CHAPTER D.5
USING MODELS TO EVALUATE THE EFFECT OF BARRIER ISLANDS ON ESTUARINE HYDRODYNAMICS AND HABITATS: A NUMERICAL EXPERIMENT

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5.1 Summary

This chapter presents a simulation model that was used to examine the influence of barrier islands on Louisiana's estuarine ecosystems. The model also examined the importance of the islands' relative location within the estuary. Using the results of a numerical experiment, habitat composition and faunal response were studied using holistic methodologies (e.g. regional HSI for a particular species). This analysis and simulation uses a comprehensive model of estuary management with emphasis on barrier island restoration and preservation in this analysis.

5.2 Introduction

The fate of coastal ecosystems depends upon sound long-term management. Among the issues faced by coastal ecosystem managers include sea level rise, land use conversion, natural subsidence, water diversion, and water quality deterioration. Sustainable development and management requires a recognition of the ecosystems' complexity. Consequently, multidisciplinary studies are a necessity. The best management approaches are rational, holistic, and able to combine information from several disciplines.

Simulation analyses can prove useful in this context, as many simulation models are capable of evaluating cumulative impacts at different temporal and spatial scales, and they can incorporate interactions between physical forcing and chemical and biotic responses. In addition,

the inherently predictive nature of simulation models allows the ecosystem manager to assess and compare diverse scenarios and their consequences. Numerical models can also be used to explore specific plant and fauna responses to the proposed alternatives. A common methodology for this type of analysis is the Habitat Evaluation Procedure (HEP) as developed by the US Fish and Wildlife Service in the early 1980s (U.S. Fish and Wildlife Service 1980), which produces Habitat Suitability Index (HSI) models for individual species. The combination of both environmental models and species specific response methodologies are used to provide a comprehensive evaluation of large-scale ecosystems on a long-term basis.

Barrier islands are one of the most conspicuous features of coastal Louisiana bays, acting as buffers to water inputs and outputs that can change the flooding regime and salinity of the surrounding marshes. Models for coastal barrier systems are used here to: (a.) quantify how the control of tidal flow, storm related surges, and residence time is altered by the presence and location of barrier islands, and (b.) assess how the transport of water influences the habitat composition and fauna response within the estuary.

5.3 Goals and Objectives

Our goal is to utilize the modeling approaches developed for the Louisiana Coastal Area study (Appendix C, Twilley et al. 2003) to assess the importance of barrier islands to estuarine flora and fauna. This overall goal was further divided in the following objectives:

(1) to determine the state-of-the-science with regard to coastal modeling with emphasis on the temporal and spatial scales appropriate for management in the northern Gulf of Mexico,

(2) to create a model at the mid- and long -range temporal and spatial scales for the barrier islands of Louisiana that explored the nearshore hydrodynamics and the response of "up-estuary" ecosystems to changes on barrier island location, and

(3) to examine the response of biologically and economically important species found in barrier island and associated environments.

5.4 Use of Modeling in Environmental Management

Effective management decisions are based on high quality information at the appropriate scale (Folke et al. 1996). For example, emergency response to natural phenomena requires instantaneous prediction and analysis using short-range models, while land use change patterns and cumulative impacts associated with long-range ecosystem interactions need to be assessed at a regional scale (Sklar et al. 1992). However, management of natural systems has often lacked adequate tools to find and evaluate potential consequences (Costanza et al. 1993; Bailey 1996; Caley and Schluter 1997; Costanza and Ruth 1998). Framing the environmental problem in its natural spatial and temporal context is critical. Assumptions at a given scale should not be translated to a different scale without recognition of the potential pitfalls of such extrapolation (Kotliar and Wiens 1990; White and Running 1994; Kirkby et al. 1996; Lewis et al. 1996). It should be noted that any modeling effort (both circulation and ecological modeling) is site-specific, i.e. any useful model needs to be calibrated and skill-assessed against long-term field data.

5.5 Dynamic Models in Estuaries

Dynamic models of estuaries solve the same set of equations as any other hydrodynamic model for lakes, rivers, or oceans that simulates estuarine hydrodynamics and water quality. The most important distinction between estuarine and riverine models, however, is whether reversing currents can be simulated (i.e. tidal input and output). Differences among estuarine models involve how the governing equations are solved, the scope of parameters, and functional structure (i.e. how many dimensions are accounted for). The equations include continuity, momentum, and constituent transport equations, along with equations of state relating density to temperature, salinity, suspended sediment and in some cases, biologically active elements (nutrients, oxygen, and chlorophyll). Another characteristic of esturaine models is how they simulate the horizontal salinity gradient between the freshwater inflow and seawater as diffusion and advection processes; conservative elements are very important. Equations for bottom shear can be critical, due to their influence on how mixing conditions are evaluated. These equations also enable modeling of water flow over sea grass beds and similar irregular topographic features.

Of the different methods of dividing the ecosystem to cover the spatial scale, the most frequently used computational grid in finite-difference scheme is the rectangular grid with fixed grid spacing (Wang et al. 1990; Wang 1992). The grid could be rectangular, but the spacing between the grid points in each dimension is rigid. The definition of spacing between points must take into account the presence of islands and channels, without making the grid spacing so small that computations could become unpractical. The determination of specific vertical or horizontal grid spacing is developed to suit the objectives of the model.

5.5.1 Dynamic Estuarine Models in Coastal Louisiana

Louisiana's bar-built estuaries are broad and shallow with a mean depth of a few meters. The upper ends of these systems often consist of a region of multiple-connected marsh, intersected by bayous or creeks, tidal channels, and streams. The regional topographic gradient is small, with the marsh being prone to frequent flooding. Estuaries in Louisiana are mostly well mixed in the vertical, and circulation is driven by tide and wind, especially during winter storms and hurricanes. Wind forcing is seasonal, with steady southeasterly winds in summer, strong winds associated with the recurrence of cold air outbreaks in winter, and strong diurnal sea breeze systems along the coast. Even in the absence of direct river influence, local freshwater contributions by rainfall and the balance of evapotranspiration can be large. Consequently, circulation can be significantly impacted by the horizontal pressure gradient due to salinity distributions caused by local runoff.

Early numerical models of some Louisiana estuaries have been described by Hacker (1973), Hart (1978), and Hart and Murray (1978). Wiseman and Swenson (1989) discussed several tidal prism models of Terrebonne Bay and Barataria Bay. Exchange of waters between estuaries and the coastal ocean have been statistically modeled by others (Chuang and Wiseman 1983; Schroeder and Wiseman 1986; Lee et al. 1990). Particle transport modeling efforts include Prager (1992) and the modeling work of the U. S. Army Corps of Engineers (The Surface-Water Modeling System, SMS), both of which are based on finite element formulation. Keen and Stavn (1999) applied the Princeton Ocean Model (POM) to the Mississippi Sound to study circulation.

This 3-D model could be coupled to a larger-domain coarse grid Gulf of Mexico model, or run independently with the use of open boundaries.

Systematic efforts to model several Louisiana estuaries using HEC-6, a hydrodynamic depth-averaged model have been initiated (Wiseman and Inoue 1994; Inoue et al. 1998; Park 1998). Models have been implemented for Terrebonne/Timbalier Basin, Fourleague Bay, and Barataria Basin to simulate circulation driven by tide and wind. The model has proven useful in studying circulation, transport, and mixing processes in those estuaries. In addition, this same hydrodynamic model has been successfully coupled to a simplified ecological model in order to simulate a spring bloom in Fourleague Bay (Inoue and Wiseman 1996) with 50-year simulation length, 1-day time step.

A regional scale modeling approach is being developed for the Mississippi Sound and adjoining rivers, bays, and shelf waters by Szczechowsi and Carron (1999) from the Naval Oceanographic Office. The modeling system consists of a three-dimensional circulation model, a sand-silt sediment transport model, and a wave model.

The Engineering Research and Development Center has applied the z-plane version of the 3D model CH3D-WES (Johnson et al. 1991; Johnson et al. 1993) to understand salinity intrusion in the Lower Mississippi River (Vemulakonda and Johnson 1999). The study grid covered the river reach from the Gulf of Mexico to the River mile 150 upstream. In the horizontal, the boundary-fitted grid had a maximum of five cells across the river and 190 cells along the river. In the vertical, a maximum of 24 layers varied with the water surface. Simulations were performed for existing conditions and two reservoir operation scenarios for six historic low-flow years. In addition, a survey done by the Gulf of Mexico Program (Batelle 1999) identified several federal and state agencies that use diverse models to examine questions regarding sediment transport, toxic element distribution, and water quality.

5.6 Methods

The role of barrier islands in estuaries is greater than the habitat value provided by the barrier footprint. The presence of barrier islands at the mouth of a bay restricts water exchange with the shelf (enhancing residence time), provides storm surge protection to wetlands and human infrastructure “up-estuary” from the islands, and modifies currents and salinity within the bay system. A simulation model was developed as part of the goal to evaluate the specific role of barrier islands in Louisiana estuarine ecosystems.

At present, a comprehensive model that can evaluate the spatial and temporal links that barrier islands have with the interior bays and coastal marshes is unavailable. To address this need, a hybrid model was developed using an approach similar to that utilized for the LCA plan formulation process. This hybrid model consisted of three linked modules. A hydrodynamic module calculated water movement, water level, current velocity, and salinity with a length of simulation of one year. The desktop habitat module (Appendix C, Twilley et al. 2003) utilized the information generated by the hydrodynamic model to calculate habitat distributions across the estuary. Time step of the desktop module is one year and length of simulation is 50 years. The results of the hydrodynamic and habitat modules were then used to examine the influence of barrier island presence and position within the estuary on habitat suitability for several animal species using the faunal habitat suitability module.

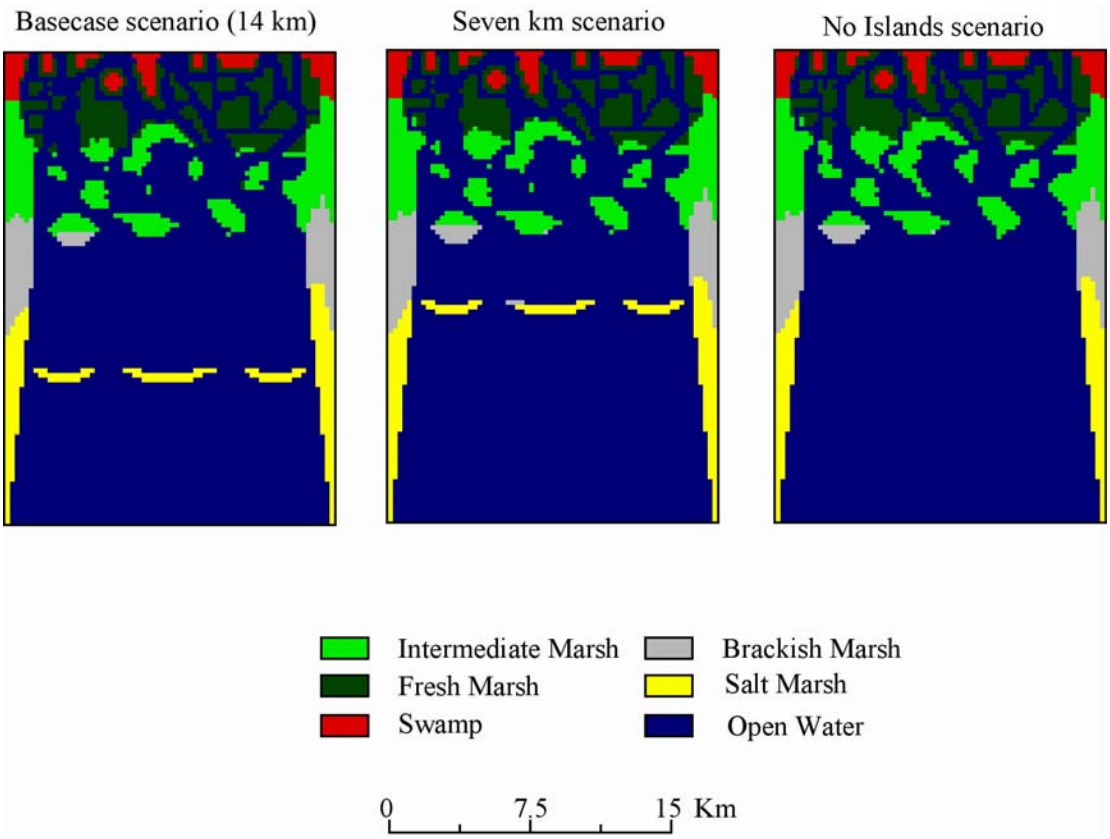

Figure D.5-1. Initial habitat distribution for scenario analysis.

