The hydric and physical properties of natural and renourished beaches along the Atlantic Coast of Florida

by

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INTRODUCTION

Sea turtles use beaches as incubators for their eggs. The female sea turtles come ashore to lay their eggs in the beach, where they are left to incubate. A female sea turtle may excavate many nest cavities before depositing her eggs in the final nest. In some way the female sea turtle is choosing one location for her nest over all of the others. How a female sea turtle determines the suitability of a nest is unknown. It is certain that if the eggs are to hatch they need to be placed in a region of the beach that will not flood, become too dry, have impeded gas exchange, or have any other event occur that will not allow the eggs to undergo proper development over the next 50 to 60 days.

Sea turtles are not the only beach users. Humans utilize beaches for many activities, most of which are recreational. There is very little impact on sea turtle nests from the people who use the beach for recreational purposes; for even where driving on the beach is allowed, the nests are in the soft sand that is further landward than most cars drive. A problem arises when a developed beach front with a natural nesting beach in front of it erodes to the point where the sea turtles are no longer able to use the beach as an incubator for their eggs.

Beach erosion is part of a natural process (Carter, 1988). In some areas sand is being added to the shore, or accreted, while at the same time sand is eroding from another site. This process has happened for thousands of years, and thus far, sea turtles have survived despite these changing conditions. Humans, on the other hand are concerned about beach erosion because it decreases property value as well as threatening structural damage to the development. Therefore, humans have proposed many solutions to the problem of beach erosion. Many of these solutions attempting to curb or prevent erosion also hamper the ability of turtles to use the beaches that are being protected. One method that has been used more recently, known as beach renourishment, may not affect the ability of a female turtle to use the beach.

The process of beach renourishment is carried out by pumping materials back onto an eroded beach (Carter, 1988). The sand is pumped up in a slurry of salt water from an offshore dredge site or from a sand trap in an inlet. This process in not likely to change erosion patterns, and after renourishment the erosion process may continue, requiring further renourishment. Beach renourishment is a temporary solution to the problem of erosion. However, renourished beaches are not deposited in the same manner as natural beaches. The impacts of beach renourishment on the sea turtle nesting environment have not been fully analyzed.

The purpose of this thesis is to characterize the renourished beach environment both with respect to the physical and the hydric properties and to compare this environment to a control. A logical choice for a control would be a beach that is known to be an effective incubator of sea turtle eggs. Natural beaches are known to be effective incubators of sea turtle eggs, therefore they will serve as the control beaches. However, the environment of the natural beaches has never been completely characterized. Therefore, the natural and renourished beaches should both be assessed at the same time in order to assure a proper comparison.

MATERIALS AND METHODS

Design

Six pairs of beaches were selected for comparison. In order for the experiment to be valid more than one pair was used to assure that one time events occurring on specific beaches would not confuse the results. Therefore, the use of six pairs of beaches provides proper replication of the experiment. Each pair consisted of a natural and a renourished beach. Renourished beaches were located along the Atlantic Coast of Florida and natural beaches were found to be in close proximity to each of the renourished beaches. These two different beach types were compared with respect to hydric and physical properties.

Beach Location

Twelve beaches used by sea turtles for nesting were examined in this study. Six were natural beaches and six were renourished. All of the beaches were located along the Atlantic Coast of Florida from Daytona Beach in the north to Boca Raton in the south. All beaches are listed from north to south in Table 1 and their location is illustrated in Figure 1. The distance between the natural and renourished beaches varied from 500 meters to 2 kilometers.

Each beach site was sampled monthly, from May to August 1990. In order to relocate the same site each month the location of each site was recorded relative to a permanent

Table 1. List of beaches involved in study, showing pair number, beach name, and type of beach

Pair #	Beach	Beach Type
1	Ponce Inlet North	Renourished
1	Ponce Inlet South	Natural
2	Sebastian Inlet North	Natural
2	Sebastian Inlet South	Renourished
3	Fort Pierce Inlet North	Natural
3	Fort Pierce Inlet South	Renourished
4	Hobe Sound National Wildlife Refuge	Natural
4	Jupiter Island Beach	Renourished
5	Delray Beach	Renourished
5	Highland Beach	Natural
6	Spanish River Park	Renourished
6	South Beach Park	Natural

landmark. Ponce Inlet, Sebastian Inlet, and Fort Pierce Inlet were sampled relative to their position on either side of the inlet and relative to a monument placed by the Army Corps of Engineers for the Florida Department of Natural Resources (FDNR). The Jupiter Island Beach and Hobe Sound National Wildlife Refuge (NWR) sampling sites were located by their position relative to the FDNR monuments. The remaining beaches of the study were not as conveniently marked, but

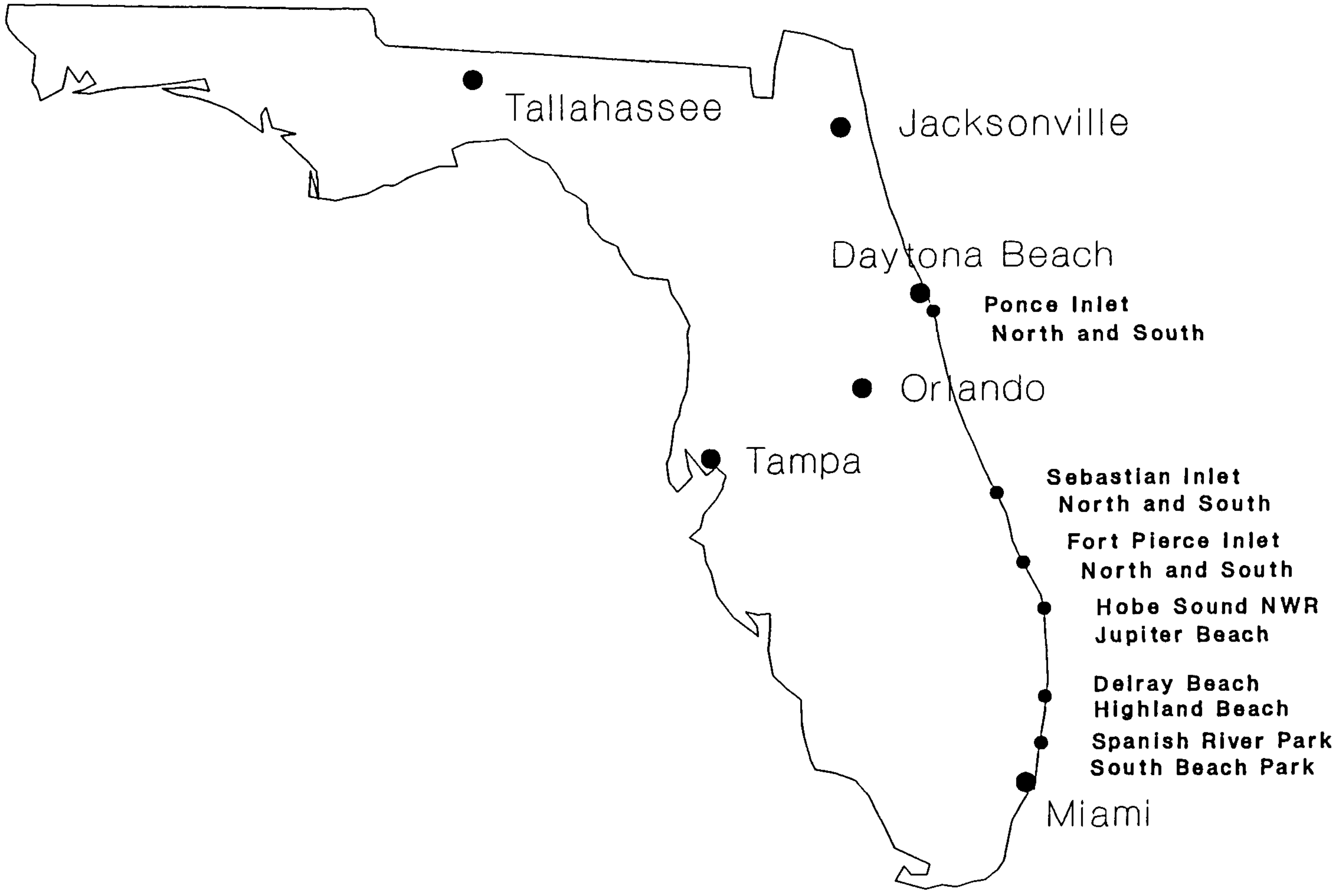

Figure 1. Map of Florida showing the location of the beaches utilized in this study

landmarks such as parking lots and building corners were recorded and located each month.

Sampling Scheme

Once the beach was located, a sampling grid was laid out in four transects. The first transect, numbered 1-3, was ten meters from the dune area. The second transect, numbered 4-8, was laid through the middle of the beach, and the third transect, numbered 9-11, was laid ten meters from the water (or very near the high tide marks). The fourth transect, consisting of only site 12, was about 1-3 meters from the water (Figure 2). Each of the sites was spaced at least ten and usually twenty meters from any other site. This distance between sites was necessary to insure that measurements at each individual site were independent of the other sites. The range of influence for soil water content measurements in sand has been established as being less than 16 meters (Warrick, Myers, and Nielsen, 1986).

Samples from the surface down to 40 cm were taken in a cross through the middle of the beach centered around site 6. The outlying sites in the sample grid were only sampled at two depths, 20 and 30 centimeters. Therefore, every site was sampled at 20 and 30 centimeters so that when averages were taken across transects there would be at least three numbers making up this average. In the comparison of natural and renourished beaches the depths of 20 and 30 centimeters were

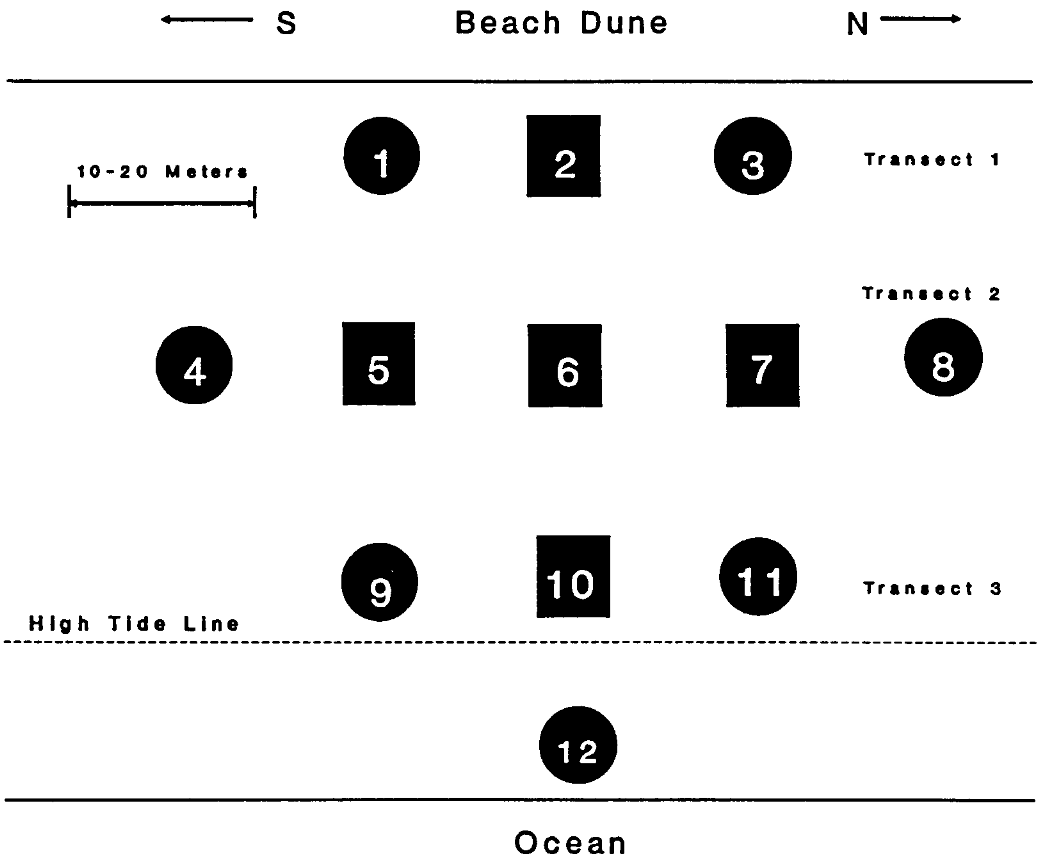

Figure 2. The layout of the sampling scheme with site locations indicated. Sites marked with a circle had samples taken at 20 and 30 centimeters. Sites marked with a square had samples taken at the surface down to 40 centimeters. Site 6 had samples taken at the surface down to 40 centimeters in May, June, and July, while in August an attempt was made to reach the water table, so samples were taken down to 120 centimeters. Additionally, at site 6 a liter of loose sand and an undisturbed core were taken

used because these two depths were expected to be near the top of the sea turtle nests. Individual sand samples of approximately 10-15 grams were taken at the surface, 5, 10, 15, 20, 30, and 40 cm from sites 2, 5, 6, 7, and 10. Sand samples were also taken at 20 cm and 30 cm from sites 1, 3, 4, 9, 11, and 12. Additionally, at site six an undisturbed core sample and one liter of sand were collected. An undisturbed core is a sand sample that is presumed to be representative of the sand in its natural state. The undisturbed core was taken by digging down 20 cm then pushing a metal cylinder into the sand. This core was then excavated out and plastic caps were secured on both ends. All of these samples were taken in May, June, July, and August.

The samples from the surface down to 20 cm were collected by digging through a tube down to the appropriate depth where approximately 15 grams of sand was taken. The tube was a plastic PVC pipe that was approximately 10 cm in diameter. Dry sand has very little structure, so it was necessary to keep the sand from different depths from contaminating the other depths. Therefore the tube was pushed into the sand and the dry sand excavated out of the tube down to the appropriate depth. The sand sample could then be collected without the possibility of contamination of the sand from outside the tube. Below a depth of 20 cm approximately 10 grams of sand was taken with a corer. The corer was hammered into the sand to retrieve samples down to the desired depth. The corer was then withdrawn from the sand with the sample retained in the corer. These samples were removed from the corer and placed in Kapac plastic bags. The sand samples were then marked with the appropriate beach identification, location, and depth. As a check on water loss from the bags, during the first trip in May, the samples were weighed immediately after sampling and then again following the return to the laboratory. The weight of the samples did not change. The Kapac plastic bags were found to be absolutely water tight in the laboratory for a period of at least two months. Samples were stored for no longer than two weeks.

In August an attempt to reach the water table on each beach was made. The samples down to 50 cm were taken as described above. Sand samples deeper than 50 cm were taken by using a post hole digger to dig to the depth of the sample, where a sample of sand of approximately 15-20 grams could be taken from the freshly withdrawn sand. The deepest the post hole digger could reach was about 1.2 meters so samples below that depth were not accessible.

Analysis of Samples

I assessed the hydric and physical properties of natural and renourished beaches by running a series of tests on the sand samples. To define the hydric properties of a beach, the variables that I needed to determine were: gravimetric water content, volumetric water content, depth to the water table, water potential, osmotic potential, and hydraulic conductivity. The variables chosen to describe the physical properties of these beaches were: particle size distribution, mean particle size, bulk density, and color.

Gravimetric water content

Gravimetric water content was determined on the 10-15 gram sand samples. The samples were weighed wet, then oven dried at 100 C until mass was constant (Gardner, 1986). Subsequently, the gravimetric water content was calculated as the mass of the liquid divided by the mass of the solid or in other words, wet weight minus dry weight divided by dry weight.

Volumetric water content

Volumetric water content is an alternate way to express water content. Volumetric water content is the measurement of water content on a per volume basis instead of a per weight basis. Volumetric water content is the volume of water divided by the volume of the solid (Gardner, 1986). Gravimetric water content can be converted to volumetric water content by multiplying gravimetric water content by the bulk density. The bulk density is defined as the ratio of the mass of the dry soil to its total volume (Blake and Hartge, 1986).

Depth to the water table

Depth to the water table was obtained by digging down into the beach until water ponded at the bottom of the hole. The equipment used to obtain samples down to the water table could only reach 1.2 meters. The sand was sampled at site six every 10 centimeters from the surface down to the water table or 1.2 meters. Water tables below 1.2 meters were not accessible.

Water potentials

The water potential for the undisturbed cores was determined by using desorption of the samples on a hanging water table (Klute, 1986). Desorption uses a saturated sample that is dried during the experiment or using the drying curve. The hanging water table is a table with a hole in the center that has a hose connected to a hollow glass rod. The table holds a layer of tiny uniform glass beads. Initially the glass beads are saturated with de-aerated water. By raising or lowering the glass rod, different pressures can be applied to the glass beads. A sample in contact with the glass beads would therefore also be under that amount of pressure. The length in centimeters of water of the water column relative to the height of the glass bead layer is the amount of pressure that is being applied to the sample and this is converted to standard pressure units (kPa). The samples placed on the glass beads were brought to saturation by wetting from the bottom up. The weight at saturation was taken and the sample was then placed on the hanging water table. Pressures of -1, -2.5, -5.0, -7.5, and -9.0 kPa were placed on the samples and at each step the weight of the samples was measured. This led to one volumetric water content value and one pressure potential at each of the different pressures.

Water potentials from -5.0 to -40.0 kPa were determined again by desorption, using the pressure plate-funnel technique (Klute, 1986). Using this technique the samples are saturated from the bottom up then placed on a porous plate in a funnel. The funnel is then sealed and pressure is applied to the sample. The pressure is also applied to a column of water or mercury so it is known exactly how much pressure is being applied to the sample. Pressures of -5.0, -10.0, -20.0, and -40.0 kPa were placed successively on each sample. The pressure forces out water which is collected in a graduated cylinder and weighed. This water is assumed to be equal to the water lost by the sample. This again led to one volumetric water content value and one pressure potential value at each pressure.

Water potentials in the -50 to -1000 kPa range were determined on a limited number of samples by using a pressure bomb with a porous plate inside, similar to the funnels but with a much finer pore size. The sand was saturated from the bottom up and then placed on the porous plate. Pressure would then be applied and after the system came to equilibrium, the sample was taken out, weighed, dried, and weighed again to determine volumetric water content under that amount of pressure. The pressures used here were -80 and -500 kPa.

Osmotic potential

Osmotic potential was determined by month and by depth, using the following procedure: First, the gravimetric water content of the sample was determined. Then the sample was oven dried, and wetted with a known volume of water. The water and sample were stirred and set aside. After 24 hours, the solution was extracted from the sand using a filter and suction. The solution was then read on an electrical conductivity meter. The electrical conductivity of the solution read from the meter could be converted the osmotic potential of the original sample (Eq. 1) (Klute, 1986; Rawlins and Campbell, 1986).

$$\Psi_o = -36\ EC \qquad (1)$$

Where Ψ_o is the osmotic potential in J/kg and EC is the electrical conductivity in dS/m. The osmotic potential was then converted to standard pressure units (kPa).

The osmotic potential was determined on several samples from the liter of sand that was taken each month. Osmotic potential was also determined as a function of depth at all site 6's from the August sampling.

Saturated hydraulic conductivity

Saturated hydraulic conductivity was determined by the constant head method (Klute and Dirksen, 1986). In this method, a sample is saturated from the bottom up, and then a pond of water is maintained on the surface of the sample. The flux of water through the sample is monitored by sampling the water coming out from the bottom. When this volume per time becomes constant, the change in storage of water will be zero. The rate of flow and the dimensions of the sample can then be used to calculate the saturated hydraulic conductivity using Darcy's Equation (Eq. 2) (Klute and Dirksen, 1986).

$$q = K\ (H_i - H_o)/L. \tag{2}$$

Where q is the volume of water flowing through a unit cross-sectional area per unit time or the flux density in cm/s. K is the hydraulic conductivity in cm/s. $(H_i - H_o)$ is the head drop across the system in cm. Where H_i is the head at the inflow boundary and H_o is the head at the outflow boundary. L is the length of the soil column in cm.

Particle size distribution

Particle size distribution was determined for undisturbed cores as well as for loose sand from the liter of sand that was taken. The sand was first oven dried, then passed through a series of standard sized sieves. The sizes used for sand fractions are 2, 1, 0.5, 0.25, 0.126, and 0.056 mm. The sieves were stacked from largest to smallest and were shaken for three minutes. The amount caught in each sieve would then be weighed. Thus by weighing the amount that would not pass through each successive sieve size, the fractional weight greater than any one sieve size could be determined (Gee and Bauder, 1986). The fractional distribution was expressed as a percent of the total sample.

Mean particle size

Mean particle size was determined using the mean weight diameter method (Van Bavel, 1949; Youker and McGuinness, 1956). This method is based on weighting the masses of different size classes. The particles are first separated by sieving, then they are weighed and the fraction in each diameter range is recorded. The mean weight diameter is then determined by adding the fractional weights of each mean size class. The mean weight diameter is calculated using the following equation (Equation 3).

$$X = \sum_{n=1}^{i} x_i w_i \tag{3}$$

Where x_i is the mean diameter of any size range separated by sieving, and w_i is the weight of the sand in that size range as a fraction of the total dry weight of the sample.

Bulk density

Bulk density is the ratio of the mass of dry soil to its total volume (Blake and Hartge, 1986). The bulk density was determined on the undisturbed core sand samples by drying and weighing the sand, then dividing by the volume of the cylindrical core. The bulk density is necessary to determine the volumetric water content that is used to calculate the characteristic curves.

Color

Munsell soil color charts were used to determine the color of the beaches under dry and wet conditions. The charts are used on dry and wet sand by matching the color on the chart to the sample. The color under each of these conditions was recorded in standard Munsell notation. The charts were used on samples from June for all beaches.

Data Analysis

The data analysis was done using the SAS statistical package available at Iowa State University (SAS/STAT User's Guide, 1990). A mean gravimetric and volumetric water content were determined for each beach using sites 1-11 at depths 20 and 30 cm. Particle size distribution, characteristic curves, mean particle size, osmotic potential by depth and by month, bulk density, and saturated hydraulic conductivity were also compared between beach types. An analysis of variance was used comparing natural to renourished beaches. Each of the variables listed above were considered the dependent variables with their appropriate independent variable assigned accordingly.

RESULTS

Natural Beaches Versus Renourished Beaches

In order to compare natural and renourished beaches the gravimetric water content was averaged at the depths of 20 and 30 centimeters. The gravimetric water content values were also averaged across months. The averages are presented in Table 2. At the bottom of Table 2, the overall averages of gravimetric water content at 20 and 30 centimeters are presented for both natural and renourished beaches. The renourished beaches appear to contain more water than the natural beaches. Gravimetric water content for the middle transect of each beach was plotted versus depth for each month (Figures 3-26). On Hobe Sound NWR and Jupiter Beach, the gravimetric water content in June, July, and August of Jupiter Beach is clearly higher than that of Hobe Sound NWR (Figures 3-6). At Sebastian Inlet the difference between natural and renourished beaches is over five percent in some sites with the renourished beach being the wetter beach (Figures 7-10). At Fort Pierce Inlet, the only time the renourished beach is wetter is in May (Figures 11-14). A comparison of Highland Beach and Delray Beach shows that in May and July, Delray is wetter by two percent below the depth of 30 centimeters, whereas in August, Delray is only wetter by 0.25% (Figures 15-18). In May, June, and August, Spanish River Park is wetter than South Beach Park, while in July, this trend is reversed

Table 2. Gravimetric water content averages and standard deviations for each beach at 20 and 30 centimeters in each of the three transects (The natural beach is listed first). The overall average for natural and renourished beach types is given at the bottom for each transect

Beach	20 cm Avg (g/g)	 Std	30 cm Avg (g/g)	 Std	Transect
Ponce Inlet South	4.64	3.82	4.80	4.45	1
	4.90	2.81	6.52	4.20	2
	3.86	2.13	4.78	3.22	3
Ponce Inlet North	6.03	7.46	7.32	8.98	1
	7.13	6.94	9.55	7.92	2
	4.89	4.89	6.92	5.64	3
Sebastian Inlet North	2.75	0.83	2.99	0.69	1
	2.90	0.56	3.02	0.44	2
	3.67	1.47	3.65	0.76	3
Sebastian Inlet South	3.59	0.79	3.77	1.02	1
	4.83	2.03	4.85	2.43	2
	5.45	2.66	6.60	3.40	3
Fort Pierce Inlet North	4.09	1.31	4.20	0.97	1
	4.58	1.41	4.74	1.40	2
	6.49	4.04	7.14	3.53	3
Fort Pierce Inlet South	5.10	2.39	5.78	2.93	1
	5.08	1.51	5.24	1.35	2
	6.05	2.85	6.41	2.47	3
Hobe Sound NWR	3.55	0.85	3.60	0.63	1
	4.23	0.87	4.52	0.83	2
	6.10	2.38	5.96	2.12	3
Jupiter Beach	5.37	0.64	5.70	0.56	1
	5.50	0.74	5.59	0.59	2
	5.74	1.28	5.61	0.88	3
Highland Beach	3.76	1.01	3.87	0.45	1
	4.26	1.07	3.98	0.75	2
	5.24	1.51	5.34	1.72	3
Delray Beach	6.07	2.69	5.81	1.93	1
	6.36	5.18	6.02	2.66	2
	3.33	1.00	3.59	0.77	3

Table 2. (continued)

South Beach Park	3.76	1.04	3.57	0.68	1
	4.23	0.90	4.01	0.86	2
	4.15	0.88	4.54	0.87	3
Spanish River Park	5.08	0.90	5.22	0.65	1
	5.15	0.75	5.04	0.56	2
	5.13	0.88	5.12	0.65	3
Natural	3.74	1.80	3.83	1.91	1
	4.17	1.55	4.41	2.06	2
	4.97	2.50	5.26	2.48	3
Renourished	5.26	3.54	5.66	4.13	1
	5.68	3.75	6.05	3.91	2
	5.09	2.74	5.71	3.06	3

(Figures 19-22). For Ponce Inlet the renourished beach is wetter in July and down to 40 centimeters in August (Figures 23-26). In August sand samples were taken down to 1.2 meters and these values are included in the previous graphs. A sharp increase in gravimetric water content is observed in the case where the water table was reached (Figures 10, 14, 22, 26). The averages for all natural beaches and for all renourished beaches are presented in figures 27-29. The renourished beach is at least 0.5% wetter than the natural beach across transects 1 and 2. In transect 3, the renourished beach is drier than the natural beach but they are within 0.25% except at the surface.

