6.0 SOILS

6.1 Introduction

A variety of soil types are found in the Everglades study area. Higher elevation rockland occupies the ridge along the southeastern urban coast, while soils in BCNP to the west are primarily sandy. The wetland soils of the central Everglades are primarily organic Histosols and Inceptisols (Gunderson and Loftus 1993). Another major soil type found within Everglades wetlands is a calcitic mud, commonly referred to as marl. It is commonly found in the shallower peripheral marshes of the Everglades subjected to shorter periods of surface water inundation (Jones 1948).

Peat and marl soils are derived in wetland regions from decaying plant matter. Stephens (1956) reported that the Florida Everglades once contained the largest single body of organic soils in the world, covering over 8,000 km^2 (3,100 mi^2). These peats and mucks accumulated to a thickness of up to 6 meters (17 feet) in what is now EAA (Stephens and Johnson 1951). The origin and perpetuation of peat and marl soils is greatly dependent upon water depth and resulting wetland vegetative communities. Soil loss or composition changes due to diminished surface water inundation may in turn result in altered vegetative communities and subsequent changes in soil type and depth as this new plant community eventually decomposes into soil.

Soil is an important characteristic of an ecosystem and soil preservation is an important aspect of ecosystem protection. The South Florida Ecosystem Restoration Task Force has adopted a series of success indices in order to define restoration goals, track ecosystem status, and measure restoration effectiveness. The Science Subgroup of the Task Force established 20 indicators and success criteria. Among these is “restoration of the natural balance of organic soil accretion and subsidence throughout the system (reduce subsidence)” (Science Subgroup 1997). Among the 23 planning objectives adopted by the Florida Governor’s Commission for a Sustainable South Florida for the USACE Central and Southern Florida Re-Study is “restore more natural organic and marl soil formation processes and stop soil subsidence” (FDCA 1996; USACE 1994).

6.2 Marsh Grid

6.2.1 Soil Thickness and Subsidence

Peat and muck soils are subject to subsidence and surface elevation loss when drained. Stephens (1984) states that soil subsidence and the resulting loss of surface elevation are due to six processes: (1) shrinkage due to desiccation; (2) consolidation by loss of the buoyant force of groundwater; (3) compaction by tillage; (4) wind erosion; (5) burning; and (6) biogeochemical oxidation. Oxidation and burning are considered the dominant forces, and are irreversible. Early in the twentieth century the peat soils of the 3,000-square-kilometer (700,000-acre) EAA were drained to facilitate agricultural production. Stephens (1956) reported that conditions were conducive for peat formation until 1906, when the first efforts began to cut canals from Lake Okeechobee through the EAA to the coast. The process of soil accumulation was reversed within the EAA and subsidence began. It soon became apparent that drainage was contributing to soil subsidence. The first soil subsidence transects within the agricultural lands were established in 1913. This led to efforts by the US Department of Agriculture and others to understand and minimize the subsidence of EAA soils. Subsidence within the EAA and efforts to control it on these agricultural lands are well documented (Clayton et al. 1942, Jones 1948, Stephens and Johnson 1951, Stephens 1969, Stephens 1984, Glaz 1997).

In contrast, subsidence of peat soils within the protected Everglades is poorly documented. The only historic images of soil thickness in the Everglades were published by Davis (1946) and Jones (1948) (Davis image scanned to generate a computer image and presented as Figure 6.1). They reported peat thickness as ranging from 0 to over 4 m (12 feet). Subsidence in the Everglades is due largely to changing water management practices during this century. The major canals draining the EAA extended southeast through the Everglades to the Atlantic Ocean and were completed by 1917. However, unimpeded surface water flow from the EAA south through the Everglades to ENP, Florida Bay, and the Gulf of Mexico occurred until the late 1950s, when levees were constructed forming the southern boundary of the EAA. During the early 1960s additional levees were completed that partitioned the Everglades into the five WCAs (Figure 6.2) (Light and Dineen 1994). By this time Everglades surface water conditions, flow, and inundation periods had been greatly altered.

A krig of soil thickness documented by the present study at 479 sampling sites during 1995 and 1996 is presented in Figure 6.1. Soil thickness was determined by inserting a metal rod, marked in tenths of feet, to the point of refusal. The rod could be lengthened by screwing on additional sections to reach a maximum length of 12 feet. Soil thicknesses throughout the study area range from 0 to over 4 m (12 feet) (Figures 6.1 and 6.3, Table 6.1). Soil depths greater than 12 feet (about 4 m) in LNWR could not be determined due to the maximum length of the sampling rod. Davis (1946) reported peat thicknesses in this area in excess of 12 feet. The deepest soils are the peat deposits within LNWR with a mean soil thickness 2.6 m (8.7 feet). Mean soil thickness for remaining portions of the study area were 1.3 m (4.3 feet) in WCA2, 0.4 m (1.5 feet) in WCA3A north of Alligator Alley (I-75), 0.8 m (2.8 feet) in WCA3 south of I-75, 0.4 m (1.3 feet) in ENP, and 0.4 m (1.2 feet) in BCNP. The deepest peat in the Everglades outside of LNWR is within WCA2 and the southern portion of WCA3, areas which receive longer surface water inundation.

Table 6.1 Summary statistics for soil parameters by subarea. Mean plus or minus standard deviation is presented. The number of samples is provided in parenthesis.

Subarea	**Soil Thickness (m)**	**Soil Thickness (ft)**	**Bulk Density (g/cc)**	**Percent Organic Matter**
Rotenberger/Holeyland	0.9±0.5 (18)	2.9±1.6 (18)	0.21±.06 (15)	76±16 (18)
WCA1	2.6±0.8 (41)*	8.7±2.6 (41)*	0.07±.02 (41)	92±7 (41)
WCA2	1.3±0.4 (42)	4.3±1.5 (42)	0.11±.04 (42)	85±6 (42)
WCA3	0.7±0.4 (180)	2.4±1.4 (180)	0.19±.16 (177)	71±23 (180)
WCA3 North of I-75	0.4±0.3 (52)	1.5±1.1 (52)	0.30±.18 (50)	47±27 (52)
WCA3 South of I-75	0.8±0.4 (128)	2.8±1.3 (128)	0.15±.12 (127)	77±19 (128)
ENP	0.4±0.3 (152)	1.3±1.0 (152)	0.34±.19 (153)	38±25 (153)
BCNP	0.4±0.3 (46)	1.2±0.9 (46)	0.77±.35 (46)	17±15 (46)
ENTIRE SYSTEM	0.8±0.8 (479)	2.7±2.5 (479)	0.28±.26 (475)	59±31 (480)

* soil thickness at some locations within WCA1 exceeded the maximum soil probe length of 12 feet

Figure 6.4 presents the difference in peat thickness throughout the Everglades as reported by the present study (1995 to 1996) and Davis (1946). The difference was determined by subtracting the soil thickness indicated by the 1946 contour map from the 1996 measured soil thickness at each of the 479 EPA sample stations (Figure 6.1). Davis (1946) reports peat thickness in 2-foot (0.6-meter) intervals and does not provide raw data. Consequently, soil thickness differences from 1946 to 1996 are presented as a maximum and minimum, depending upon whether the high or low threshold value within each 2-foot (0.6-meter) contour interval from Davis (1946) is used. Calculation of soil loss during the last 50 years indicates that the portion of WCA3 north of Alligator Alley has lost between 39% and 65% (6.0×10^8 m^3) of its soil. Davis (1946) reports that this area had 3 to 5 feet of peat in 1946, while the present study found only 1 to 3 feet of soil, with less than 1 foot in some areas. The worst case estimate indicates that the southeastern part of WCA3 (WCA3B) and the northeast Shark Slough portion of ENP may have lost up to 0.9 m (3 feet) of soil or a loss of 53% of volume in Northeast Shark Slough, and a loss of 42% of volume in WCA3B. These three portions of the Everglades all have been subjected to less surface water inundation since completion of the WCAs about 40 years ago. Estimates of soil volume change for the Everglades Protection Area during the last 50 years vary from an average loss of 5.4×10^8 m^3 (11% loss in soil volume) to a maximum of 17×10^8 m^3 (28% loss in volume).