The modeling effort used simplistic assumptions to provide a preliminary evaluation of barrier islands in the estuary context. These assumptions included the conceptualization of an idealized estuarine basin for coastal Louisiana (Figure D.5-1), the use of average habitat distribution (Table D.5- 1) and average land loss rates (Figure D.5-2). The basin is idealized in the sense that it does not represent a specific location on the Louisiana coast. However, the habitat distributions and land loss rates used to initialize the model and drive land change in the marsh areas were derived from parts of the Breton Sound Basin.

Table D.5- 1. The Extent of Habitats for Coastal Louisiana Estuaries (%)

	Caernarvon	Barataria	Terrebonne	Acadiana Bays
Fresh Marsh	12.68	25.41	38.92	41.40
Intermediate Marsh	3.40			9.77
Brackish Marsh	46.73	24.71	27.54	42.70
Salt Marsh	30.90	15.48	19.16	3.85
Swamp	6.30	34.40	14.37	2.28

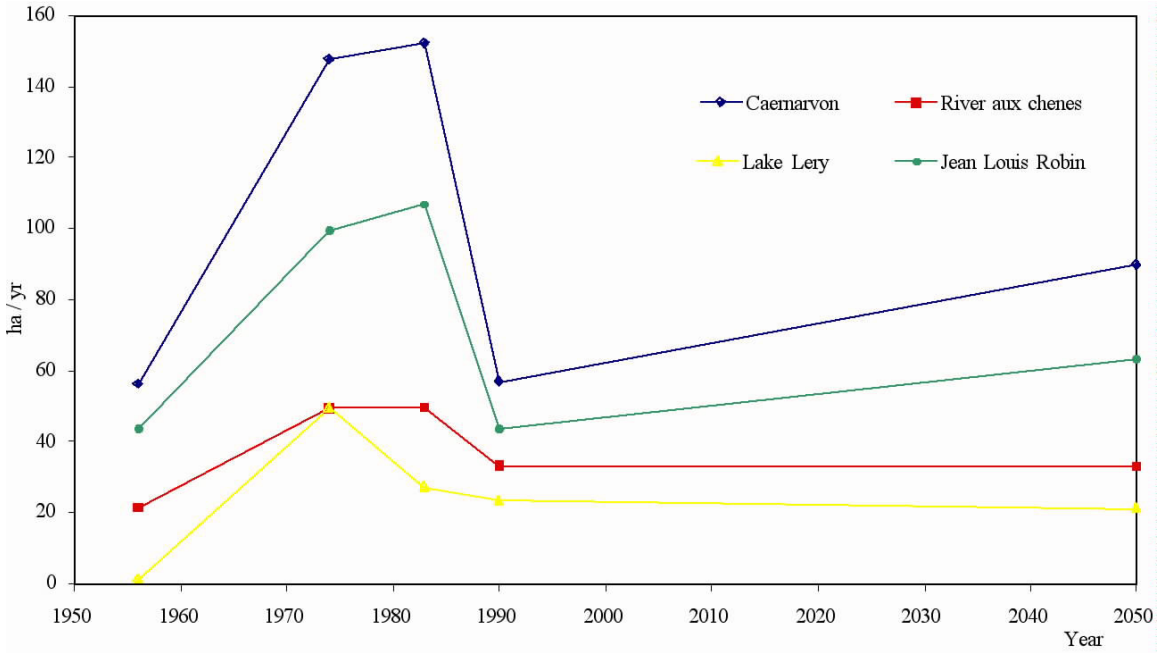

Figure 1.4-2 Measured and predicted land loss rates in Caernarvon Watershed (modified from Coast 2050, Appendix D)

Figure D.5-2. Measured and predicted land loss rates in Caernarvon watershed (modified from Coast 2050, Appendix D).

5.6.1 Hydrodynamic Module

The hydrodynamic model selected was the Princeton Ocean Model (POM; Blumberg and Mellor 1980; Mellor and Yamada 1985; Blumberg and Mellor 1987). The POM is a terrain following sigma-free surface three-dimensional primitive equation model that computes water surface elevations, velocities, and the transport of temperature and salinity (Blumberg and Mellor 1987). The model incorporates the mode splitting technique to first solve for the horizontal (explicit - external) two-dimensional mode to compute water surface elevations, and the vertical (implicit - internal) three-dimensional mode to solve for velocity, temperature, and salinity. It contains a full turbulence closure scheme based on the Mellor-Yamada formulation to provide for vertical mixing coefficients, and it incorporates non-linear advective terms and couple density-velocity fields (Mellor and Yamada 1985). The model was used to provide hydrodynamics and transport information such as water levels, potential flooding frequency, temperature, and salinity to the ecosystem model.

In order to minimize interpolation efforts, the horizontal domain was set to the resolution required by the habitat and faunal modeling components, in order to identify the habitats associated with the footprint of Louisiana barrier islands. This included a domain with equal horizontal resolution of 500 m2 cells comprised by 70 x 100 nodes in Cartesian coordinates. The basin topography was a hybrid formulation with borrowed features from the Caernarvon Basin and minor manual adjustments to describe salt, intermediate, and freshwater marshes. The model bathymetry included an offshore depth of about 4 meters slowly rising to the bay and eventually

the shallow marshes to a depth of 0.25 m. For comparison purposes, no shoals were present. The basin was set up with an open tidal boundary to the south (the Gulf of Mexico). Three cases were tested: a base case with an island configurations at 14 km from the upper basin marshes (e.g. a bay width of approximately 14 km), and a two scenarios: a basin with no islands and a basin with islands at 7 km (e.g. a bay width of approximately 7km) (Figure D.5-1). The north boundary was left open but adjusted the boundary condition to be an inflow condition, in order to simulate freshwater flows from small steams and bayous present in coastal Louisiana. The two lateral boundaries west and east of the basin were closed, simulating essentially a bay enclosed by distributary ridges. Other forcing included wind from the year 1996, lateral temperature and salinity, and surface heat flux. The latter was used to realistically simulate the annual temperature cycle. Evapotranspiration was pre-computed based on the basin area using evaporation estimates for coastal Louisiana, and was entered in the model as added inflow to the north.

The model was run for one year for all three cases. Each time, before execution, the islands were place in the domain by adjusting local bathymetry and switching water cells into land cells. To estimate flooding frequency and potential inundation, water levels were propagated inland (i.e. across the marsh surface) every hour and were compared to the local topography. A counter was excited for a potentially dry cell, and at the end of each day a percent wet value was reported. All variables including percent dry, salinity and temperature, and land water ratio were submitted as monthly averages for the ecological model runs.

5.6.2 Desktop Habitat Type Module

Salinity and flooding duration results from the hydrodynamic module were used to calculate habitat changes on the ecosystem under a 50-year long scenario. The assumptions and mechanics for calculating habitat changes (e.g. a change from brackish marsh to saline marsh) are based on those presented by Reyes et al. (2000) and similar to that implemented by Visser et al. (2003) for the LCA desktop modeling effort.

Using the grid designed for the landscape by the hydrodynamic module, each grid cell was assigned a habitat type according to the yearly salinity average from the hydrodynamic module (Figure D.5-1). This initial representation then was submitted to decadal land losses for years 10, 20, 30, 40 and 50. Different land loss rates were spatially applied to the watershed and based on the calculations presented by Coast 2050 (Appendix C; Figure D.5-2).

The resulting maps were then portioned in functional zones (i.e. interior marsh, bay and offshore) to allow comparison of the scenarios across the estuarine basin. These functional zones were derived from the extent of the marsh, the presence of a bay leeward from the barrier island, and the area exposed to unrestricted tidal input. For this numerical experiment, we compared the results of the base case scenario (14 km bay width) with each of the other two scenarios (no islands and 7 km bay width).

5.6.3 Faunal Habitat Suitability Module

The habitat suitability index (HSI) methodology developed by the US Fish & Wildlife Service was used to determine the amount of habitat available for particular species of fauna

under the three scenarios. The determination of the HSI was based on published indices and modified according to parameters provided by the hydrodynamic and habitat modules.

Habitat suitability indices were calculated for nine species of fish and seven species of invertebrates (Table D.5- 2). We selected this group of aquatic species because they depend on barrier islands, whether utilizing habitat found only on or near the islands.

Table D.5- 2. List of species and variable(s) used to compute habitat suitability index.

Species	Stage	Variable(s)
Blue crab	Eggs Juvenile	Salinity Salinity
Brown shrimp	Adult	Salinity, substrate
Hard clam	Adult	Salinity, substrate
Oyster	Adult	Salinity, substrate
Pink shrimp	Adult	Salinity, substrate
Rangia clam	Adult	Salinity, substrate
White shrimp	Adult	Salinity, substrate
Bull shark	Juvenile Adult	Salinity Salinity
Croaker	Juvenile	Salinity
Flounder	Adult	Salinity
Menhaden	Adult	Salinity
Pompano	Juvenile Adult	Salinity Salinity
Red drum	Larvae-pre juvenile Juvenile	Salinity Salinity
Spanish Mackarel	Larvae Juvenile Adult	Salinity Salinity Salinity
Spotted trout	Juvenile Adult	Salinity Salinity
Sturgeon	Sub-adult	Salinity

This group also represented the vast number of species that use the habitats between the islands and the main shoreline. The omission of some conspicuous estuarine species from this list reflected either their lack of dependence on a barrier island system, or a certain level of life history redundancy with other estuarine species discussed. For example, the bay anchovy is the most numerous fish species in coastal Louisiana, but was not included in this analysis since its life history is only weakly connected to barrier island habitats. Conversely, the Gulf menhaden was included in the list because of its use of barrier island passes for larval transport, as well as its ecological and economical importance.

For each of the species discussed here, relevant literature on habitat and life history requirements was reviewed to develop relationships describing species response to changing habitat conditions. In some cases, an HSI model had previously been created. These models were then used, but with limited variables. Salinity, temperature, and water depth information were provided for each cell by the hydrodynamic module. In addition, estimates of substrate character for the idealized basin were made based upon surveys of substrate sediments in Louisiana estuaries conducted by Barrett et al. (1972). Substrate was characterized as hard (dominated by sands), firm (dominated by silts), and soft (dominated by clays). As discussed below, there was very little difference among scenarios for temperature or water level. As a result, most species

habitat evaluations were based on salinity and in some cases, substrate condition. Table D.5- 2 shows which variables were included in the HSI calculations for each species.

In cases where both salinity and substrate character were important drivers of habitat suitability, the values for each variable were combined using geometric means and weightings as indicated by literature surveys or previously developed HSI models. Thus a comprehensive HSI was calculated for each cell in the conceptual basin grid. The sum of this spatial index evaluated the total habitat suitability value for each species, or life history stage, for each one of the simulated scenarios.

5.7 Results – Hydrodynamic Module

The mean annual salinity variation for each run is shown in Figures D.5-3 to D.5-5. The figures show the long-term (1 Year) average of surface salinity on the longitudinal axis (from south-left, to north-right). The figures also show an envelope of the lateral (west to east) fluctuation of the average. The range of salinity values is from over 25 ppt at the offshore boundary (lower basin), to approximately freshwater values (0.2 ppt) in the marshes (upper basin). Figures D.5-3, 4 and 5 appear to be fairly similar, indicating that there is little difference between each case, with respect to the mean annual average. When considering the difference, however (Figures D.5-6 and D.5-7), the annual salinity differences between the scenarios become apparent. In Figure D.5-6, the differential of the base case (14 km) to the 7 km shows a strong localized variability envelope of 3 ppt in the bay salinity (25 km from the south boundary), with a 1 ppt increase and a 2 ppt decrease. Annual changes in the upper basin and offshore were smaller of the order 0.5 ppt. Figure D.5-7 shows a similar plot for the base (14 km) compared to the no islands case. The overall changes in salinity appear to be smaller and uniform; less than 1.0 ppt for the upper basin, approximately 1.5 ppt for the bays, and 0.5 ppt for the offshore zone. Table D.5- 3 shows a summary of these changes.

