NOAA Technical Memorandum NMFS-SEFSC-540

AN ANALYSIS OF THE POTENTIAL FISHERY VALUE OF THE "DEMONSTRATION MARSH" ON ATKINSON ISLAND IN GALVESTON BAY, TEXAS

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Introduction

Wetlands are important nursery habitats for many fishery species in the northern Gulf of Mexico (Boesch and Turner 1984, Rozas and Zimmerman 2000, Zimmerman et al. 2000), and extensive wetland loss in the region and in Galveston Bay has created an incentive to restore these wetland systems. The overall project goal of the Beneficial Uses Group is to use dredged material to create marshes that are ecologically similar to natural marshes in Galveston Bay (Rozas et al. 1995). For a variety of reasons, however, created wetlands often do not function like natural wetlands (Matthews and Minello 1994, Minello and Webb 1997, Minello 2000, Minello and Rozas 2002). An important ecological function of Galveston Bay marshes is their support of fishery populations, and the marsh surface can provide food for growth and structure that increases survival (Minello et al. 2003). This ecological function is largely determined by access to the marsh surface; and access is controlled by tidal dynamics and the amount of marsh-water edge in the system (Rozas 1995, Zimmerman et al. 2000, Minello and Rozas 2002).

The Demonstration Marsh was created on Atkinson Island (Figure 1) to show that valuable wetlands could be constructed using material from the widening and deepening

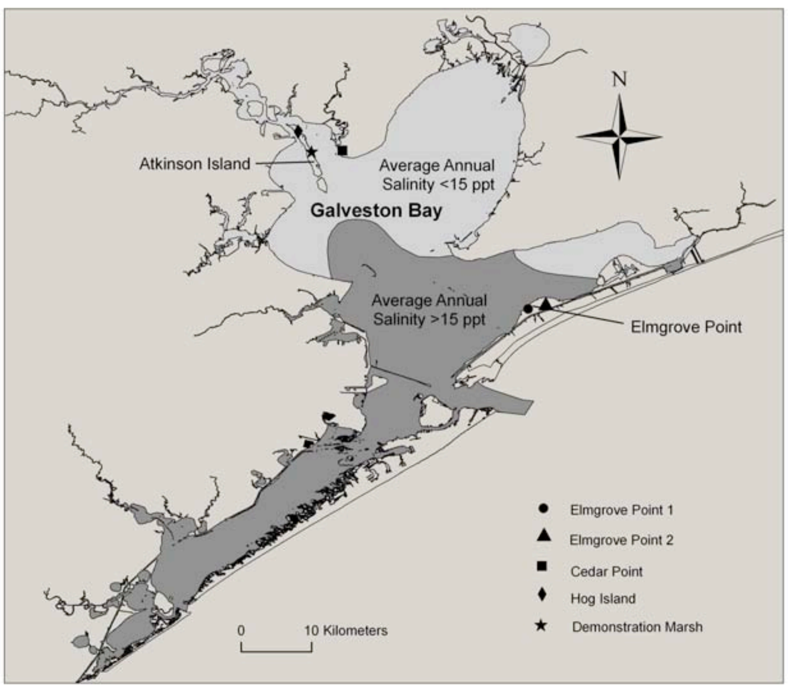

Figure 1. Location of the Demonstration Marsh and reference marshes in Galveston Bay, Texas.

of the Houston Ship Channel. A levee was built around the site in spring 1993. Over 1.2 million m^3 of maintenance dredged material was used to fill the site to 6.56 ft above mean low tide (MLT) in July 1993[1]. Planting of *Spartina alterniflora* occurred in spring and summer of 1995. Various attempts have been made to increase the amount of marsh-water edge in the Demonstration Marsh following construction (Turner Collie & Braden Inc. 2002).

The Fishery Ecology Branch of the NMFS Galveston Laboratory has developed an approach to estimate the nursery value of different Galveston Bay wetland systems for fishery species such as penaeid shrimps and blue crabs. This approach involves a landscape-scale analysis of land water patterns in wetlands combined with spatial models of the fine-scale (1-10 m) density distributions of nekton on the marsh surface (Minello and Rozas 2002, Rozas et al. 2005). The land-water patterns are determined using aerial photography and a Geographic Information System (GIS) to estimate the amount of water within wetlands and the amount of marsh edge habitat. Nonlinear regression models have been developed (for brown shrimp *Farfantepenaeus aztecus*, white shrimp *Litopenaeus setiferus*, and blue crabs *Callinectes sapidus*) to describe a general decline in density (both into the marsh vegetation and out into open water) from a peak just within the vegetation at the marsh edge (Figure 2). By combining these models with estimated densities for nekton species in vegetated marsh edge habitat, we can develop density surfaces for different areas within the marsh at a 1-m pixel resolution. Nekton population size can then be estimated for a marsh complex by summing these data.

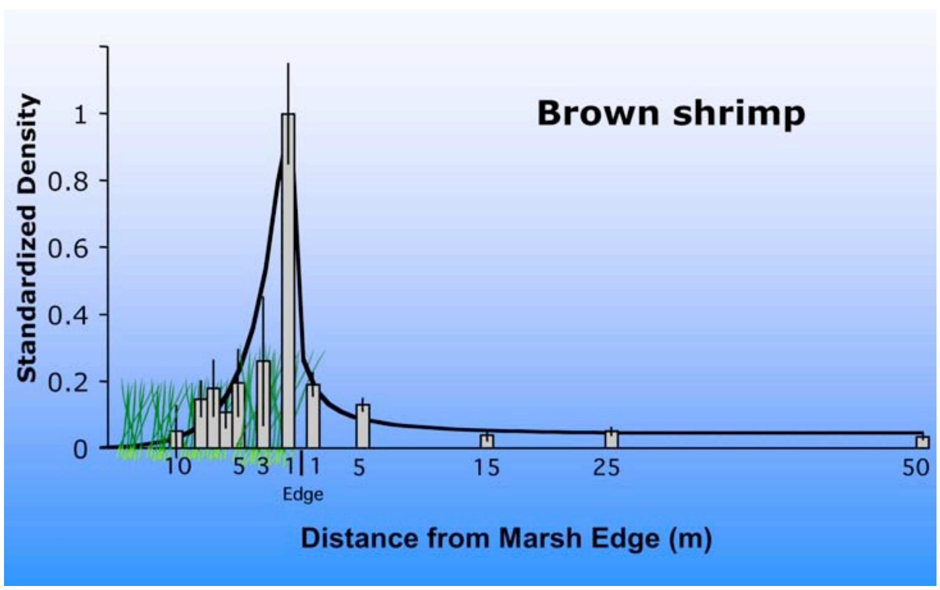

Figure 2. Fine-scale distribution of juvenile brown shrimp in relation to the marsh edge. Densities are standardized to 1.0 at 1 meter within marsh vegetation and decline as you move into the vegetation (left) and into open water (right). Bars represent measured densities, and the black line is the modeled regression curve.

[1] Bayport Demonstration Marsh Project. Undated Report from Turner Collie & Braden Inc./Gahagan & Bryant Associates, Inc. to the Port of Houston Authority and the U.S. Army Corps of Engineers.

