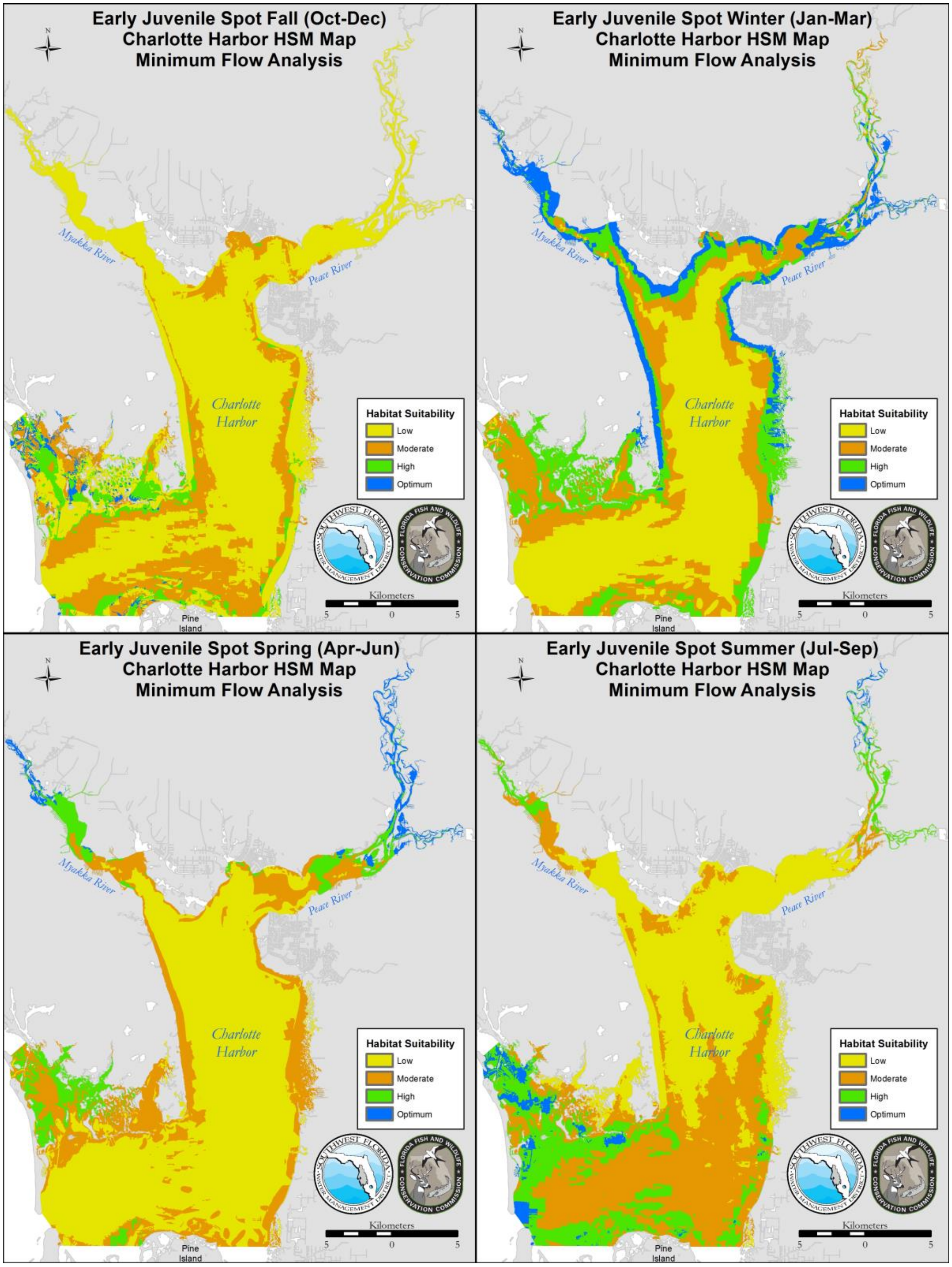

Figure 17b. HSM maps for early-juvenile Spot depicting changes in Optimum zones between seasons for MF scenario.