Although the annual cycle and the mean annual salinity values show some variability (Table D.5- 3), the seasonal variations are stronger. Figures D.5-8 to D.5-16 show the seasonal variations between the three scenarios. The seasonal average surface salinity was considered for all three scenarios, and the average differential salinity was plotted. Adjacent to every plot, a graph showing the envelope of the lateral salinity variation was also plotted.

Table D.5- 3. Summary of annual salinity differential for each study wit respect to the base case.

Basin zones	14 km - No Islands (ppt)	14 km - 7 km (ppt)
Upper	-0.4	-0.9
Bay	-0.7	-1.9
Offshore	0.0	-0.5

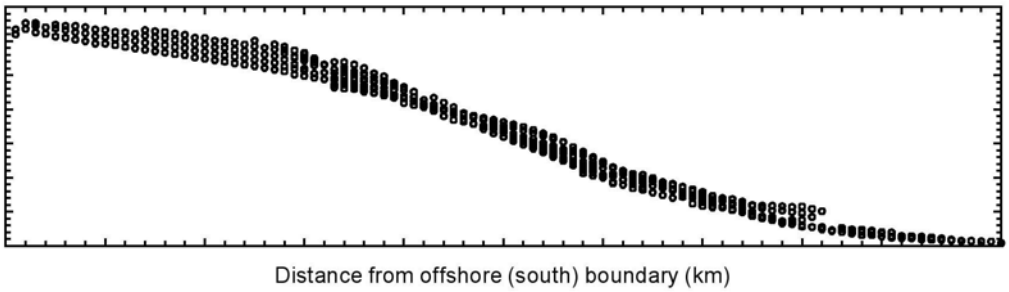

Figure D.5-3. Mean annual salinity distribution along a south-north transect, with lateral variability (Islands at 14 km)

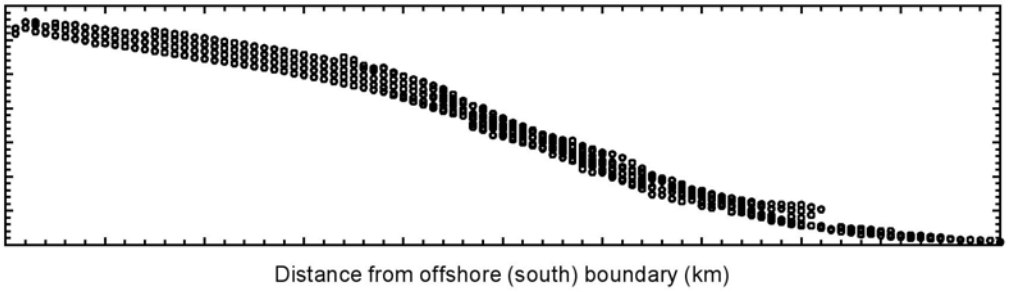

Figure D.5-4. Mean annual salinity distribution along a south-north transect, with lateral variability (Islands at 7 km)

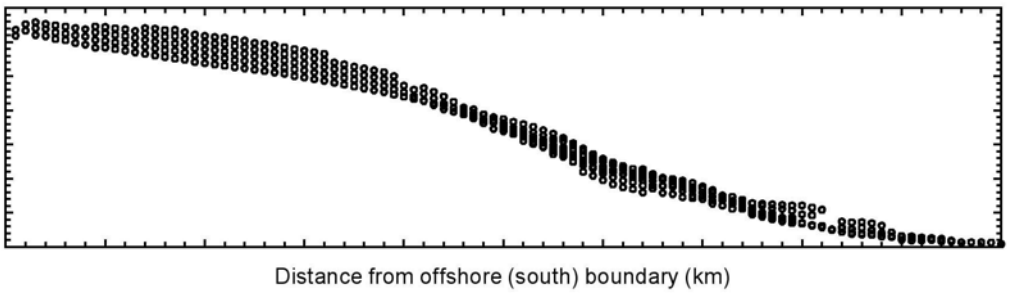

Figure D.5-5. Mean annual salinity distribution along a south-north transect, with lateral variability (No Islands).

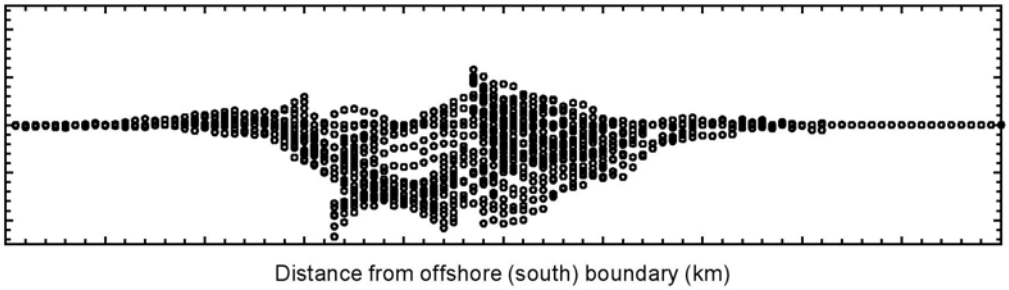

Figure D.5-6. Mean annual longitudinal distribution of salinity differential (14 - 7 km). Negative values indicate higher salinity at specific locations in the estuary for 7 km scenario vs 14 km scenario.

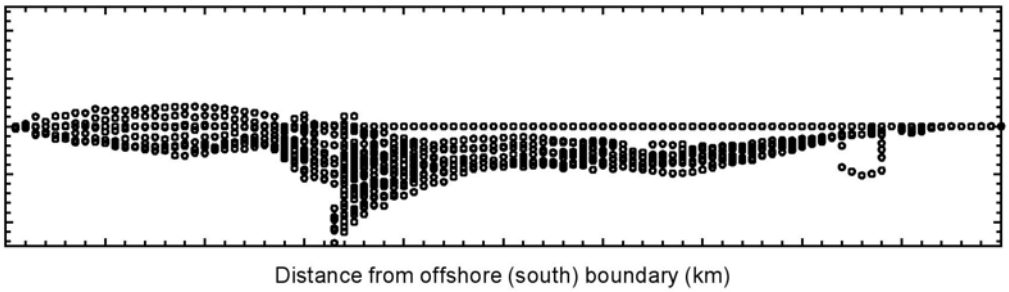

Figure D.5-7. Mean annual longitudinal distribution of salinity differential (14 - 0 km). Negative values indicate higher salinity at specific locations in the estuary for no islands scenario vs 14 km scenario.

5.7.1 Salinity

Salinity variations were computed for each season and are shown in Figures D.5-8 - D.5-15. The modeled salinity differential for the season of December through February from Figure D.5-8 shows a maximum salinity difference of approximately 3 ppt in the middle to upper basin for the 14 - 7 km (envelope is ~1.2 ppt), while for the 14 - 0 km case (Figure D.5-9), the simulated maximum was only 1 ppt with a smaller envelope of around 0.8 ppt. In addition, for this case, an increase in salinity was computed in the lower basin on the offshore side of the barrier islands. Similarly, for the March through May season, the salinity change was much the same (~2 ppt) in the middle basin, with increased variability (~1 - 2 ppt) near the lower basin and around the islands (Figures D.5-10 and 11). Salinity in the upper basin was reduced in both cases ranging from 0.3 ppt (14 - 7 km) to 0.5 ppt (14 - 0 km). The largest reduction in salinity was simulated during the summer from June to August. Similar differences were computed for both cases, with typical values ranging from as little as 0.3 ppt in the upper basin to 4 ppt in the middle basin, and back to about 0.5 ppt in the lower basin (Figures D.5-11 and 12). The maximum variability was found in the middle of the basin near the islands. Finally, for the September to November season, salinity was reduced for both cases in the upper basin. The differential was disproportional in this case with a change of 2 ppt (14 - 0 km) and ~10 ppt (14 - 7 km). In the lower basin, the opposite change was simulated for the 14 - 0 km case (~2 ppt),

while for the 14 - 7 km case the change was small. Typical modeled salinity changes based on the seasonal mean values are shown in Table D.5- 4.

5.7.2 Temperature

The model correctly captured the observed temperature cycle throughout the year. This typical cycle consists of temperatures ranging from 14.5 C in the winter months to above 30 C in the summer months. Spatial variations were small, on the order of 1 C ±0.5 C. Variations in the temperature between the base case and the other scenarios did not exist. This is primarily due to the fact that temperature is dependent on climate more that it is on geometry. In fact, geometric effects on temperature are negligible.

5.7.3 Basin Circulation

The general circulation consisted of north-south currents due to flood and ebb tides and a weak counter clockwise rotation due to wind shear and Coriolis acceleration. Wind shear was constant for all scenarios and uniform throughout the basin. The net rotational circulation pattern varies with the basin geometry, and the individual effects from each factor (Coriolis force, wind, basin geometry) were not fully evaluated. To correctly assess the wind and Coriolis effects on circulation, runs without these forcings are required for further comparison. There is a small reduction in the tidal range as a result of the barrier islands, generally limited to less than 5 cm. The barrier islands inlet size considered here were not very effective in reducing the tidal amplitude. The reason for this is that the loss of tidal energy depends on the strength of the current through the gap. The smaller the gap, the stronger will be the current and the greater the decrease in the tidal range.

5.7.4 Tidal Prism

For each scenario of island configuration, the tidal inlets (inlet width and depth) were kept constant for comparison purposes. To evaluate possible effects on the tidal prism or net flow exchange between the offshore zone and the bay, flow monitors were installed in the model. Flow through the inlets was calculated by integrating the velocity over the vertical layers throughout the water column. Figure D.5-17 shows the resulting flow (m3/s) for both cases (islands at 14 km, and 7 km). The figure clearly shows that by moving the islands from 14 km to 7 km, the resulting flow through the inlets is approximately halved. This is primarily due to the reduction of the bay area to half the original value. The flow through the inlets is proportional to the available head and hence fluctuates with the tidal amplitude (Figure D.5-16). The back-bay acts as a reservoir and provides storage capacity. As the tide floods, the reservoir fills up with a given rate of increase in elevation. The rate of increase is proportional to the area of the reservoir. Therefore, when the islands are at 14 km and regardless of the inlet cross-sectional area, the available area for storage is double, hence the rate of increase is higher than the previous (7 km) case. As a result, the total flow through the inlets doubles as well.

Table D.5- 4. Summary of annual salinity differential for each study with respect the base case.

Basin zones	14 km - No Islands (ppt)			
	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
Upper	-0.6 (0.3)	-0.2 (0.2)	-0.7 (0.3)	-0.3 (0.2)
Bay	-0.8 (0.4)	-0.2 (0.3)	-1.0 (1.0)	-0.9 (0.6)
Offshore	+0.6 (0.4)	-1.0 (0.8)	-0.8 (0.5)	+1.0 (0.6)
	14 km - 7 km (ppt)			
	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
Upper	-1.0 (0.2)	-0.1 (0.2)	-0.2 (0.3)	-2.5 (2.0)
Bay	-0.7 (0.3)	-0.2 (1.5)	-2.0 (2.0)	-5.0 (4.0)
Offshore	-0.2 (0.2)	-1.0 (0.5)	-0.9 (0.3)	-0.2 (0.2)

Table D.5- 5. Initial habitat composition for conceptual basin under base case and scenarios (in percentage).

