PHYSICAL AND MORPHOLOGICAL CHARACTERISTICS OF CAROLINA BAY WETLAND SOILS AFTER 15, 20, AND 30 YEARS OF DRAINAGE AND AGRICULTURAL PRODUCTION

Abstract: Wetland hydrology is being restored to a drained Carolina bay wetland in Robeson County, North Carolina called Juniper Bay that was drained for agriculture 30 years ago. The objective was to examine the physical and morphological properties of the soil in Juniper Bay, compare the changes relative to undrained reference Carolina bays, and evaluate the potential for successful restoration. Sampling locations in Juniper Bay were determined by randomly placing an equilateral triangle grid over a map of Juniper Bay. Paired pits for each location were dug, profiles described, and sampled. Three reference bays were selected on their similarity to soils present in Juniper Bay and lack of management. Transects were cut through the dense vegetation from the outer rim to roughly the center of each reference Carolina bay. Sampling locations were chosen randomly along the transect. Profiles were described and samples taken using a bucket auger and McCauley peat sampler. Three general soil types were identified in all the Carolina bays, organic soils, and mineral soils with (histic) and without histic epipedons (mineral). Comparisons within soil types were made using SAS procedure PROC MIXED. Agricultural production in Juniper Bay has resulted in the removal of the Oi and Oe horizons that is present in the reference bays. Organic soils in Juniper Bay are thinner due to subsidence resulting in increased bulk density, and have stronger grades of structural development due to tillage and desiccation resulting in increased saturated hydraulic conductivity and volumetric plant available water. Bulk density in the organic soils increases with increased time of drainage and the areas near the ditch have

increased grade of structure and hydraulic conductivity compared to the areas near the center of the fields. Soils with histic epipedons in Juniper Bay do not have the Oi and Oe horizons present in the reference bays and have a stronger grade of structure development, however, all other physical properties were similar. The ditch locations in the soils with histic epipedons tended to have an Ap horizon at the surface rather than the Oa horizon present at the crest. The mineral soils at Juniper Bay did not have the Oi horizon present at the reference bays. There were no other differences between bays or between crest and ditch locations at Juniper Bay. Restoration efforts maybe hampered or influenced by the change in hydraulic properties and soil structure in Juniper Bay. The loss of organic soil material from clearing activities and subsidence may result in a water table that is above the surface if hydrology is restored to levels that existed prior to drainage.

INTRODUCTION:

Section 404 of the Clean Water Act (1977) requires the replacement, or mitigation, of destroyed wetlands. Wetland mitigation includes enhancement and preservation of current wetlands, creation of new wetlands, or the restoration of prior wetlands (USCOE, 2002). Success of such mitigation projects is mixed. Erwin (1991) found that of 40 mitigation projects in south Florida 60% were judged incomplete or failures, Wilson and Mitsch (1996) found that only 38% of the desired wetland was established at mitigation sites in Ohio, and Gallihugh and Rogner (1998) found that 99 ha of 128 mitigation sites involving 144 ha were found to have unsatisfactory hydrology. The probability of success should be greater in an area that once supported wetland hydrology, hydric soils, and hydrophytic vegetation.

Drained Carolina bays found along the Atlantic Coast in the southeastern U.S. are being utilized for wetland restoration. Carolina bays are elliptical depressions in the landscape that are orientated along the long axis SE to NW. They range in size from 10 m to >4 km along the long axis. The bays are usually surrounded by a light colored sandy rim and have a dark colored depression resulting from high amounts of organic matter (Johnson, 1942). The extent of these bays range from Northern Florida to Delaware with the highest concentration in North and South Carolina. Estimates on the number of these bays are as high as 500,000 (Johnson, 1942), but the actual number maybe less than 100,000 (Nifong, 1998). Many theories for bay formation have been proposed, from the most popular, meteor impact (Johnson, 1936) artesian springs (Prouty, 1952; LeGrand, 1953), whale wallows (Grant, 1945), and ice push (Bliley and Burney, 1988). Currently the most plausible explanation is that originally there were shallow depressions in the landscape with an aquitard that allowed the water table to be held above the surface. Prevailing winds then shaped the depression into the now familiar orientated shape (Thom, 1970; Odum, 1952). During the past century agricultural and community development have led to the drainage and agricultural use of these bays. It is estimated that 50% of all Carolina bays were drained and developed in some manner in Bladen County, NC by 1982 (Weakley and Scott, 1982). This figure would be higher if other management practices such as logging were included. As these bays are used for agriculture and other activities, their defining characteristics of sand rims and organic surfaces, become blurred into the surrounding landscape.