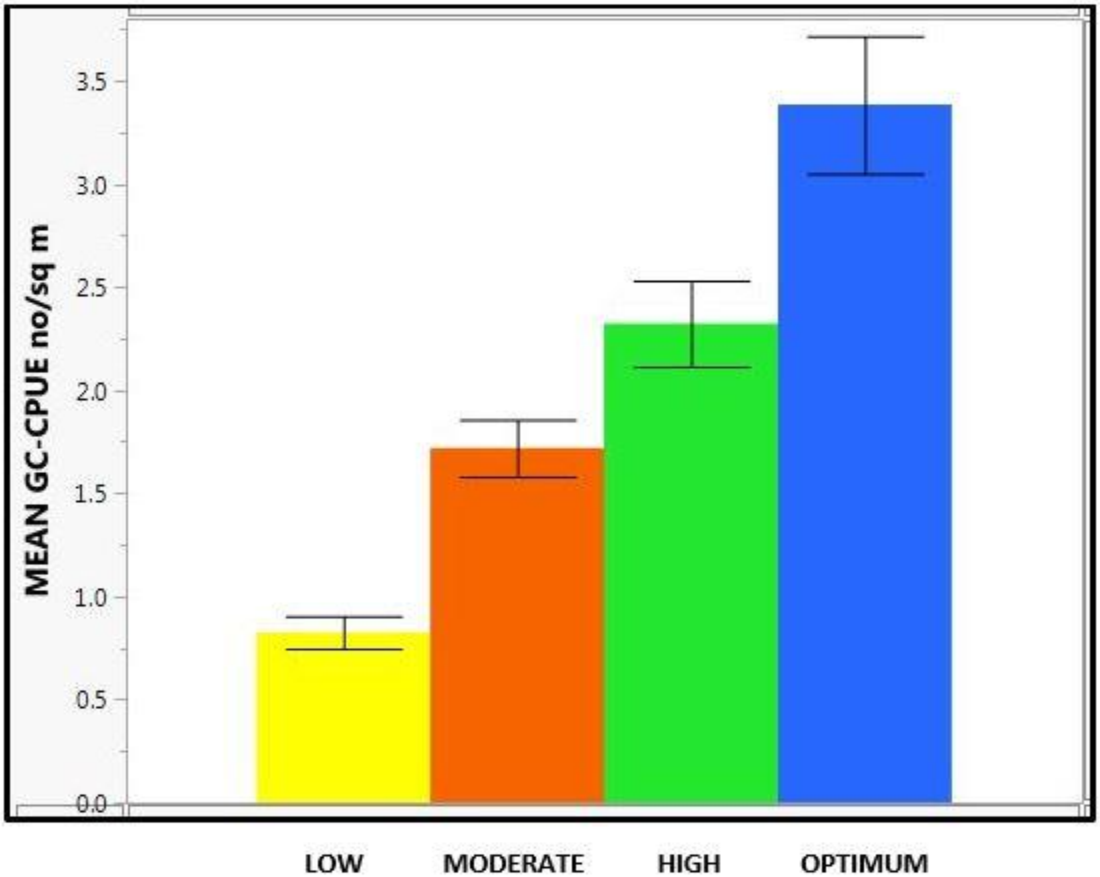

FIGURE 18. VERIFICATION GRAPH ADULT BAY ANCHOVY CHARLOTTE HARBOR IN SUMMER MEAN GEAR-CORRECTED OBSERVED CPUE VERSUS PREDICTED HSM ZONE MINIMUM FLOW

Table 1. Statistical significance of factors determined from Delta-type gamma GAMs for species life-stages in Charlotte Harbor and Lower Peace River (P≤0.0 01=* **, P≤0.001=**, P≤0.05=*, P>0.05 and P≤0.1=ns (non-significant), blank spaces=factors not included in models) for Baseline (BL) scenario.