Our goal in this project was to examine the development of fishery value in the Demonstration Marsh on Atkinson Island using our modeling approach. Our specific objectives were to 1) identify the marsh-water landscape characteristics of the Demonstration Marsh over time as the vegetation developed, the sediment compacted, and various approaches were used to add marsh edge to the area; 2) estimate projected standing crops of brown shrimp, white shrimp, and blue crabs for the marsh at different time periods and stages of development; 3) compare nekton population estimates for the Demonstration Marsh with various natural reference marshes in Galveston Bay; and 4) provide information on the additional amount of creeks and marsh edge needed to approach natural marsh configurations. Our results provide an objective estimate of the fishery value of the created marsh system in relation to the original value of open bay bottom and establish a trajectory of marsh development from initial construction to the present. These results also can help plan future modifications of this created wetland system and other marsh creation projects to optimize land water patterns for the benefit of fishery species.

Methods and Materials

Analysis of Imagery

We analyzed three aerial photographs of the Demonstration Marsh taken in 1997, 1999, and 2005 by Aerial Viewpoint Inc. (Spring, TX) to identify marsh, upland, and water (creeks, channels, and ponds). The raw images were geo-rectified to the first order with ERDAS Imagine 8.6 software (Lieca Geosystems; Norcross, GA). The rectified images were incorporated into a Geographic Information System project, using ArcView 9.0 software with Spatial Analyst (Environmental Systems Research Institute Inc.; Redlands, CA). Unsupervised classification of the images into land and water was difficult because of the variation present in spectral signatures. Some of the base features identified with the image analysis were saved and converted to vector format, but a digitization process was used to delineate the vegetation, water, and non-applicable areas. Quality control was established by interviewing managers and researchers familiar with the project, comparing analyzed images with other available photography, examining previous reports on the Demonstration Marsh, and by field ground truthing supported with GPS. Because the quality and specifications of the three aerial images varied (see Appendix I), comparisons of land-water patterns among different years should be considered approximations and interpreted with some caution.

We classified the vegetation and water areas in each image into different categories based on the distance to the nearest marsh-water edge at 1 m increments (e.g., 0-1 m, 1-2 m, etc.) using Spatial Analyst. Distances greater than 25 m from the edge were combined into one category. After calculating the overall areal coverage of each distance-to-edge category within the water and vegetation for each image, we applied modeled densities for each category using Microsoft Excel to estimate nekton populations for the Demonstration Marsh and the reference marshes.

Elevation data in feet above mean low tide (MLT) were obtained from surveys conducted by Gahagan and Bryant Associates Inc. and Turner Collie & Braden Inc. for the years 1996[1] and 1998 (Turner Collie & Braden Inc. 2002). The elevations from these surveys were attributed to image files, matching the 1996 survey to the 1997 image and the 1998 survey to the 1999 and 2005 images. Survey maps were scanned and rectified to develop elevation overlays for the Demonstration Marsh. Elevation data were converted to vector data with a contour at 2.4 ft (0.73 m) MLT used to separate high and low elevation marsh. The edge and nekton population data for each year analyzed were then broken out for low-elevation marsh areas, defined as areas below this 2.4 ft MLT contour. To examine the tidal flooding characteristics of these low-elevation areas, we downloaded 2005 tide data for Tide Station 8770613 - Morgan's Point, TX from NOAA/NOS/COOPS (Center for Operational Oceanographic products and Services; http://140.90.121.76/data_res.html). We used these data to calculate monthly inundation periods in 2005 for marsh areas below 2.4 ft MLT.

Four reference marshes were selected to provide a range of land-water patterns present in natural marsh systems of Galveston Bay (Figure 1). The reference marshes at Hog Island and Cedar Point were located near the Demonstration Marsh in upper Galveston Bay. The other two reference marshes are on Elmgrove Point, located on Bolivar Peninsula in East Bay. Aerial photographic images (taken in 1995) for the reference marshes were acquired from Digital Ortho-photo Quarter Quads (DOQQ) downloaded from the Texas Natural Resource Information System (http://www.tnris.state.tx.us/). Land water patterns from these images were classified using both unsupervised classification techniques and digitization. Methods for calculating area values and nekton populations were identical to those used for the Demonstration Marsh.

Application of Fishery Density Models

We used the modeling approach of Rozas et al. (2005) to estimate potential nekton populations at the Demonstration Marsh and the reference marshes. All of the models (brown shrimp, white shrimp, and blue crab) predict nekton densities within a marsh system based on the density at the vegetated marsh edge. We used marsh edge densities derived from enclosure samples collected in the upper portion of the Galveston Bay system (mean annual salinity <15 ‰) on various projects between 1982 and 1997. Mean densities were estimated for periods when a species was abundant in the Galveston Bay system. These periods and the associated mean densities were April-September for brown shrimp (3.2 per m^2), June-November for white shrimp (14.3 per m^2), and April-November for blue crabs (6.5 per m^2). These densities are for juveniles, and most specimens were smaller than 50 mm total length or carapace width. Because the purpose of selecting reference marshes was to examine different natural patterns of land and water, we applied these low salinity densities to all reference marshes, even though the Elmgrove Point marshes were located in higher salinity areas of the Bay.

Results

The landscape characteristics of the Demonstration Marsh in 1997, 1999, and 2005 are shown in Appendix Figures 1 – 3. The total area of the marsh system analyzed was 70.9 ha. We estimated the area of marsh vegetation to be 58.6, 60.6, and 63.1 ha in 1997, 1999, and 2005, respectively (Table 1). The amount of water (creeks, channels,

Table 1. Landscape characteristics and nekton population estimates for different years at the Demonstration Marsh. Values also are shown for only low-elevation areas of the marsh (below 2.4 ft MLT).

	Entire Marsh Complex			Low Elevation Areas (< 2.4 MLT)		
Year	1997	1999	2005	1997	1999	2005
Marsh Vegetation (ha)	58.6	60.6	63.1	23.5	36.8	38.3
Vegetated Edge (ha)	2.9	5.4	4.1	1.6	3.6	3.1
Water (ha)	7.7	10.3	7.1	5.6	6.8	5.5
Total Area (ha)	70.9	70.9	70.9	29.2	43.6	43.8
% Marsh Vegetation	82.8%	85.5%	89.0%	80.7%	84.4%	87.5%
% Edge in Vegetation	4.1%	7.7%	5.7%	5.6%	8.2%	7.1%
% Water	10.9%	14.5%	10.0%	19.3%	15.6%	12.5%
Brown shrimp						
Population	275,603	530,926	419,878	148,915	334,524	308,467
No. per ha	3,889	7,492	5,925	5,104	7,671	7,044
White shrimp						
Population	1,503,497	2,862,803	2,324,129	800,230	1,773,429	1,689,383
No. per ha	21,215	40,395	32,794	27,426	40,666	38,579
Blue Crab						
Population	994,992	1,671,214	1,412,663	497,182	1,029,786	980,884
No. per ha	14,040	23,581	19,933	17,040	23,613	22,400

and ponds) within the Demonstration Marsh increased from 1997 to 1999 and then decreased to 7.1 ha (or 10.0% of total area) in 2005 (Figure 3). The area of marsh edge followed a similar pattern. The overall nekton population estimates in 2005 for the Demonstration Marsh were 419,878 brown shrimp, 2,324,129 white shrimp, and 1,412,663 blue crabs.

Our models predict densities of 0.048 brown shrimp, 0.021 white shrimp, and 0.112 blue crabs per m^2 in shallow open water greater than 25 m from vegetation. If we use these densities to represent the population in the area before the Demonstration Marsh was constructed, we would predict preconstruction populations in the 70.9 ha area to have been 33,827 brown shrimp, 15,109 white shrimp, and 79,479 blue crab. These calculations indicate that by 2005, the Demonstration Marsh had increased these nekton populations by a factor of 12 for brown shrimp, 154 for white shrimp, and 18 for blue crabs.