6.2.2 Percent Organic Matter

A krig of soil percent organic matter for 0 to 10 cm observed during 1995 and 1996 at 480 points within the marsh is presented in Figure 6.5. Percent organic matter at sampling sites ranged from <1% to 97% (Table 6.1, Figures 6.3 and 6.5). Peat soils are highly organic, while marl soils and sandy soils are primarily mineral. Highest organic matter was found in the peat soils within LNWR with a mean of 92 ± 7%. WCA2A, the Rotenberger Tract, and WCA3 south of I-75 also had soils exceeding 75% organic matter. These highly organic zones coincide with the current deeper soil portions of the system. Soils in the ENP, which include the peat soils within the Shark Slough trough as well as the marl soils of adjacent shorter hydroperiod areas, had a mean organic content of 38 ±25%. The area of maximum soil loss within WCA3 north of I-75 had a mean soil organic matter content of 47%, the lowest within the WCAs. The sandy soils of BCNP had a mean percent organic matter of 17 ±15%. Portions of ENP outside the Central Shark Slough trough also had lower organic matter content, often in the 10% to 20% range.

Table 6.2 Everglades soil volumes by subarea reported for 1946 and 1995 through 1996. The 1946 data are from Davis (1946), and 1995 through 1996 data are from the present study. Volumes are reported as cubic meters x 10^8. Note: A minus (-) indicates soil loss while a plus (+) indicates soil gain.

Subarea	1946 Thickness (feet)	1946 Volume	1995–1996 Volume	Volume Minimum Change (%)	Volume Maximum Change (%)
WCA1	7.9±1.9	11–15	14.5	-0.2 (-1%)	+3.0(+23%)
WCA2	4.9±1.4	6.8–10	7.31	+0.53 (+8%)	-2.7 (-27%)
WCA3AN	3.4±1.0	5.2–9.2	3.21	-2.0 (-39%)	-6.0 (-65%)
WCA3AS	3.0±1.5	8.6–16	11.3	+2.7 (+32%)	-4.5 (-28%)
WCA3B	4.8±1.4	3.4–5.1	2.94	-0.4 (-13%)	-2.1 (-42%)
NESS	2.4±1.7	1.6–3.2	1.49	-0.1 (-0.1%)	-1.7 (-53%)
ENP	0.83±0.65	0.81–4.5	4.02	+3.2 (+400%)	-0.4 (-9%)
TOTAL	**3.4±2.5**	**38–62**	**44.8**	**+6.9 (+18%)**	**-17.7 (-28%)**

6.2.3 Bulk Density

A krig of soil bulk density for 0 to 10 cm as sampled in 1995 and 1996 at 475 marsh points is presented in Figure 6.6. Bulk density ranged from 0.05 to 1.50 g/cc. The highly organic peat soils of LNWR had the lowest bulk density with a mean 0.07 ±0.02 g/cc as compared to the mineral soils of BCNP, which had a mean of 0.77 ±0.35 g/cc (Table 6.1, Figure 6.3). Bulk density in WCA3 north of Alligator Alley had an average of 0.30 g/cc, the highest in the WCAs. Within the WCAs, this portion of northern WCA3 had the lowest organic matter content, the highest bulk density, and the greatest soil loss. All of these observations are consistent with formerly deeper peat soils being subjected to drier conditions due to water management changes over the last 50 years. Surface water inundation has been reduced, soils have subsided, and the resulting surface soil has become less organic. There was a very strong negative linear correlation (r^2 =0.84) between the logarithm of bulk density and percent organic matter (Figure 6.7). These bulk densities are consistent with those recently observed in 1992 for WCA3 (Reddy et al. 1994), those reported for WCA2 (Reddy et al. 1991a), those observed in LNWR in 1991 (0.06 ±0.003 g/cc, Newman et al. 1997), and those observed in the Holeyland (Reddy et al. 1991b). The present study is the first to consistently document bulk density throughout the entire system.

6.2.4 Soil Redox

Marsh soil Eh was measured with an in situ probe described in Chapter 3.0. Measurements were made at 2.5-, 5-, 10-, 15-, and 20-centimeter depths. Eh data are presented as the mean of all five depths at a sample location. A box and whisker plot of the mean reference corrected Eh is presented by subarea in Figure 6.8. Figure 6.9 shows the average Eh for all cycles. The only subarea in which the median Eh was found to be less than 100 mV was WCA2. The presence of an Eh less than 100 mV indicates anoxic or reducing conditions are occurring in the soils in this subarea. It is also apparent, that while the occurrence of anoxia was exhibited in each of the other subareas in isolated locations, most of the areas had oxic soil conditions. The presence of oxic soils throughout most of the Everglades marsh is atypical of most marsh systems. Most wetland ecosystems have anoxic or reducing soil conditions similar to those found in WCA2 on at least a seasonal basis (Mitch and Gosselink 1986). Figure 6.10 shows the average soil Eh for each cycle.

6.3 Transects

6.3.1 Soil Thickness

Soil thickness along the four April 1994 marsh transects (Figure 2.1) is presented in Figure 6.11. Soil thickness was highly variable depending upon location. Soil thicknesses observed in WCA3 and ENP were generally about 0.3 m (1 foot), while soil thickness within WCA2 was about 1.5 m (5 feet). Soil thickness in LNWR exceeded 7 feet (about 2 m) (the maximum depth that could be measured with the field probe used for the April 1994 transect sampling).

6.3.2 Soil Organic Matter

Soil organic matter observed along marsh transects also varied depending upon location (Figure 6.12). LNWR had the highest organic matter content (about 90%). ENP had the lowest soil organic matter observed (about 40%) while WCA2 and WCA3 soils were of intermediate organic content.

6.3.3 Soil pH

Transect soil pH is presented in Figure 6.13. Soils were of neutral pH with one exception. The interior soils of WCA1 were acidic with a low pH of 5.8 at several interior sites. A pronounced pH gradient was observed in this transect with pH increasing approaching the L7 canal. This gradient may be due to the influence of alkaline water in the L7 canal. This observation is consistent with that of McPherson (1973).

6.3.4 Soil Redox

Soil Eh observed along the transects during April 1994 is presented in Figure 6.14. A soil core was collected in a clear polycarbonate corer. Eh measurements were made onsite by inserting probes into the intact soil core at a soil depth of 5 cm and allowing 15 minutes for equilibration. The only negative Eh measurements occurred within LNWR at the two stations closest to the L-7 canal. During the transect sampling Eh measurements were not obtained at the other likely location of negative Eh, along WCA2A transect at the eutrophic stations immediately downstream of S-10C, because of an equipment malfunction.