The matric water potential was plotted versus volumetric water content for each beach and the resulting characteristic curves are presented in figures 30 and 31. The natural and renourished characteristic curves have the same shape but the

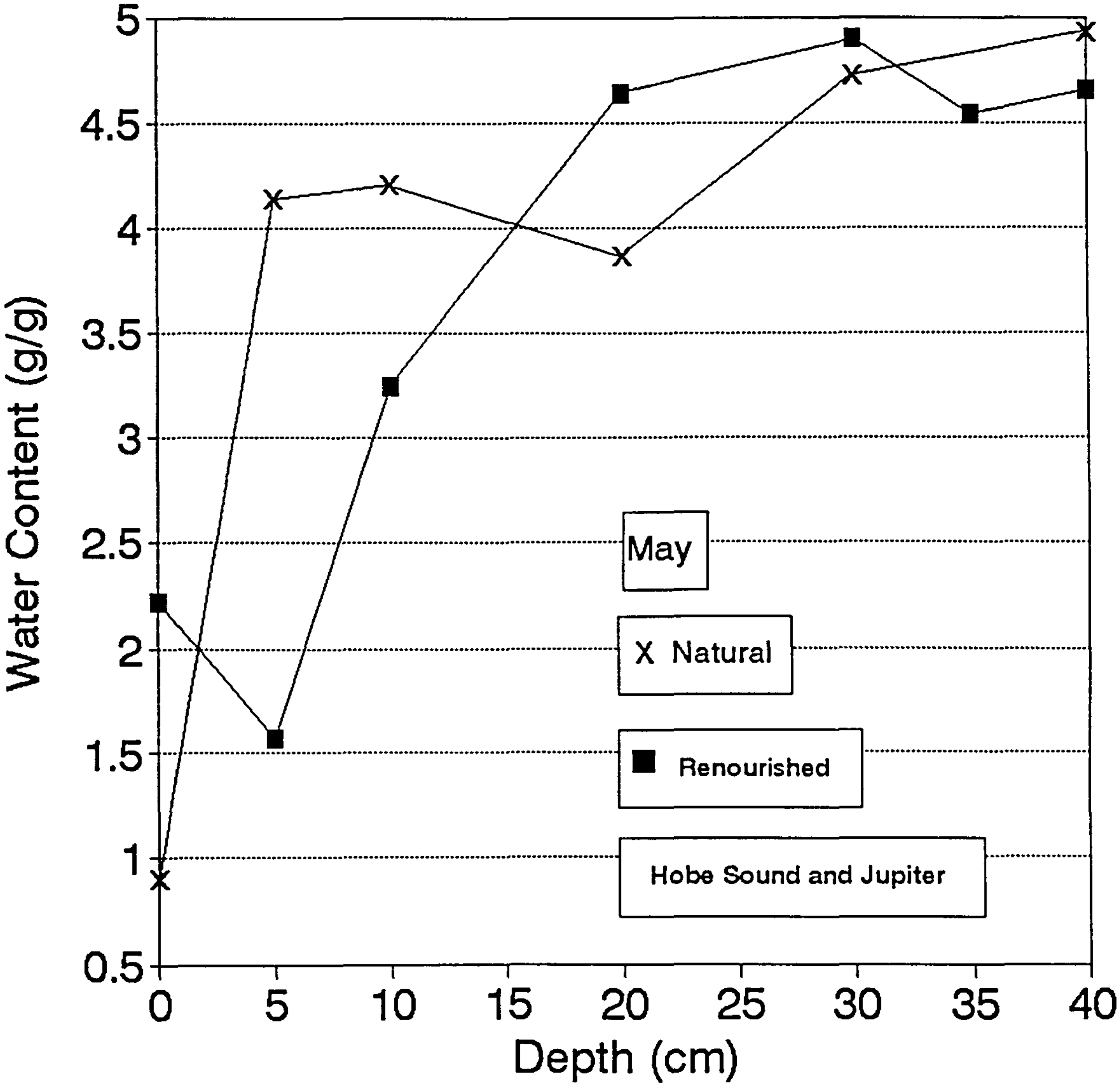

Figure 3. Water content as a function of depth for the middle transect of Hobe Sound and Jupiter beaches from May (X - natural and filled square - renourished)

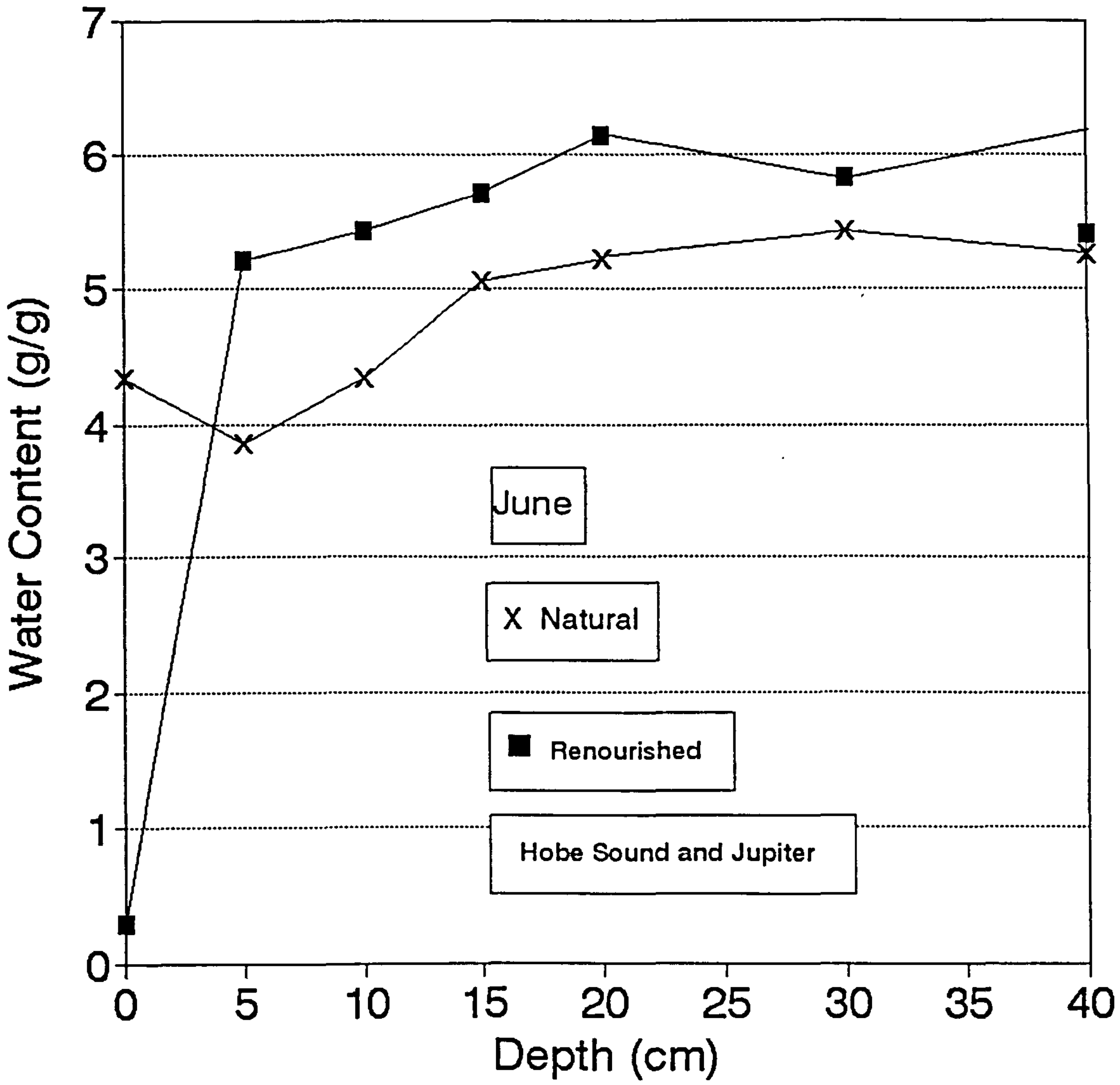

Figure 4. Water content as a function of depth for the middle transect of Hobe Sound and Jupiter beaches from June (X - natural and filled square - renourished)

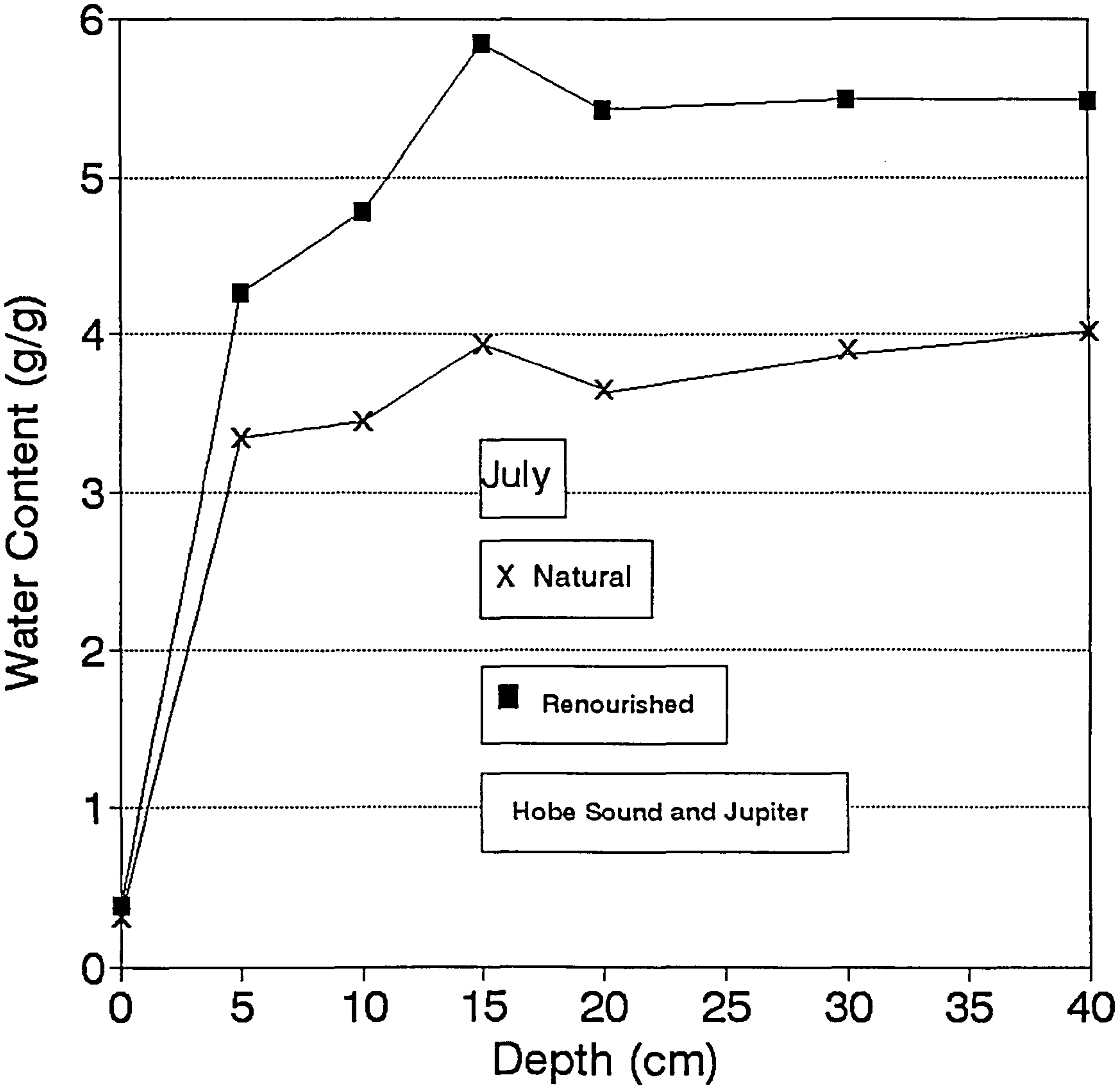

Figure 5. Water content as a function of depth for the middle transect of Hobe Sound and Jupiter beaches from July (X - natural and filled square - renourished)

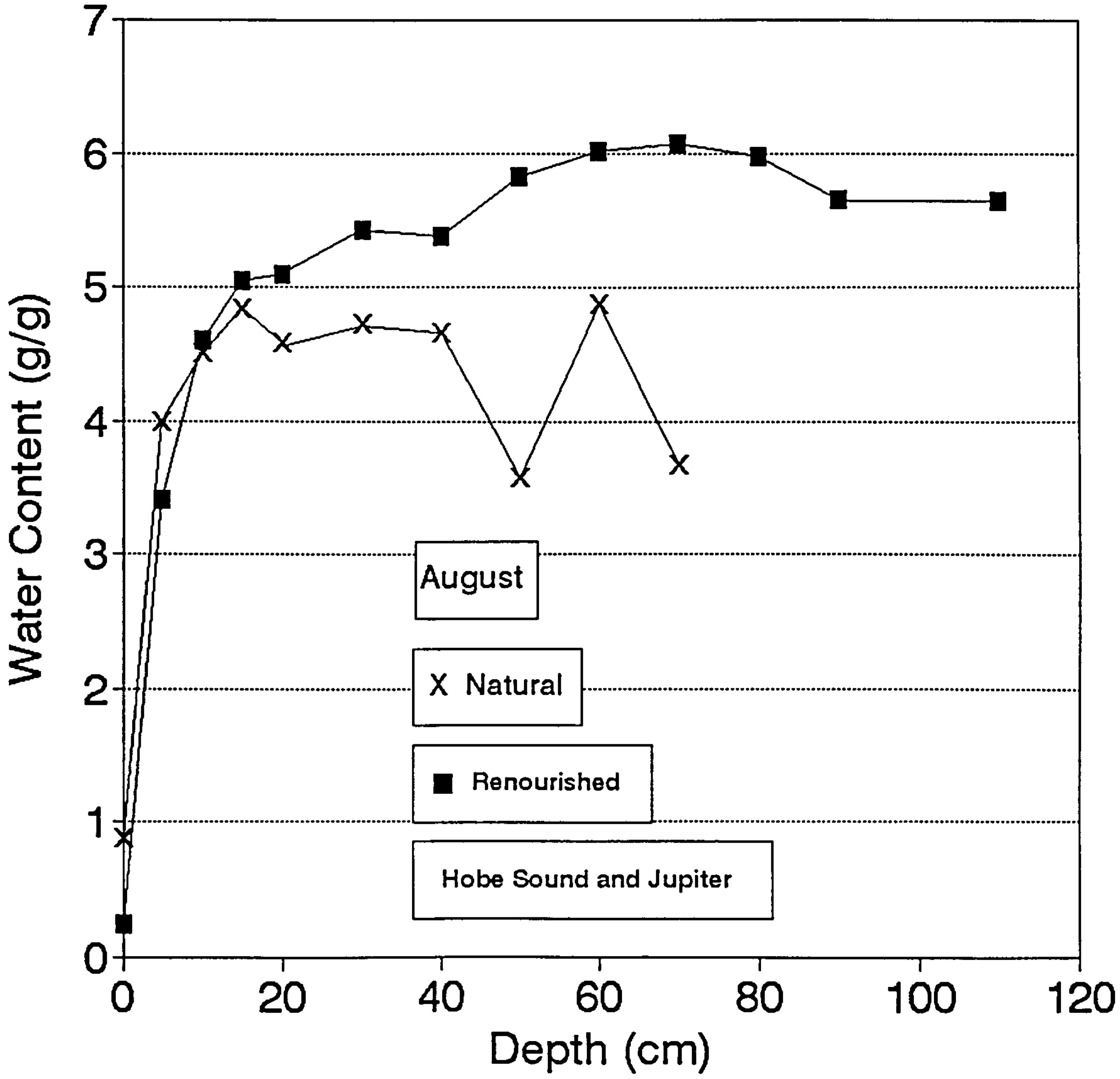

Figure 6. Water content as a function of depth for the middle transect of Hobe Sound and Jupiter beaches from August (X - natural and filled square - renourished)

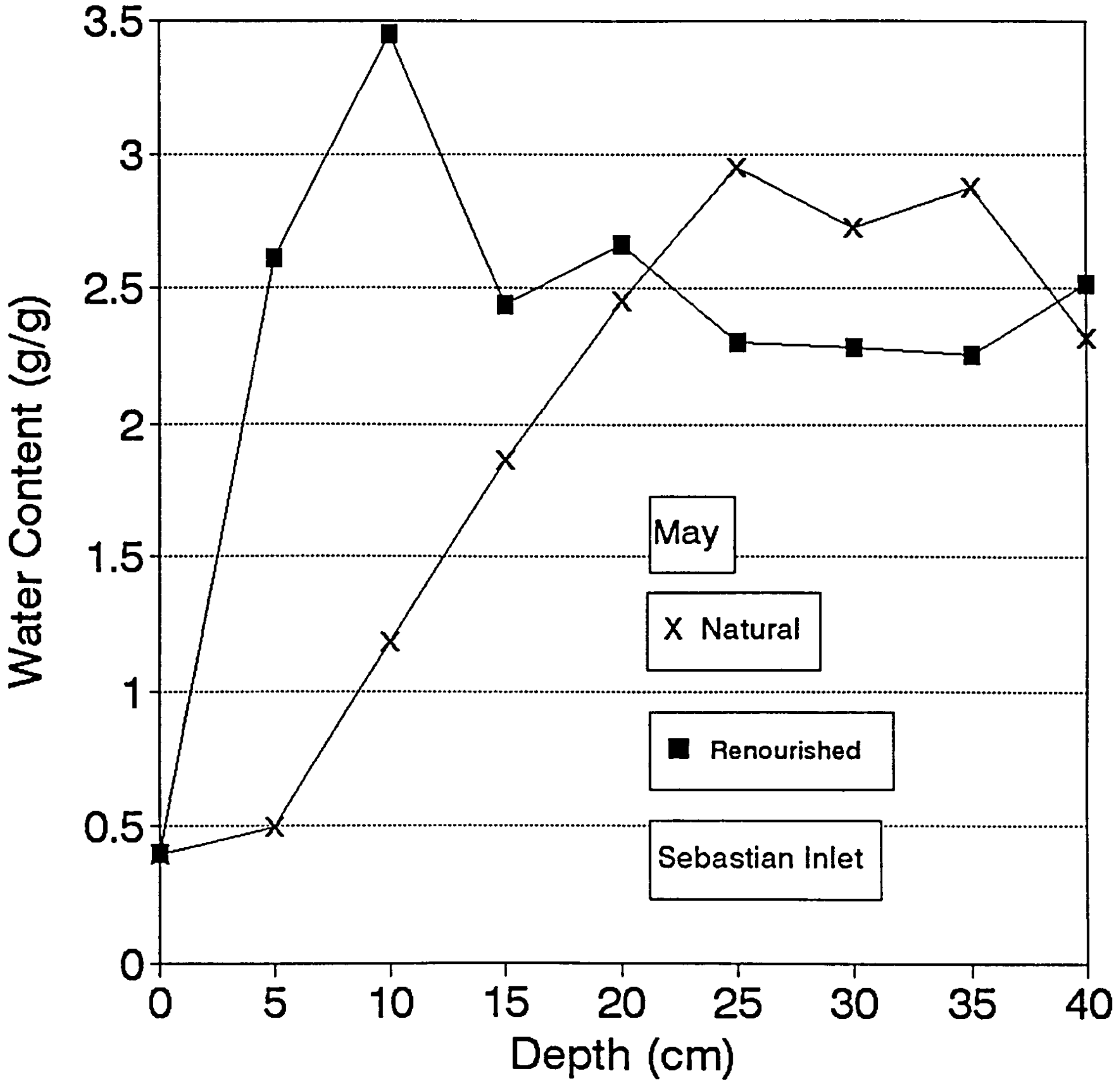

Figure 7. Water content as a function of depth for the middle transect of Sebastian Inlet beaches from May (X - natural and filled square - renourished)

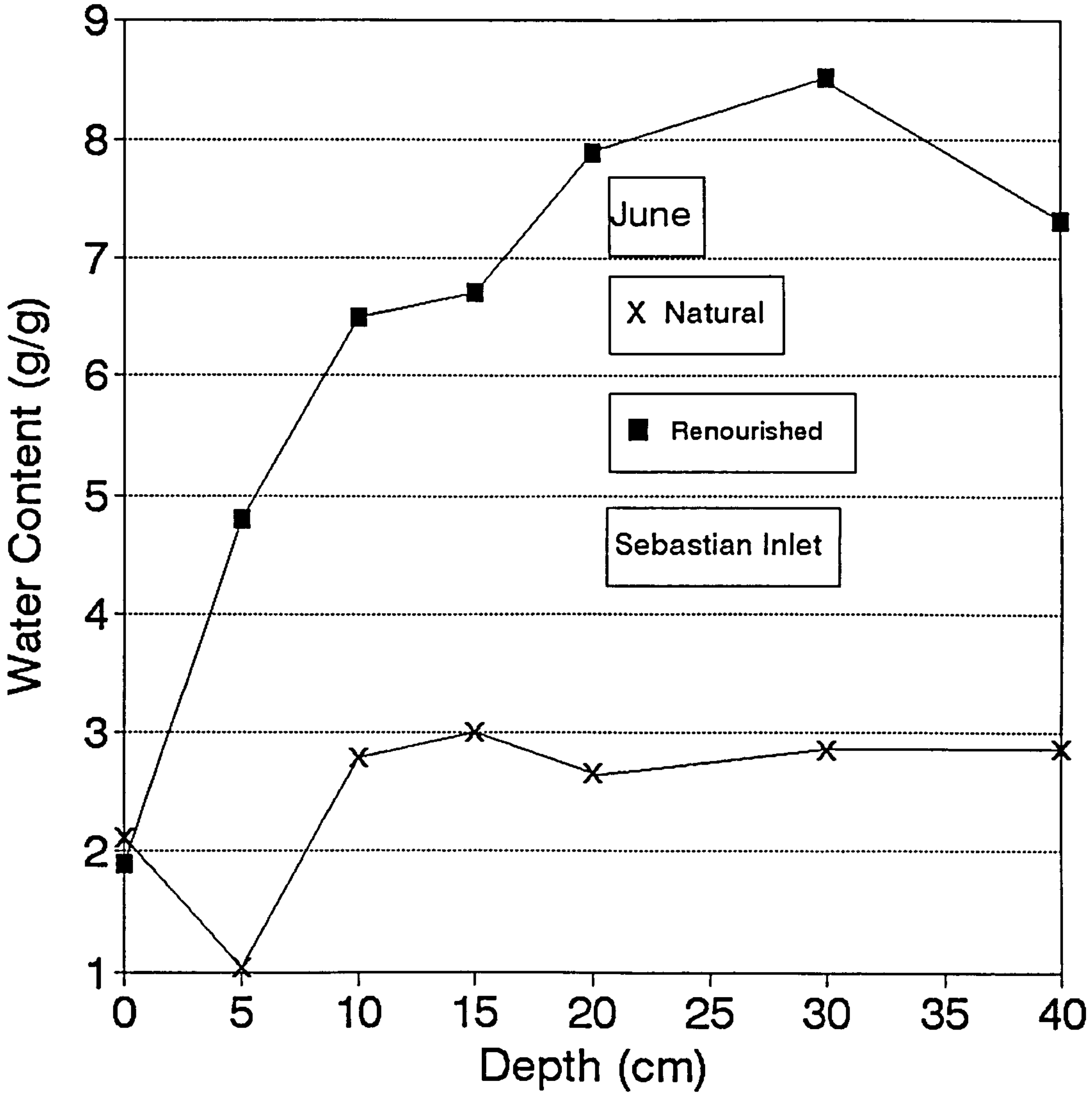

Figure 8. Water content as a function of depth for the middle transect of Sebastian Inlet beaches from June (X - natural and filled square - renourished)