Low elevation marsh areas were identified and analyzed separately, because the marsh surface in these areas is expected to be flooded more regularly and be more readily available to nekton. The area of low-elevation marsh (below 2.4 ft MLT) increased from 29.2 ha in the 1996 survey to almost 44 ha in the 1998 survey (Table 1). The 43.8 ha of low-elevation marsh (61.8% of total marsh area) in the 2005 analysis had relatively more edge vegetation and higher population estimates per unit area than the entire marsh area.

Reference Marshes

The four reference marshes selected for comparison with the Demonstration Marsh ranged in size from 9.2 to 84.7 ha in area (Appendix Figures 4-7, Table 2). Overall, these marshes all had a higher percentage of water associated with marsh

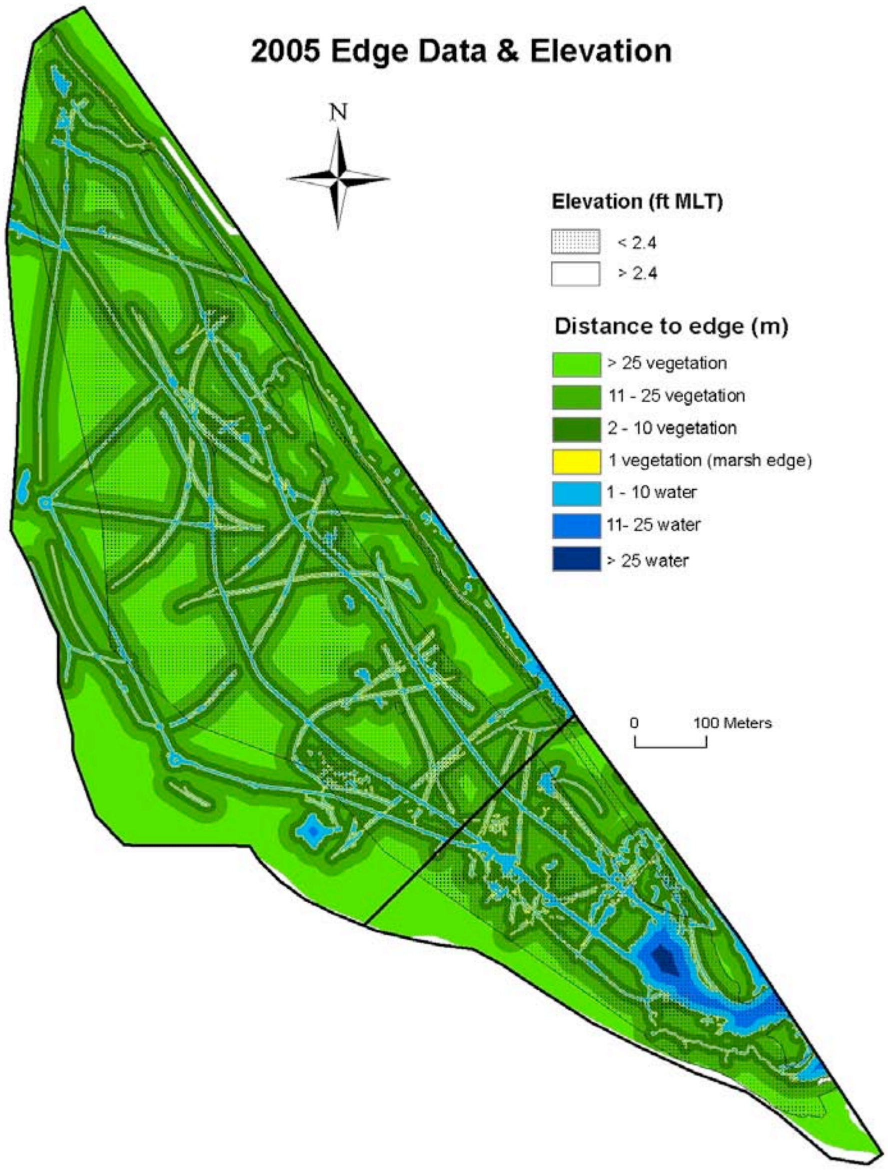

Figure 3. Land water analysis of the Demonstration Marsh from a 2005 aerial photograph. Vegetation and water are identified in relation to their distance from the marsh-water interface. The black line separates the marsh into a North and South region

Table 2. Landscape characteristics and nekton population estimates for four reference marshes in the Galveston Bay system based on analyses of 1995 imagery.

	Elmgrove 1	Elmgrove 2	Cedar Point	Hog Island	Means
Marsh Vegetation (ha)	56.9	48.4	10.3	6.9	30.6
Vegetated Edge (ha)	11.1	6.7	1.4	0.5	4.9
Water (ha)	27.8	29.3	4.2	2.3	15.9
Total Area (ha)	84.7	77.8	14.5	9.2	46.5
% Marsh Vegetation	67%	62%	71%	75%	69%
% Edge in Vegetation	13%	9%	10%	5%	9%
% Water	33%	38%	29%	25%	31%
Brown shrimp					
Population	968,131	692,555	151,874	58,836	467,849
No. per ha	11,426	8,905	10,474	6,421	9,307
White shrimp					
Population	5,037,852	3,696,219	778,728	320,627	2,458,357
No. per ha	59,459	47,526	53,706	34,991	48,920
Blue Crab					
Population	2,525,556	1,932,005	410,888	190,117	1,264,642
No. per ha	29,808	24,842	28,337	20,748	25,934

vegetation and higher percentages of marsh edge within the vegetation. Nekton population estimates per unit area were substantially higher at the Elmgrove Point and Cedar Point marshes than at the Demonstration Marsh; estimates were more comparable at the Hog Island reference marsh. Even the low elevation areas of the Demonstration Marsh appeared to support lower nekton populations than the reference marshes. The population estimates (per unit area) for low-elevation areas of the Demonstration Marsh in 2005 were between 75-86% of the mean estimates for the reference marshes (Tables 1 and 2).

Tidal Flooding Characteristics

The low elevation areas (< 2.4 ft MLT) were identified and delineated in the Demonstration Marsh on the assumption that these areas were regularly flooded by tidal water and would be accessible to nekton. The marsh edge habitat cannot be used by shrimp and crabs unless water levels are above the elevation of the marsh surface. Based on the record from the Morgan's Point tide gage, the marsh surface at 2.4 ft MLT was flooded 41% of the time in 2005. Flooding was highest in September and lowest in December (Figure 4). We also examined flooding data for the reference marshes at Elmgrove Point, using a virtual tide gage developed from the Pier 21 NOAA gage (Minello and Webb 1997). In 2005, the marsh edge was flooded more often (88.0% of the time) in these marshes located in the lower bay.