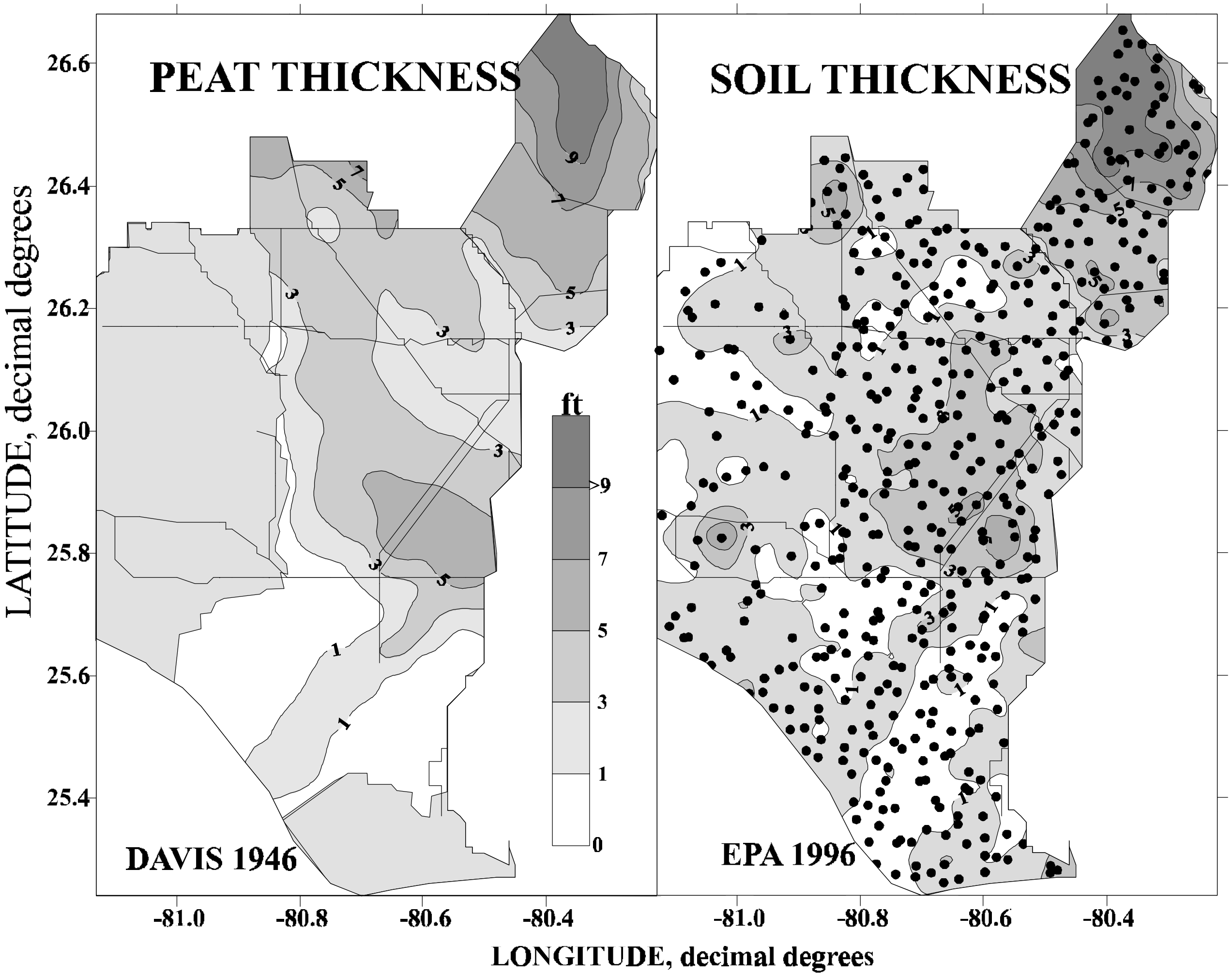
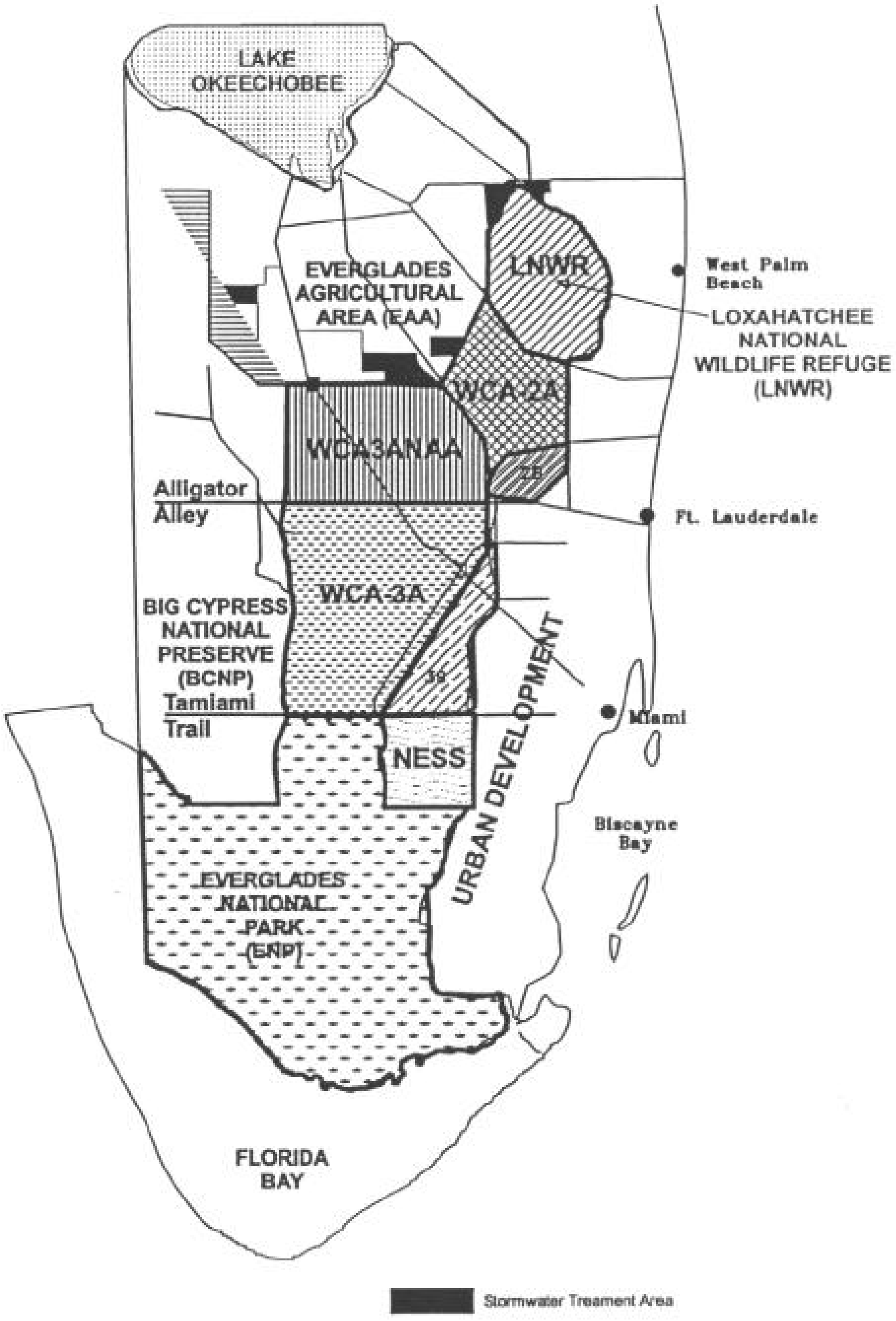


Figure 6.1 Comparison of 1946 peat thickness (Davis, 1946) and 1995-1996 soil thickness from the present study.