	Juv Bay Anchovy				Adult Bay Anchovy				JA Blue Crab				JA Hogchoker			
	FL	SM	SP	WN	FL	SM	SP	WN	FL	SM	SP	WN	FL	SM	SP	WN
MU																
sal	**	***	**		**	***	**		*	***	***	***	***	***	***	***
tem									***	**	**			***	**	*
do	***				***			ns		ns		**	***	***	*	*
dep		*	*			*	*		**				ns			
Mud		*				*			***			**		***	*	
SAV	*		***		*		***				*			ns		
NU																
sal	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
tem	***	*			***	*		***	***						***	
do		***		**		***										**
dep			***				***		***	*	*	***				
Mud	*		ns		*		ns				***	**	ns		***	***
SAV													***	***		

Table continued

	EJ Red Drum				EJ Kingfish				EJ Spot				Juv Sand Seatrout			
	FL	SM	SP	WN	FL	SM	SP	WN	FL	SM	SP	WN	FL	SM	SP	WN
MU																
sal	*				*	***	***	**	***	*	**		***	***		***
tem	*		*								***		**			
do		ns			ns				***	*						
dep	*							**	***			**	***	***		***
Mud		*										**				**
SAV	ns	***	ns						***	**	*					
NU																
sal		**		***	***		***	***	*	*			***	***	***	***
tem							***		**	ns	***	***	**	*	***	*
do			ns	ns							*					
dep	***		***	ns									ns			**
Mud		ns			**	*	*	***			ns		***		***	*
SAV	*	ns		ns		ns	**	*		ns				ns		

Table 2. Example for Adult Bay Anchovy in Summer showing how zonal areas and population numbers were estimated for each HSM zone for Baseline (BL) and Minimum Flow (MF) conditions respectively.

Adult Bay Anchovy	Summer				
ZONAL AREA TABLE	CHAANSM-BL	Baseline			
HSM	**MEAN GC-CPUE**	**CELL**	**ZONAL AREA**	**Percent Of**	**POPULATION**
ZONE	**no/sq m**	**COUNT**	**sq m**	**Total Area**	**NUMBER**
Low	0.09968869	1007962	226791450	52.86	22608542
Moderate	0.74742077	420087	94519575	22.03	70645894
High	1.15578342	290363	65331675	15.23	75509267
Optimum	2.51527922	188271	42360975	9.87	106549680
TOTAL		**1906683**	**429003675**	**100.00**	**275313382**

Adult Bay Anchovy	Summer				
ZONAL AREA TABLE	CHAANSM-MF	Minimum Flow			
HSM	**MEAN GC-CPUE**	**CELL**	**ZONAL AREA**	**Percent Of**	**POPULATION**
ZONE	**no/sq m**	**COUNT**	**sq m**	**Total Area**	**NUMBER**
Low	0.06942287	1031378	232060050	54.09	16110276
Moderate	0.70279680	388602	87435450	20.38	61449354
High	1.46806908	300320	67572000	15.75	99200364
Optimum	2.42303317	186383	41936175	9.78	101612743
TOTAL		**1906683**	**429003675**	**100.00**	**278372737**

Table 3. Percentage area changes of habitat suitability model zones between Baseline and Minimum Flow scenarios for Lower Peace River and Charlotte Harbor.

Species	Fall				Winter			
	Low	Moderate	High	Optimum	Low	Moderate	High	Optimum
Adult Bay Anchovy	-2.26	0.60	1.02	0.64	0.37	-0.42	0.18	-0.13
Juvenile Bay Anchovy	-2.25	0.60	1.02	0.64	-0.57	0.35	0.16	0.06
Juvenile Sand Seatrout	-1.41	1.43	-0.03	0.02	-0.42	0.44	-0.02	0.00
Juv-Adult Blue Crab	-0.98	0.19	0.78	0.01	-1.85	-0.34	-0.03	2.22
Juv-Adult Hogchoker	-0.27	0.27	0.00	0.00	0.13	-0.07	-0.08	0.03
Early-Juvenile Southern Kingfish	-1.81	1.29	0.79	-0.27	-1.21	1.02	0.14	0.05
Early-Juvenile Spot	0.94	-0.69	-0.06	-0.19	-0.13	-0.14	-0.29	0.57
Early-Juvenile Red Drum	-0.31	-0.10	0.02	0.39	-0.38	0.40	0.17	-0.19