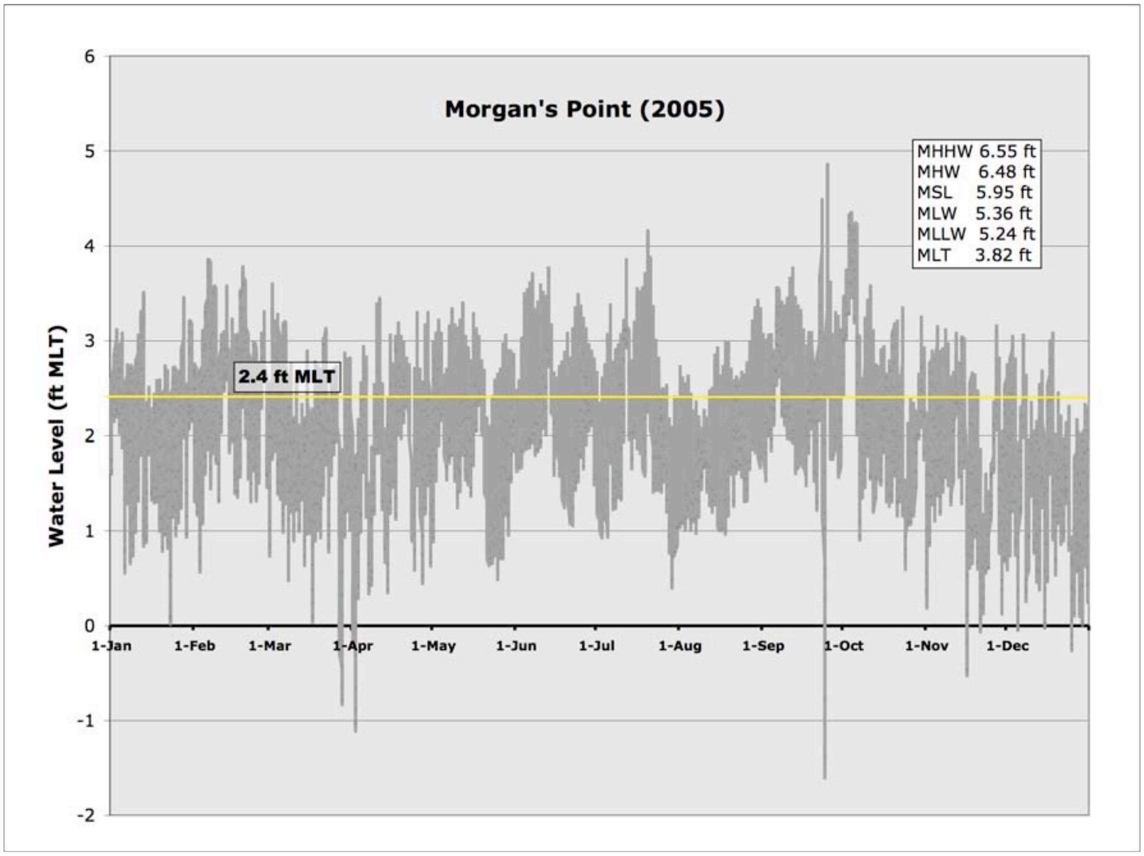

Figure 4. Hourly water level data in ft above Mean Low Tide (MLT) from the NOAA gage at the Morgan's Point (Tide Station 8770613) near the Demonstration Marsh. 2.4 ft MLT is shown by yellow line.

Variability Within the Demonstration Marsh

We divided the Demonstration Marsh arbitrarily into a North and South Region (Figure 3) to examine whether different areas of the Demonstration Marsh had the potential to support different nekton populations. The southern region appeared more similar to natural land-water patterns, having a higher percentage of water and more edge in the marsh vegetation (Table 3). The low elevation areas of the southern region had 24.9% water within the marsh complex, and 8.2% of the vegetation was marsh edge (within 1 m of water). These low elevation areas in the southern region were the closest to the reference marshes in supporting nekton populations, and our population estimates for these areas in the South region were between 88 and 94% of the mean values for the reference marshes.

Discussion

Development of Landscape Characteristics in Demonstration Marsh

The amount of marsh vegetation within the Demonstration Marsh increased from 1997 through 2005, but the amount of marsh edge peaked in 1999 before declining slightly by 2005. This decline in marsh edge from 1999 to 2005 coincided with slight declines in modeled nekton populations, because shrimp and crabs aggregate in marsh edge habitat. The decline also coincided with a decrease in the area of water within the

Table 3. Landscape characteristics and nekton population estimates for the North and South sections of the Demonstration Marsh in 2005. Values also are shown for only low-elevation areas of the marsh (below 2.4 ft MLT).

	Entire Marsh Complex		Low Elevation Areas (< 2.4 MLT)	
	North	South	North	South
Marsh Vegetation (ha)	50.8	12.3	30.6	7.7
Vegetated Edge (ha)	3.1	1.0	2.3	0.8
Water (ha)	4.2	2.9	2.9	2.6
Total Area (ha)	55.0	15.2	33.5	10.3
% Marsh Vegetation	92.4%	80.8%	91.3%	75.1%
% Edge in Vegetation	5.5%	6.6%	6.8%	8.2%
% Water	7.6%	19.2%	8.7%	24.9%
Brown shrimp				
Population	315,845	104,033	224,075	84,392
No. per ha	5,744	6,835	6,689	8,217
White shrimp				
Population	1,759,551	564,578	1,235,023	454,360
No. per ha	31,998	37,095	36,866	44,242
Blue Crab				
Population	1,087,716	324,948	729,730	251,154
No. per ha	19,780	21,350	21,783	24,455

Demonstration Marsh as some ponds and channels became overgrown with vegetation. The low elevation (< 2.4 MLT) areas of the marsh appeared to support relatively higher populations of nekton than the higher elevation areas, and the southern region of the Demonstration Marsh supported larger populations (per unit area) than the northern region. All population modeling for shrimp and crabs in the Demonstration Marsh indicated that populations were substantially higher (12 to 154 times) than the populations expected in the area before the Demonstration Marsh was constructed. Similar patterns should be expected for juveniles of other species that aggregate near marsh edge such as red drum and spotted seatrout (Minello 1999). However, for species that are associated more with shallow open water areas such as gulf menhaden, this pattern would likely to be reversed.

Comparisons with Natural Marshes

We selected four different reference marshes for comparison with the Demonstration Marsh, and these marshes ranged in their percent vegetation from 62 to 75%. The percentage of marsh edge within the vegetation varied among these marshes from 5 to 13%, and modeled nekton populations also varied substantially (Table 2). In 2005, the Demonstration Marsh supported between 64 and 77% of the mean nekton population estimates from the four reference marshes. This percentage increased for the low-elevation areas of the Demonstration Marsh.

The creeks and ponds and the associated marsh edge added to the southern area of the Demonstration Marsh made the land-water patterns in the marsh approximate the landscape patterns of natural marshes in the bay. The low-elevation areas in this southern portion of the Demonstration Marsh had the highest nekton population estimates (between 88 and 94% of the mean values for the reference marshes). A comparison of the additional construction costs required to add marsh edge in the southern area with the incremental increase in nekton populations in this area compared with the northern area of the Demonstration Marsh, should be useful in conducting a cost: benefit analysis.

Elevation and Tidal Flooding

The annual flooding durations for the low elevation marsh surface (< 2.4 ft MLT) at the Demonstration Marsh was 41% in 2005, and this value was comparable to the flooding durations measured at Atkinson Island and Hog Island natural marshes for *S. alterniflora* edge in 1993 (45.6%) and 1994 (45.8%) by Rozas and Zimmerman (2000). Marshes in the upper bay appear to flood less than those in the lower bay. In contrast to the 41% flooding duration for the Demonstration Marsh, the flooding duration for the Elmgrove Point marshes in 2005 was 88%. Rozas and Zimmerman (2000) reported flooding durations for *S. alterniflora* edge at these Elmgove Point marshes of 66.6% in 1993 and 66.2% in 1994.

Acknowledgments

We would like to sincerely thank Dick Gorini, who supported this investigation from the outset. The U.S. Army Corps of Engineers (Galveston District) funded this research. Wendell Mears was particularly helpful in obtaining images for analysis. Rusty Swafford was a valuable source of historical information on the construction and development of the Demonstration Marsh. Rob Roman provided assistance with tidal datums.

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Appendix I. Imagery used in landscape analysis.

1997 image. Supplied by Turner Collie & Braden Inc. in TIFF Format, color infrared, unrectified.