Everglades Ecosystem:

Figure 6.2 Water conservation areas created in early 1960s: LNWR, WCA-2A, WCA-2B, WCA-3A, and WCA-3B.

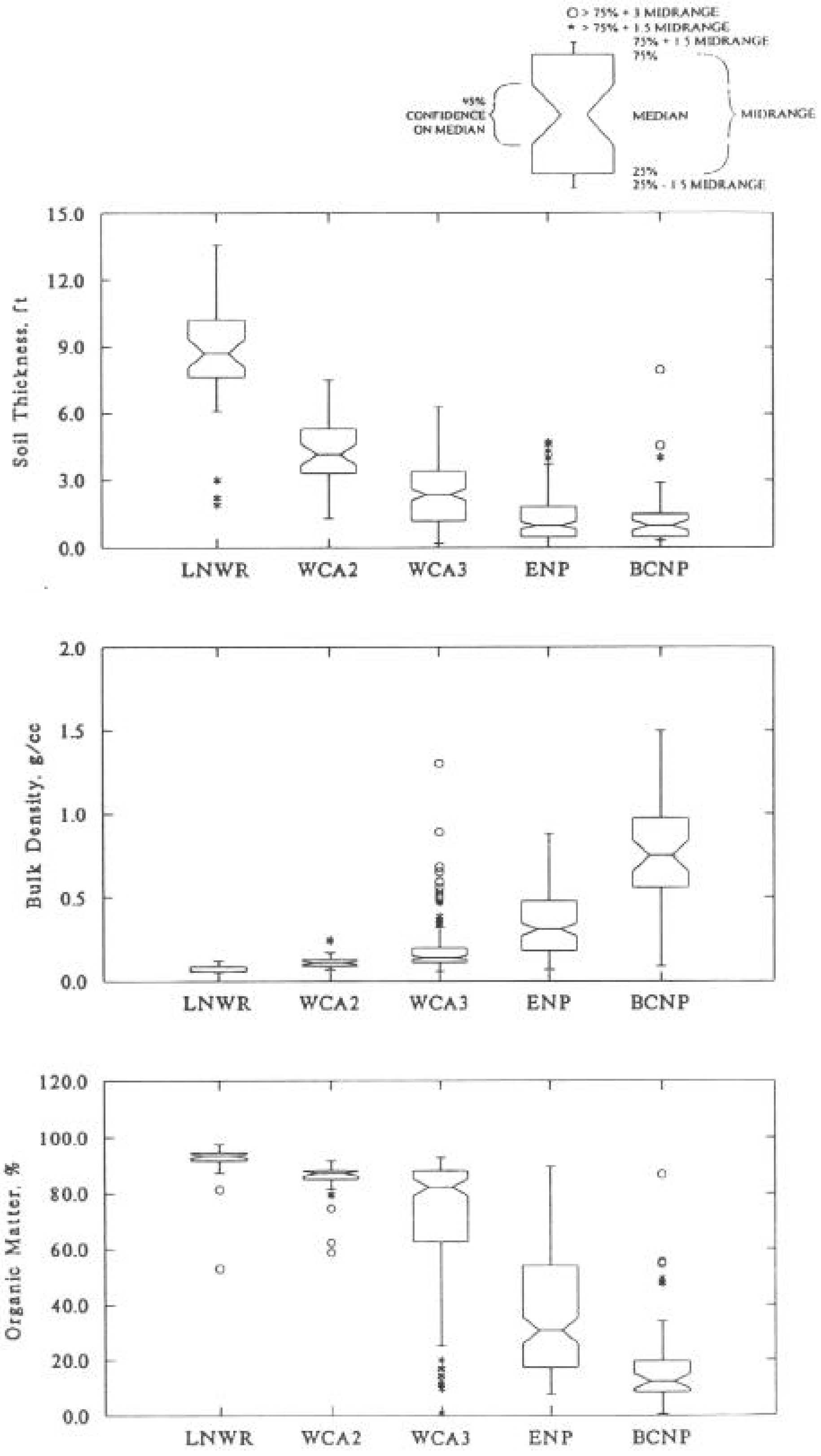


Figure 6.3 Notched box and whisker plots of marsh soil thickness, bulk density and organic matter by subarea.

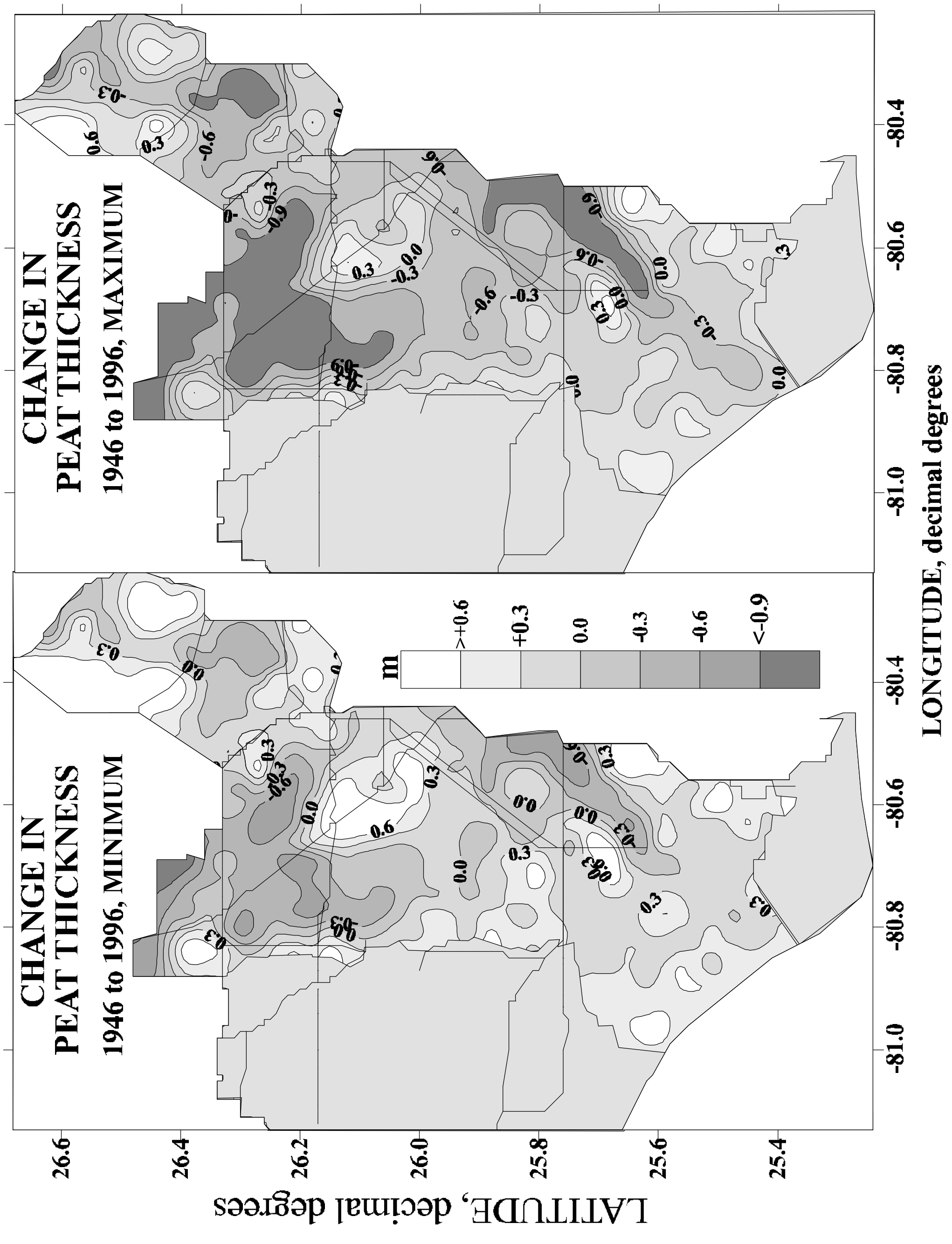


Figure 6.4 Maximum and minimum difference in peat thickness 1946 to 1996.