Habitat Type	Base case	Base case yr 50	No Isles	No Isles yr 50	7km	7km yr 50
Interior marsh	20.0	16.0	22.0	16.0	20.0	16.0
Bay	4.0	3.0	0.0	0.0	2.0	2.0
Offshore	3.0	3.0	6.0	5.0	5.0	5.0

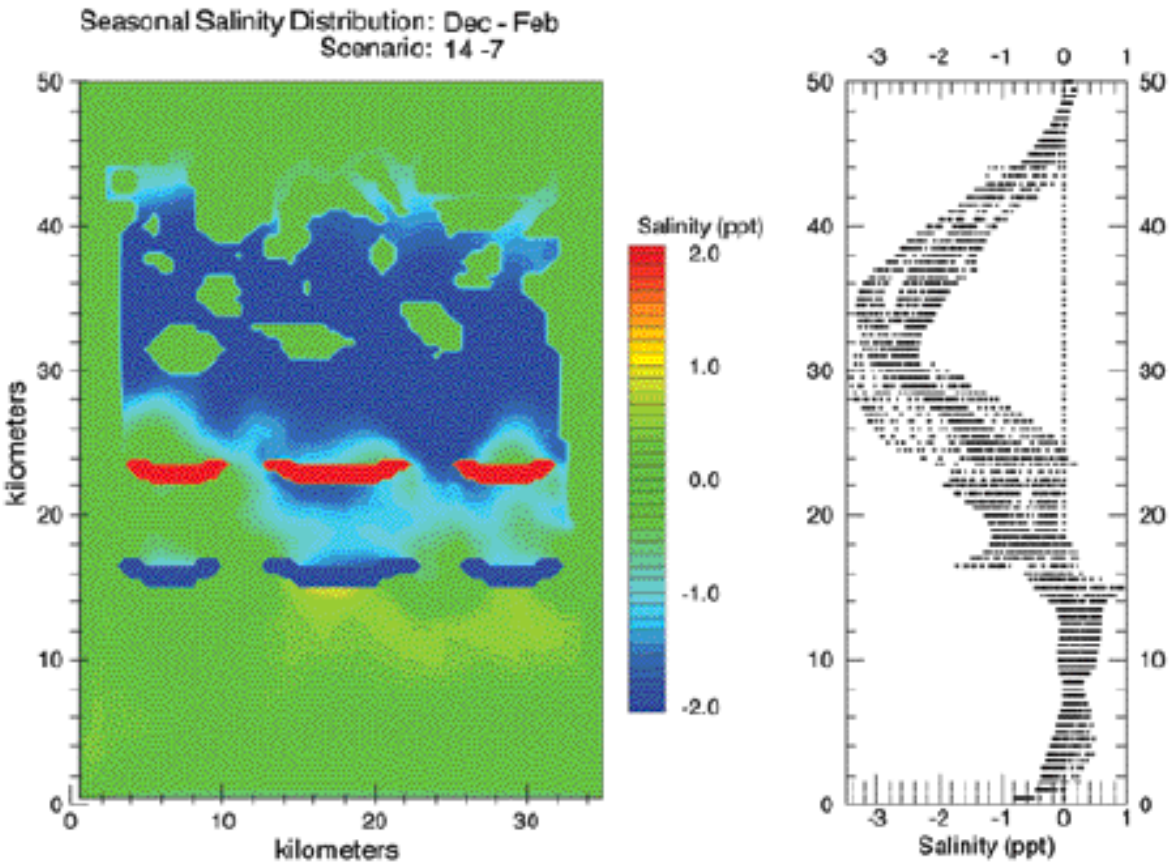

Figure D.5-8. Seasonal salinity differential distribution for the period of December through February (case: 14 - 7 km).

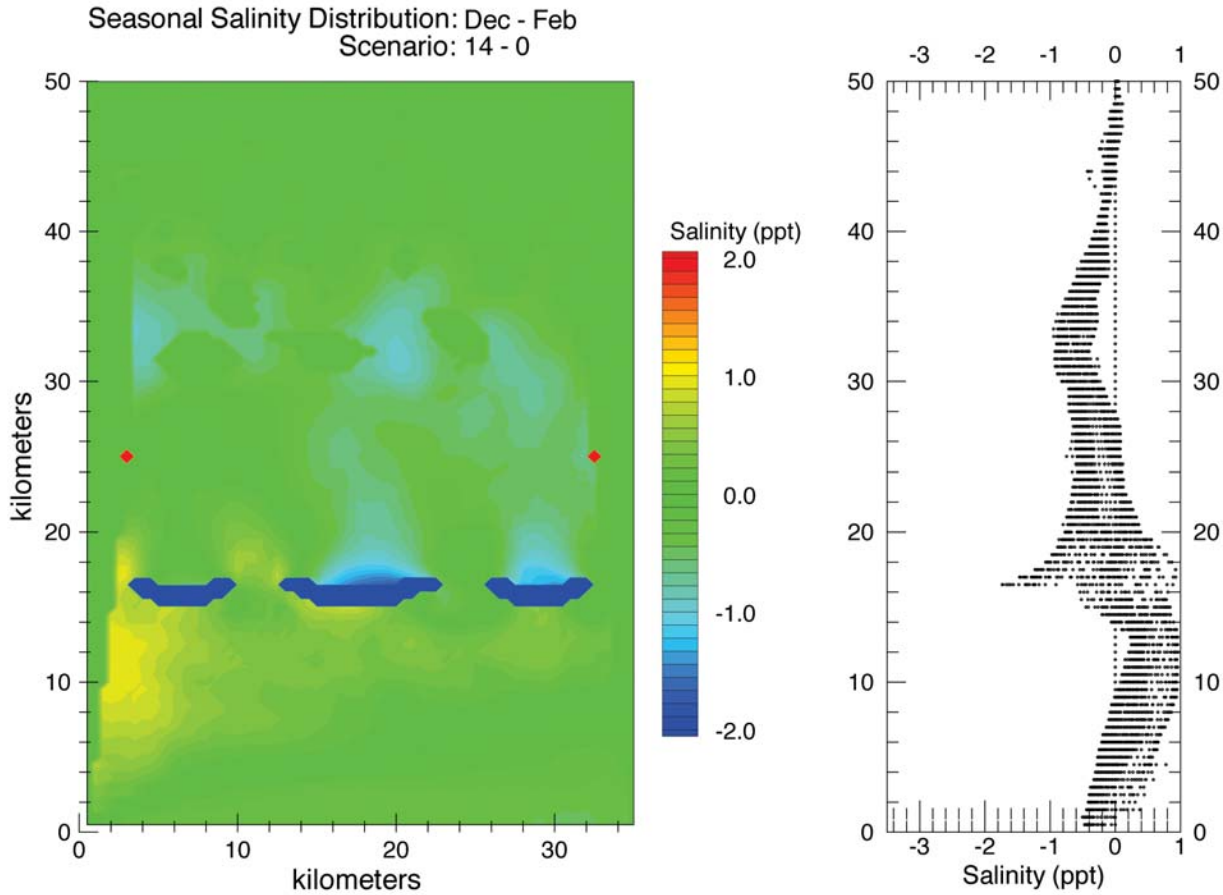

Figure D.5-9. Seasonal salinity differential distribution for the period of December through February (case: 14 - 0 km).

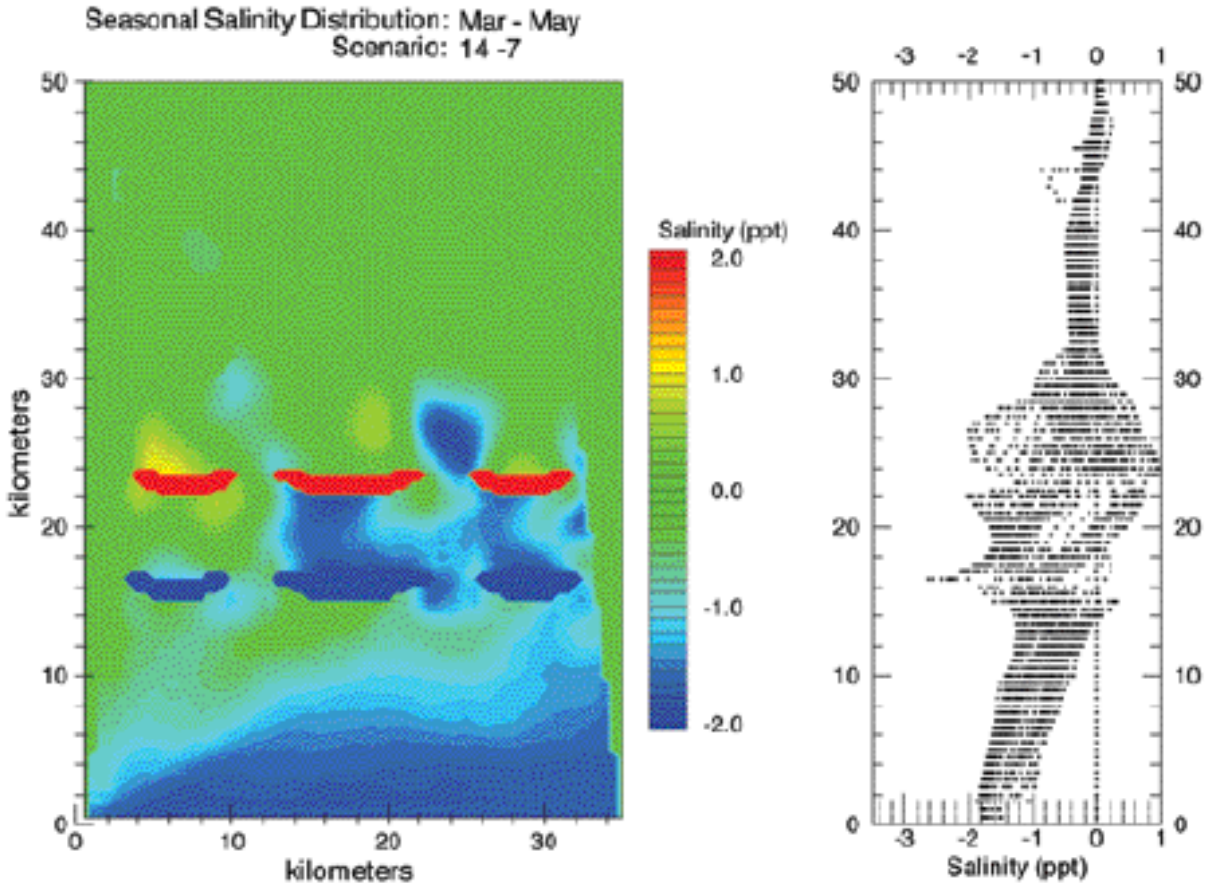

Figure D.5-10. Seasonal salinity differential distribution for the period of March through May (case: 14 - 7 km).

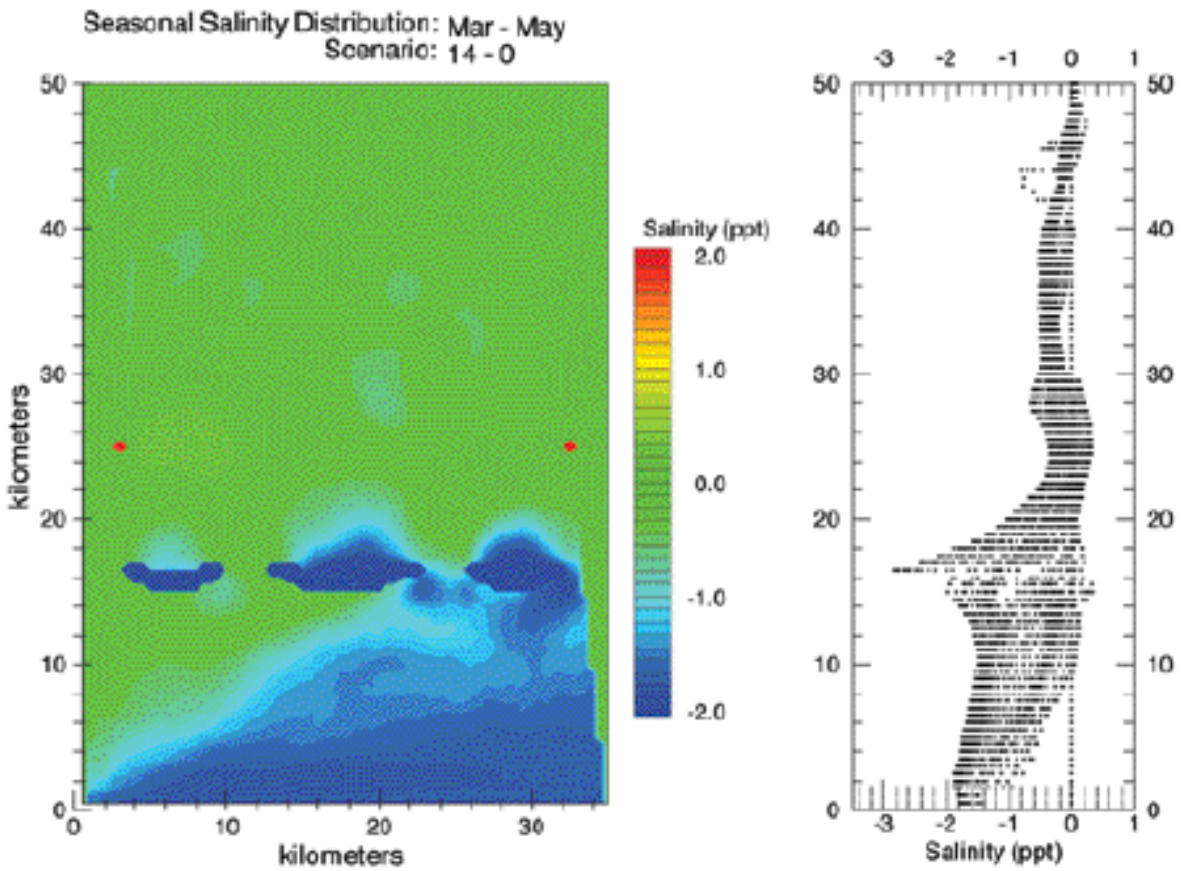

Figure D.5-11. Seasonal salinity differential distribution for the period of March through May (case: 14 - 0 km).