1999 image. Supplied by Turner Collie & Braden Inc. as printed photograph. Photo taken September 17, 1999; scale 1" = 300'; natural color, unrectified. Scanned by G.A. Matthews (NOAA Fisheries).

2005 image. Purchased from Aerial Viewpoint, Inc. (http://www.aerialviewpoint.com) as 9" x 9" negative (copy); natural color, unrectified. Scanned by NASA Regional Application Center (http://www.rac.louisiana.edu/). This image did not include the extreme north end of the project area; data from the 1999 image were used for this area.

All images were geo-rectified to the first order with ERDAS Imagine 8.6 software (Lieca Geosystems; Norcross, GA). State Plain Projection.

Appendix Figures

Appendix Figure 1. Aerial photograph and landscape analysis of the Demonstration Marsh in 1997. Vegetation and water are identified in relation to their distance from the marsh edge.

Appendix Figure 2. Aerial photograph and landscape analysis of the Demonstration Marsh in 1999. Vegetation and water are identified in relation to their distance from the marsh edge.

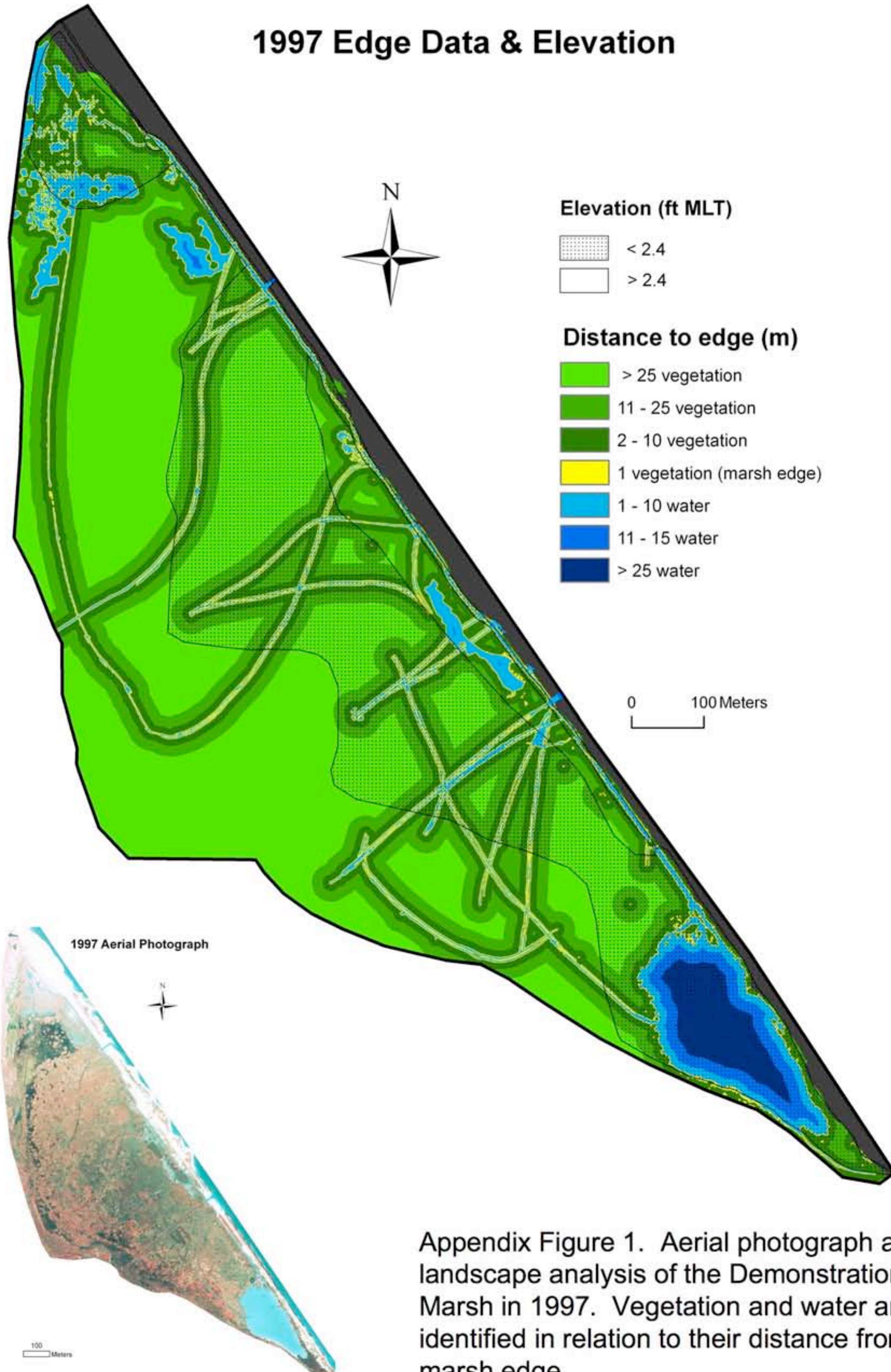
Appendix Figure 3. Aerial photograph and landscape analysis of the Demonstration Marsh in 2005. Vegetation and water are identified in relation to their distance from the marsh edge.

Appendix Figure 4. Landscape analysis of the Cedar Point reference marsh based on aerial photography taken in 1995 (background). Vegetation and water are identified in relation to their distance from the marsh edge.

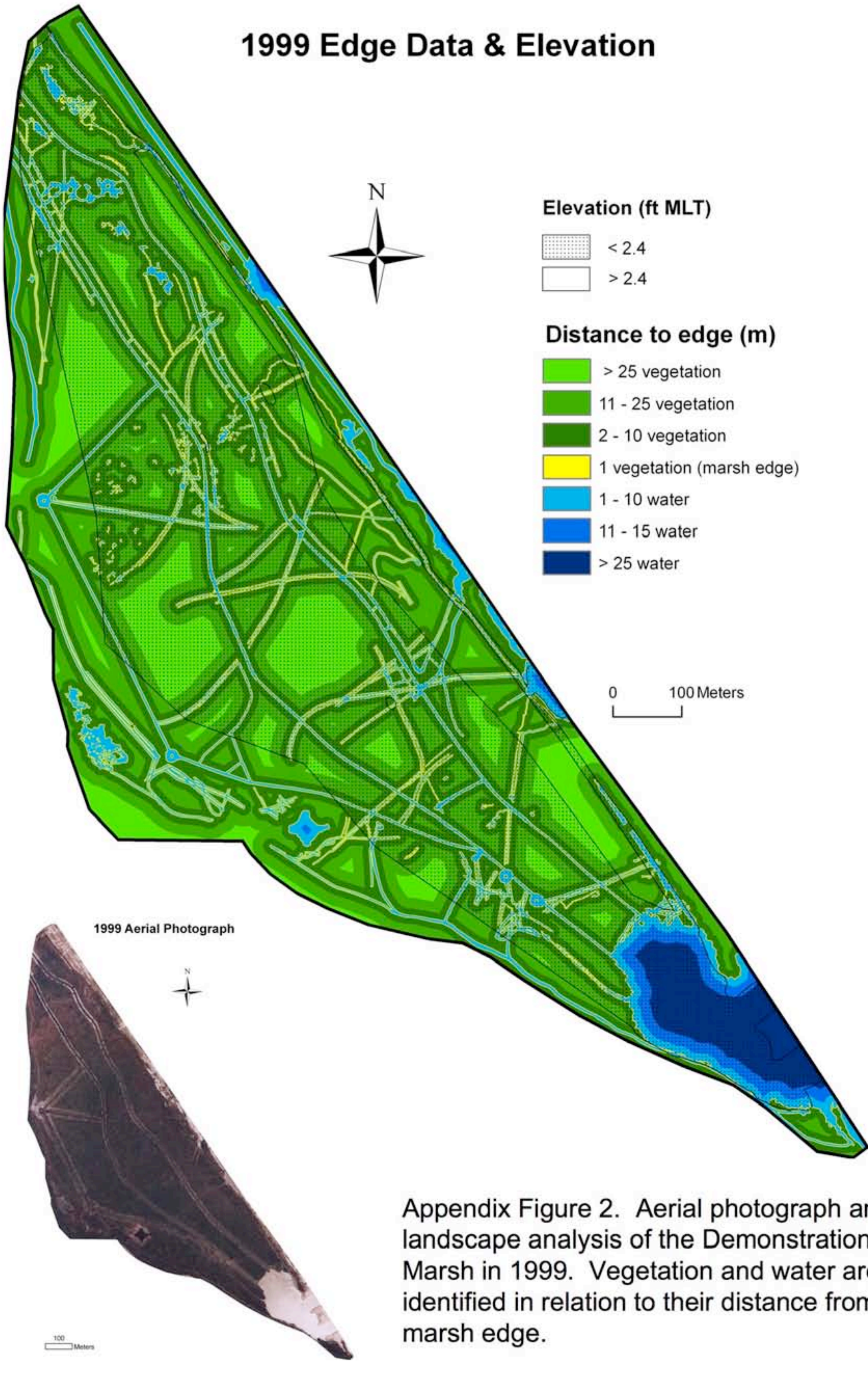
Appendix Figure 5. Landscape analysis of the Hog Island reference marsh based on aerial photography taken in 1995 (background). Vegetation and water are identified in relation to their distance from the marsh edge.