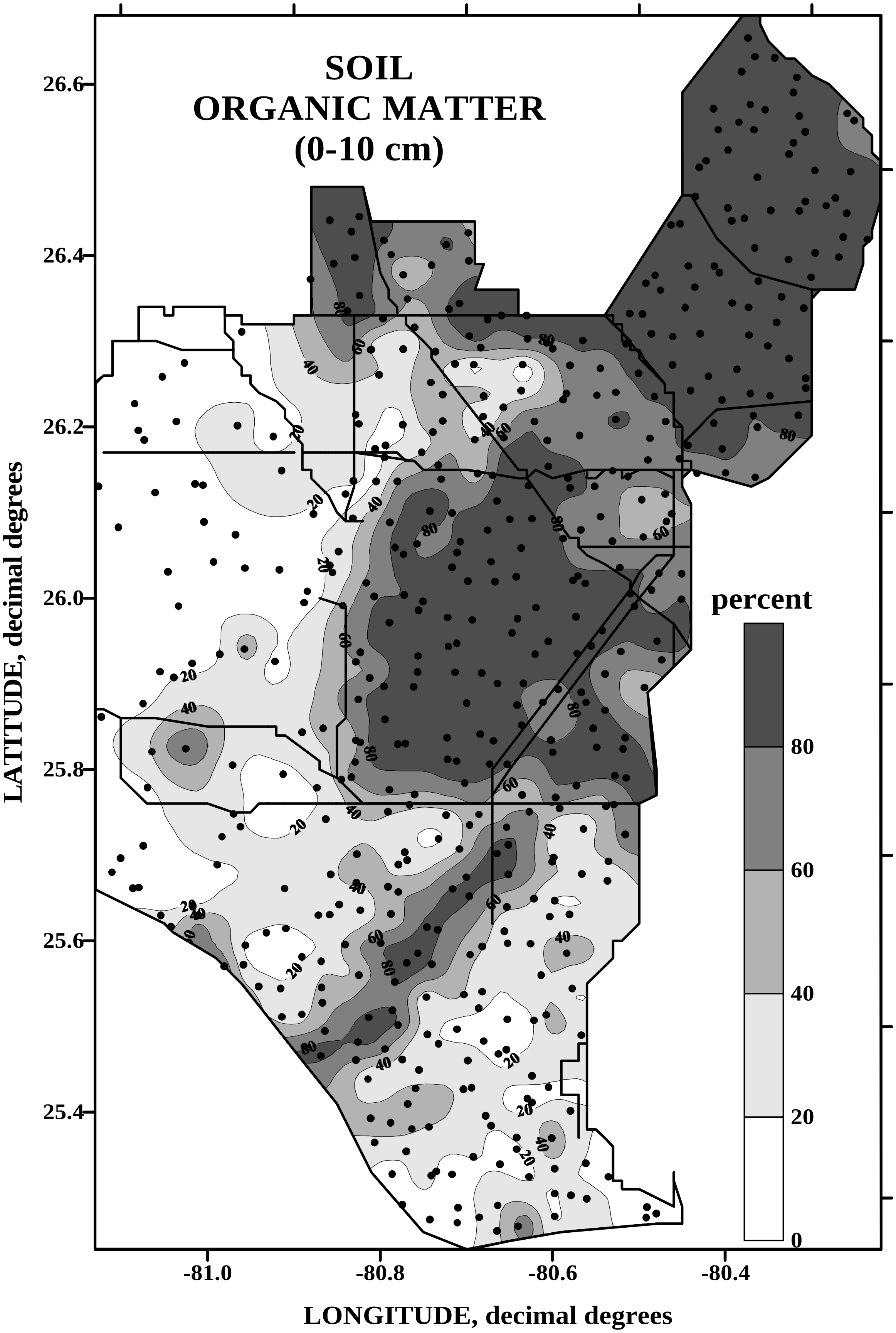


Figure 6.5 Percent organic matter observed for all cycles.