Species	Spring				Summer			
	Low	Moderate	High	Optimum	Low	Moderate	High	Optimum
Adult Bay Anchovy	-1.33	0.96	0.57	-0.20	-1.23	1.65	-0.52	0.10
Juvenile Bay Anchovy	-1.33	0.96	0.57	-0.20	-1.23	1.65	-0.52	0.10
Juvenile Sand Seatrout	-1.83	0.53	0.87	0.43	-3.29	1.61	1.46	0.22
Juv-Adult Blue Crab	-0.55	0.64	0.00	-0.09	-0.52	-0.31	0.15	0.68
Juv-Adult Hogchoker	-0.98	0.97	0.00	0.01	-0.60	0.50	0.11	0.00
Early-Juvenile Southern Kingfish	-0.88	0.49	0.23	0.15	-1.46	0.05	2.42	-1.02
Early-Juvenile Spot	0.12	0.00	-0.20	0.08	0.57	0.38	-0.98	0.03
Early-Juvenile Red Drum	0.00	-0.06	0.02	0.04	-3.02	1.07	1.28	0.67

Table 4. Changes in Population Numbers Estimated Between Baseline and Minimum Flow Analyses				
Species Life-Stage	**Season**	**Total Population No**	**Total Population No.**	**Percent Change**
		Baseline	**Minimum Flow**	**Population Number**
Juv-Adult Hogchoker	Fall	701,377	620,900	11.47
	Winter	553,351	482,250	12.85
	Spring	126,269	102,233	19.04
	Summer	124,983	109,281	12.56
Juv-Adult Blue Crab	Fall	337,046	315,615	6.36
	Winter	5,577,933	5,338,615	4.29
	Spring	204,920	189,248	7.65
	Summer	93,881	89,385	4.79
Juvenile Sand Seatrout	Fall	983,889	863,283	12.26
	Winter	16,827	14,446	14.15
	Spring	4,527,044	4,388,843	3.05
	Summer	2,999,378	2,369,853	20.99
Juvenile Bay Anchovy	Fall	411,688,848	386,446,156	6.13
	Winter	1,278,661,747	1,213,423,074	5.10
	Spring	2,098,586,359	1,996,069,439	4.89
	Summer	301,026,145	278,322,245	7.54
Adult Bay Anchovy	Fall	409,669,579	386,497,346	5.66
	Winter	1,114,145,755	1,069,235,403	4.03
	Spring	2,098,463,644	1,995,985,434	4.88
	Summer	275,313,382	278,372,737	1.11
Early-Juvenile S. Kingfish	Fall	480,831	414,399	13.82
	Winter	289,190	267,599	7.47
	Spring	289,894	255,701	11.80
	Summer	177,108	146,191	17.46
Early-Juvenile Red Drum	Fall	12,599,998	12,357,379	1.93
	Winter	2,771,344	2,762,907	0.30
	Spring	363,119	363,129	0.00
	Summer	265,019	250,736	5.39
Early-Juvenile Spot	Fall	6,153	6,635	7.83
	Winter	107,931	106,339	1.48
	Spring	783,736	770,237	1.72
	Summer	58,781	61,605	4.80

Table 5. Seasonal verification scores for mean GC-CPUEs versus HSM Zones associated with BF and MF. Increasing across four zones=1. increasing across two or three zones=0.5 and not increasing across zones=0.

Species life-stage	BL FL	BL WN	BL SP	BL SM	MF FL	MF WN	MF SP	MF SM
JA-Hogchoker	0.5	1	0.5	0.5	1	1	1	1
JA-Blue Crab	1	1	1	1	1	1	1	1
J-Sand Seatrout	1	0.5	1	1	1	0.5	1	1
EJ-Southern Kingfish	1	1	1	1	1	1	1	1
J-Bay Anchovy	1	0.5	1	1	1	0.5	1	1
A-Bay Anchovy	1	1	1	1	1	1	1	1
EJ-Red Drum	1	1	1	1	1	1	1	1
EJ-Spot	1	1	1	1	1	1	1	0.5
TOTALS	7.5	7	7.5	7.5	8	7	8	7.5