Appendix Figure 6. Landscape analysis of the first Elmgrove Point reference marsh based on aerial photography taken in 1995 (background). Vegetation and water are identified in relation to their distance from the marsh edge.

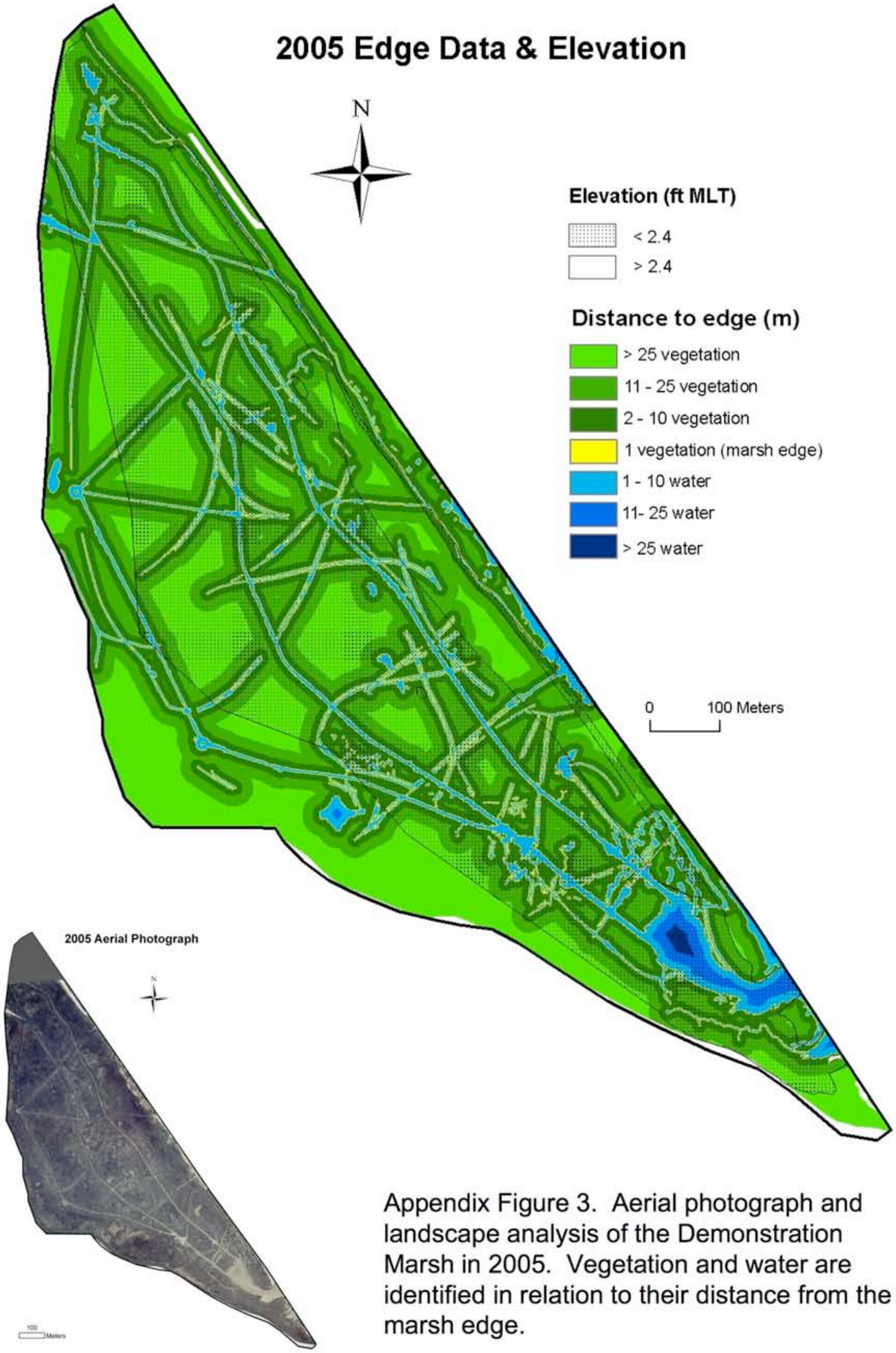
Appendix Figure 7. Landscape analysis of the second Elmgrove Point reference marsh based on aerial photography taken in 1995 (background). Vegetation and water are identified in relation to their distance from the marsh edge.