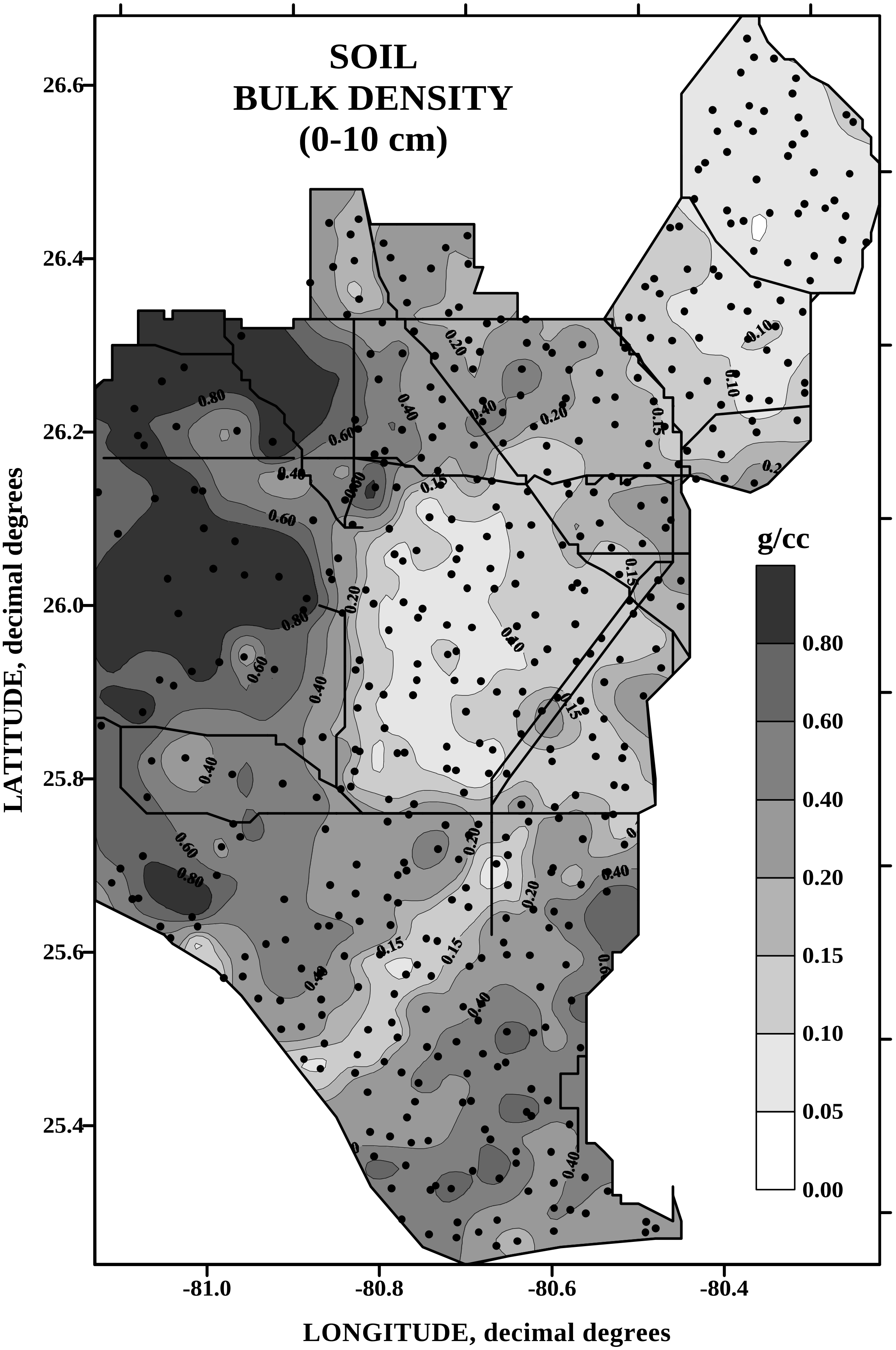


Figure 6.6 Bulk density for all cycles.

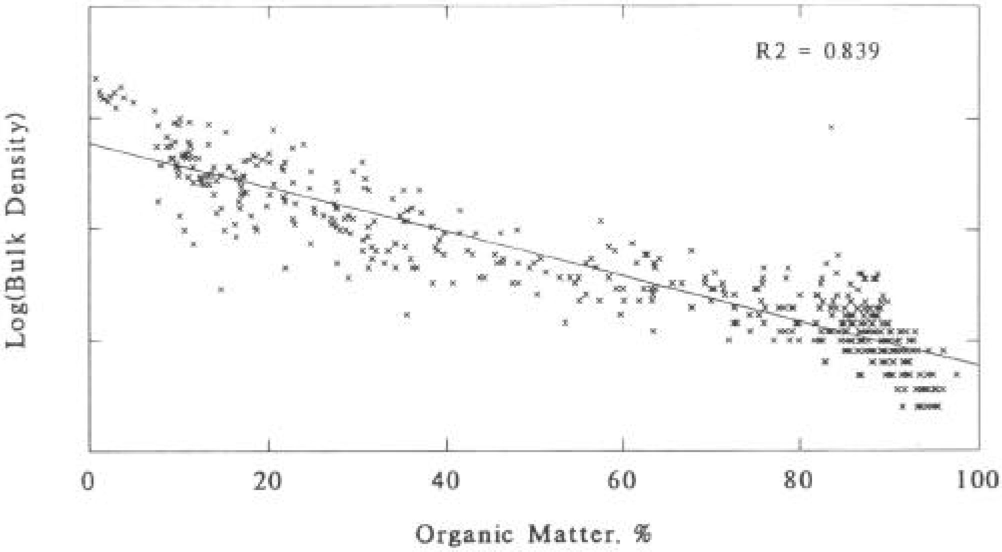


Figure 6.7 Linear relationship between Log (bulk density) and percent of organic matter.

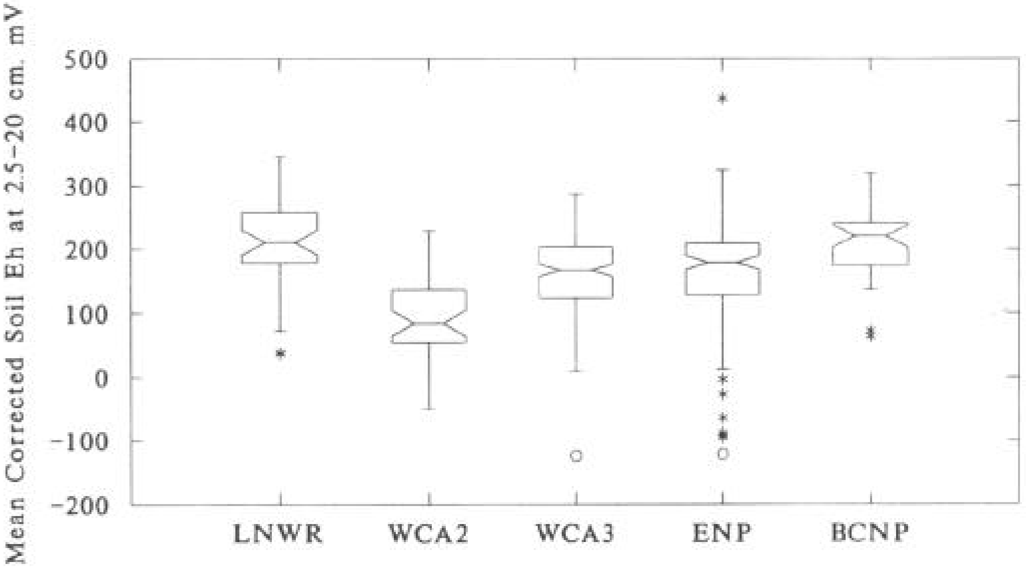


Figure 6.8 Mean corrected soil Eh vs. marsh subarea.