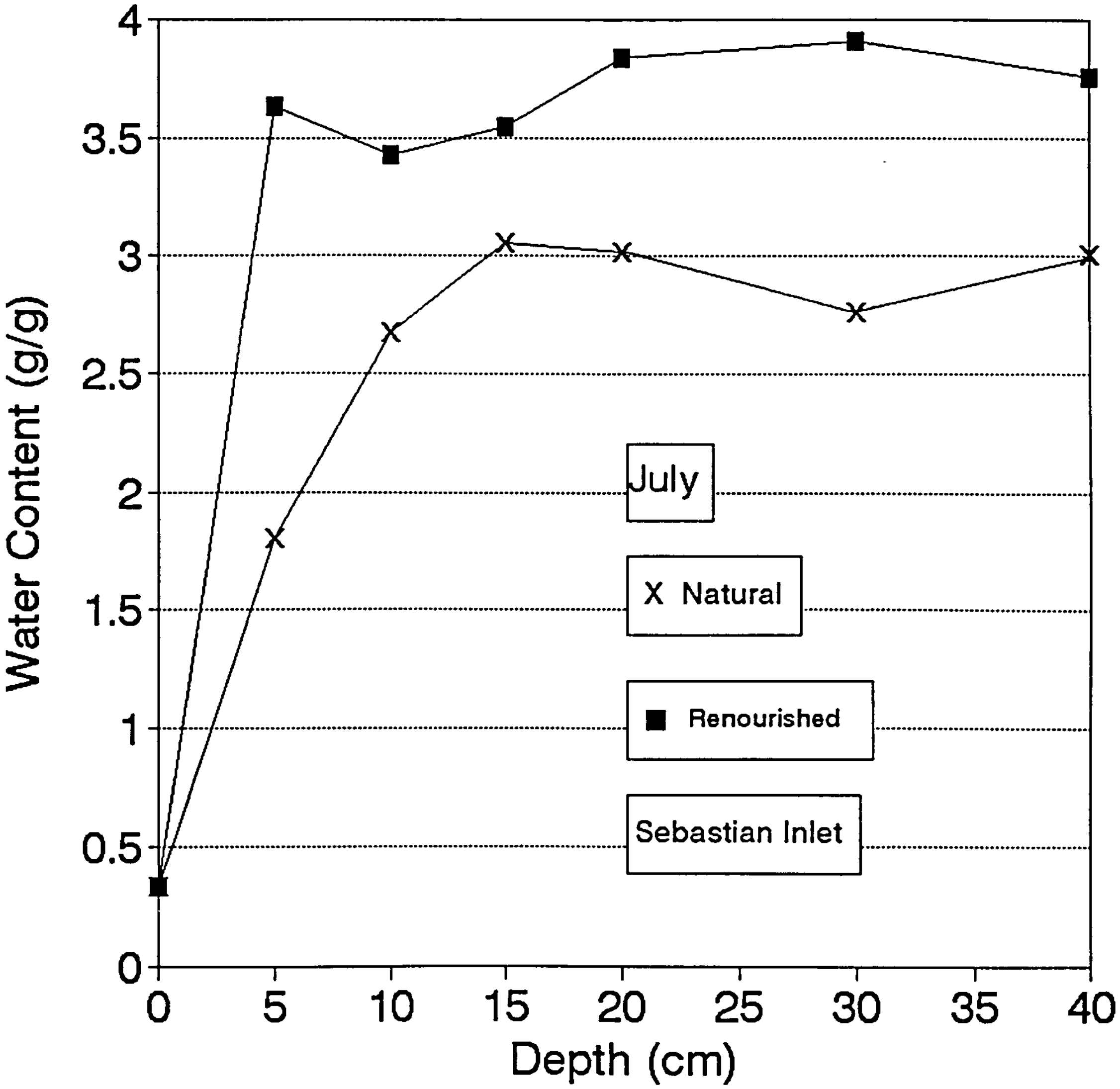

Figure 9. Water content as a function of depth for the middle transect of Sebastian Inlet beaches from July (X - natural and filled square - renourished)

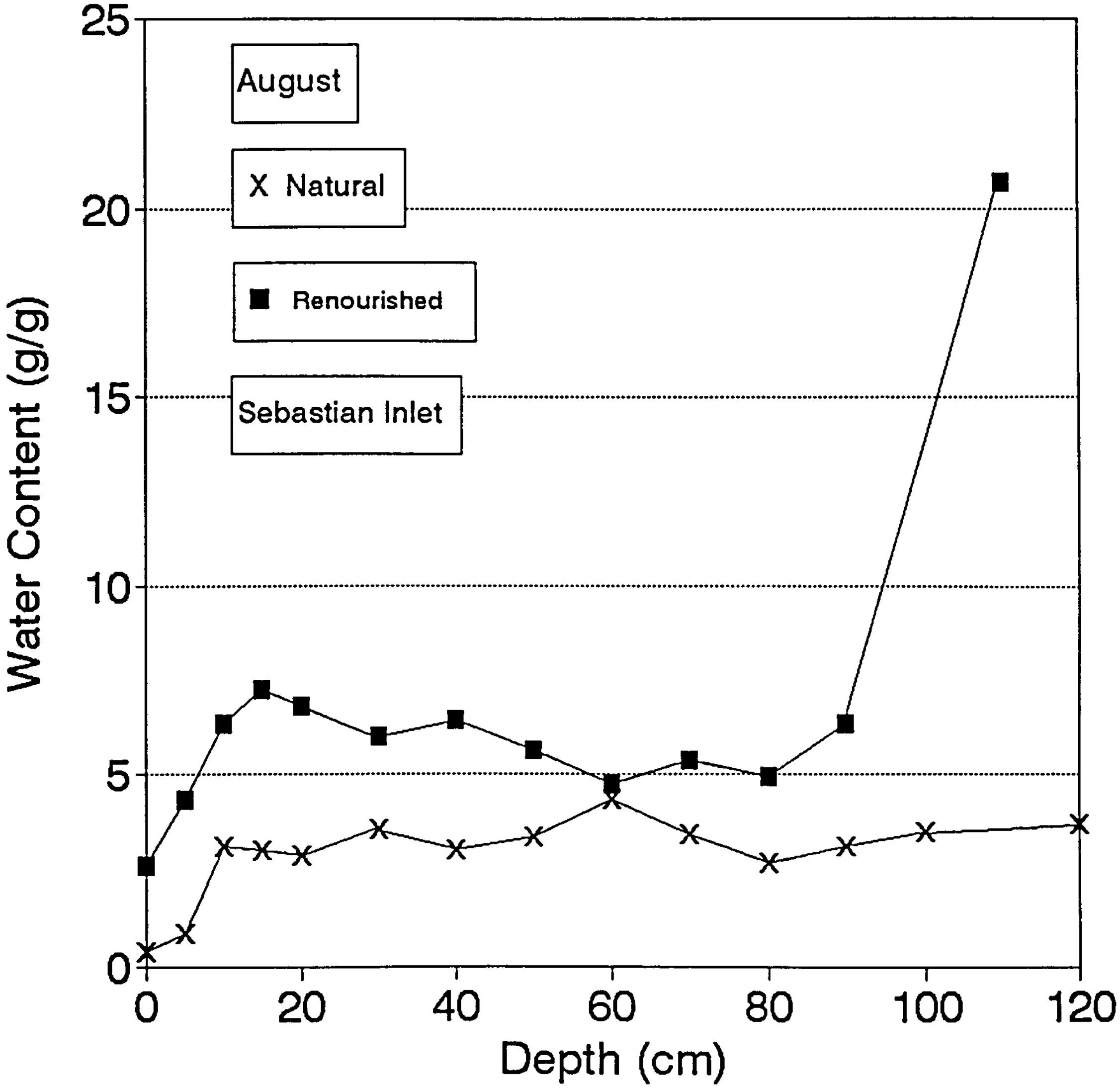

Figure 10. Water content as a function of depth for the middle transect of Sebastian Inlet beaches from August (X - natural and filled square - renourished)

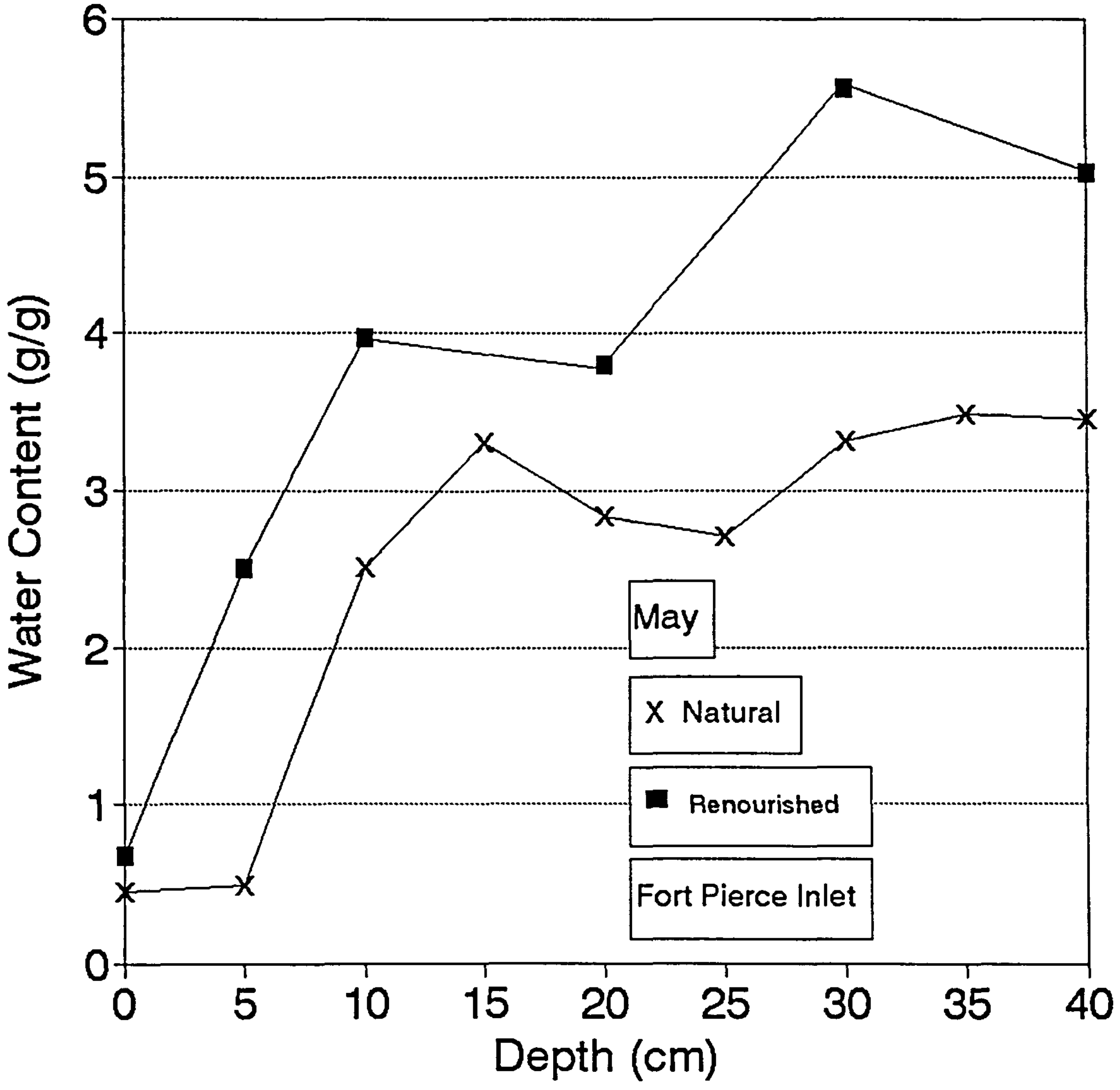

Figure 11. Water content as a function of depth for the middle transect of Fort Pierce Inlet beaches from May (X - natural and filled square - renourished)

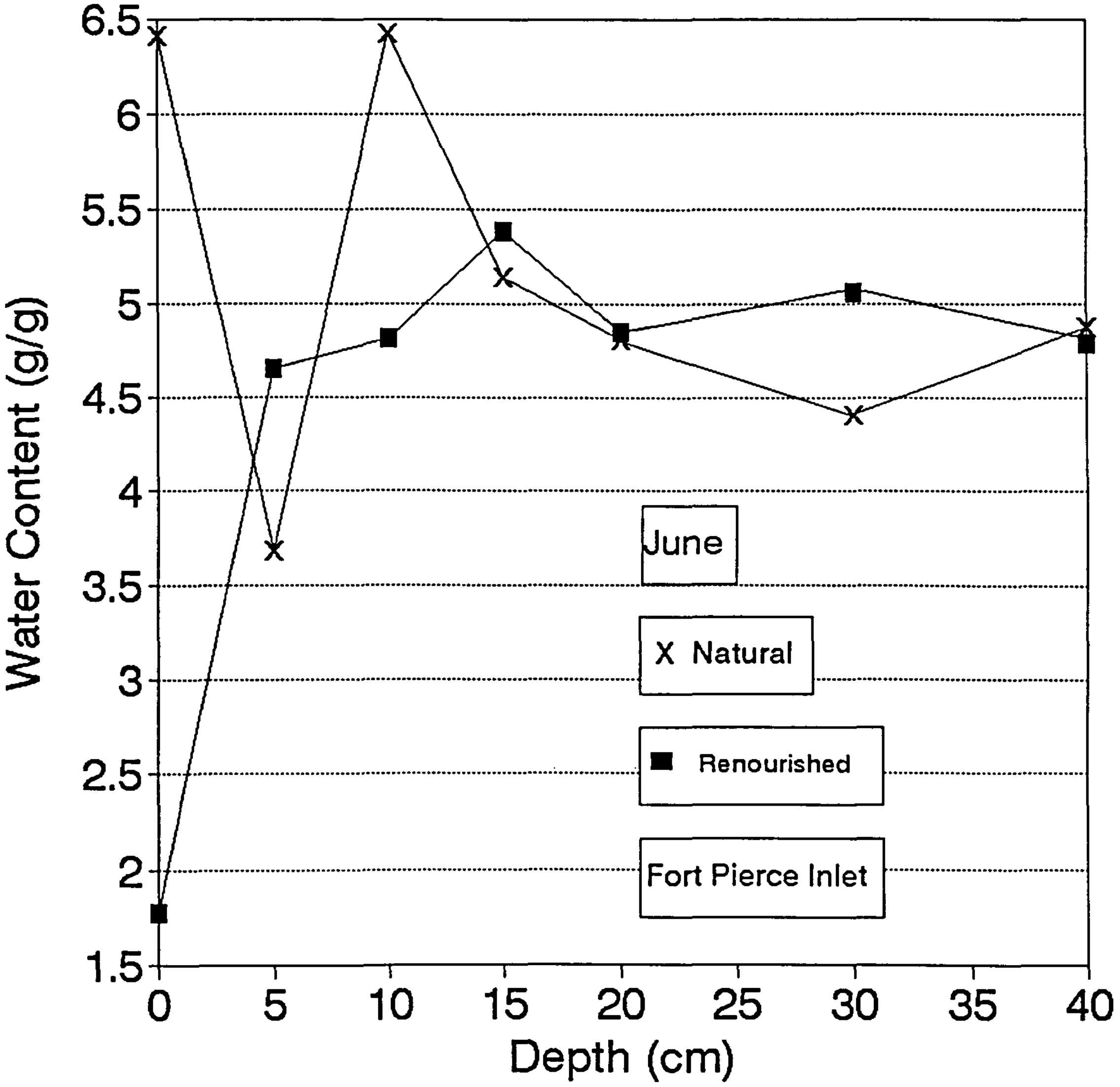

Figure 12. Water content as a function of depth for the middle transect of Fort Pierce Inlet beaches from June (X - natural and filled square - renourished)

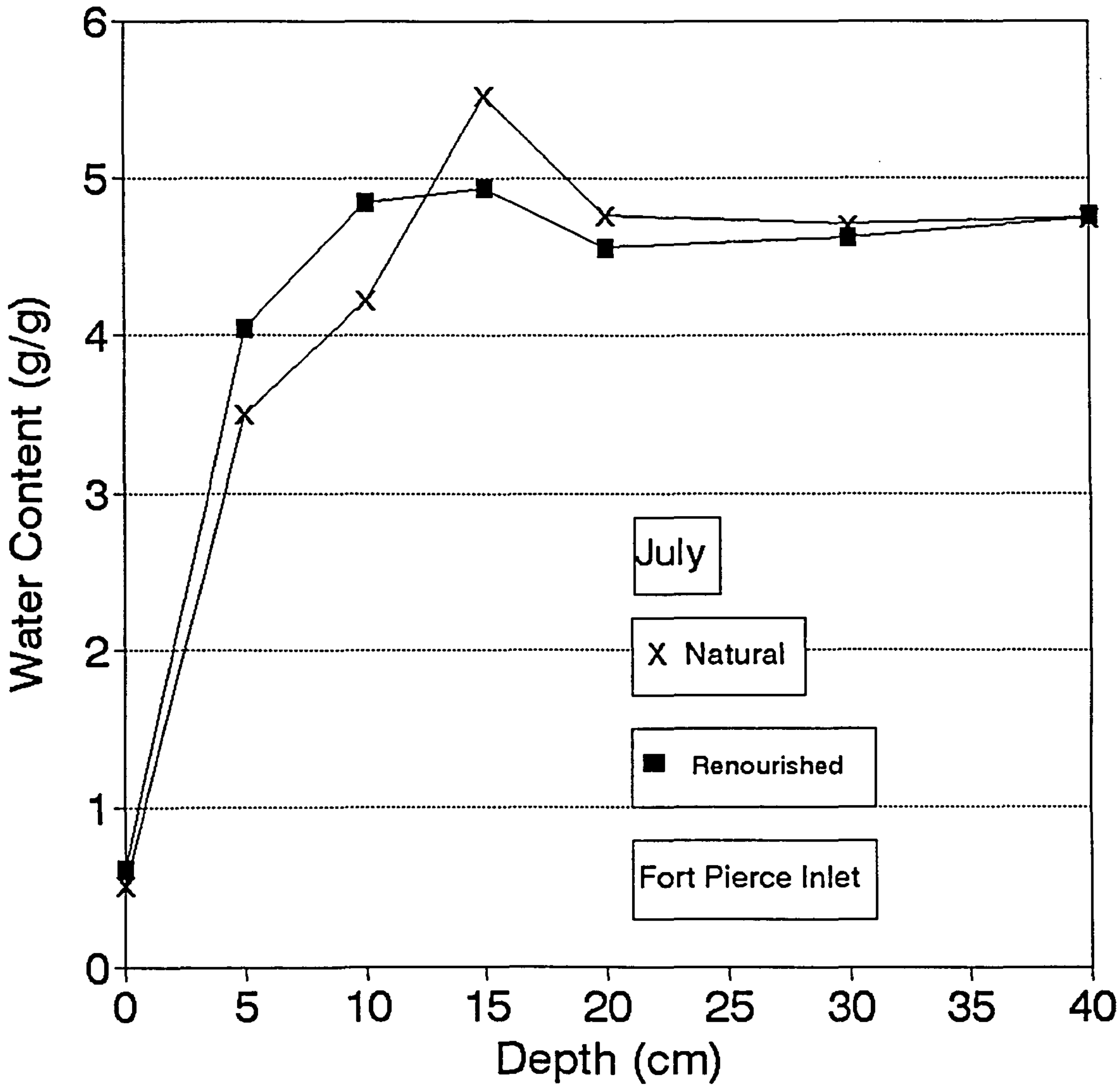

Figure 13. Water content as a function of depth for the middle transect of Fort Pierce Inlet beaches from July (X - natural and filled square - renourished)

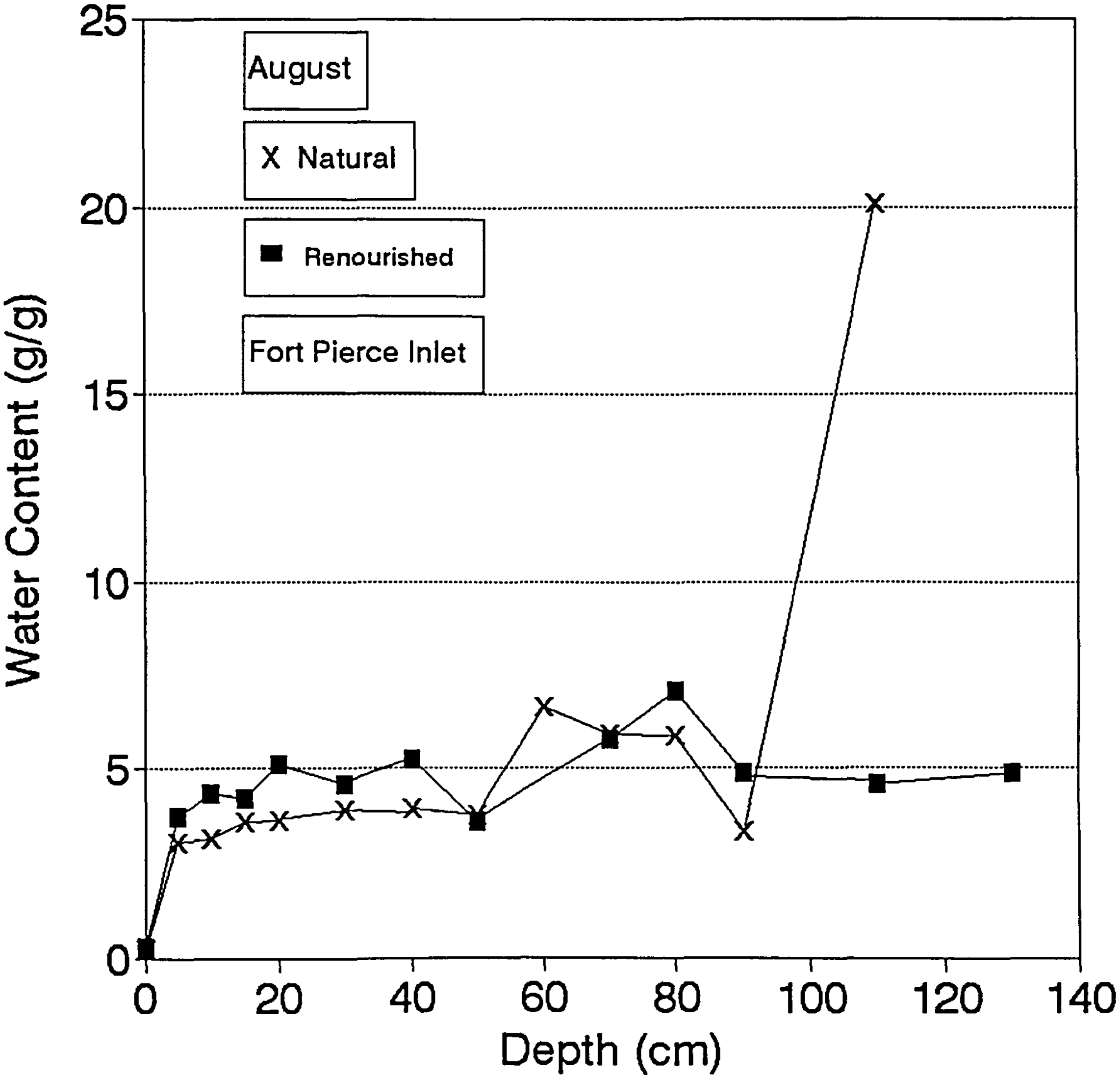

Figure 14. Water content as a function of depth for the middle transect of Fort Pierce Inlet beaches from August (X - natural and filled square - renourished)