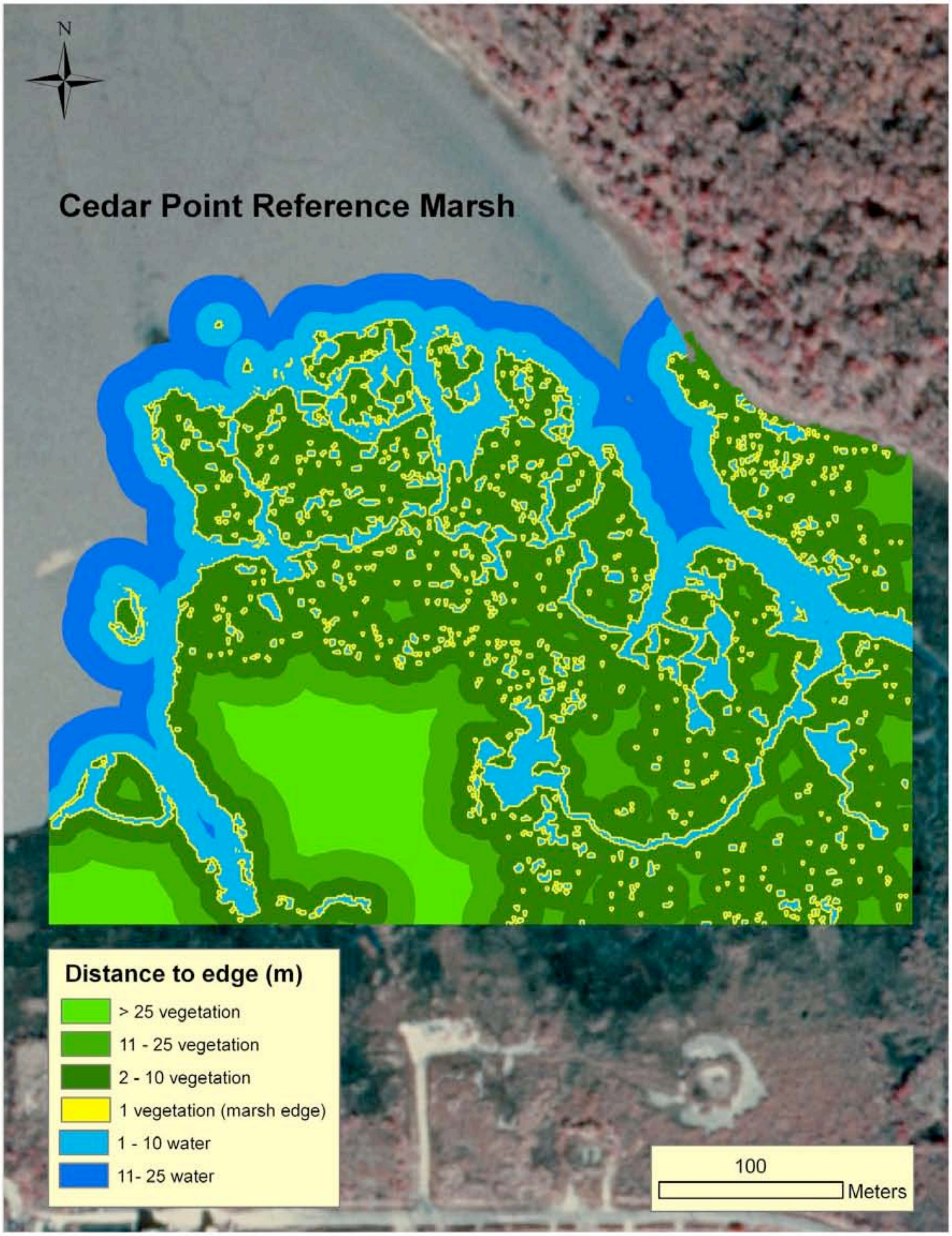
Appendix Figure 1. Aerial photograph and landscape analysis of the Demonstration Marsh in 1997. Vegetation and water are identified in relation to their distance from the marsh edge.



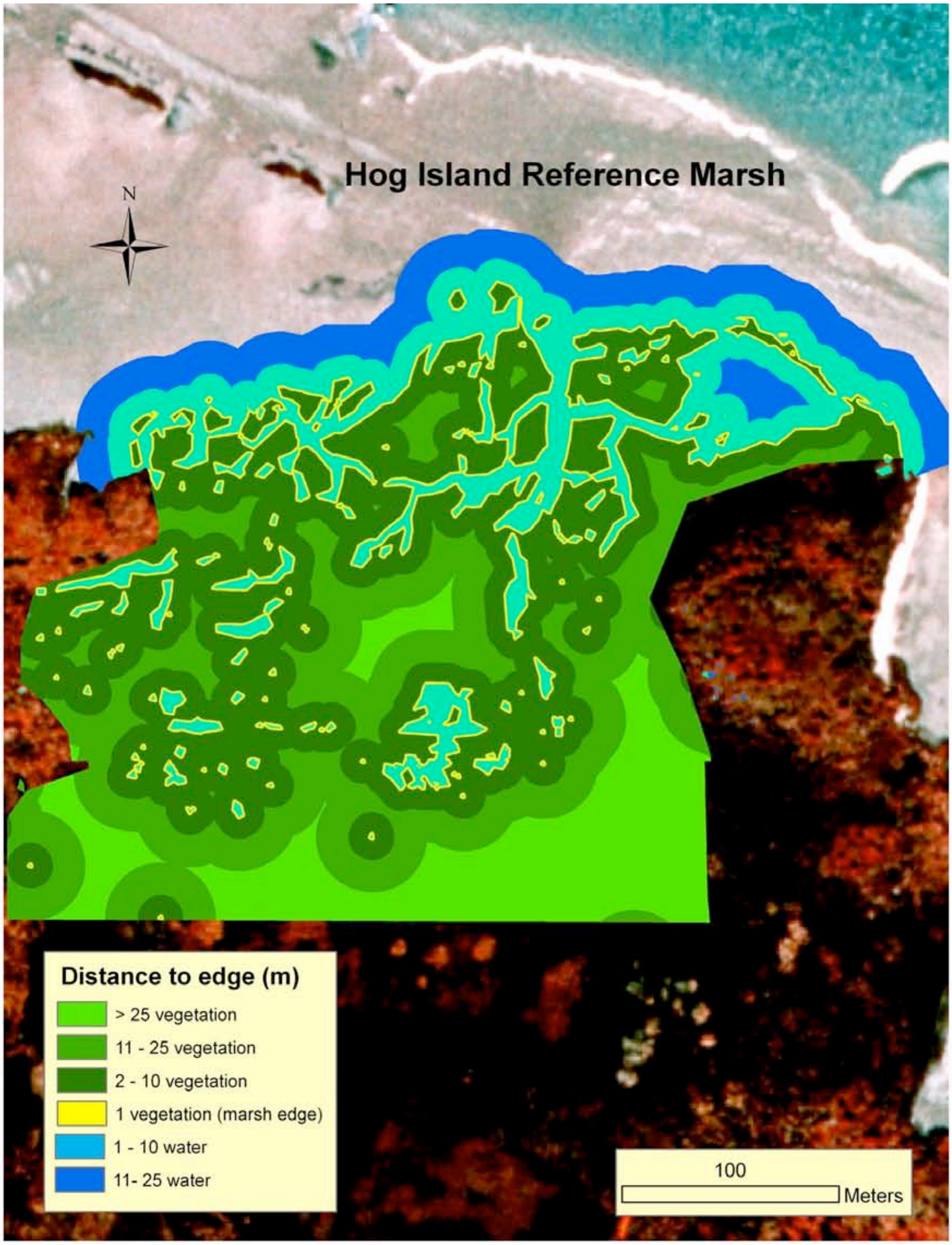
Appendix Figure 2. Aerial photograph and landscape analysis of the Demonstration Marsh in 1999. Vegetation and water are identified in relation to their distance from the marsh edge.