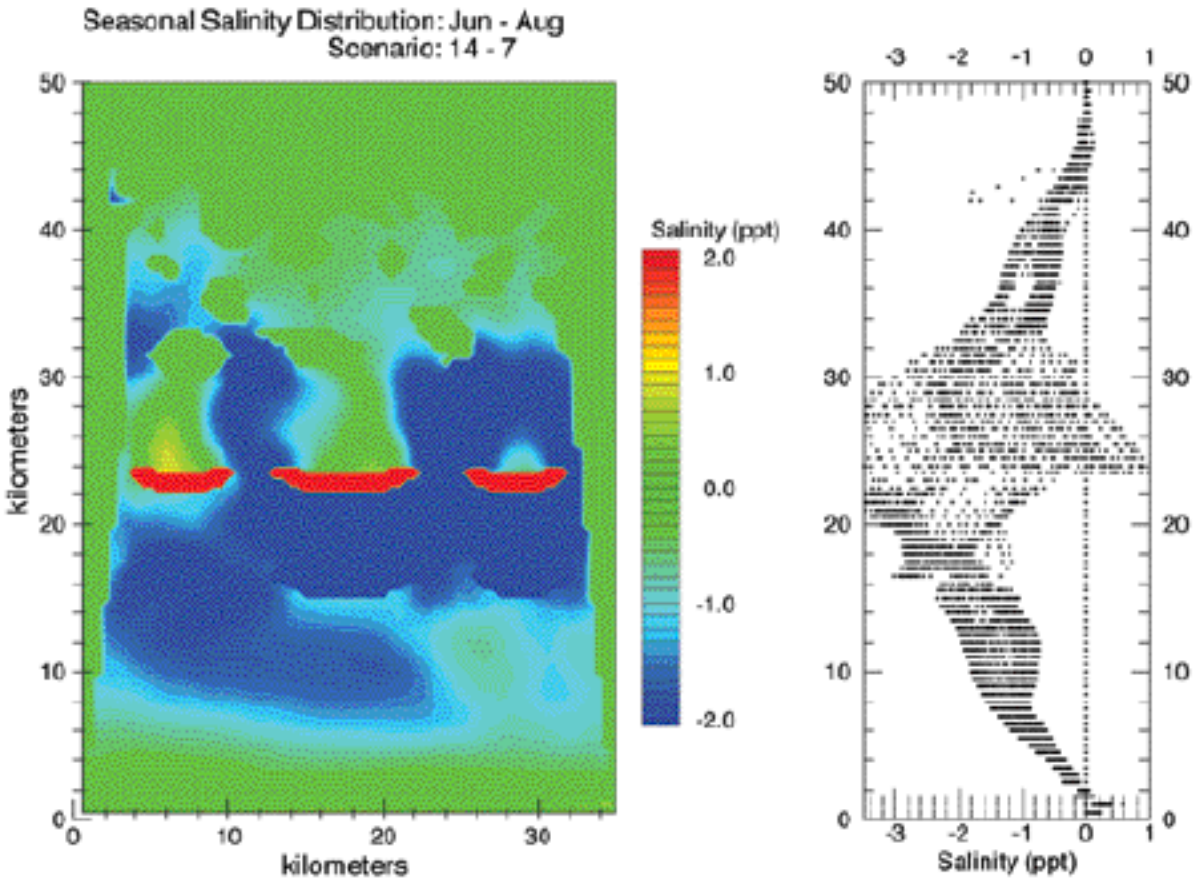

Figure D.5-12. Seasonal salinity differential distribution for the period of June through August (case: 14 - 7 km).

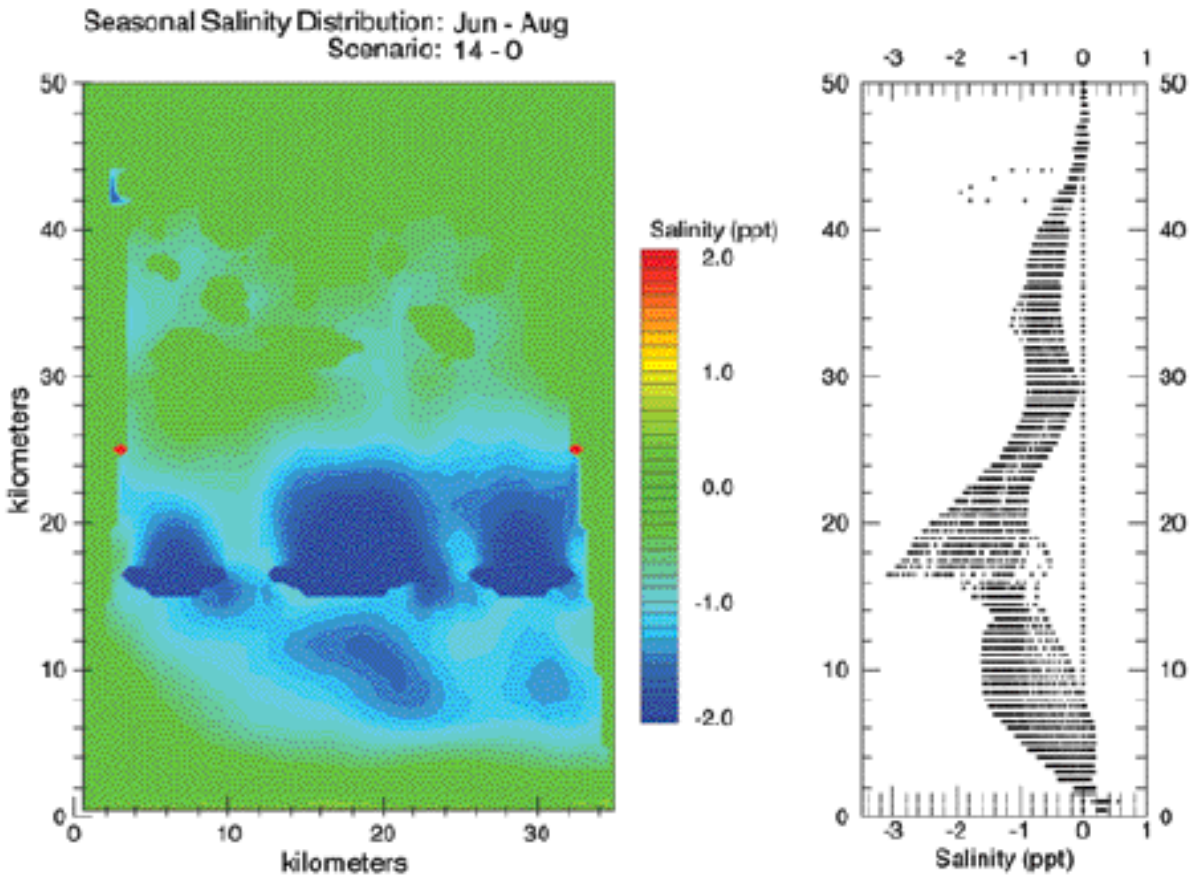

Figure D.5-13. Seasonal salinity differential distribution for the period of June through August (case: 14 - 0 km).

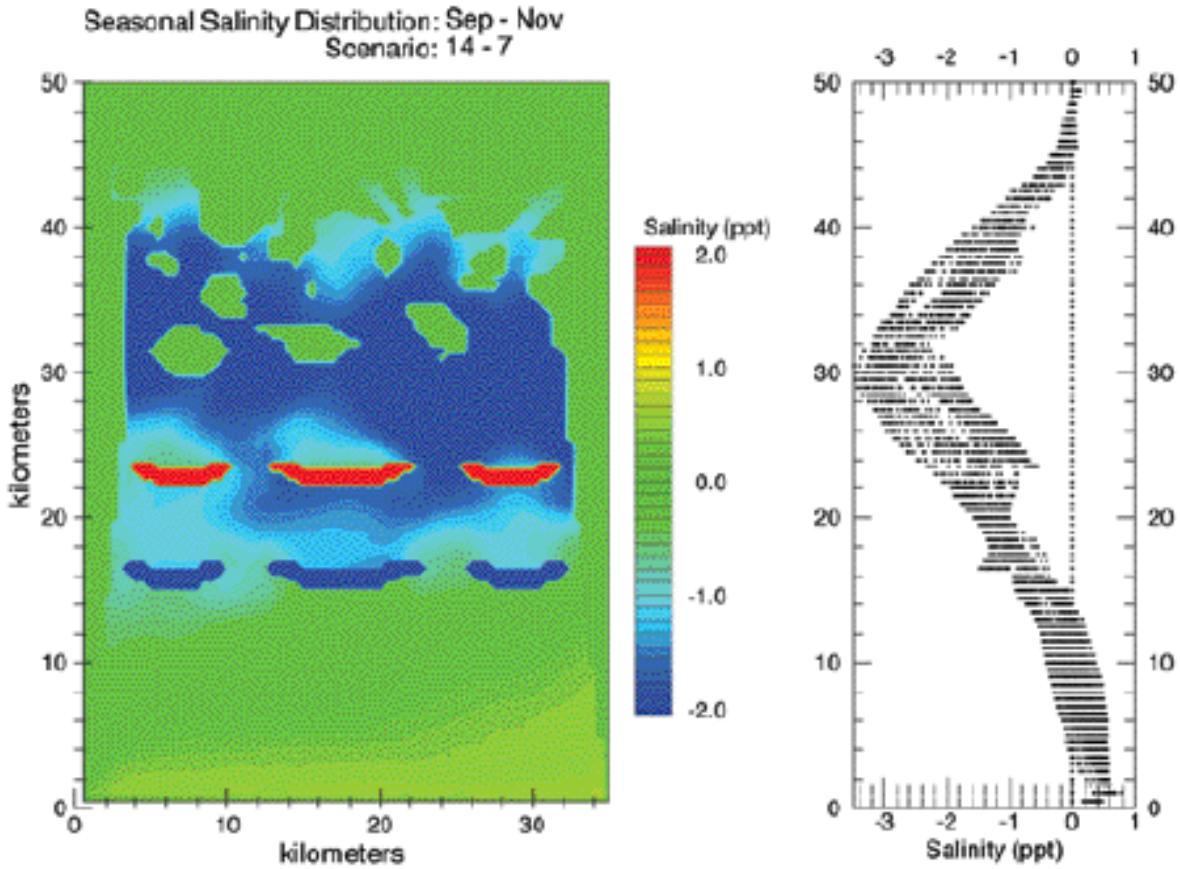

Figure 14. Seasonal salinity differential distribution for the period of September through November (case: 14 - 7 km).

Figure D.5-14. Seasonal salinity differential distribution for the period of September through November (case: 14 - 7 km).