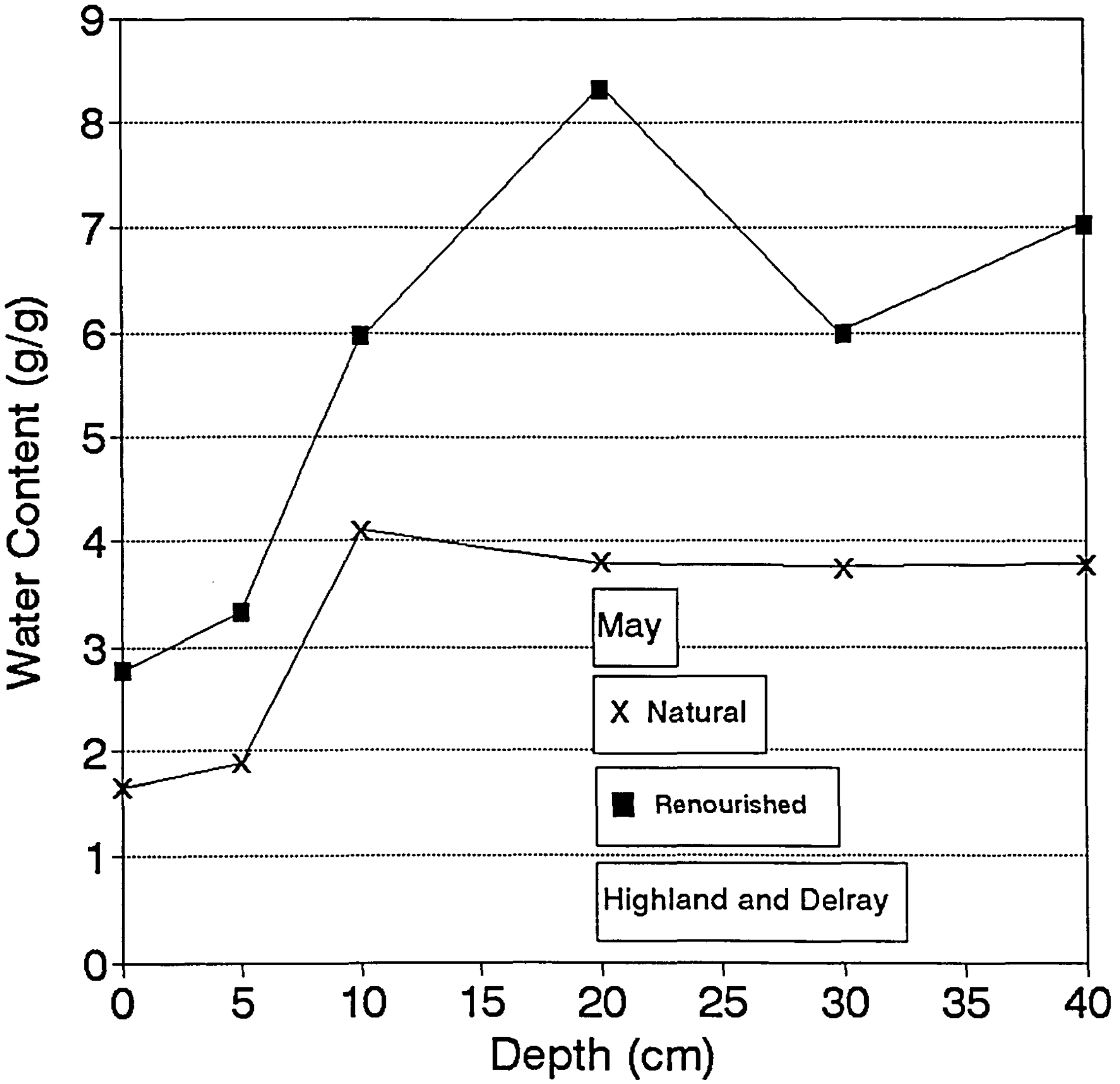

Figure 15. Water content as a function of depth for the middle transect of Highland and Delray beaches from May (X - natural and filled square - renourished)

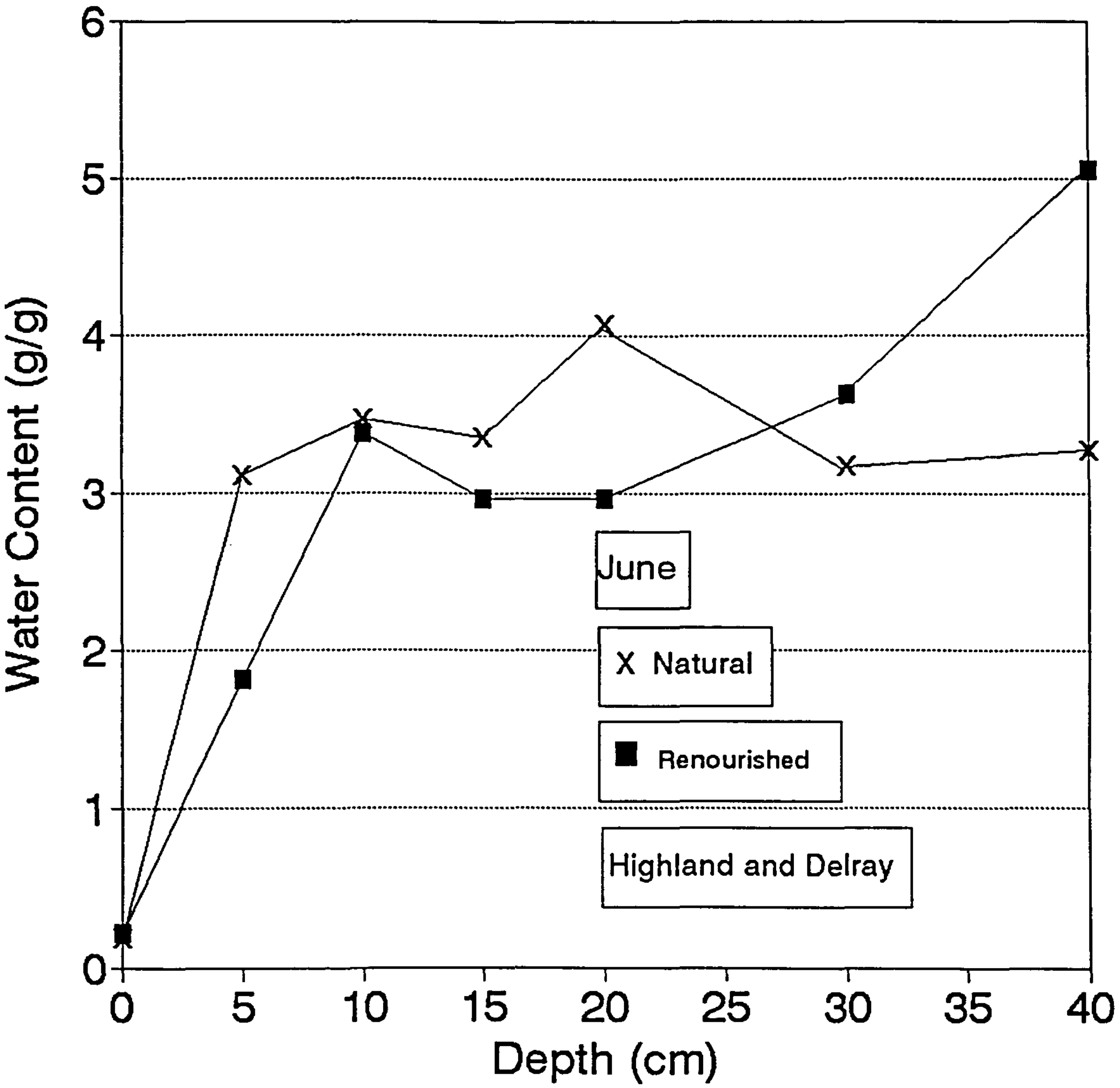

Figure 16. Water content as a function of depth for the middle transect of Highland and Delray beaches from June (X - natural and filled square - renourished)

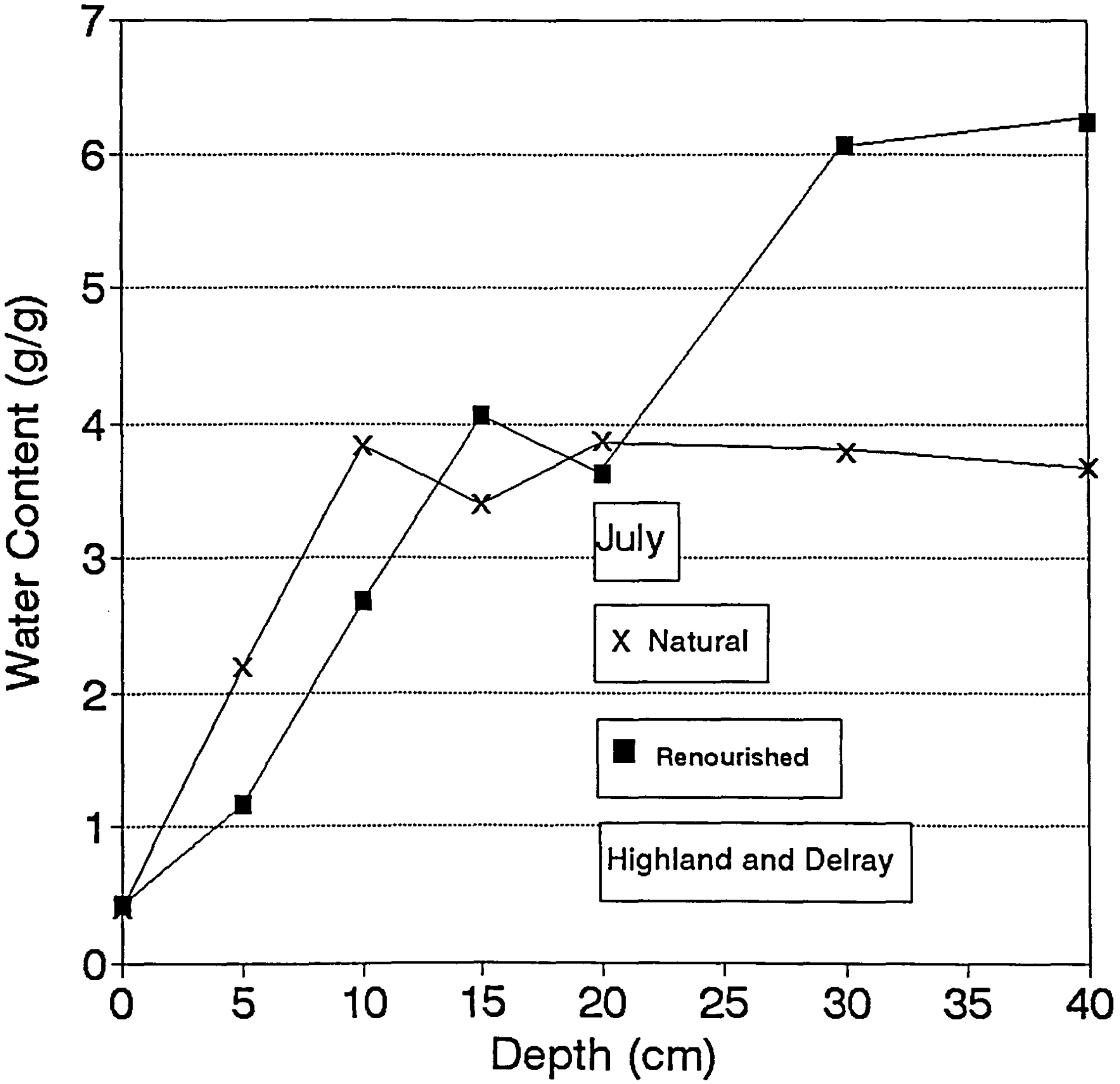

Figure 17. Water content as a function of depth for the middle transect of Highland and Delray beaches from July (X - natural and filled square - renourished)

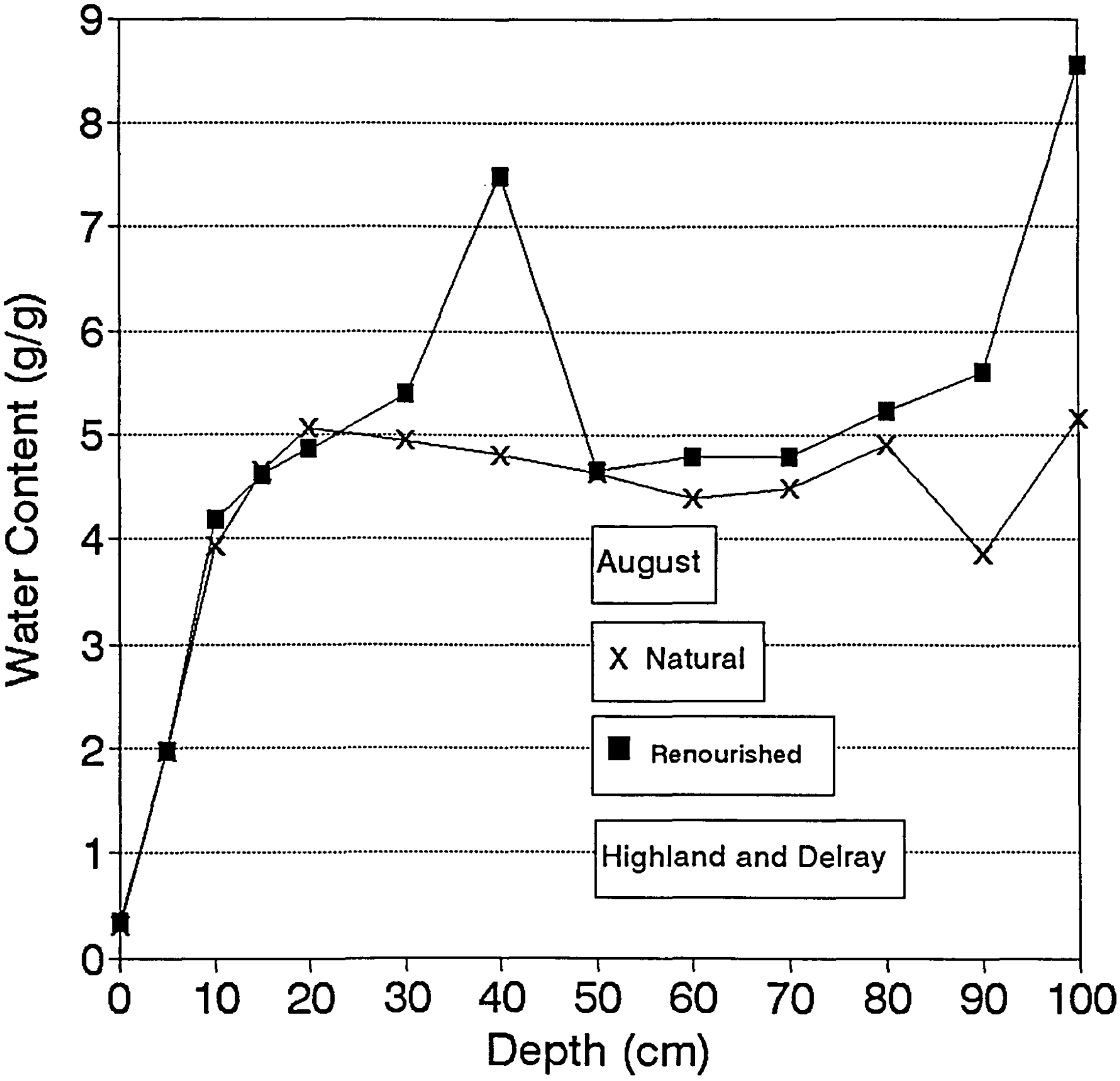

Figure 18. Water content as a function of depth for the middle transect of Highland and Delray beaches from August (X - natural and filled square - renourished)

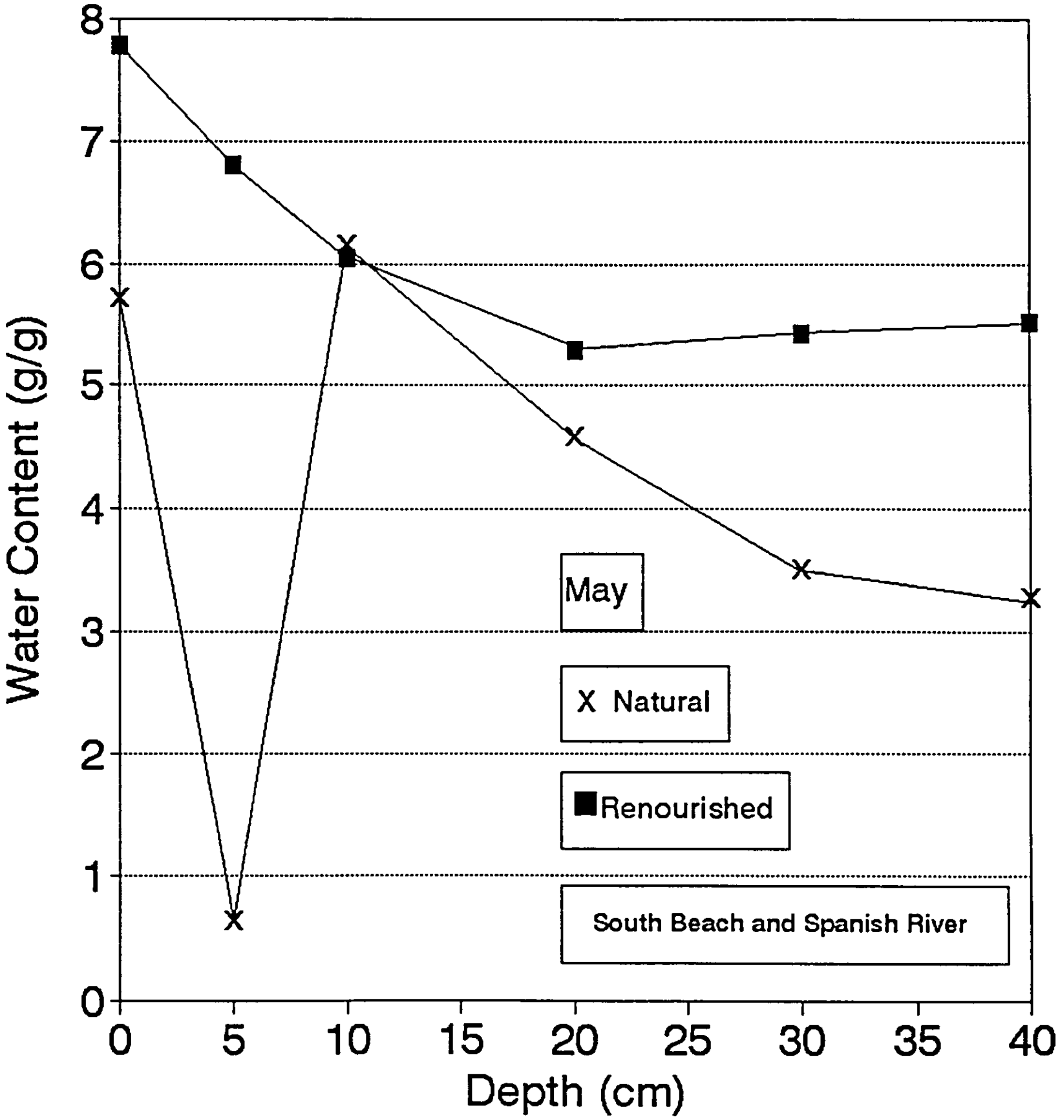

Figure 19. Water content as a function of depth for the middle transect of South Beach and Spanish River parks from May (X- natural and filled square - renourished)

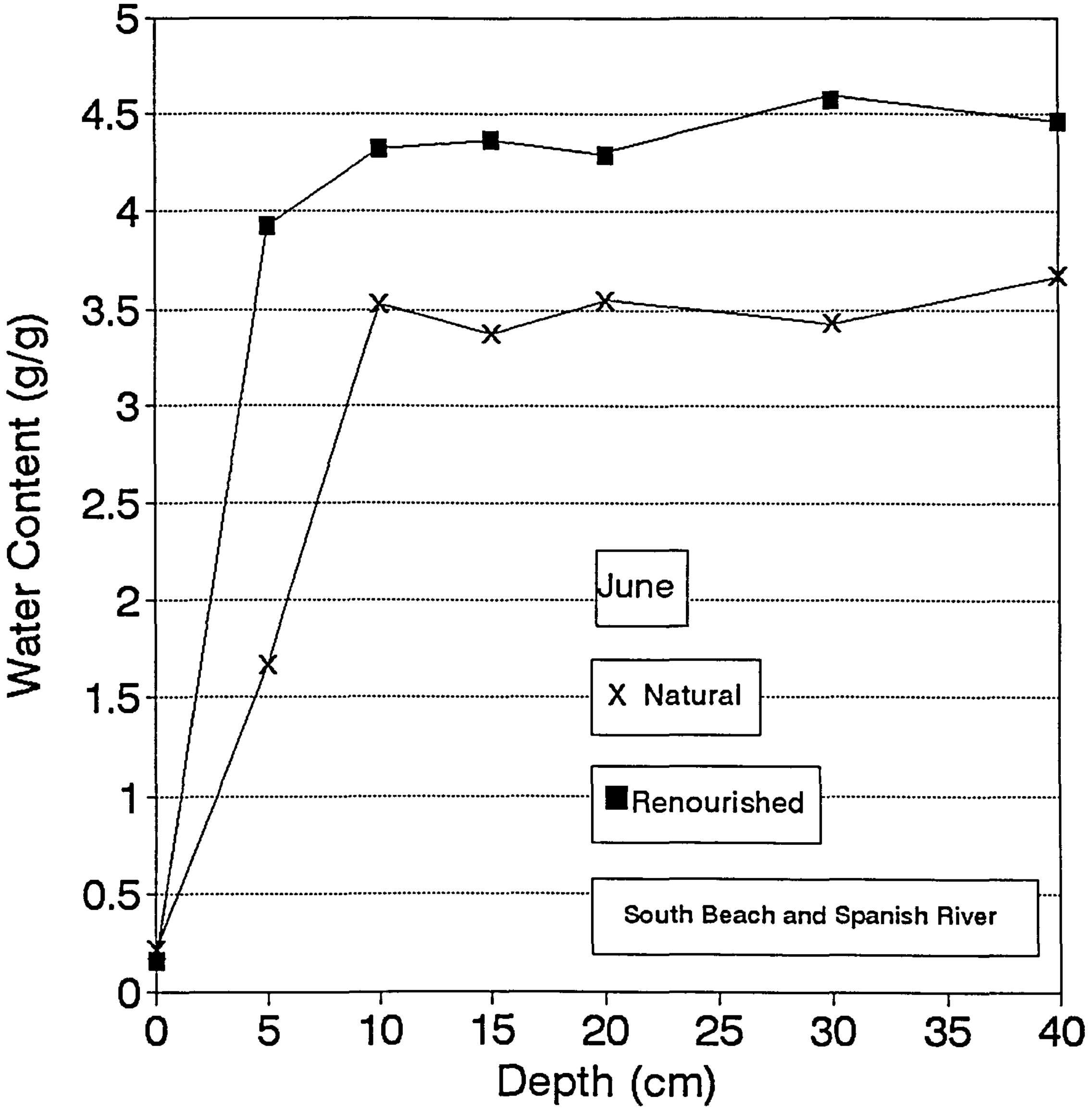

Figure 20. Water content as a function of depth for the middle transect of South Beach and Spanish River parks from June (X - natural and filled square - renourished)