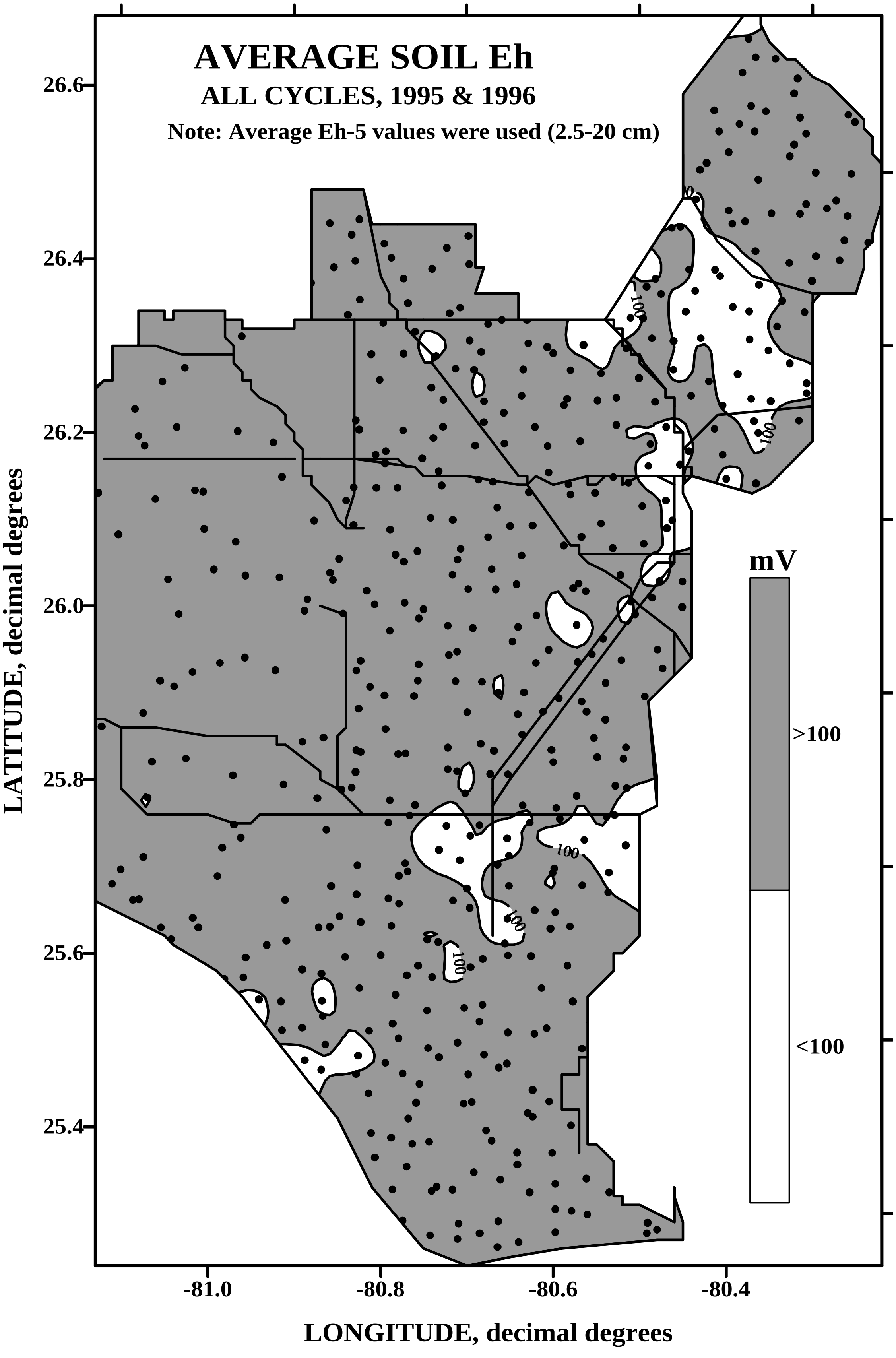
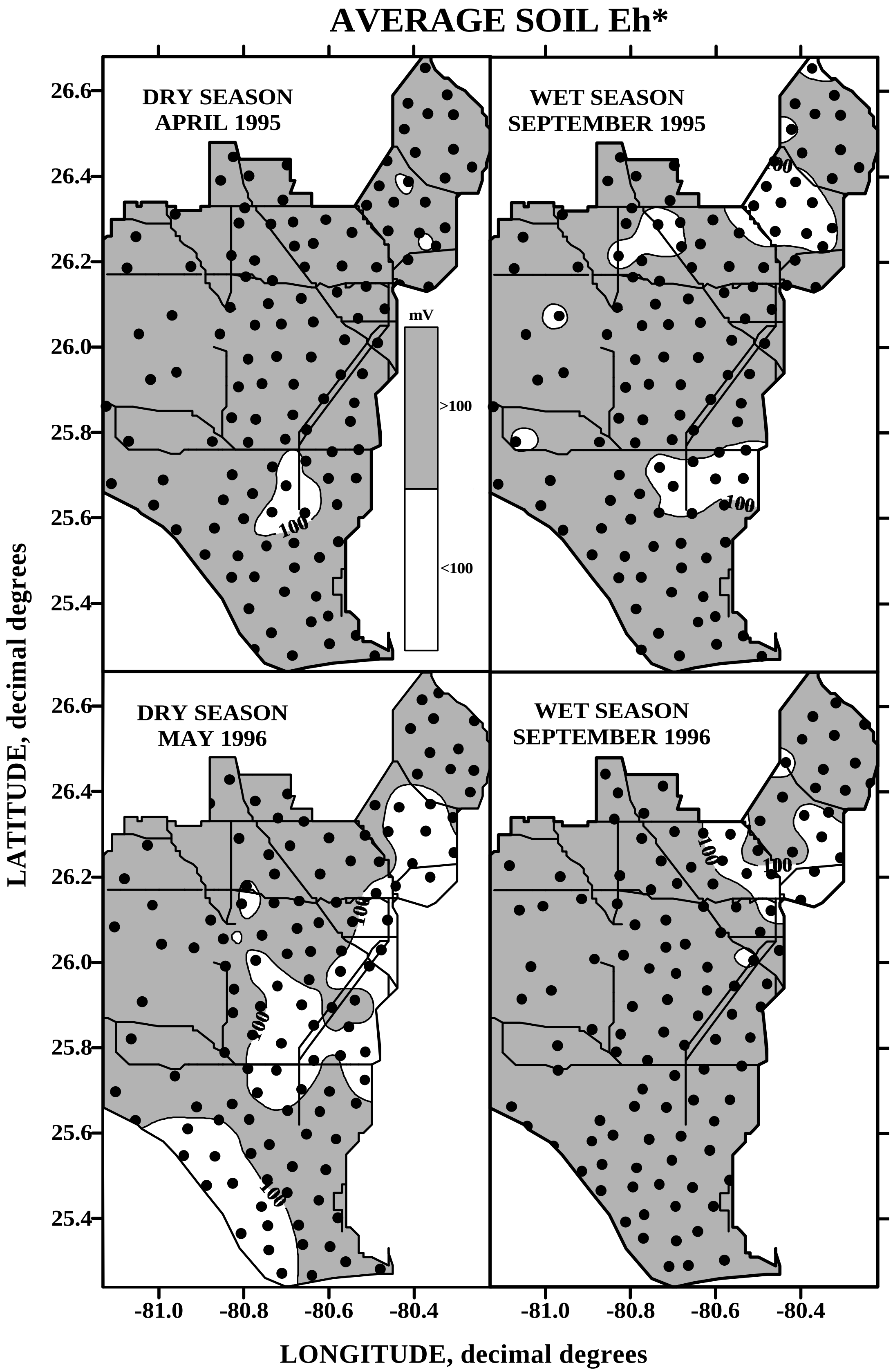


Figure 6.9 Average soil Eh for all cycles.



***Average Eh values were used (2.5-20 cm)**

Figure 6.10 Average soil Eh for each cycle.

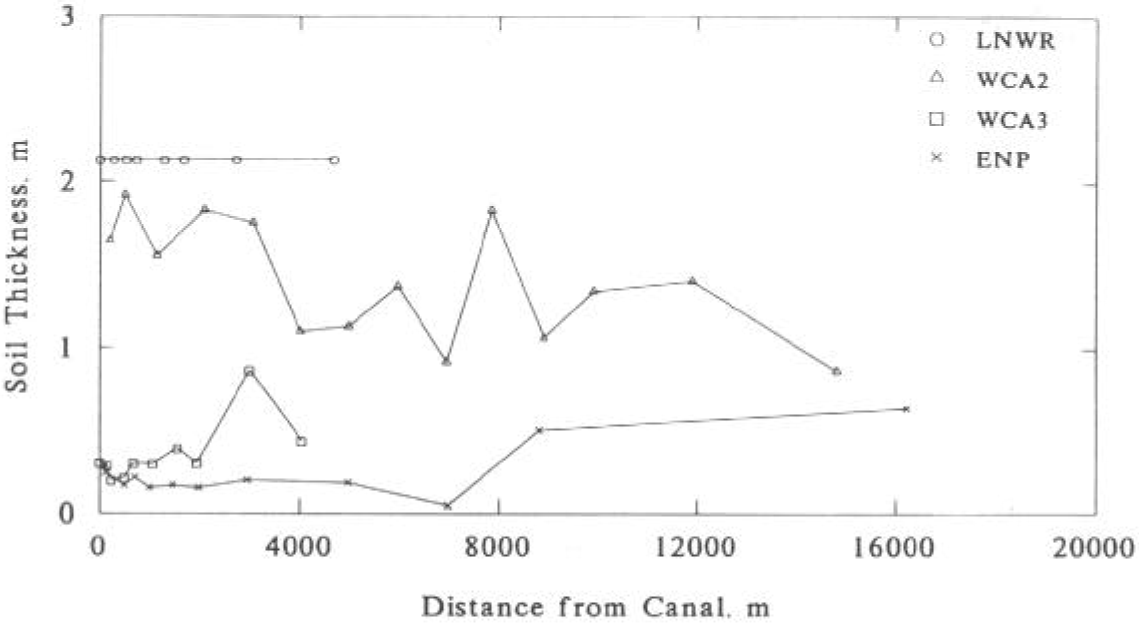


Figure 6.11 Soil thickness along each transect.