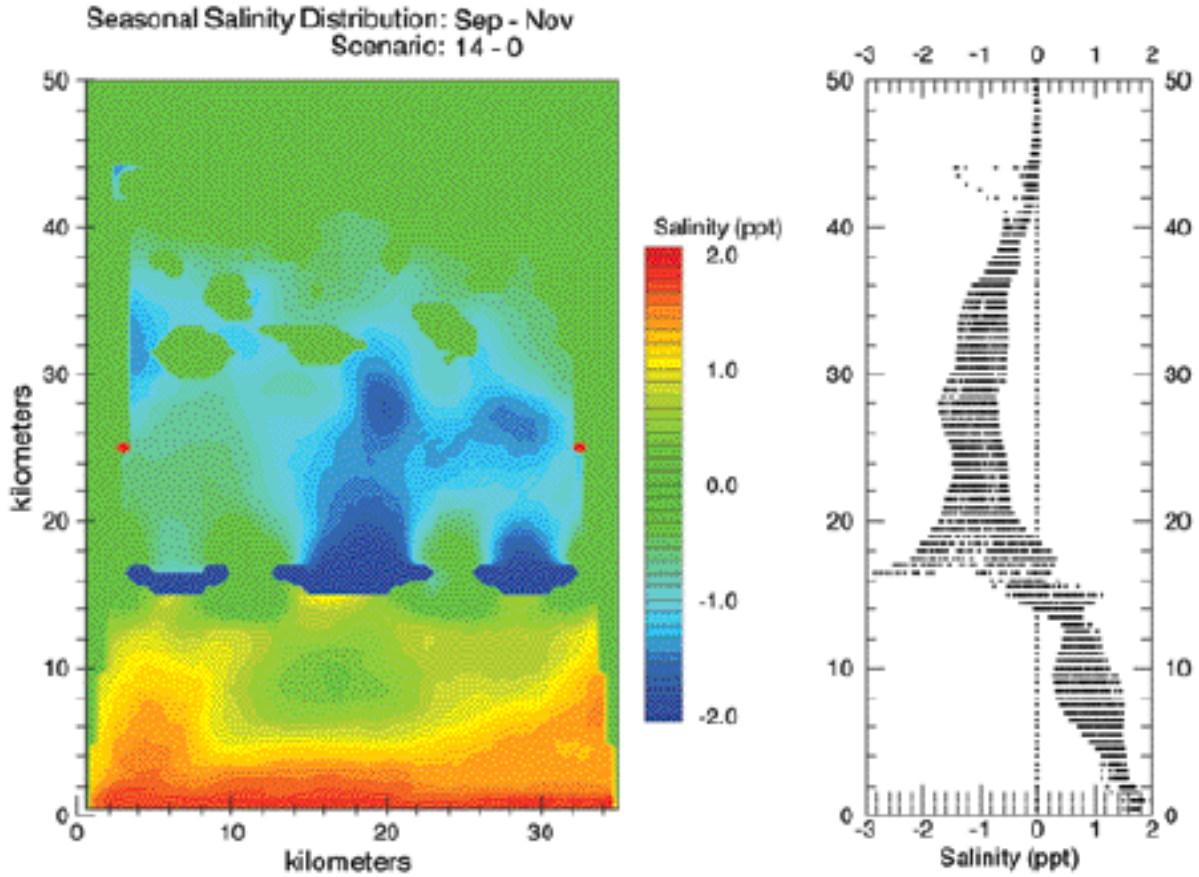

Figure D.5-15. Seasonal salinity differential distribution for the period of September through November (case: 14 - 0 km).

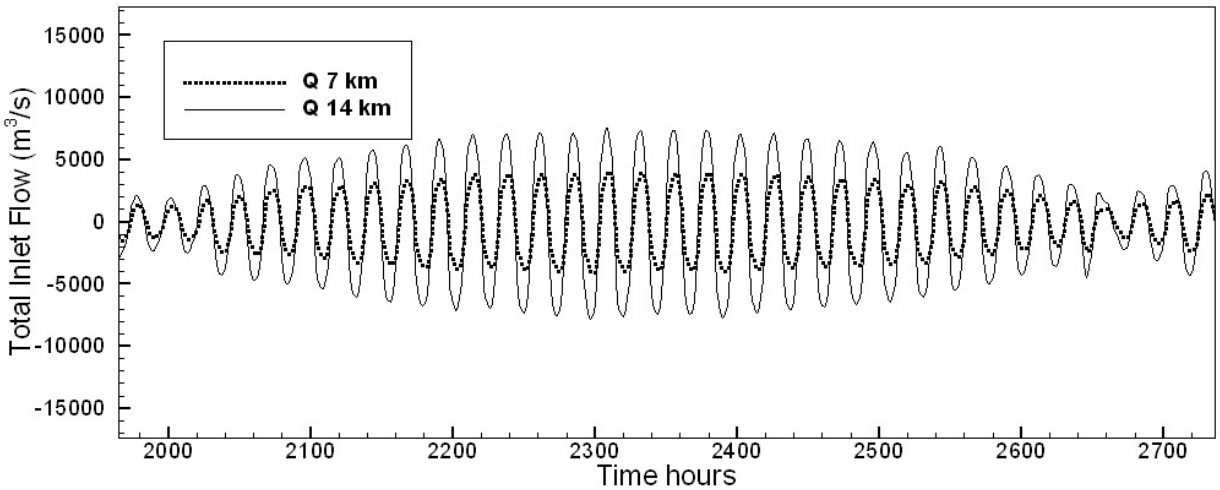

Figure D.5-16. Inlet flow comparisons over several tidal cycles for the 14 km and 7 km cases. Note that the total flow through the inlets is proportional to the surface area of the bay.

5.8 RESULTS – DESKTOP HABITAT CHANGE MODULE

The base case scenario placed the barrier islands 14 km away from the shore. This location was determined to be a typical distance and representative of the coast of Louisiana. The other two scenarios were derivations of this concept (no islands and islands at 7 km from the coast). Table D.5- 5 presents the percentage habitat composition of each functional zone (interior marsh, bay and offshore) for each scenario. The different percentages among the initial scenarios were due to the varying spatial extent of the habitats, namely the lack of bay zone in the no isles scenario and a reduced bay zone in the 7 km scenario (Table D.5- 5). Figure D.5-16 presents the results of a 50-year simulation for the base case scenario. The results showed a reduction of the interior marshes of 4%. The bay zone losses amounted only to 1%, while the offshore area showed no loss.

When compared with the results of the No Isles scenario (Table D.5- 5), the functional zones changed in extension (namely, the lack of a bay zone). However the interior marsh extent was the same, and the calculated changes reflect a loss of 6% of habitat after 50 years. The lack of barrier islands on this scenario had also consequences for the offshore zone where losses amounted to 1% of the initial map (Figure D.5-17).

The results of the 7 km simulation (Figure D.5-18) showed minimal differences with the base case scenario (Table D.5- 5). The presence of the barrier islands in such proximity to the coast did not produce noticeable changes in salinity or inundation regime. Overall, the brackish and intermediate communities presented the highest land losses, particularly in the bay zone (Figure D.5-18). The comparison between this scenario and the base case demonstrated how the location of barrier islands maintain an extended mixing area that helps preserve habitat (Table D.5- 5).

5.9 RESULTS – FAUNAL HABITAT SUITABILITY MODULE

Results from the HSI computation for each scenario are depicted in Figures D.5-19 to D.5-22. Twenty-four individual and life stages were computed. The resulting HSI values reflect the extent of optimal habitat for particular species. The only common feature of these habitat response to the scenarios is that for none of the species examined in this study did the 7 km scenario provide the best habitat conditions of the three.

The group of invertebrates was proportionally evenly distributed in their habitat preferences. Out of seven species (one with two life stages, i.e. blue crab), four showed an increase in their habitat preferences towards the No Isles scenario and four retained a strong affinity for the base case scenario. These differences can be mostly attributed to substrate preferences. The presence of barrier islands increased the amount and extension of sandy soils, thereby allowing species such as, hard clam and Rangia to find favorable habitat for settlement.

The majority of the species in the group of fishes showed a greater affinity for the No Isles scenario. Only three species (Gulf Sturgeon, Menhaden and juvenile croaker) had preferences towards the base case scenario. Larvae of Spanish Mackerel, for example, had

similar preferences for the No Isles and the 7 km scenario, with a much lower total index for the base case scenario.

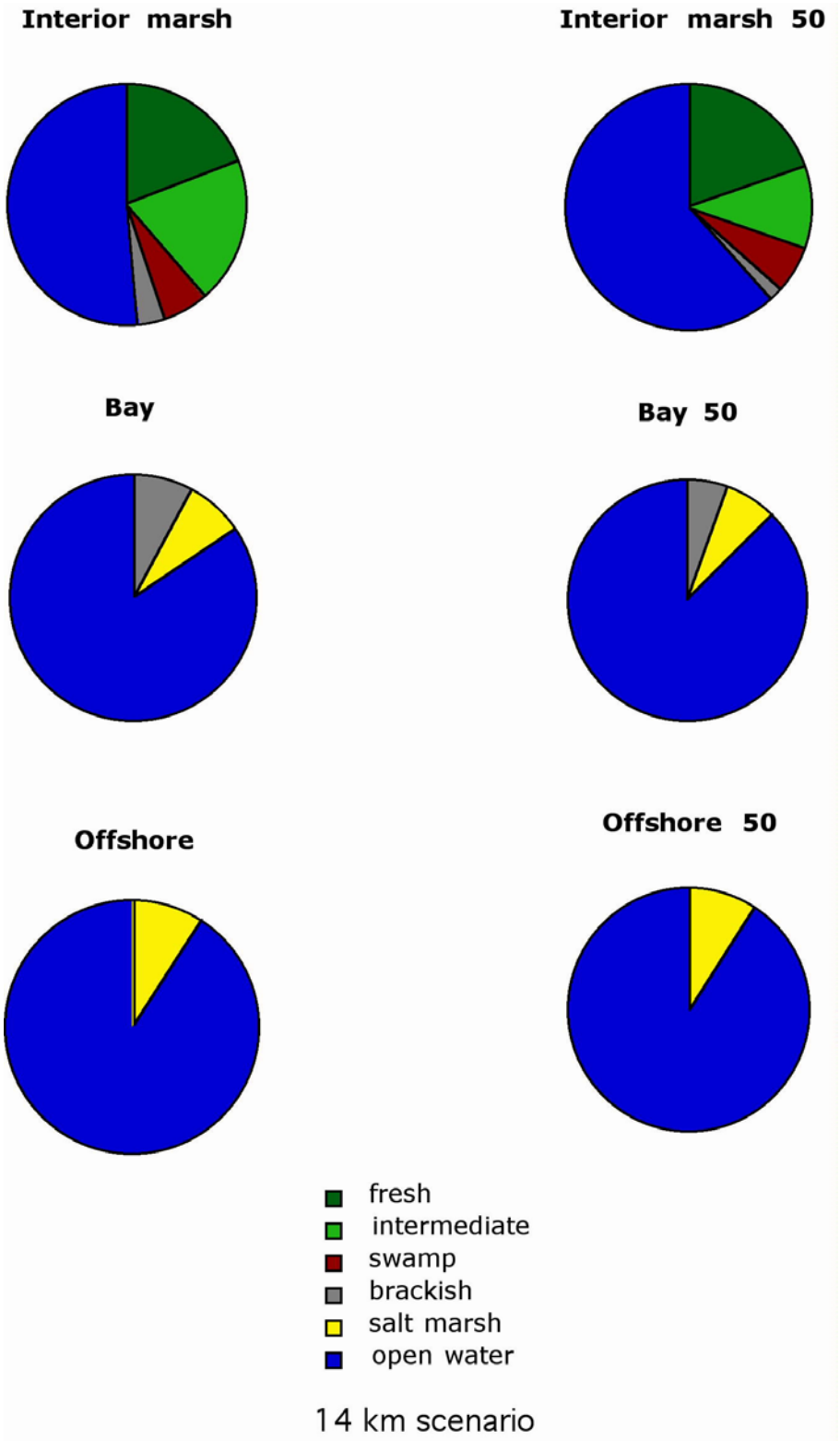

Figure D.5-17. Habitat distribution in estuary zones for Year 0 and Year 50- 14 km scenario.