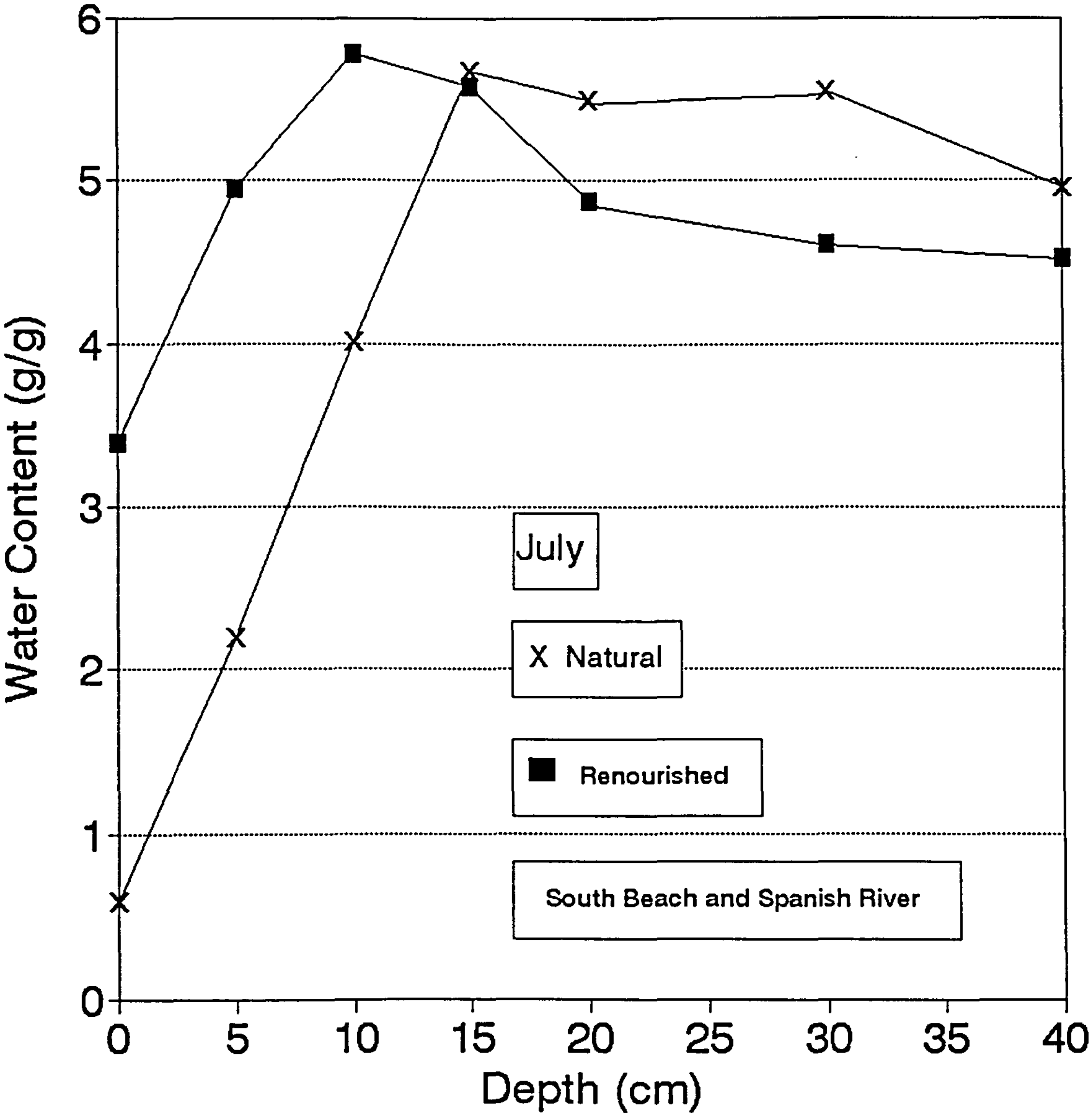

Figure 21. Water content as a function of depth for the middle transect of South Beach and Spanish River parks from July (X - natural and filled square - renourished)

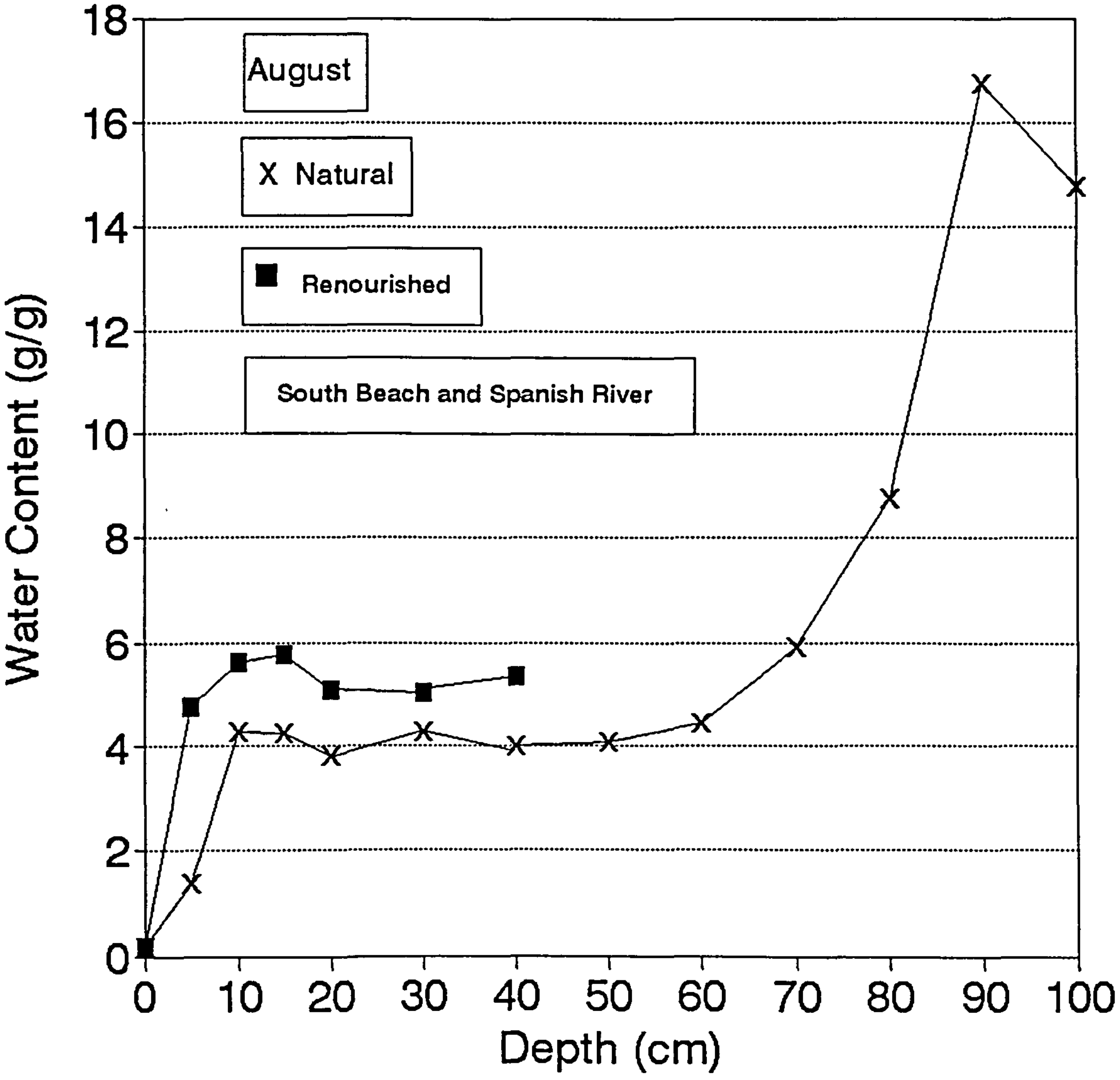

Figure 22. Water content as a function of depth for the middle transect of South Beach and Spanish River parks from August (X - natural and filled square - renourished)

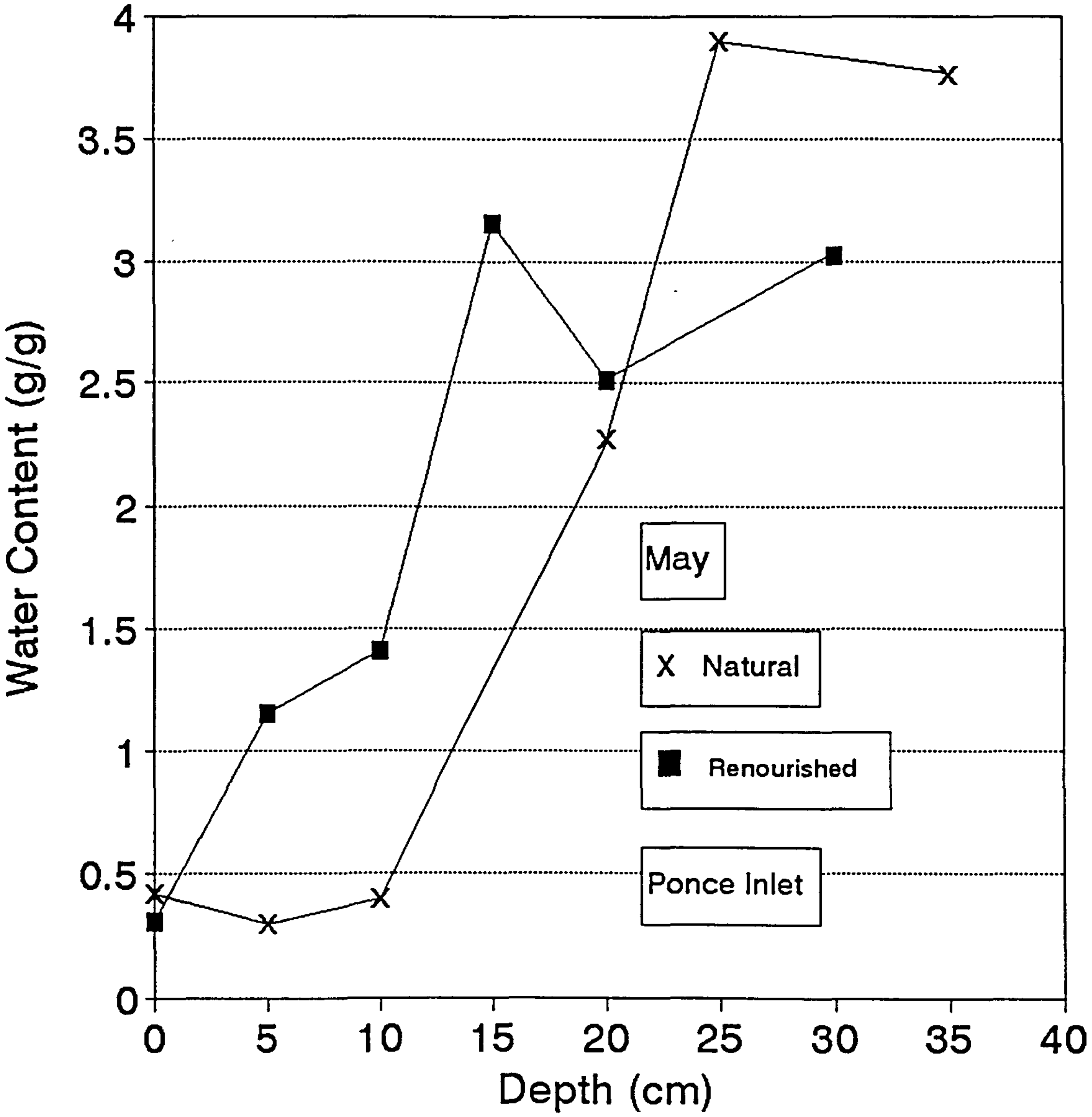

Figure 23. Water content as a function of depth for the middle transect of Ponce Inlet beaches from May (X - natural and filled square - renourished)

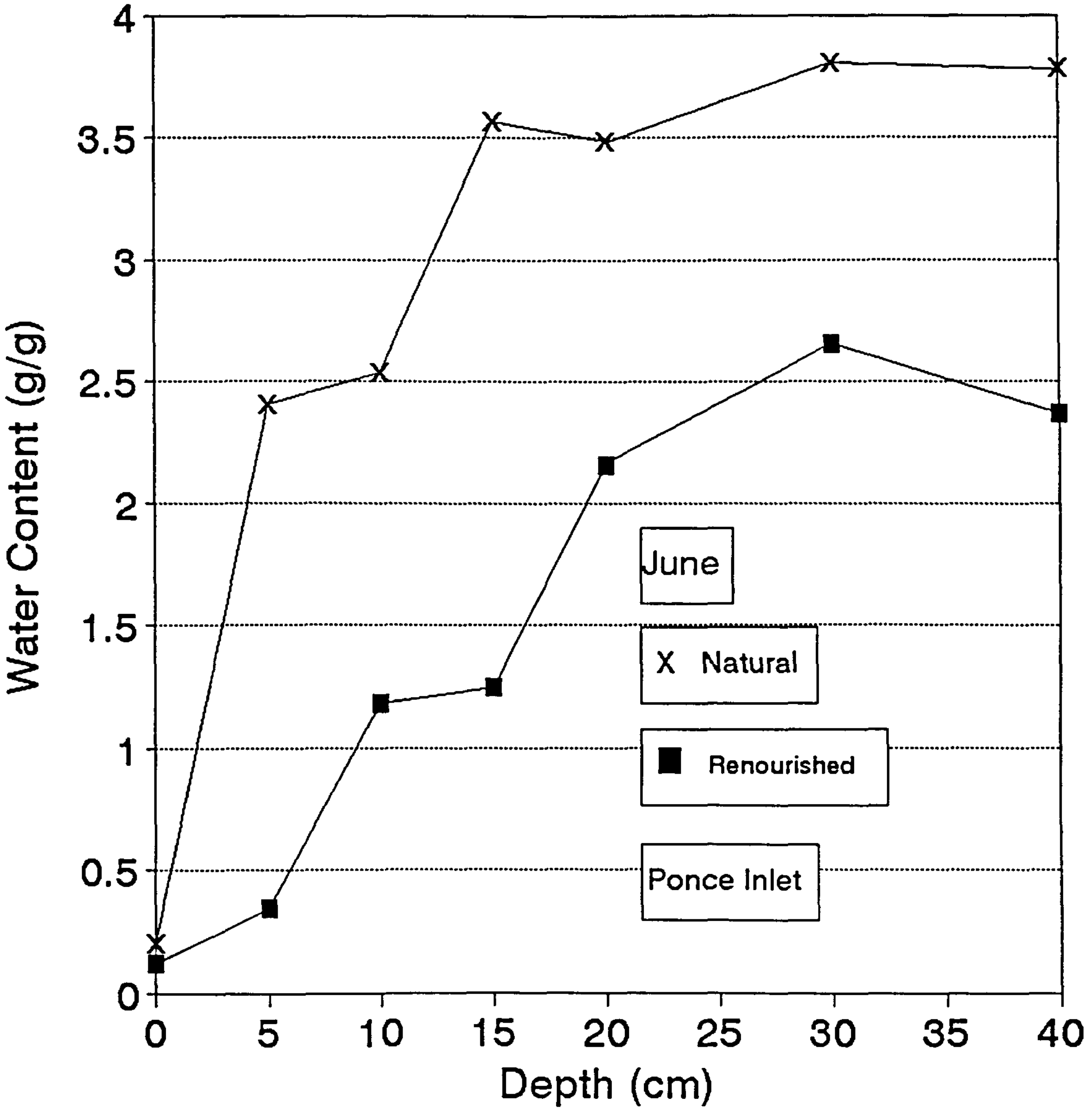

Figure 24. Water content as a function of depth for the middle transect of Ponce Inlet beaches from June (X - natural and filled square - renourished)

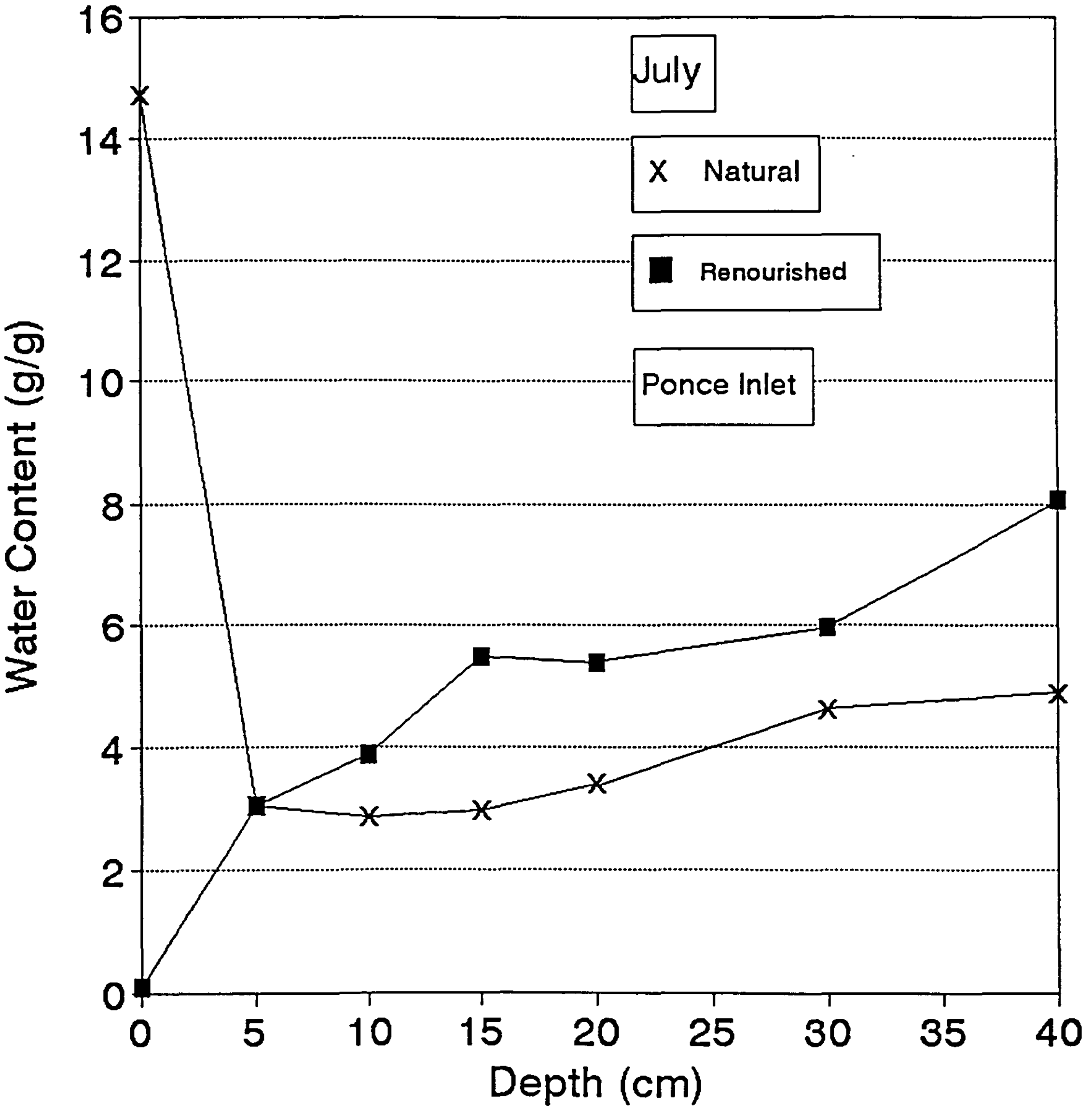

Figure 25. Water content as a function of depth for the middle transect of Ponce Inlet beaches from July (X - natural and filled square - renourished)

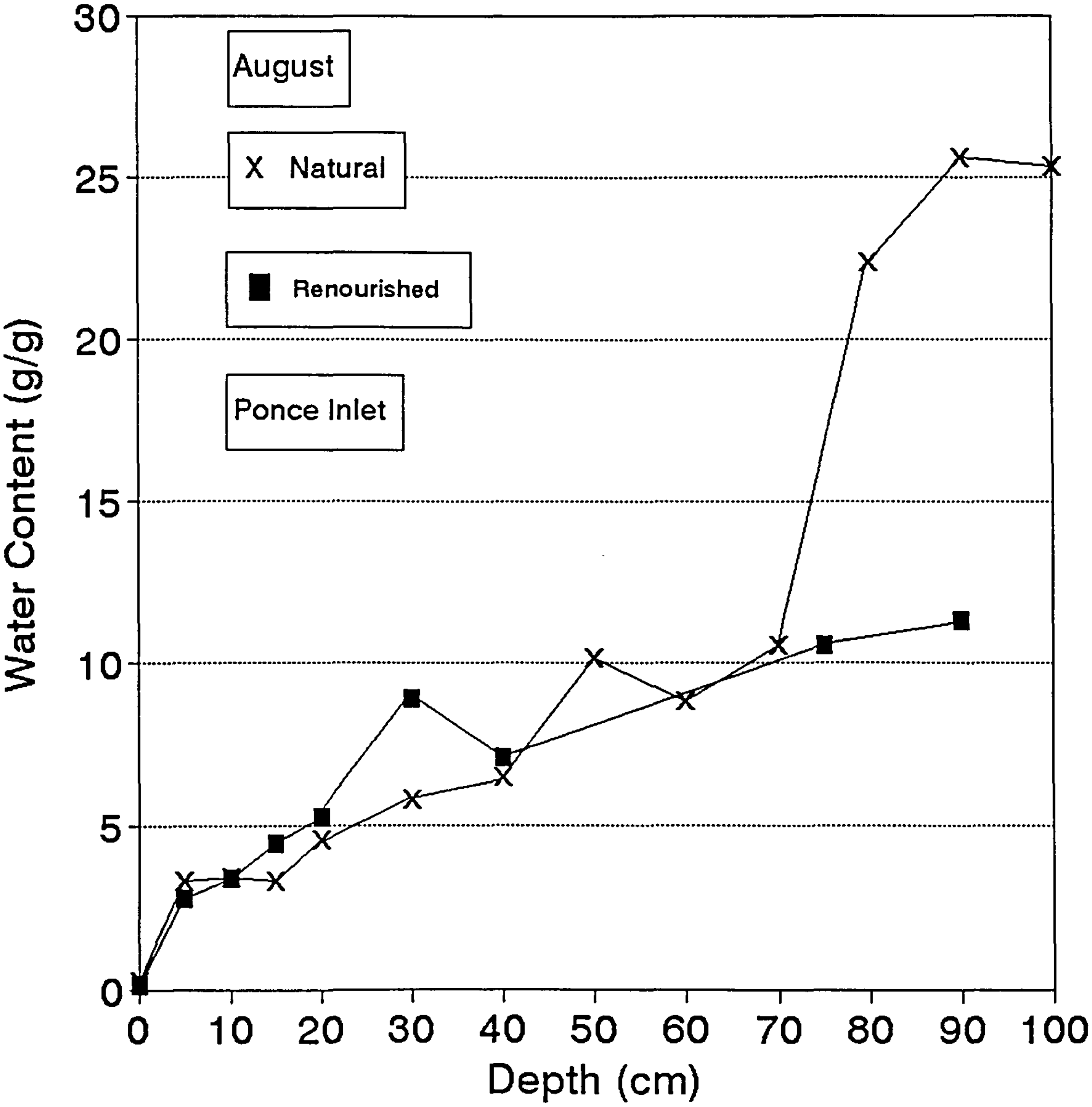

Figure 26. Water content as a function of depth for the middle transect of Ponce Inlet beaches from August (X - natural and filled square - renourished)

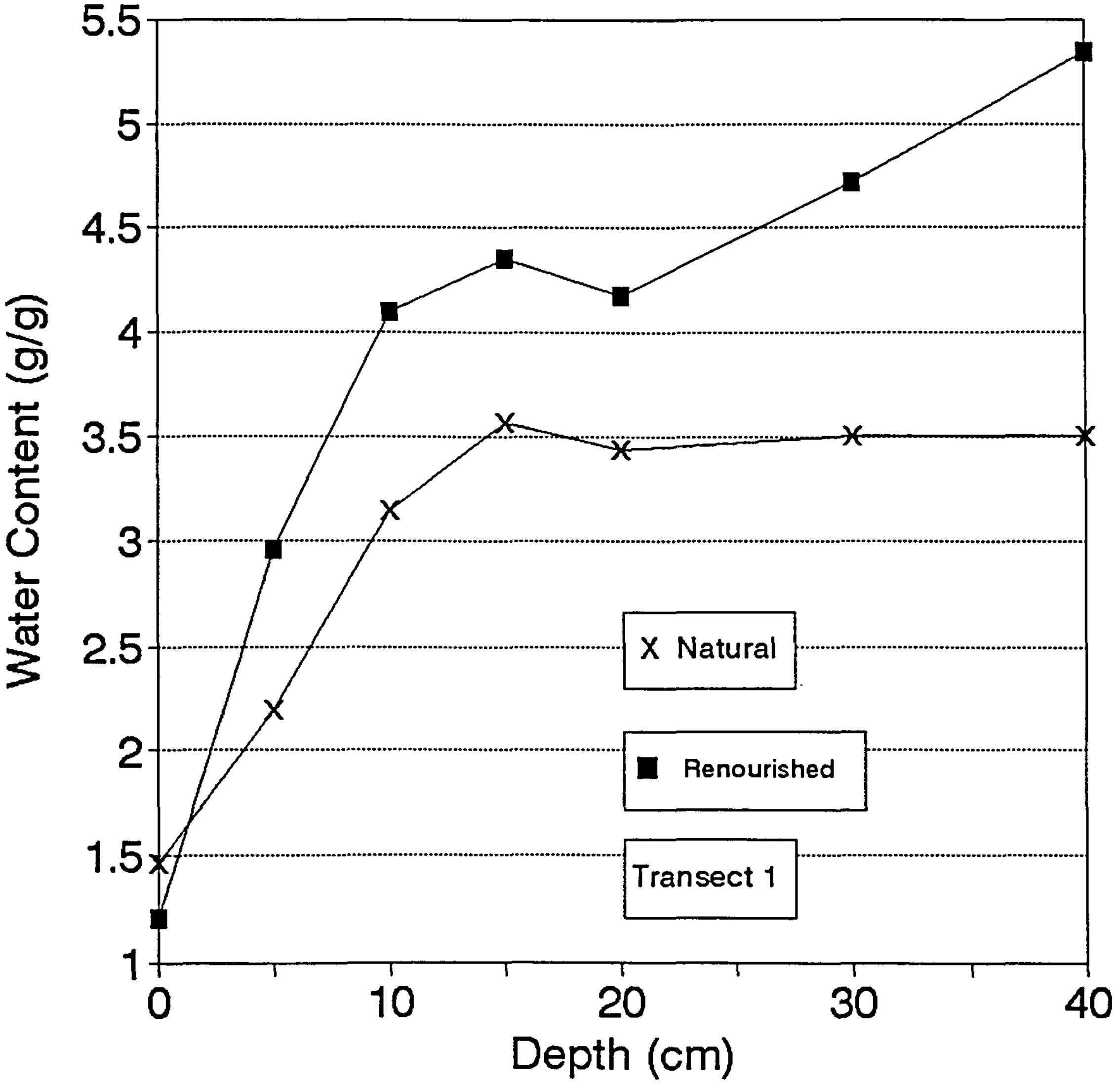

Figure 27. Water content as a function of depth for transect 1 with all natural and all renourished beaches averaged over all months (X - natural and filled square - renourished)