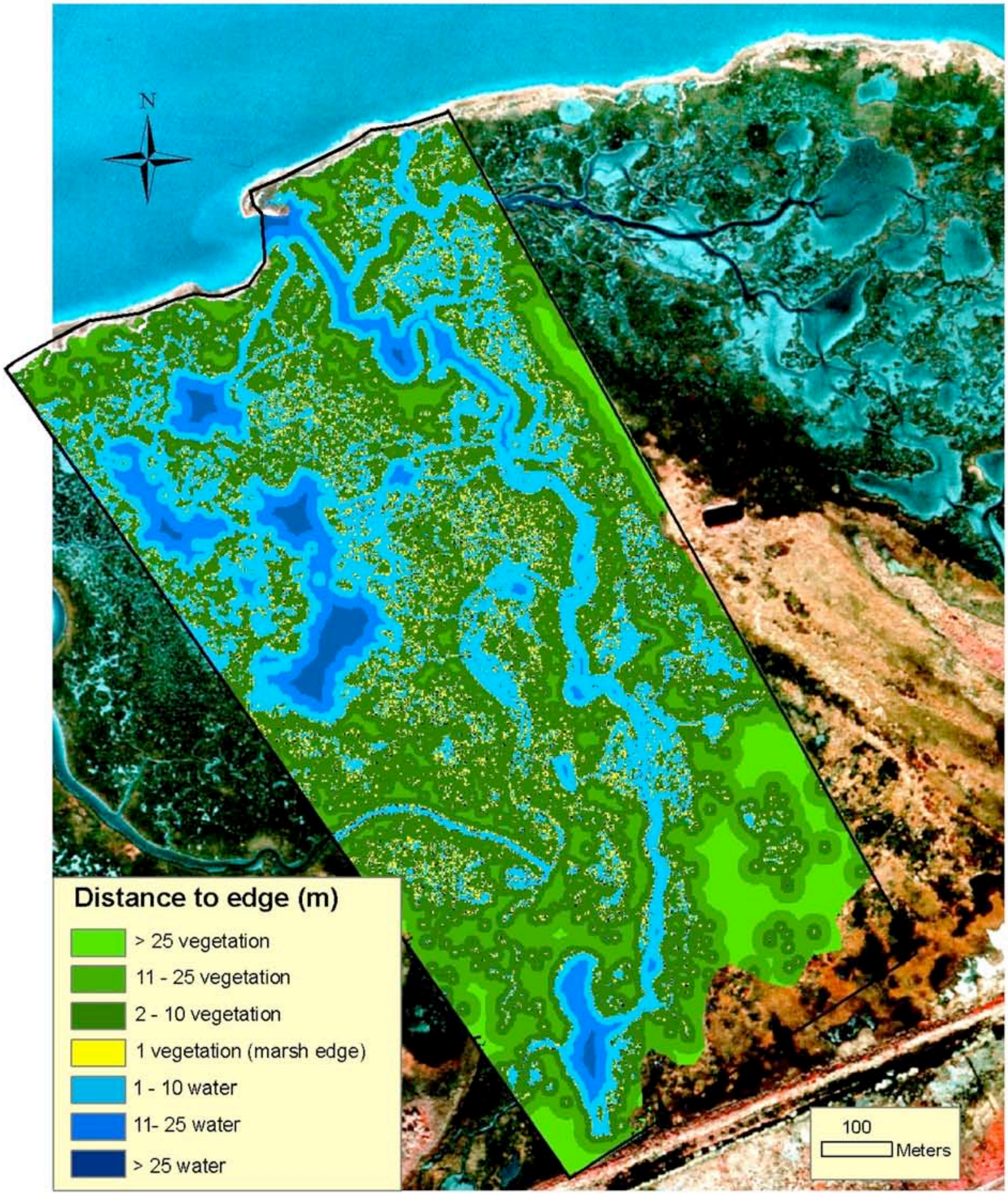
Appendix Figure 3. Aerial photograph and landscape analysis of the Demonstration Marsh in 2005. Vegetation and water are identified in relation to their distance from the marsh edge.



Appendix Figure 4. Landscape analysis of the Cedar Point reference marsh based on aerial photography taken in 1995 (background). Vegetation and water are identified in relation to their distance from the marsh edge.

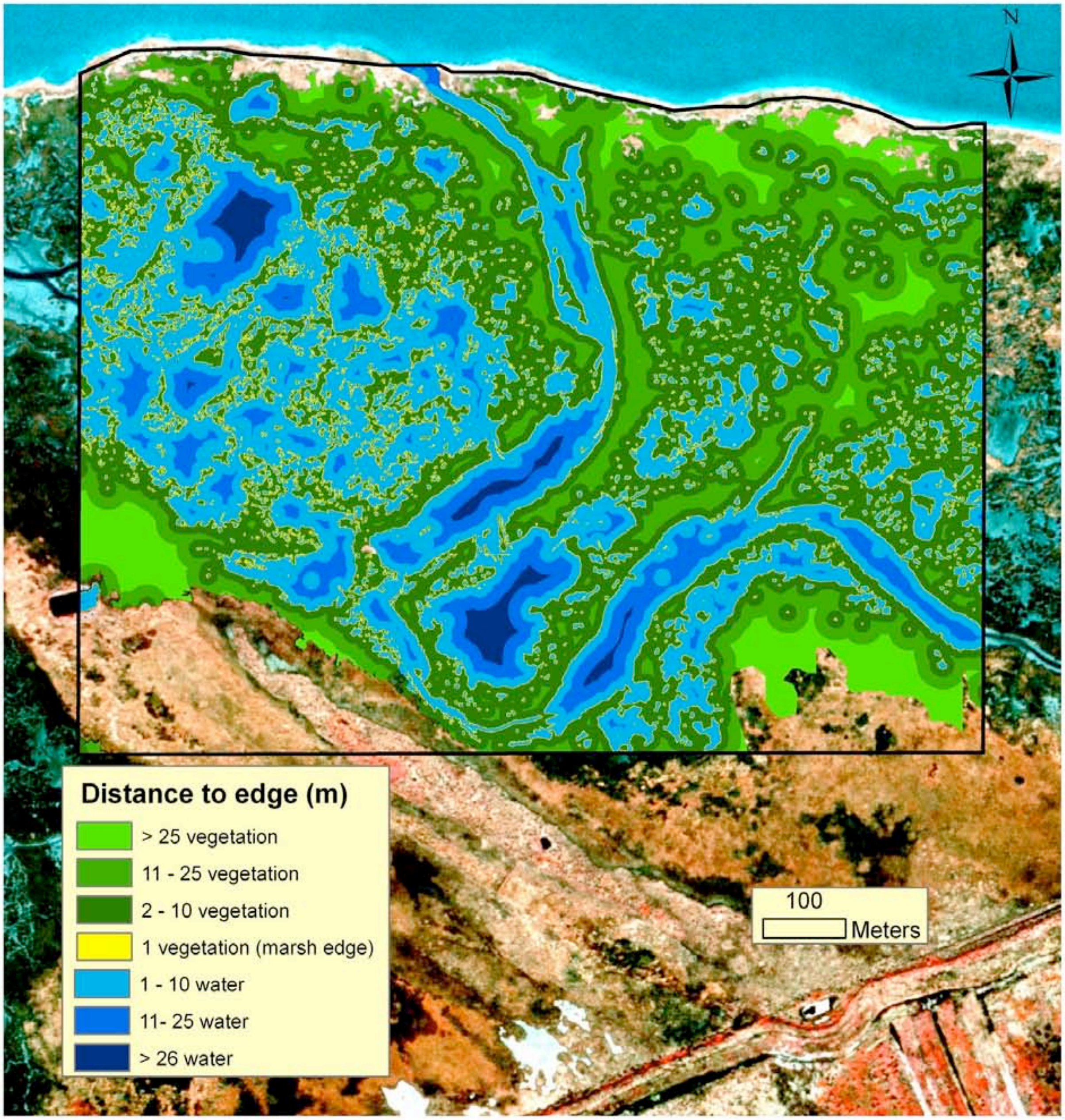


Appendix Figure 5. Landscape analysis of the Hog Island reference marsh based on aerial photography taken in 1995 (background). Vegetation and water are identified in relation to their distance from the marsh edge.



Appendix Figure 6. Landscape analysis of the first Elmgrove Point reference marsh based on aerial photography taken in 1995 (background). Vegetation and water are identified in relation to their distance from the marsh edge.

Elmgrove Point Reference Marsh 2



Appendix Figure 7. Landscape analysis of the second Elmgrove Point reference marsh based on aerial photography taken in 1995 (background). Vegetation and water are identified in relation to their distance from the marsh edge.