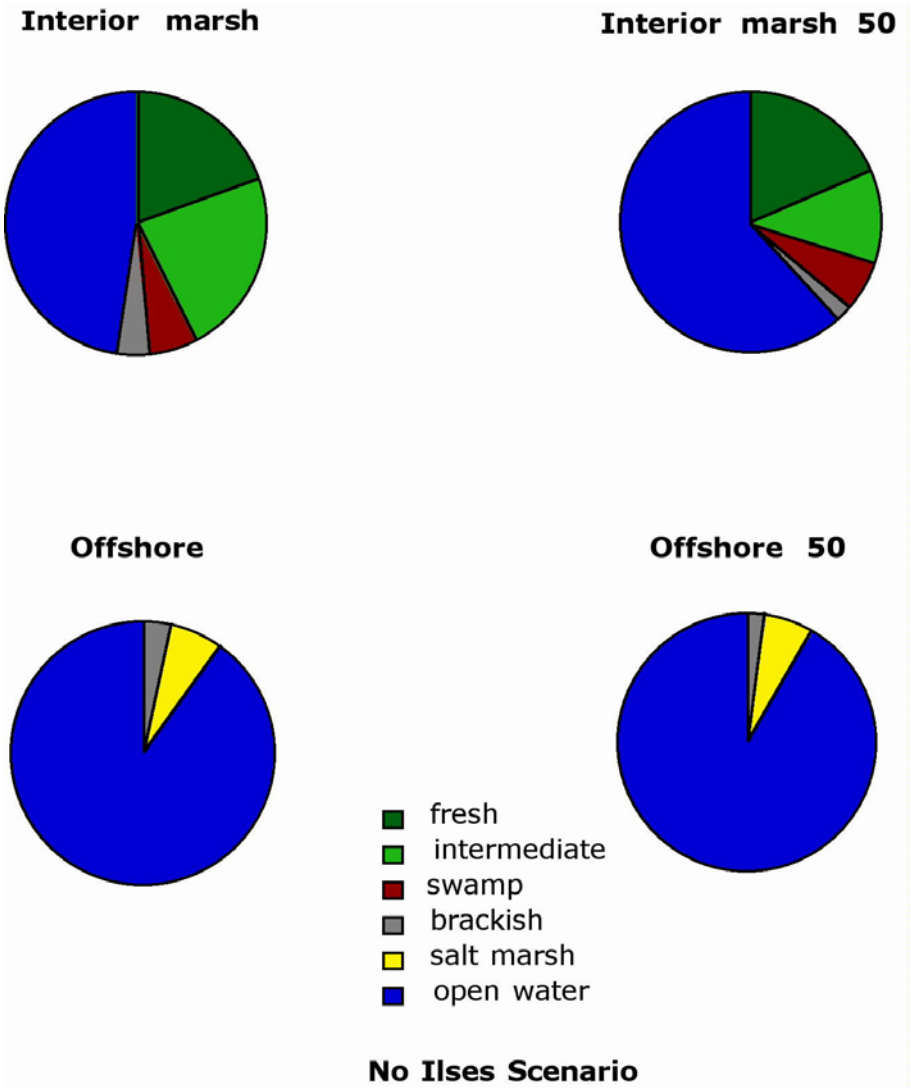

Figure D.5-18. Habitat distribution in estuary zones for Year 0 and Year 50- No Islands scenario.

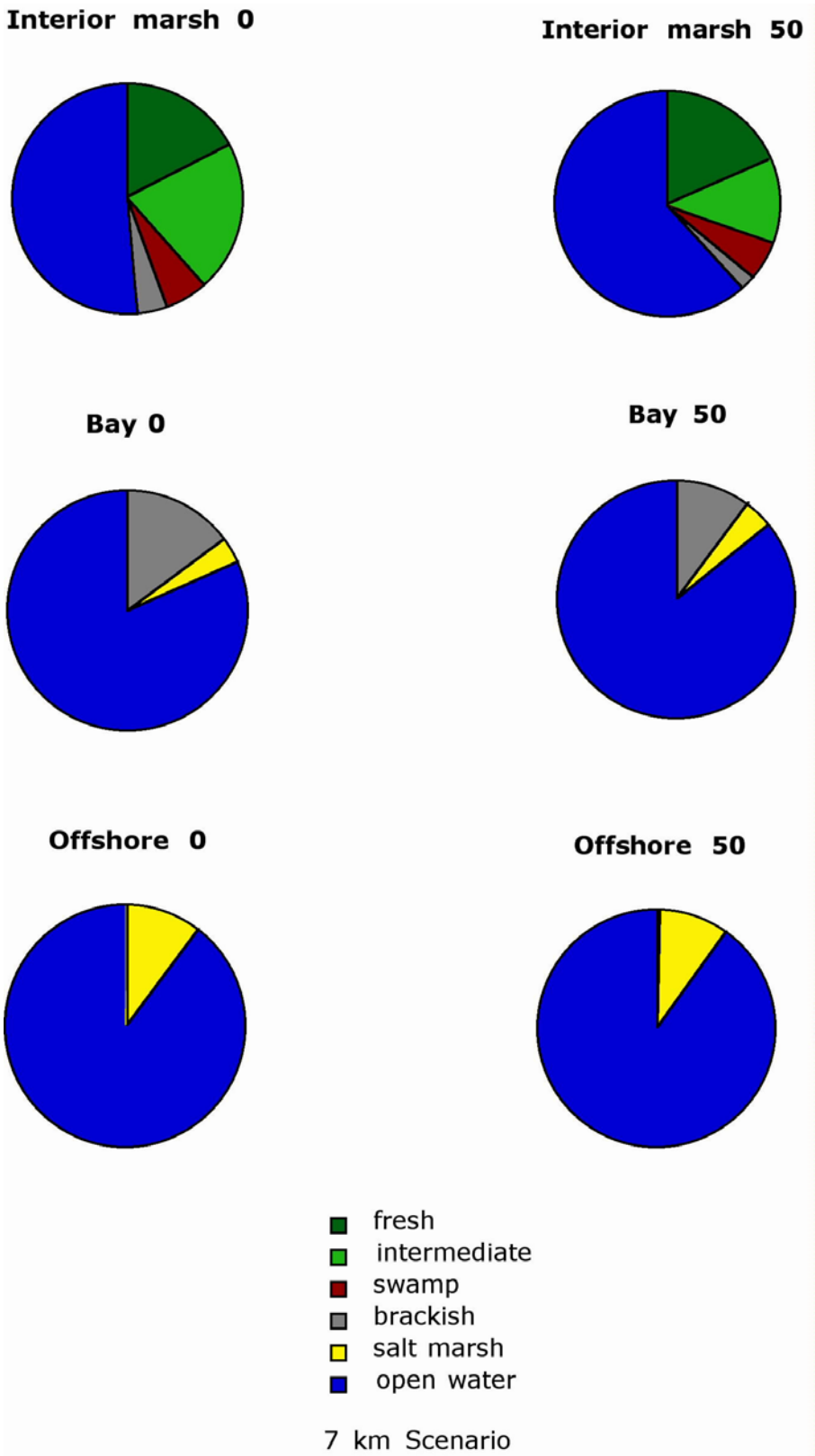

Figure D.5-19. Habitat distribution in estuary zones for Year 0 and Year 50- 7 km scenario.

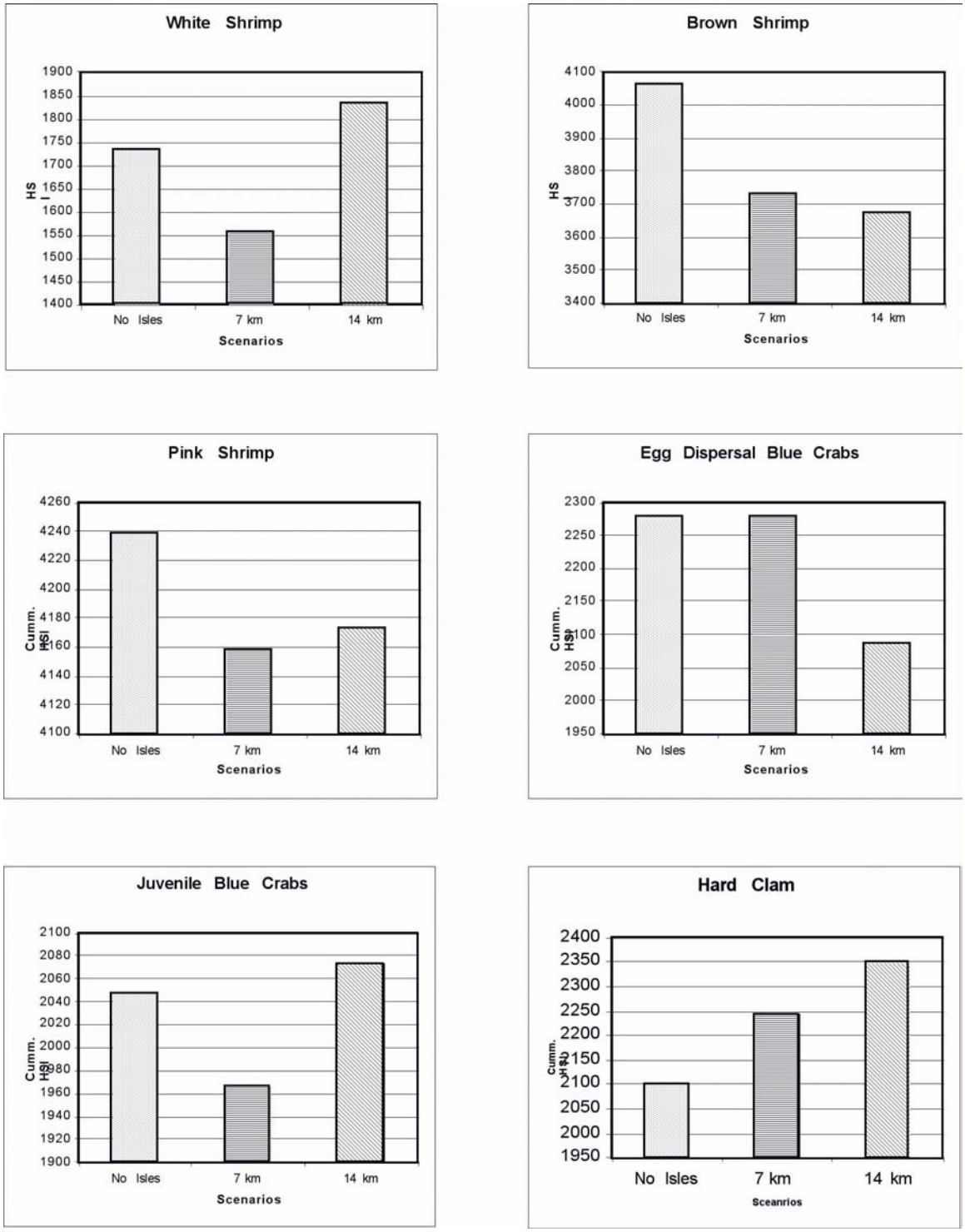

Figure D.5-20. Cumulative HSI values for shrimp, blue crab and hard clam.