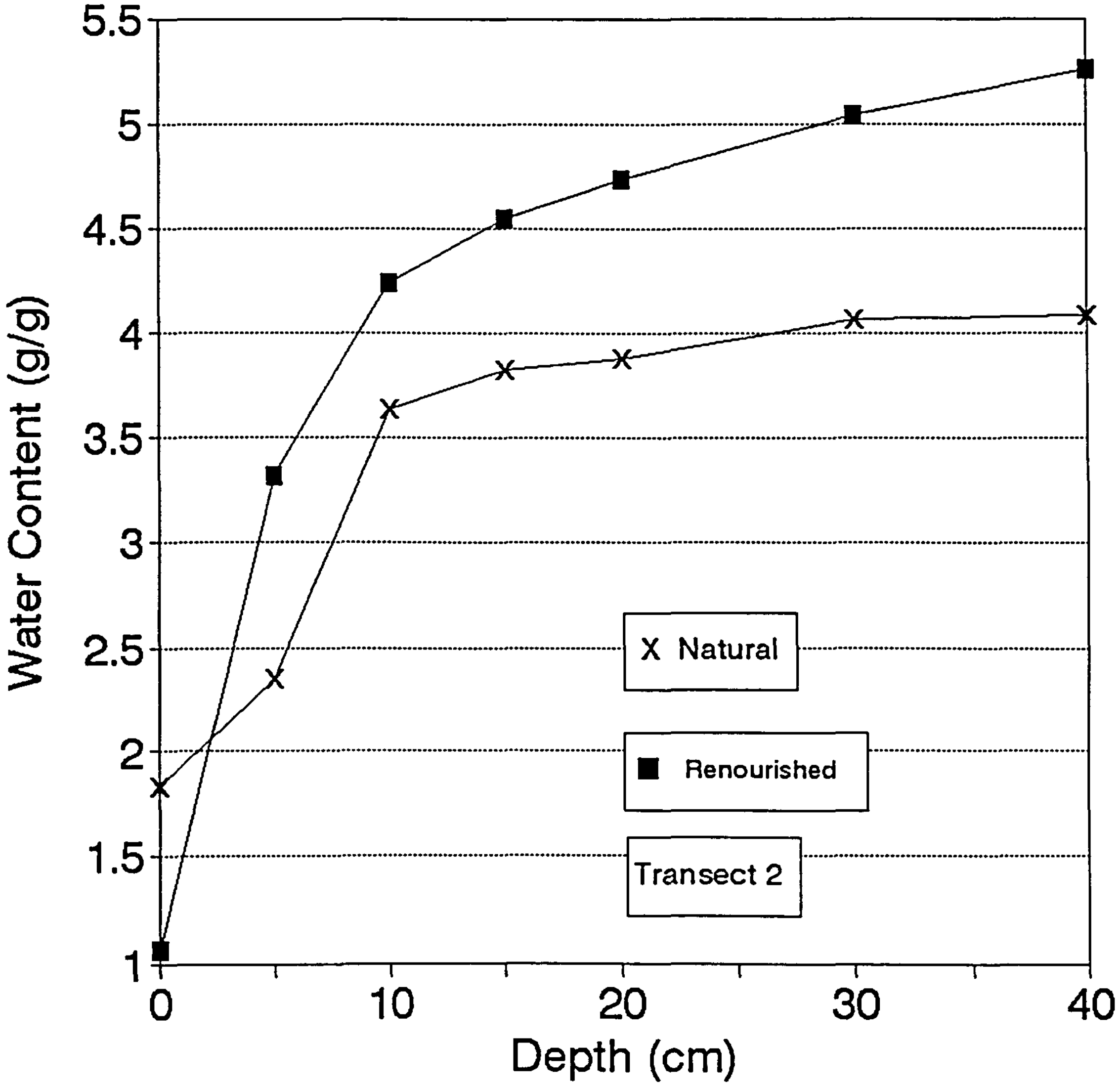

Figure 28. Water content as a function of depth for transect 2 with all natural and all renourished beaches averaged over all months (X - natural and filled square - renourished)

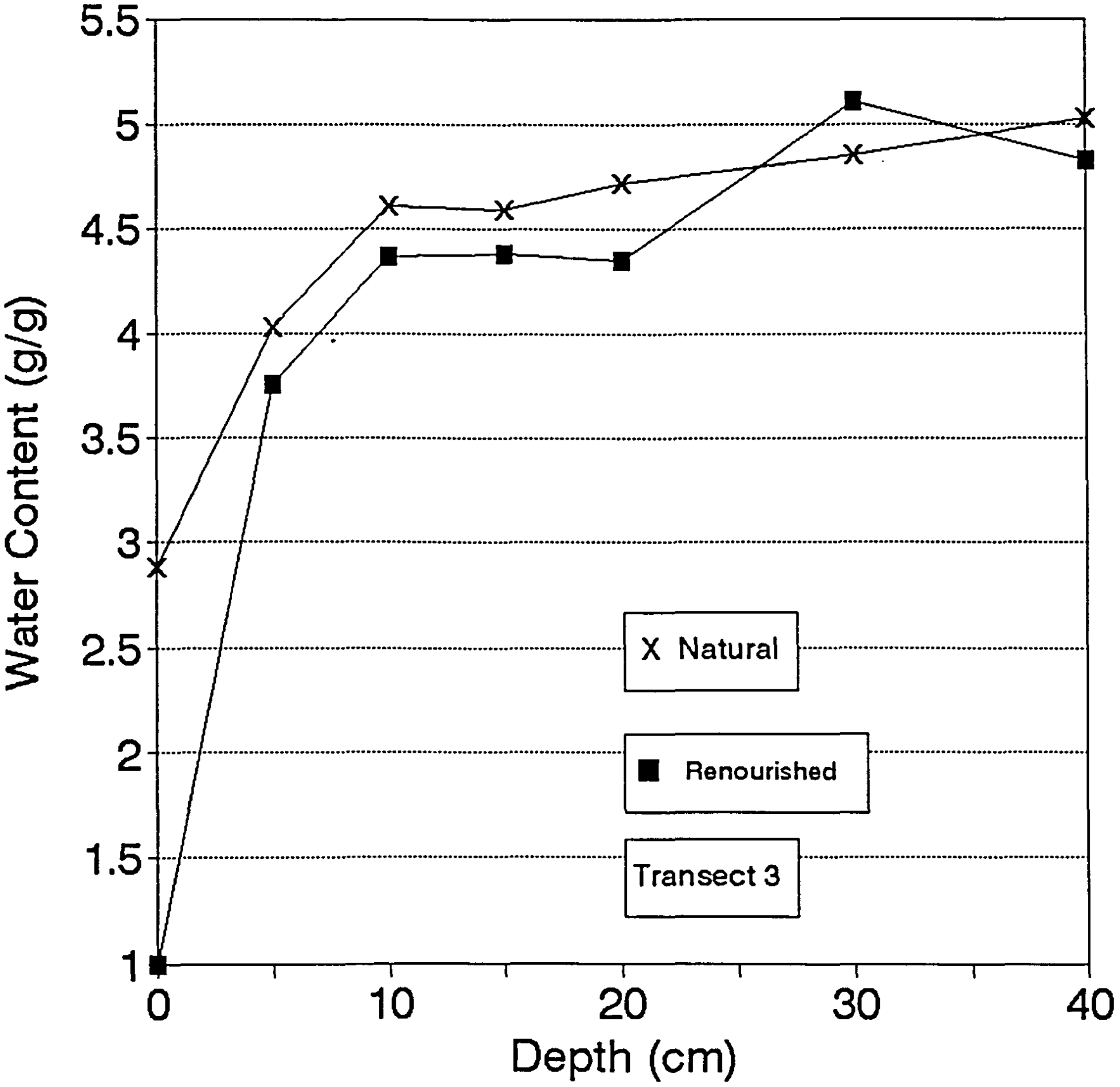

Figure 29. Water content as a function of depth for transect 3 with all natural and all renourished beaches averaged over all months (X - natural and filled square - renourished)

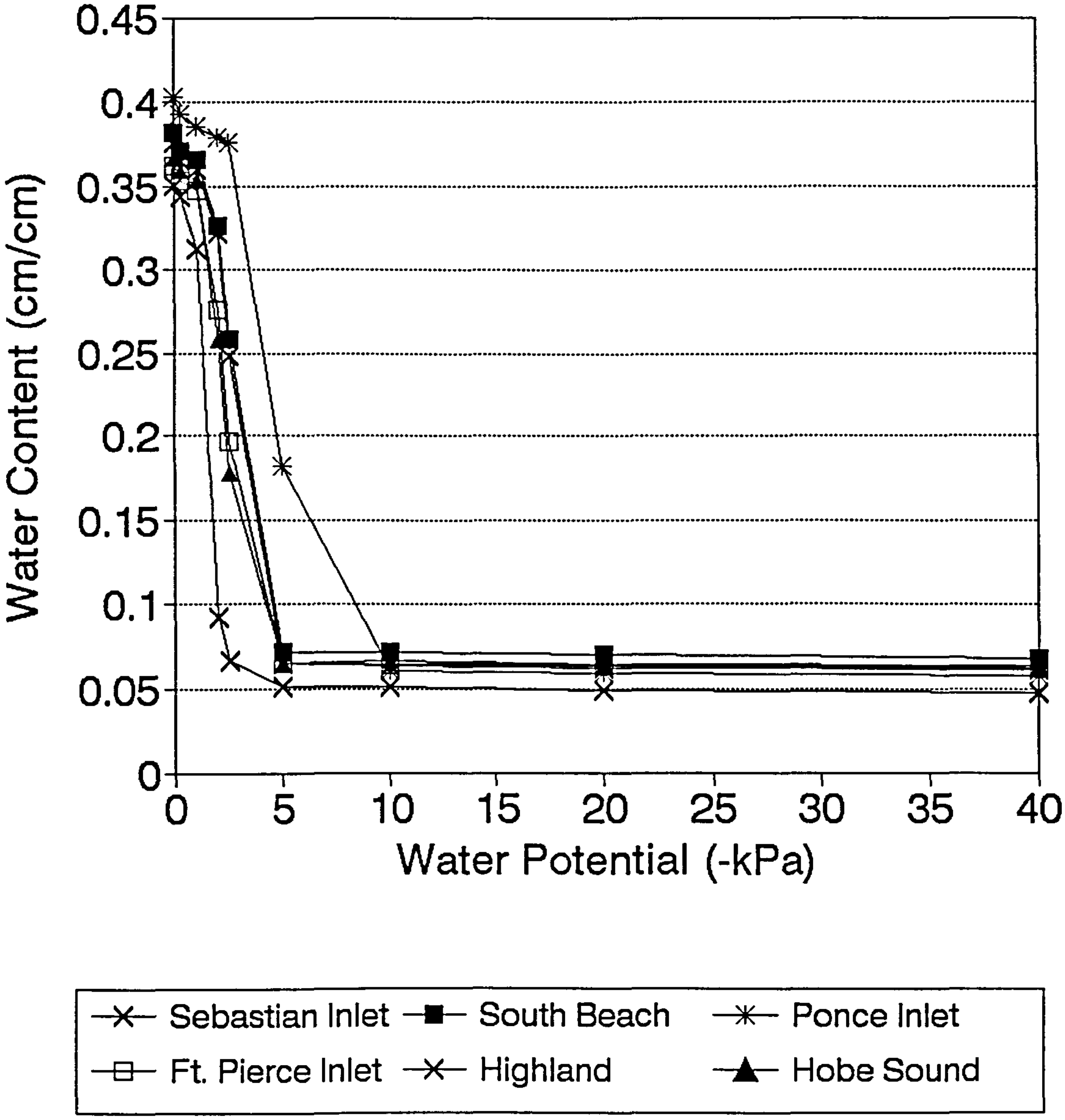

Figure 30. Characteristic curves for natural beaches from undisturbed cores

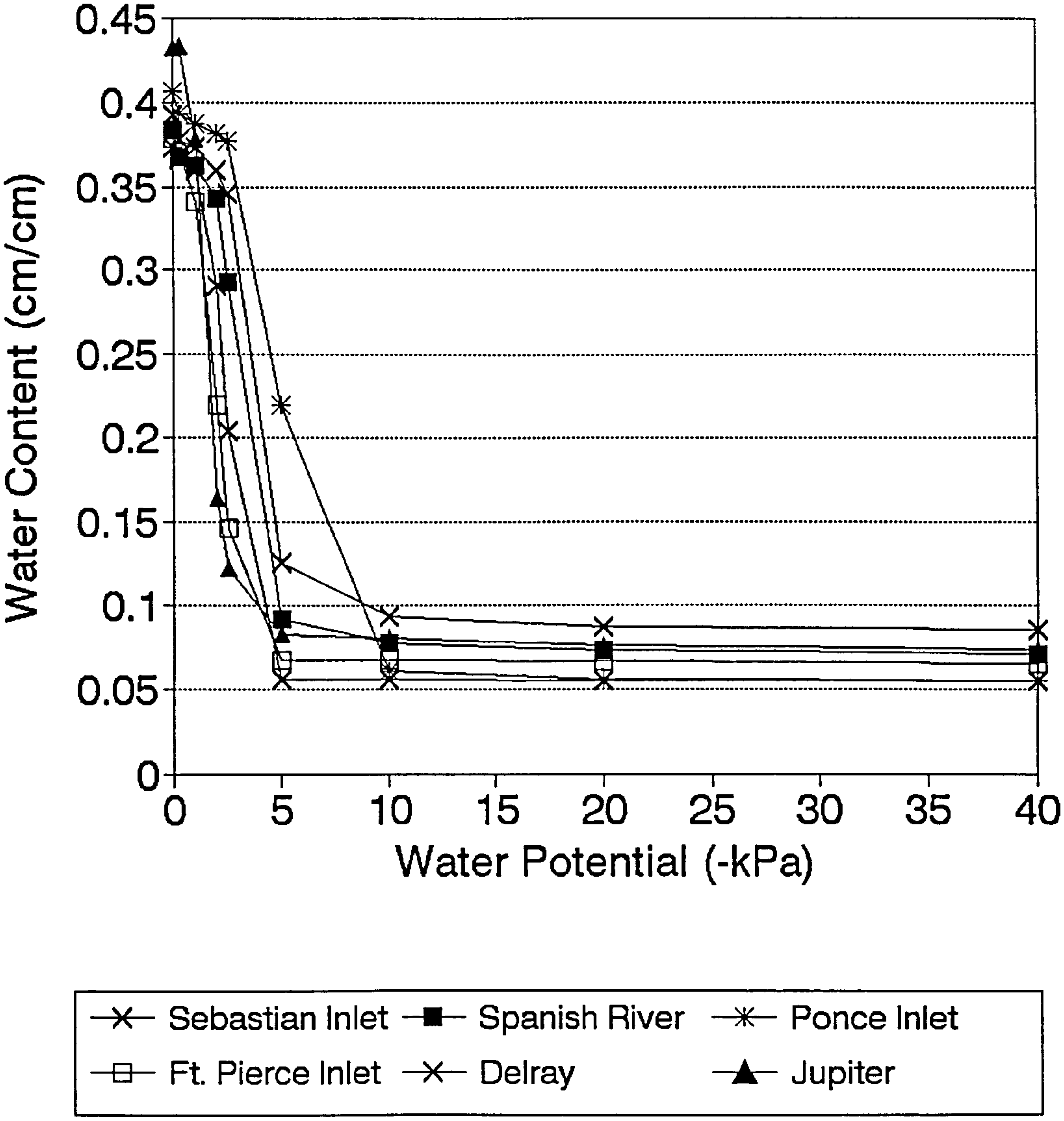

Figure 31. Characteristic curves for renourished beaches from undisturbed cores

renourished curves seem to have higher water content values for the same water potentials. The Ponce Inlet beaches hold the greatest amount of water from 0 to -5 kPa and on the natural beach it continues to hold the greatest amount of water down to a pressure of -40 kPa. In the averaged characteristic curves, the renourished curve has higher water content values for each water potential value (Figure 32).

Bulk density values are presented in Table 3. The natural beaches tended to have higher bulk density values. Saturated hydraulic conductivity was determined on samples from June and the results are presented in Table 3. A wide range of saturated hydraulic conductivities were observed on both natural and renourished beaches. The water potential of the 20 and 30 centimeter samples was determined by converting the gravimetric water content to volumetric water content. The volumetric water content and the characteristic curves could then be used to determine the appropriate water potentials (van Genuchten, 1980). These values are presented in Table 4.

Osmotic potential by month was obtained from four samples from each month and the averages are presented in figures 33-34. It can be noted that the salinity of the two types of beaches changed monthly. Hobe Sound had an osmotic potential that registered more negative than -70 kPa two months out of four. The Ponce Inlet natural beach also had one instance

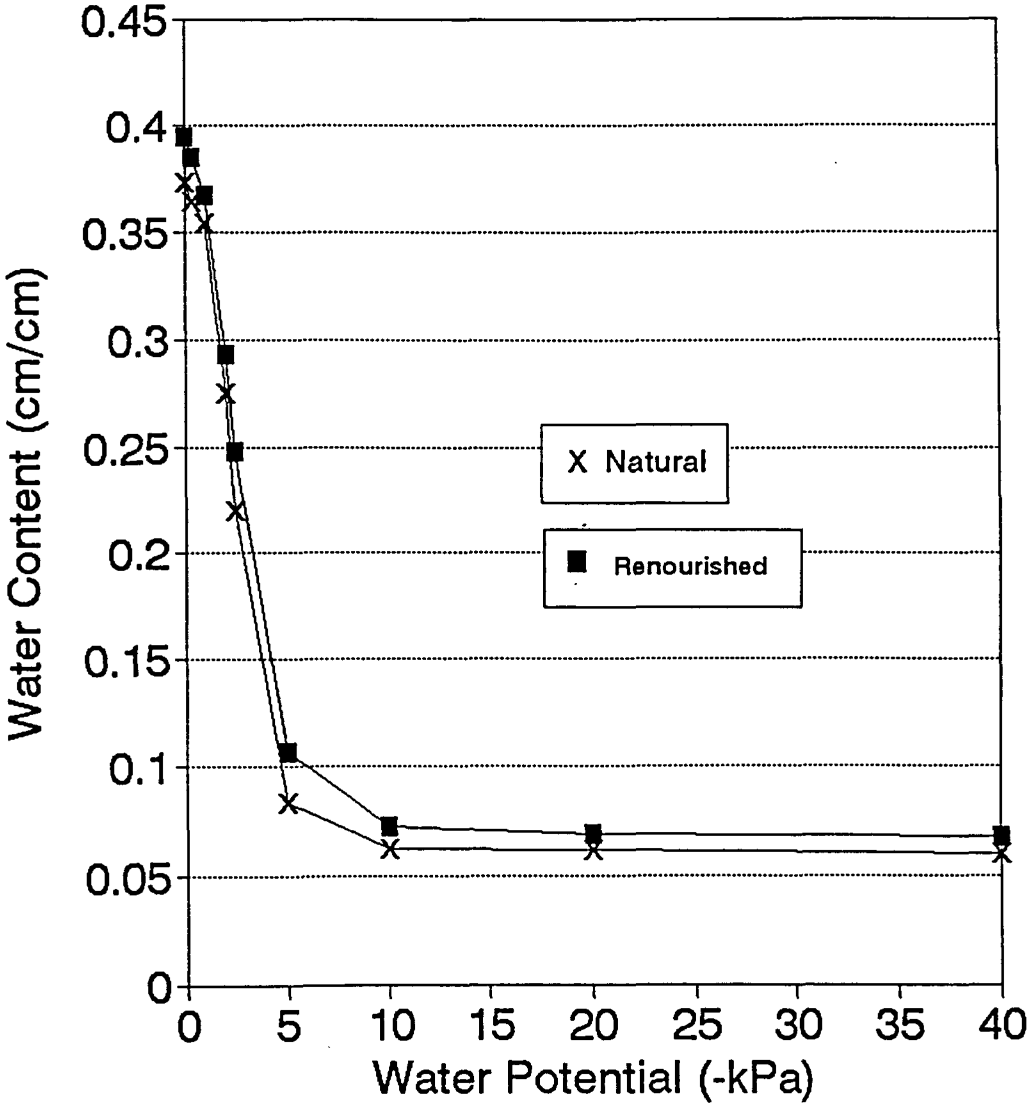

Figure 32. Characteristic curves with averages taken for all natural and all renourished beaches from undisturbed cores

Table 3. Bulk density and saturated hydraulic conductivity values for each beach (beaches are arranged in pairs with the natural beach listed first)

Beach	Bulk Density g/cm^3	Saturated Hydraulic Conductivity cm/s
Ponce Inlet South	1.42	0.0092
Ponce Inlet North	1.41	0.0101
Sebastian Inlet North	1.60	0.0503
Sebastian Inlet South	1.54	0.0234
Fort Pierce Inlet North	1.50	0.0156
Fort Pierce Inlet South	1.51	0.0350
Hobe Sound NWR	1.54	0.0300
Jupiter Beach	1.46	0.0273
Highland Beach	1.58	0.0240
Delray Beach	1.56	0.0239
South Beach Park	1.59	0.0410
Spanish River Park	1.54	0.0138
Natural	1.56	0.0324
Renourished	1.52	0.0221

where the osmotic potential value was highly negative. It should also be noted that the osmotic potential was slightly more negative in May and June for Fort Pierce South. In July and August, the osmotic potential became less negative on Fort Pierce South and this is very near the level seen on the other beaches. The remainder of the beaches had a relatively constant osmotic potential from month to month. Osmotic potential versus depth measures were conducted on sand that was taken in August at site 6 and the results are presented in

Table 4. Water potential averages and standard deviations for each beach at 20 and 30 centimeters in each of the three transects (The natural beach is listed first). The overall average for natural and renourished beach types is given at the bottom for each transect

	20 cm		30 cm		
Beach	Avg (kPa)	Std	Avg (kPa)	Std	Transect
Ponce Inlet South	-8.92	1.75	-9.84	5.17	1
	-8.67	2.26	-7.54	1.52	2
	-9.33	1.49	-8.74	1.74	3
Ponce Inlet North	-11.41	7.17	-10.12	6.91	1
	-9.38	5.31	-7.41	3.00	2
	-10.49	4.88	-8.19	2.18	3
Sebastian Inlet North	-3.39	0.51	-3.25	0.51	1
	-3.26	0.33	-3.17	0.21	2
	-3.15	0.72	-2.92	0.25	3
Sebastian Inlet South	-6.97	0.93	-6.98	1.84	1
	-6.12	1.55	-6.27	1.82	2
	-5.71	1.48	-5.20	1.73	3
Fort Pierce Inlet North	-8.36	3.27	-7.74	1.58	1
	-7.38	1.73	-7.10	1.43	2
	-6.31	2.57	-5.64	2.22	3
Fort Pierce Inlet South	-11.56	15.83	-8.36	7.50	1
	-6.96	2.38	-6.49	1.41	2
	-6.70	4.38	-5.64	1.95	3
Hobe Sound NWR	-8.89	1.84	-8.62	1.22	1
	-7.57	1.29	-7.14	1.20	2
	-5.89	1.86	-5.91	1.66	3
Jupiter Beach	-6.51	0.95	-6.05	0.62	1
	-6.37	0.98	-6.21	0.76	2
	-6.24	1.42	-6.25	1.05	3
Highland Beach	-7.44	0.92	-7.21	0.50	1
	-6.91	0.92	-7.14	0.80	2
	-6.12	0.95	-6.08	1.02	3
Delray Beach	-8.60	2.82	-8.51	2.18	1
	-9.06	3.41	-8.37	2.12	2
	-12.78	3.09	-11.70	1.58	3

Table 4. (continued)

South Beach Park	-8.58	1.34	-8.76	1.06	1
	-7.84	1.07	-8.13	1.10	2
	-7.90	0.89	-7.43	0.89	3
Spanish River Park	-7.68	0.85	-7.48	0.61	1
	-7.57	0.68	-7.66	0.57	2
	-7.61	0.77	-7.60	0.68	3
Natural	-7.57	2.68	-7.54	3.06	1
	-6.91	2.22	-6.68	1.98	2
	-6.38	2.42	-6.10	2.26	3
Renourished	-8.89	7.37	-8.01	4.49	1
	-7.58	3.10	-7.07	1.96	2
	-8.26	3.95	-7.43	2.69	3

figures 35-36. It should be noted that when the water table was reached, the samples had a highly negative osmotic potential (Figures 35-36).