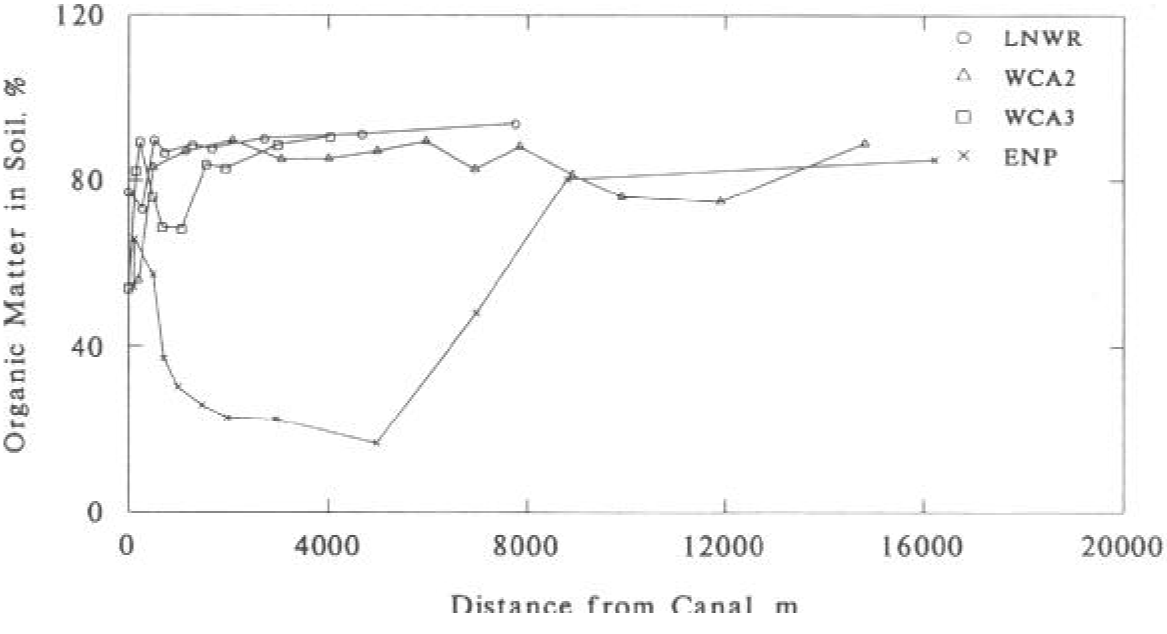


Figure 6.12 Percent organic matter along each transect.

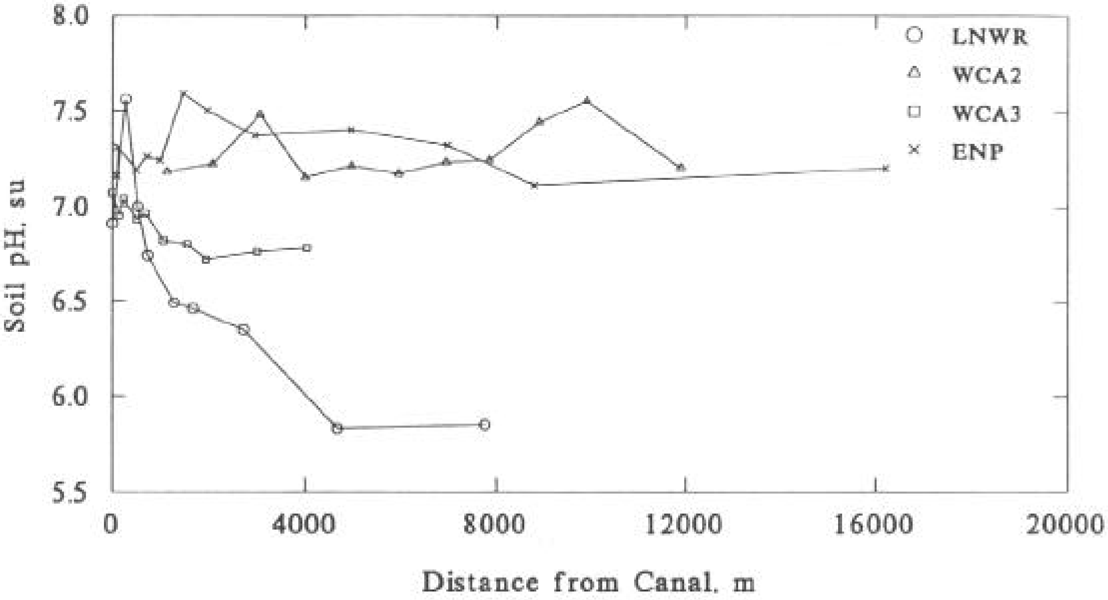


Figure 6.13 Soil pH along each transects.

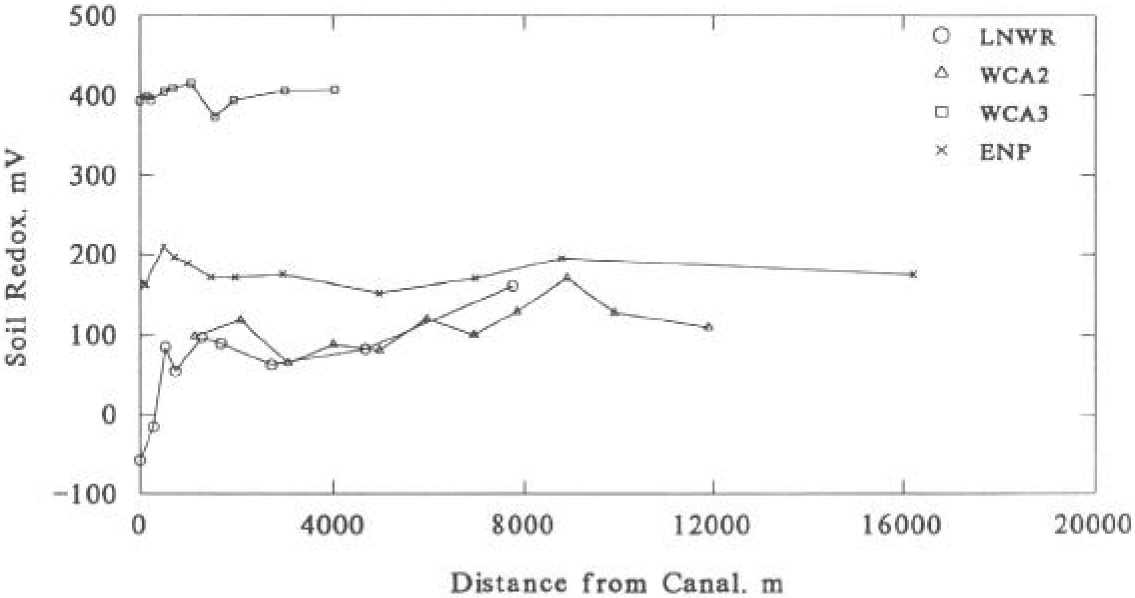


Figure 6.14 Soil Eh along each transects.