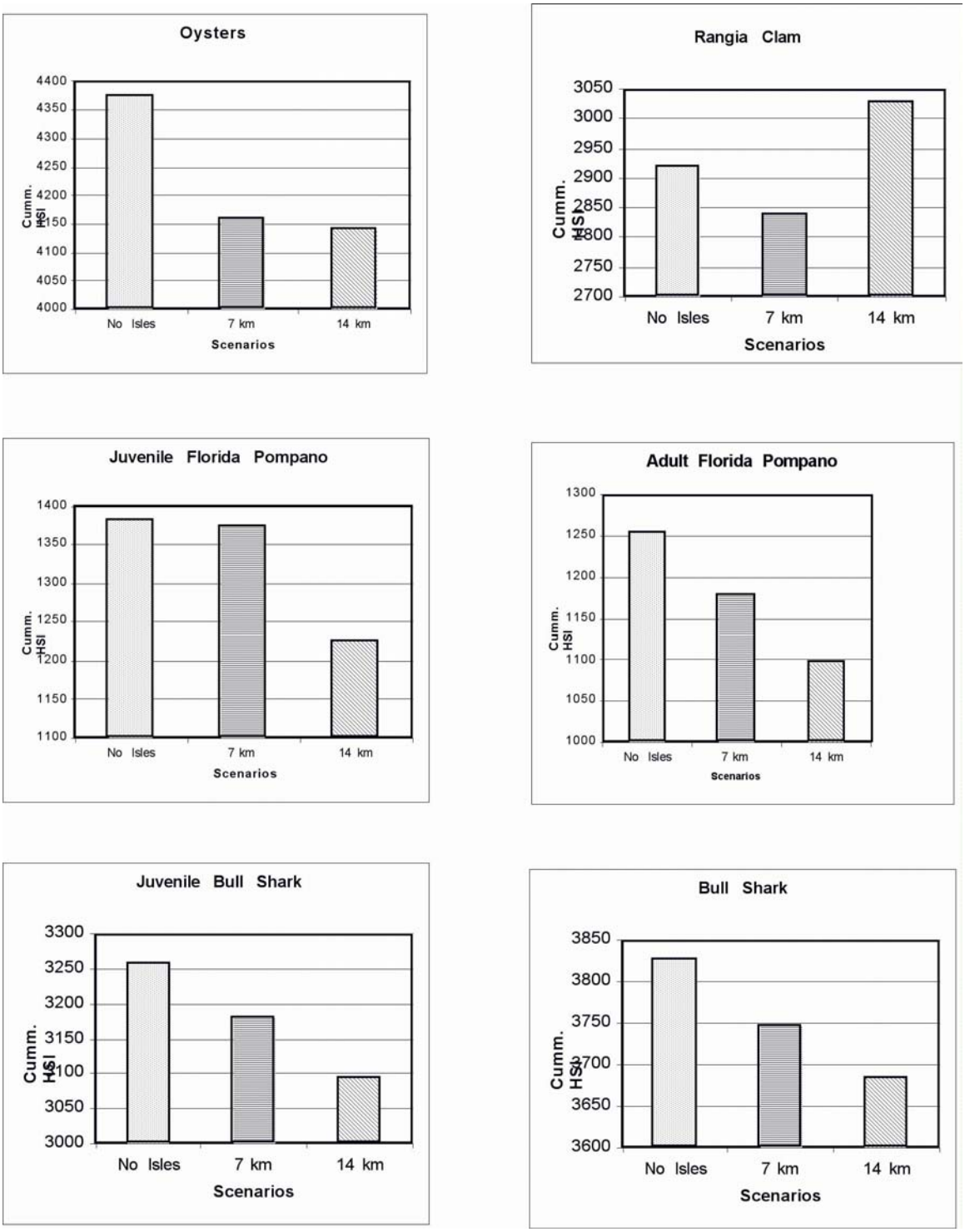

Figure D.5-21. Cumulative HSI values for oyster, Rangia clam, pompano and bull shark.

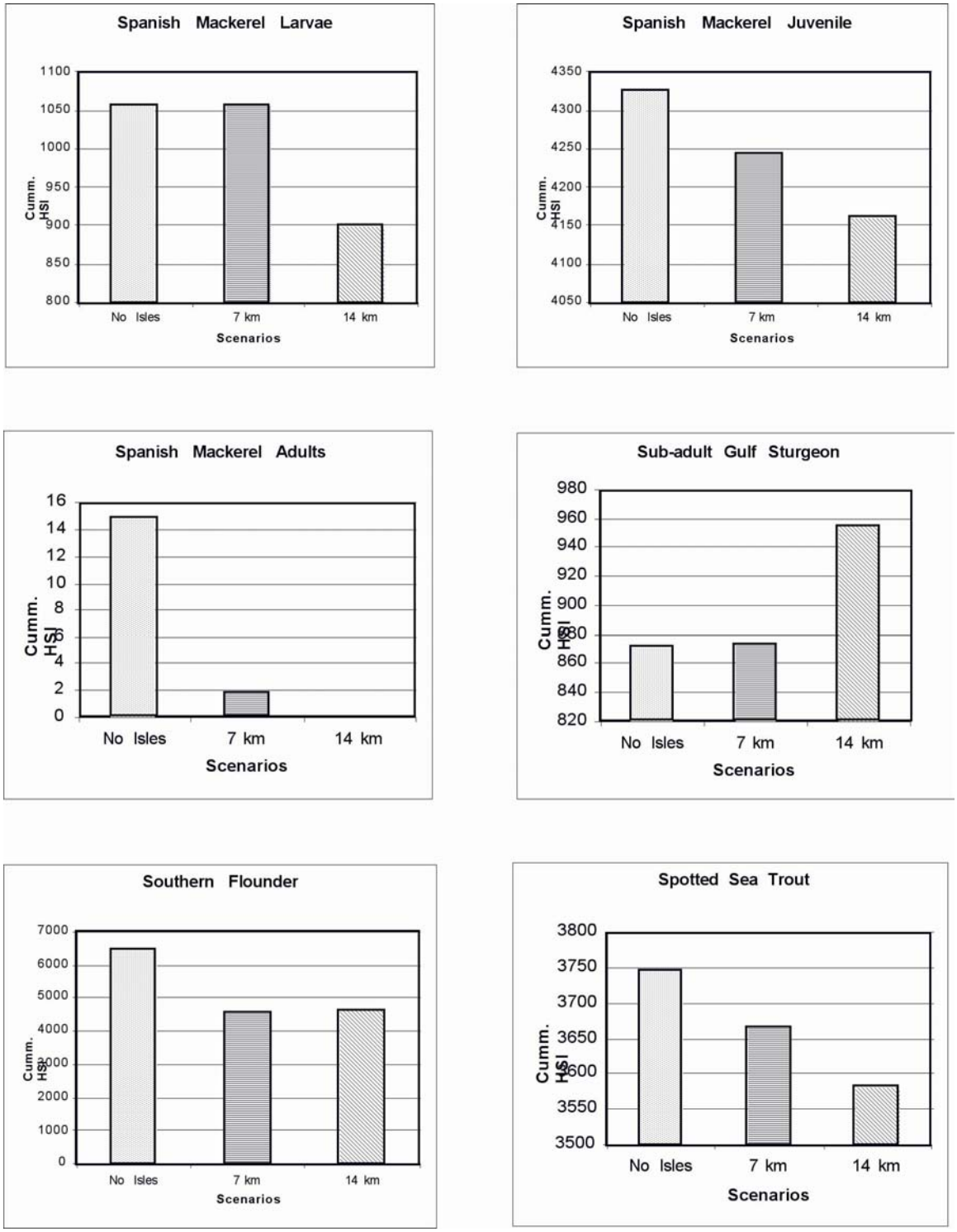

Figure D.5-22. Cumulative HSI values for mackerel, sturgeon, flounder and sea trout.

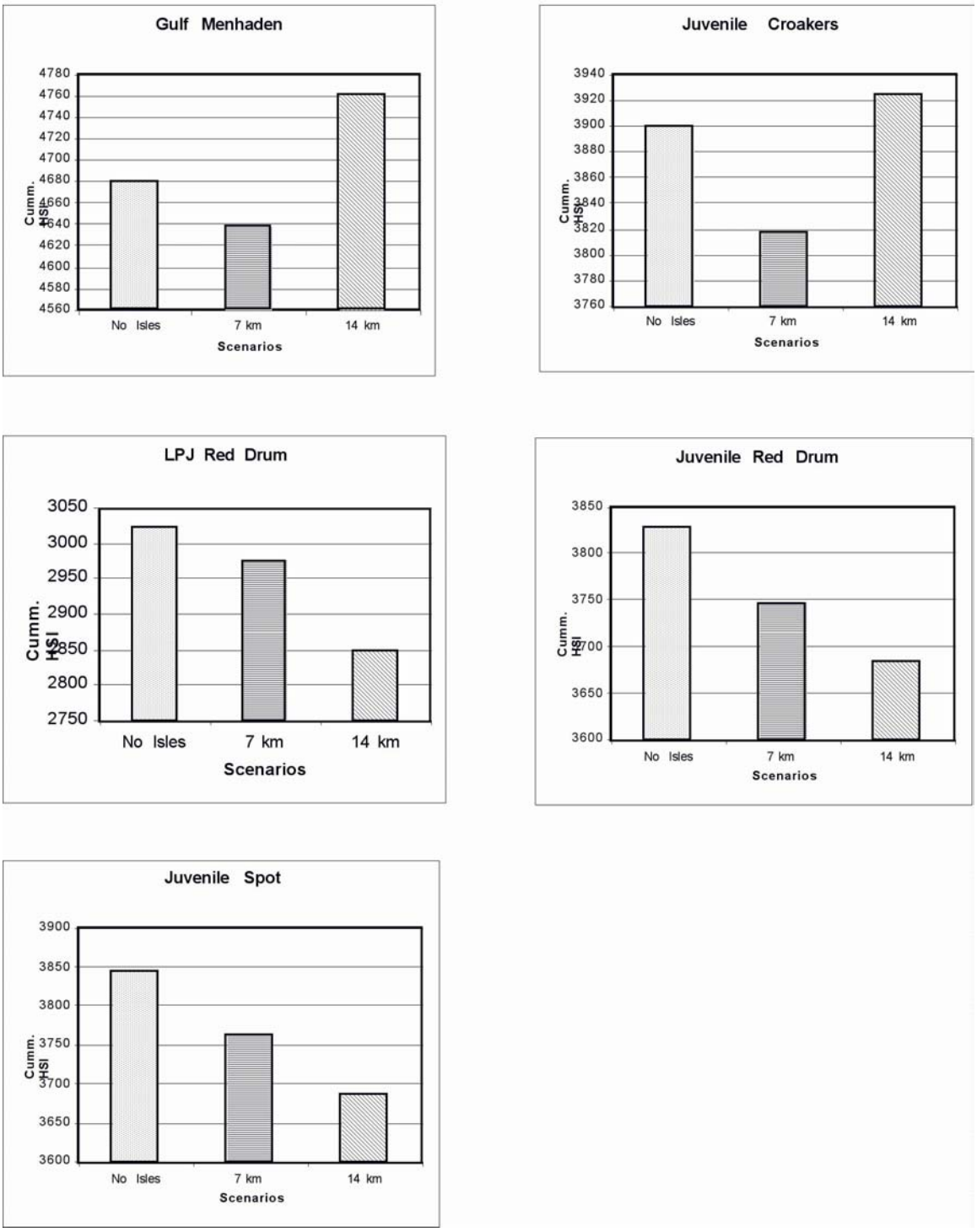

Figure D.5-23. Cumulative HSI values for menhaden, croaker, red drum and spot.

5.10 DISCUSSION

Hydrodynamic modeling has shown how the presence/absence of barrier islands within Louisiana estuaries and their positions, in so far as they control the area of the inner bay and marsh, controls the location of the gradient of the mixing zone of fresh and saltwater. Other factors influencing the location of this important mixing zone are the fresh water supply, the hydraulic conveyance of the marsh and bay zones, as well as the wind and wave induced currents. This study has shown that the hydrodynamics of the mixing zone are influenced by the location of the barrier islands, however, the hydraulic conveyance of the embayment and the marsh are probably more important. The more open water and conveyance channels in the marshes resulting from subsidence and other factors, the greater will be the penetration of tidal energy into the marsh. Open water and channelization represents an increase in the hydraulic conveyance of the marsh. The mixing zone of fresh and salt water will thus move landward as the flow capacity of the marsh increases.

Another aspect of barrier island location is that fetch between the islands and the marsh increases with the distance between the barrier islands and the marsh. This fetch determines the wind energy that can be transferred to the embayment and the wave energy that is available for shore processes. In addition, the barrier islands provide a local wake or shadow zone that is sheltered from onshore winds and tidal currents.

This approach also examined the long-term benefits barrier island presence and position to the character of interior marsh habitats. As barrier islands moved closer to shore, substantial changes occurred in the durations of salinity and flooding. This, in turn, influenced the marshes in the upper estuary. The changes in habitat type shown in this study with the habitat change module reflect the findings of the hydrodynamic assessment: that is that the salinity mixing zone moved towards the shore, as barrier island position prevented salt water from mixing into the estuary by limiting the tidal prism and thus the exchange with the offshore zone.

As the location of the barriers was changed in the experiment, many locations within the estuary experienced a change in salinity, especially during some seasons, and substrate type. The interplay of these two factors, or salinity independently, is found in this study to result in complex response in species habitat suitability. While the individual species responses shown here can inform managers concerning the potential consequences of various barrier island restoration options for aquatic species, the information must be considered in relation to the other effects of barrier island presence and position. Numerical experiments such as those presented here can allow managers to test hypotheses and evaluate the sensitivity of various ecosystem structures and functions to restoration measures.