Particle size distribution for each beach is presented in figures 37 and 38. The same variation seems to exist for both natural and renourished beaches. Mean particle size is presented in Table 5 and the overall averages for natural and renourished beaches appear to be close. Particle color for dry and wet sand from each beach is presented in Table 6. Dark colors such as gray and dark gray only appear in the renourished beach types.

Each variable that was analyzed for differences between natural and renourished beach types was tested for significant differences using an analysis of variance. The average, standard deviation, F value, and F probability are listed in Table 7. Significant differences existed at the $P < 0.05$ level for bulk density and characteristic curve values. There

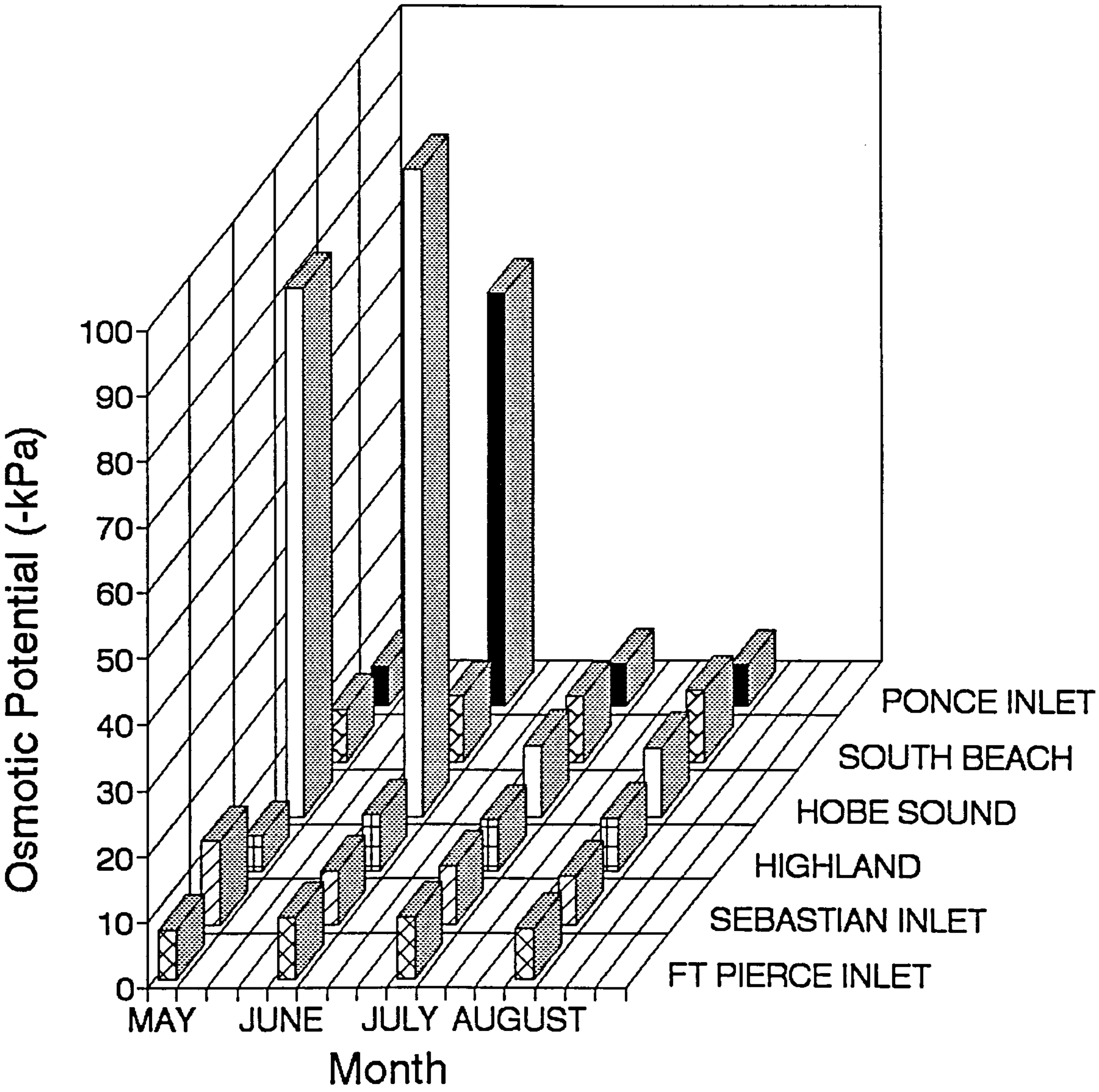

Figure 33. The osmotic potential recorded each month for each of the natural beaches

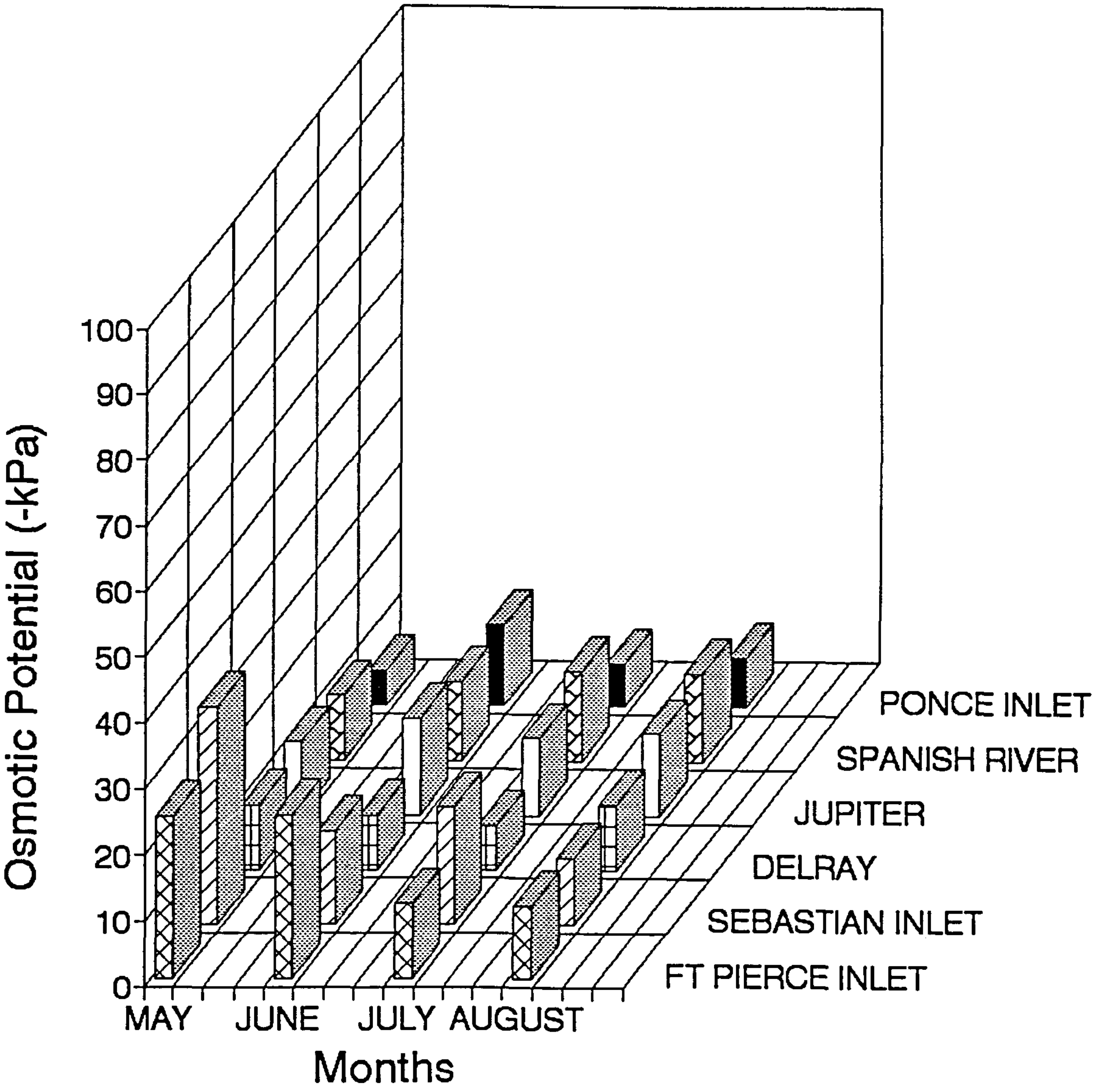

Figure 34. The osmotic potential recorded each month for each of the renourished beaches

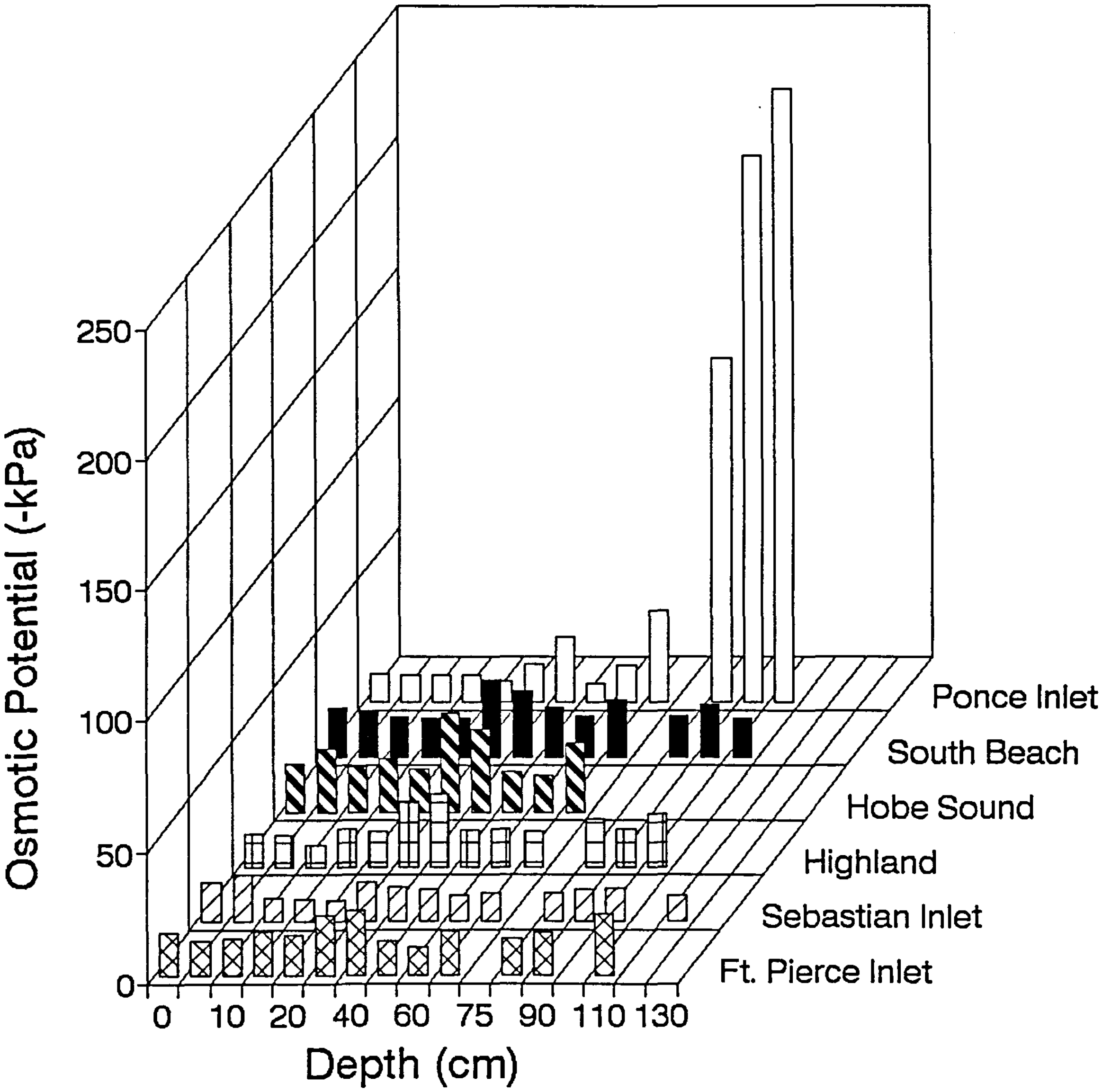

Figure 35. Osmotic potential as a function of depth for each of the natural beaches

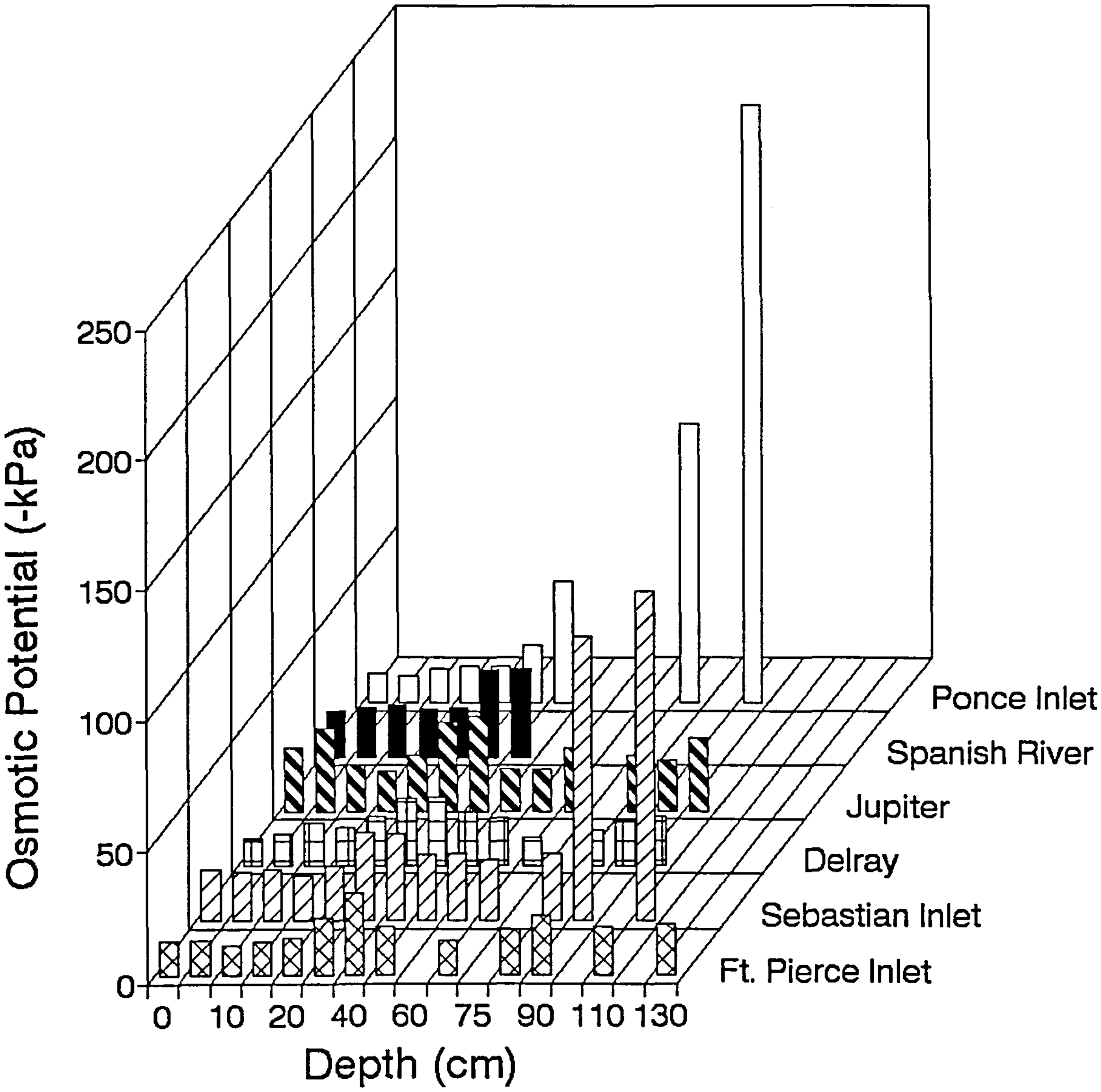

Figure 36. Osmotic potential as a function of depth for each of the renourished beaches

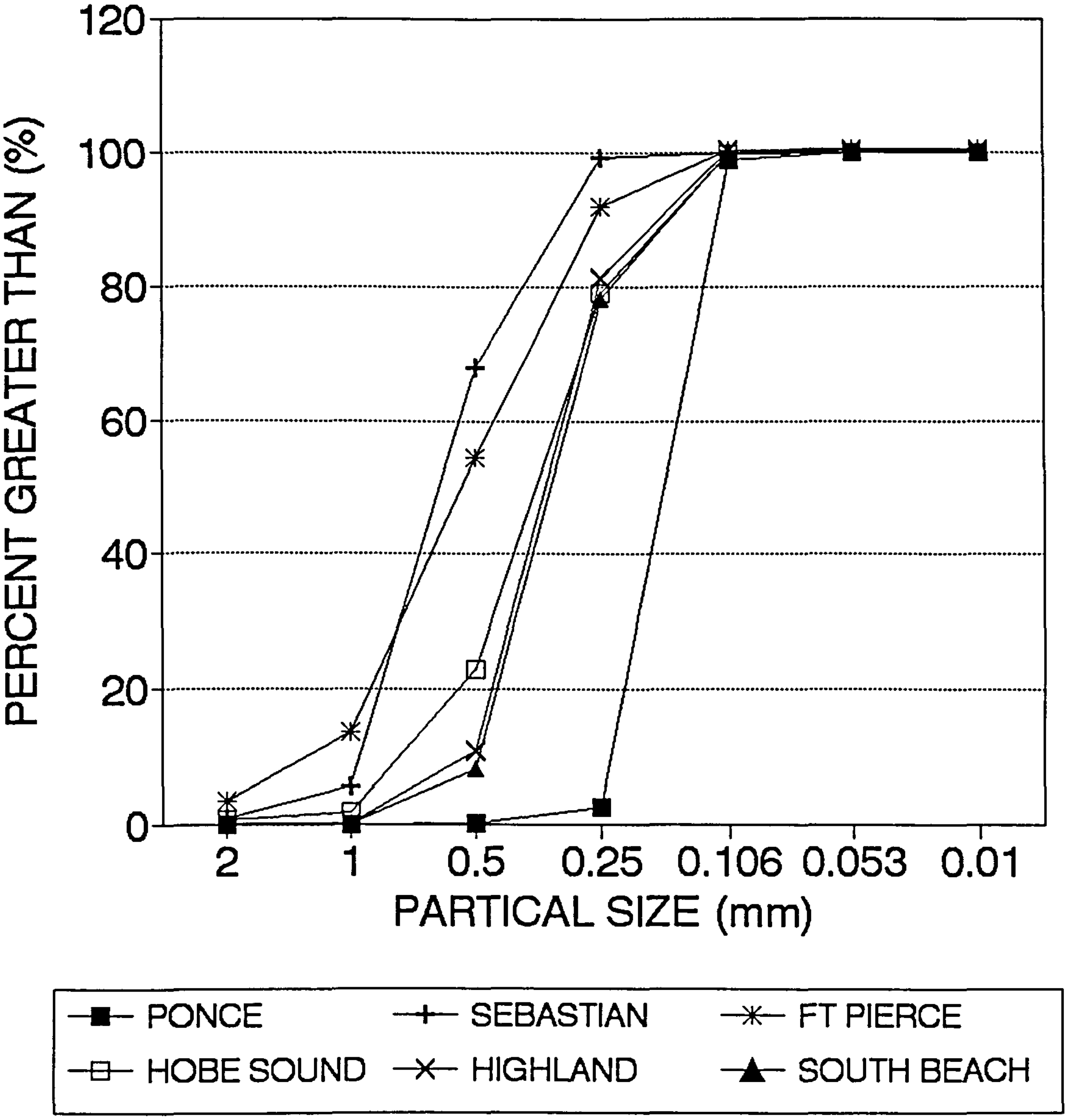

Figure 37. Particle size distribution for natural beaches listed as a cummulative percent

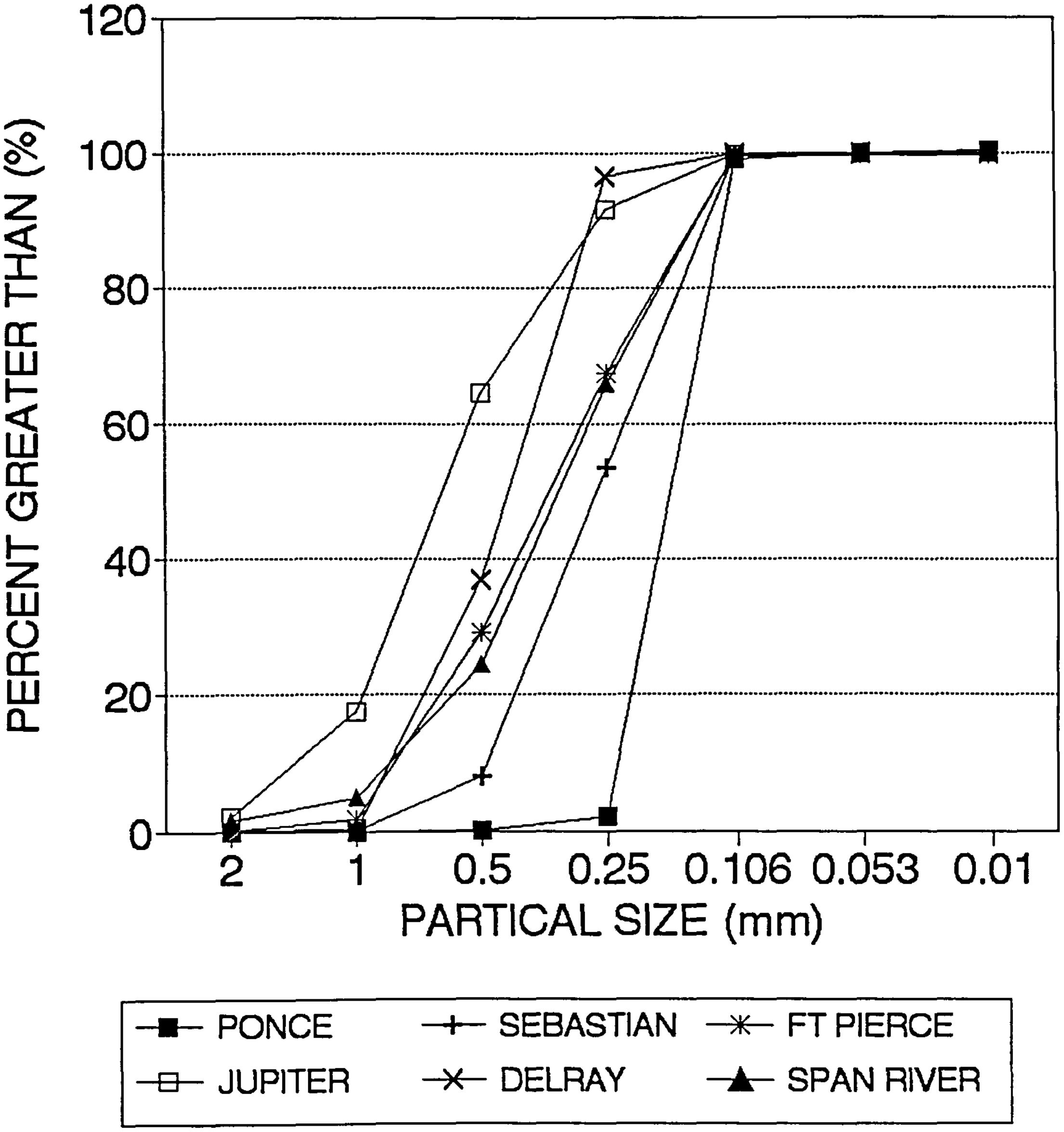

Figure 38. Particle size distribution for renourished beaches listed as a cummulative percent

Table 5. Mean weight diameter averages and standard deviations (the natural beach is listed first for each pair)

Beach	Average	Std.
Ponce Inlet South	0.18	0.0012
Ponce Inlet North	0.18	0.0011
Sebastian Inlet North	0.70	0.0233
Sebastian Inlet South	0.43	0.1074
Fort Pierce Inlet North	0.44	0.1386
Fort Pierce Inlet South	0.62	0.1368
Hobe Sound NWR	0.51	0.0420
Jupiter Beach	0.75	0.0528
Highland Beach	0.38	0.0112
Delray Beach	0.47	0.0617
South Beach Park	0.47	0.1468
Spanish River Park	0.47	0.0408
Natural	0.45	0.1784
Renourished	0.49	0.1900

were also significant differences at the $P < 0.01$ level for gravimetric water content values as well as volumetric water content values. No other tests proved to be significant.

Beach Description

Ponce Inlet south and north

Ponce Inlet beach south is 100 meters wide. The high tide marks are 48 meters from the dunes. Site 6 is on line with Florida Department of Natural Resources (FDNR) monument R-150. Ponce Inlet beach north is 162 meters wide, with 17 meters of dune with a small amount of growth present. A

Table 6. Particle color, hue, and chroma/value for each beach in the wet and dry state (the natural beach is listed first for each pair

Beach	State	Hue	Chroma/Value	Color
Ponce Inlet South	dry	5Y	8/1	white
	wet	2.5Y	6/2	light brown gray
Ponce Inlet North	dry	2.5Y	8/0	white
	wet	10YR	6/1	light gray to gray
Sebastian Inlet North	dry	10YR	8/2	white
	wet	10YR	6/3	pale brown
Sebastian Inlet South	dry	5Y	8/2	white
	wet	5Y	6/2	light olive gray
Ft. Pierce Inlet North	dry	5Y	8/3	pale yellow colored
	wet	10YR	6/3	pale brown
Ft. Pierce Inlet South	dry	10YR	7/1	light gray
	wet	10YR	6/3	pale brown
Hobe Sound NWR	dry	2.5Y	8/2	white
	wet	10YR	6/2	light brown gray
Jupiter Beach	dry	7.5YR	5/0	gray
	wet	5Y	4/1	dark gray
Highland Beach	dry	5Y	7/1	light gray
	wet	2.5Y	5/2	gray brown
Delray Beach	dry	10YR	8/2	white
	wet	10YR	6/3	pale brown
South Beach Park	dry	2.5Y	7/2	light gray
	wet	10YR	5/1	gray
Spanish River Park	dry	5Y	6/1	light gray to gray
	wet	5Y	5/1	gray

Table 7. Analysis of variance averages, standard deviations, F values, and F probabilities for each of the tests that were performed on the two beach types

Test Variable	Beach	Average	Std	F Value	F Prob.
Gravimetric water content	Natural	4.37	2.07	32.03**	0.0024
	Renourished	5.65	3.62		
Volumetric water content	Natural	6.69	3.01	27.99**	0.0032
	Renourished	8.46	5.21		
Characteristic curves	Natural	0.16	0.13	8.60*	0.0326
	Renourished	0.17	0.14		
Bulk density	Natural	1.56	0.06	11.45*	0.0196
	Renourished	1.52	0.06		
Saturated hydraulic conductivity	Natural	0.0324	0.014	2.14	0.2037
	Renourished	0.0221	0.009		
Water potential	Natural	-6.85	2.42	1.72	0.2462
	Renourished	-7.72	3.92		
Osmotic potential by month	Natural	-24.42	37.61	0.29	0.6122
	Renourished	-18.31	14.14		
Osmotic potential by depth	Natural	-23.12	36.23	0.74	0.4289
	Renourished	-27.29	32.08		
Particle size distribution	Natural	14.29	23.41	2.68	0.1528
	Renourished	14.28	20.22		
Mean weight diameter	Natural	0.448	0.178	0.29	0.6149
	Renourished	0.486	0.190		

* significant at 0.05 level.

** significant at 0.01 level.

second dune is at 36 meters, the high tide line is at 107 meters, and the water is at 162 meters. Site 6 is on line with FDNR monument T-147.

Sebastian Inlet north and south

Sebastian Inlet beach north is 32 meters wide with the high tide marks 24 meters from the dune area. Site 6 is 25 meters north of the northernmost beach access between two beach markers, OK and KO, which are surfing markers. Sebastian Inlet beach south is 45 meters wide with high tide marks located 34.5 meters from the dunes. Site 6 is on line with FDNR monument R-01.

Fort Pierce Inlet north and south

Fort Pierce Inlet beach north is 45 meters wide with high tide marks 32 meters from the dune area. Site 6 is on line with FDNR monument R-32. Fort Pierce Inlet beach south is 33 meters wide with high tide marks 24 meters from the dune area. Site 6 is on line with FDNR monument R-35.

Hobe Sound NWR and Jupiter

Hobe Sound NWR beach is 40 meters wide from the wash zone to the heavily vegetated dune with an average high tide mark at 20 meters from the dune. Site 6 was located 50 meters north of monument number R-76A and 2 meters west of the normal high tide line. Jupiter Beach is 25 meters wide from the sea wall to the wash zone with a high tide mark at 13 meters from the sea wall. Site 6 was 2 meters west of the high tide marks in line with monument number R-99.

Highland and Delray beaches

Highland Beach is 35.5 meters wide with 4 meters of dune and 19.5 meters to the high tide marks. Site 6 is on line with the southern corner of a green house that is across from Town Hall of Highland Beach. Delray Beach is 60 meters wide with high tide marks 45 meters from the dune area. Site 6 is 10 meters north of life guard stand N1 across from the Governor's Mansion.

South Beach and Spanish River parks

South Beach Park is 52 meters wide with high tide marks 36 meters from the dune area. Site 6 is on line with FDNR monument R-216 and life guard stand number 6. Spanish River Park is 62 meters wide with a drop off 40 meters from the dune area. The drop off is 4.5 meters wide and the high tide is 46.5 meters from the dune area. Site 6 is midway between lifeguard stands 18 and 19.

DISCUSSION

Literature Review

The natural nesting environment of sea turtle eggs has not been extensively described. Bustard and Greenham (1968) compared successful and unsuccessful sea turtle nests by measuring water content, salinity, and tree rootlet density in the nest cavity. Turtles had the greatest success in constructing a nest when the sand was moist and many tree rootlets were present. Salinity did not differ between successful and unsuccessful nesting attempts. Ackerman (1977) evaluated the gas exchange for sea turtle eggs in man-made nests, constructed from natural sands, by monitoring the change in partial pressures of oxygen and carbon dioxide throughout incubation. During the incubation period the depletion of oxygen and release of carbon dioxide by the eggs cause relative partial pressures of these gases to change over the length of incubation. Stancyk and Ross (1978) analyzed sand from green sea turtle nesting beaches on Ascension Island for organic content, water content, calcium carbonate content, pH, color, and grain size distribution. There were no correlations found between nesting frequency and any of the variables observed. Johannes and Rimmer (1984) looked at characteristics of nesting beaches of green turtles noting that lower salinity and shelter from prevailing winds distinguished nesting beaches from non-nesting beaches.

Mortimer (1990) studied the influence of beach characteristics on nesting behavior and clutch survival of green turtles. Mortimer measured particle size distribution, mean diameter, sorting coefficient, particle shape, electrical conductivity, water content, water potential, and porosity. Highly negative water potentials were correlated with high hatchling mortality. Maloney, Darian-Smith, Takahashi, and Limpus (1990) studied the natural environment of loggerhead sea turtle nests by examining gas exchange, water table depth, and temperature. The results proved to be consistent with previous studies. Partial pressures of oxygen and carbon dioxide changed with duration of incubation and metabolic heating was evident.

The nest environments of many reptiles have also been characterized to some extent and may be compared to the nest environment of sea turtles. Lutz and Dunbar-Cooper (1984) characterized the nest environment of the American Crocodile by monitoring changes in temperature, soil water, and gaseous resistance of the nest soil. Particle size distribution was also analyzed. The nest temperatures and gaseous conditions were similar to that of *Chelonia* nests as reported by Ackerman (1977). The soil water and the particle size distribution were similar to previous studies. Packard, Paukstis, Boardman, and Gutzke (1985) described the hydric properties of *Chelydra serpentina* nests using matric water potentials. The water potentials ranged from 0 to -2750 kPa over the length of incubation that was observed. Ratterman and Ackerman (1989) studied the soil water potential near *Chrysemys picta* nests and also evaluated the soil water content profile near these nests. Matric water potential averaged -29 kPa and ranged from 0 to -77 kPa. Soil water content for the loam soil was found to be between 10 and 20% at the level of the nests.

Another important study was conducted by De Jong (1979). The study was not on sea turtles but on beach species of plants. It is an important study because the depths and the measurements made are similar to those needed to assess the environment of sea turtles. He sampled depths of 10, 30, and 100 cm, assessing particle size distribution, salinity, and water potentials. He concluded that the soil remained moist at 100 cm but that in rainless periods it dried out at the shallower depths. The salinity of the water table was always less than 3% of seawater and the concentration decreased landward of the ocean. The osmotic potential was between 0 and -1000 kPa at 100 cm. The osmotic potential was substantially more negative at the lower depths in the rainless periods.

The process of renourishment has only begun to be studied as to the effects such a process has on the incubation environment of sea turtles. The materials that are used in the renourishment process were the original focus of most studies. Nelson and Mayes (1986) studied the shear resistance, particle size distribution, and particle shape of a material used at St. Lucie Inlet. Some turtles encountered difficulties when trying to excavate nests in this particular material. Parkinson (1990) assessed particle size distribution, color, mean diameter, and sorting coefficient of an offshore sand deposit to determine if the sand should be used for the nourishment of the south side of an inlet. In this particular case, the sand was considered to be compatible with the material that was present. Ryder (1990) compared a natural nesting beach to a renourished beach by recording the compaction and the temperature of the two types of beaches while comparing the hatching success, length of incubation, and percent of false crawls on the two beach types. She concluded that there were no differences that affected the nesting of the turtles nor the hatchability of the eggs once deposited.

Natural Environment

In order to assess the impact of renourishment on the environment of sea turtle nesting beaches it was necessary to characterize the natural environment. I examined the hydric and physical properties of the natural beaches. The hydric properties will determine the availability of water to the incubating sea turtle eggs. The hydric environment present will be able to be explained by the physical characteristics of the sand on a natural beach.

In order to define the hydric properties of a beach, the variables needed were gravimetric water content, volumetric water content, depth to the water table, hydraulic conductivity, osmotic potential, and matric water potential. This data allowed me to determine the amount of water that would be available in any beach for a sea turtle egg. The variables that were chosen to define the physical properties of these beaches are particle size distribution, mean particle size, bulk density, and color. Each of these variables allowed me to determine the water holding capabilities of the sand as well as giving me insight as to what type of thermal environment is available to the turtle eggs.

Because many factors influence hydric climates, it is important to understand how each of the above variables interact and effect the hydric climate. Gravimetric water content is a relative term used to describe the amount of water that is held in a substrate. Once the gravimetric water content has been determined, the beach can be compared in time and space with respect to its own wetness. Volumetric water content is similar but also depends on the changes that might have occurred since the last sample. Volumetric water content is more sensitive to changes in compaction because the measurement is on a per unit volume basis. The depth to the water table allowed me to determine how deep in the substrate eggs can be buried without encountering sand that is fully saturated. Fully saturated sand, as well as sand that is near saturation, will not allow proper gas exchange for the developing hatchlings, because the pore space is filled with water instead of air (Ackerman, 1977). The saturated hydraulic conductivity along with the hydraulic gradient present will predict the speed and ease that water will move through the beach. Water potentials can be used to determine the amount of water that is available to the eggs at any instance in time. The total water potential is composed of three parts: the gravitational water potential, the osmotic water potential, and the matric water potential. The gravitational water potential is a relative term that predicts the flow of water from a higher elevation to a lower elevation because of gravitational forces. The reference point is arbitrary and therefore it is not very useful. The osmotic potential will only be a factor in water movement where a semipermeable membrane is present (Hillel, 1982). The shell and membrane of a sea turtle egg may act as a semipermeable membrane. Water in a system that contains a semipermeable membrane will flow towards the body that has the higher osmotic potential or the body with a greater concentration of solute. The reference or zero point for osmotic potential is pure water. If sea turtle eggs were incubated in a salt free environment, the free water would move towards the sea turtle eggs throughout incubation. The matric water potential is the affinity that the particles have for the water or an indication of how tightly the water is held in the substrate by capillary forces. Matric water potential is not a relative but an absolute condition of the substrate and it can be influenced by many factors, some of which have already been explored. The reference point is a surface of free water usually the water table. Therefore the measurement of osmotic and matric water potentials will allow me to determine the amount of water available to the sea turtle eggs. Also, the osmotic and matric water potentials will allow me to determine which beaches will have more or less water available to the incubating sea turtle eggs.

Many of the physical properties that were measured can be used to explain why the observed water potentials were present. The particle size distribution as well as mean weight diameter will give insight to the pore sizes and their relative number, and this will estimate how tightly water will be held by the particles. The bulk density will help determine the pore size and spacing and indicate how tightly the particles are packed together; this will again help estimate how much water can be held in the substrate. The bulk density of the particles will not only assist in predicting the water potential, but will also give insight into the compaction of the sand and the ease with which a female turtle will be able to dig and excavate a proper nest chamber. The sand color will not have any effect on the female turtle but it may affect the hatchlings. The color of the beach will influence the amount of heat that is absorbed at the surface of the beach. Darker beaches will absorb greater amounts of radiation and this will cause this type of beach to be warmer than a lighter colored beach. The temperature of the beach will affect the temperature of the sea turtle nests that are laid in that beach. These are important consequences because sea turtles have temperature dependent sex determination (TSD) (Yntema and Mrosovsky, 1980 and 1982). Therefore sex ratios may be altered by being exposed to a beach of a different color.

The hydric environment of a natural sea turtle nesting beach can be described by using the concepts of soil water distribution established by soil physicists (Keulen and Hillel, 1974; Hillel and van Bavel, 1976; Koorevaar et al., 1983; Campbell, 1985; and Ackerman, 1991). The proposed concepts predict the presence of four zones which can be differentiated by the relative amount of water in each of the zones. The first zone is the dry zone that is present at the surface of the soil and, in the absence of rain, is air dry. There is a predicted zone between the dry and humid zone that is the transition zone where the soil is neither dry nor at the 99.99% relative humidity level. The next zone predicted in theory, is the humid zone in which the water is held by the matric potential of the material, where the humidity in this zone is greater than 99.99%, but not 100%. The humid zone extends down to the capillary fringe of the water table. At the capillary fringe of the water table the soil quickly approaches saturation and the relative humidity is now at 100%. The saturated zone is the fourth and final zone.

Many forces are acting that cause these zones to exist. The thickness of the dry layer will be dependent on the length of time between precipitation events. This dry layer is produced by evaporation at the surface and internally by drainage. This dry zone was evident on many of the beaches (Figure 3-26). Initially the process of drying is rapid, then as time progresses the surface dry layer protects the underlying soil from rapid evaporation. The second force that acts to set up the dry layer is the draining of water from the surface to lower depths. The thickness of the dry layer will therefore be dependent on the structure of the materials that are present in the soil and on the length of time between precipitation events and the depth to the water table.

The next zone, the transition zone between the dry and humid layers, is usually the least expansive zone and therefore it is not seen in all the beaches, but was observed in some beaches (Figures 3, 7, 9, 16, 17, 18, 20, and 21).

Forces acting to determine the width of the transition zone are the same forces that determine the width of the dry zone. The next zone is the humid zone and the factors that determine its width are matric water potential and the depth of the water table. On many beaches there is a clear presence of a humid layer (Figures 4, 5, 6, 10, 13, 14, 16, 20, 22, and 25). This is the zone where sea turtles lay their eggs, at depths of 25 to 40 centimeters to the nest top and 45 to 65 centimeters to the bottom (Coker, 1906; Caldwell, 1959). Depths of 20 and 30 centimeters are in the humid zone in all of the beaches examined. The humid zone is relatively constant in gravimetric water content throughout its depth. Therefore, it is reasonable to assume that these values are representative of the environment that a sea turtle egg would experience. The fourth and final zone encountered is the full saturation zone. This zone has been recorded in some of the beaches studied (Figures 10, 14, 22, and 26).

Natural Beaches Compared to Renourished Beaches

The natural beaches show a wide range for many of the variables that were analyzed. This is important because this will determine if a renourished beach falls within the range of the natural beaches. If the renourished beaches are within the range of the natural beaches with respect to all variables then they will be considered compatible. I do not claim that the variation that was seen on the beaches that I studied is the entire range that will be acceptable for sea turtle nesting, rather that the renourished beaches are much less likely to have great impacts on the females and hatchlings if they fall within the same range as the natural beaches studied.

The differences between the natural and renourished beaches can now be examined in greater detail. The gravimetric water contents was significantly higher by approximately 1% on the renourished beaches, while the volumetric water content was significantly higher by approximately 1.5-2% on the renourished beaches (Table 7). The depths used for this comparison were 20 and 30 centimeters. These depths were used because they fall near the top of where the nest cavities would be and also the greatest number of samples were taken at these depths. Therefore, the averages across transects would always contain at least three numbers. This overall difference between natural and renourished beaches is likely to be due to a difference in their physical characteristics or their construction. In the construction of a renourished beach, the material is deposited without the layering and sorting that occurs in the formation of a natural beach (Carter, 1988).

In the comparison of gravimetric water content with depth through transect 2 of the beaches, the renourished beaches were not always wetter. On Hobe Sound NWR, a natural beach, the gravimetric water content is lower than at Jupiter beach (Figures 3-6). Jupiter beach is more elevated than Hobe Sound NWR and this would tend to cause the beach with a higher elevation to have a lower gravimetric water content at any given depth due to differences in water table depth. Despite the differences in elevation Jupiter still has the higher gravimetric water content in June, July, and August. At Sebastian Inlet the differences between the natural and renourished beaches are enhanced by the natural beach being elevated compared to the renourished beach (Figures 7-10). Therefore the water table is much lower on the natural beach and lower gravimetric water content would be expected. This will account for the sometimes greater than 5% higher gravimetric water content observed on the renourished beaches.

At Fort Pierce Inlet the renourished beach is only wetter in May (Figures 11-14). This difference may be due to rain in other months or it could be due to the difference in the two size classes of particles seen here. The difference in the gravimetric water contents seen at Delray and Highland beaches are most prevalent in May and July (Figures 15-18) and again rain may have increased the Highland gravimetric water content, or the difference may be due to a structural difference as Delray beach is a highly elevated beach. Spanish River Park and South Beach park show the renourished beach being wetter in three of four months. The month where the trend is reversed is likely due to rain at South Beach Park and not at Spanish River Park (Figures 19-22). Ponce Inlet has the renourished beach being wetter for two months and in one of these months it is only wetter down to 40 cm (Figures 23-26). The reason being that the water table on the natural beach is closer to the surface than that seen on the renourished beach.

The next comparison is the natural beaches averaged across all transects and renourished beaches averaged across all transects (Figures 27-29). In this instance, the renourished beaches are wetter in transects 1 and 2 by 0.5%, while on transect 3 the natural beaches are wetter by 0.25%. These differences as one moves toward the water line can be explained by the structure of the beaches and the sampling grid setup. The renourished beaches tended to be large and it was easy to get three rows of samples. However, some of the natural beaches were very narrow and I was forced to take the samples for transect 3 very near the water. This would account for the differences in wetness, because as one moves toward the water, the gravimetric water content increases.

These differences in gravimetric water content may be caused by differences in physical or hydric properties, therefore the results of the other tests must be examined. The first of these variables that will be discussed is the depth to the water table. The water table was only reached on

4 beaches because our methods would only allow us to sample to a depth of 120 centimeters. Therefore it is difficult to compare the depth to the water tables on natural versus renourished beaches. It should be noted that when the water table is encountered the increase in gravimetric water content is abrupt (Figures 10, 14, 22, and 26). Because not all water tables were encountered, there are still some questions to be answered as to whether the differences seen can be attributed to water table depth differences. A greater effort should be made in the future to reach the water table. The saturated hydraulic conductivity of natural and renourished beaches were not significantly different (Table 7). Therefore the differences observed between the natural and renourished beaches is not due to different saturated flow properties of the different sand types. The particle size distribution and the mean particle size were compared between natural and renourished beach types and no differences were observed (Table 7). Therefore it is logical to conclude that the sizes chosen for renourishment were comparable to the size classes present on the natural beaches. Future renourishment projects should also pay close attention to particle size. The bulk densities of natural and renourished beaches were compared and significant differences existed (Table 7). These differences would infer that the natural beach is more highly compacted. The reason for this observation is likely due to the length of

time the natural beaches have existed compared to renourished beaches. The natural beaches have been worked and reworked by the water and other factors, including human usage. As time passes, the particles are shifted and compressed as they fall into an optimum configuration, while the renourished beaches have been deposited all at once and have not had the time to be sorted and reworked as the natural beaches have. The overall effect that this will have is that the renourished beaches will have greater pore space and therefore the ability to hold greater amounts of water; this is one reason that a higher gravimetric water content could be observed on the renourished beaches. The characteristic curves of natural and renourished beaches were compared next and significant differences were observed (Table 7). These differences will partially explain the differences in gravimetric water contents observed earlier. Using the overall averages for characteristic curves (Figure 32), it can be demonstrated that a difference in gravimetric water content from the humid layer can produce little or no difference in water potential. This is important because at a given instant the water potential and not the gravimetric water content will determine the availability of water to the eggs.

The water potentials observed on these beaches were affected by the differences in bulk densities and characteristic curves. Examining the total water potential is impractical since the total water potential is composed of more than one part. The total water potential must be analyzed component by component. The osmotic and matric water potentials were measured on the two beach types. Osmotic potentials were compared between natural and renourished beaches both at depths and monthly. No differences were found (Table 7). The matric water potential of natural and renourished beaches was assessed. The matric water potentials observed on natural and renourished beaches were not different either (Table 7). Therefore, the differences observed in the gravimetric water content values were offset by the differences observed in bulk densities and characteristic curve values to produce no differences in the water potentials.

The overall differences observed between natural and renourished beaches, with respect to the hydric environment available to sea turtle eggs, appear to be small. The renourished beaches studied here provided a very similar environment to that of the natural beaches with respect to the hydric and physical properties.

One concern left unattended is the difference in color observed on natural and renourished beaches. Dark colored material was only found on the renourished beaches. The absorbance of light by dark materials is higher than the absorbance for lighter colored materials and therefore the renourished beaches would be warmer than the natural beaches. Because sea turtles have temperature dependent sex determination, the temperatures present on each of the beach types is very important (Yntema and Mrosovsky, 1980 and 1982). If the renourished beaches are warmer they may be producing hatchlings that are heavily skewed toward the female sex. Temperature studies will have to be conducted in order to assess if there are truly difference in the thermal environment of the eggs on natural and renourished beaches.

The final test as to whether or not a renourished beach is compatible with a natural beach is if sea turtles use these renourished beaches as incubators for their eggs and the eggs hatch. Numbers were made available to me from Gumbo Limbo Nature Center in Boca Raton, Florida for one of the beach pairs presented here. The number of nests per mile were 140/mile on Spanish River Park, the renourished beach, and 190/mile on South Beach Park, the natural beach. In a study by Broadwell (1991), the hatching success is slightly higher on the renourished beach. More sea turtles are using the natural beach, but other factors such as shelter from prevailing winds, etc. have not been assessed. The ideal experimental procedure would be to study the same beach as a natural beach and after renourishment. This would eliminate the other factors. Renourished beaches are used by sea turtles and the hatchlings survive. Therefore, renourished beaches are a viable resource for sea turtles in the absence of a natural beach.

Conclusions

1. Renourished beaches had a higher gravimetric water content than natural beaches.
2. There were no differences in the matric and osmotic water potentials of natural and renourished beaches.
3. Water potentials and not water contents will dictate the amount of water available to eggs at any instance in time.
4. The renourished hydric environment studied here parallels the natural hydric environment.
5. Color differences do exist between natural and renourished beaches.
6. The effects of these color differences on the temperatures found on natural and renourished beaches needs to be examined.
7. Sea turtles nest on renourished beaches and their hatchlings survive.

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