Plant communities typically found in undrained Carolina bays include non-riverine swamp forest, low pocosin, high pocosin, pond pine woodland, peatland Atlantic White Cedar forest, and Bay forest (Schafale and Weakly, 1990). These plant communities are found in nutrient poor soils that maybe either organic soil or mineral soils. Variability in these plant communities depends on depth of organic soil material, seasonal water table depths, fire and mineral input if any (Schafale and Weakly, 1990). Soils associated with these plant communities (Croatan, Pamlico, Ponzer, Lynn Haven, Torhunta, Rutlege, and Pantego Series) are very strongly acidic (4.5-5.0) to ultra acidic (<3.5). Effective Cation exchange capacity tends to be very low ranging from 1 to 30 cmol kg^{-1}, but can be as high as 100 cmol kg^{-1} in the surface layers and is pH dependent. Extractable phosphorus has found to be strongly limiting to plant production in High Pocosin plant communities (Schafale and Weakly, 1990).

The North Carolina Department of Transportation (NCDOT) purchased a 256 ha drained Carolina bay in 1999, near Lumberton, North Carolina. This land was purchased with the intent of earning wetland mitigation credits. The Carolina bay being restored by the NCDOT is called Juniper Bay. Juniper Bay was drained, cleared, and put into agricultural production incrementally in 1971, 1981 and 1986. A review of the history of the clearing process was described in chapter 2. Agricultural practices in organic soils include the addition of lime to achieve a pH of 5.5 to 5.0 (Lilly and Baird, 1993). To reach this target pH up to 13470 kg ha^{-1} may have to be applied to overcome the large reserve of acidic cations present in organic soils (Lilly, 1981). The North Carolina Cooperative Extension Service recommends the application of 135-180 kg N ha^{-1}, 35-55 kg P_2O_5 ha^{-1}, and 90-115 kg K ha^{-1} for corn production (Crozer, 2000). Nitrogen and phosphorus have been shown to leach readily from the plow layer of organic soils (Lilly, 1981). Crop cultivation, included the use of chisel plows, moldboard plows, disks, and sub-soilers. In addition, the fields were usually crowned to promote surface runoff. The overall objective of the Juniper bay project is to restore Juniper bay to an ecosystem that is typical of undisturbed Carolina bays. This includes restoration of hydrology, vegetation, and soils typically found in Carolina bays.

The objective of this investigation was to describe and compare the physical and morphological properties found in a natural Carolina bay, and those found in Juniper Bay.

MATERIALS AND METHODS

Juniper Bay (JB) is located approximately 10 km southeast of Lumberton, North Carolina in Robeson County (($34^{o}30'30''$N $79^{o}01'30''$E). Juniper Bay was logged, drained and put into agricultural production in three stages. The western third of Juniper Bay was drained in 1971, the central third and most of the eastern third was drained in 1979, the area to the north in the eastern part was drained in 1986 (Fig. 6.1). There is a perimeter ditch around the entire bay, two main drainage ditches that run NE/SW and many lateral ditches that run NW/SE through the bay. The perimeter ditch and the main ditches are approximately 7 m across and 4 m deep. The lateral ditches that empty into the main ditches are roughly 1.5 m wide and 1m deep and spaced parallel at irregular intervals. Areas that are enclosed by ditches are called ‘cuts’. There is only one outlet in Juniper Bay and it is located at the SW end of the main ditch on the western side. Our initial soil survey of Juniper Bay allowed us to group the soils into three units based on the thickness of the organic layer. The soil groups were classified as: Aquic Haplorthods (<20cm organic material), no histic epipedon and are referred to as mineral; Histic Humaquepts (20-40 cm organic material) had a histic epipedon and are referred to as histic; and Terric Haplosaprist (>40 cm organic material) are referred to as organic (Fig 6.1).

Sampling locations were chosen by randomly placing an equilateral triangle grid over the soils map. There were a total of 24 locations inside of Juniper Bay, 10 in organic soils, 8 in mineral soils, and 6 in mineral soils with histic epipedons. Those points were then found in the field using GPS. Using the point from the grid as a reference, a 1.0-1.5 m pit was dug at the center of cut and near the closest lateral ditch, resulting in a pair of pits at each location. Figure 6.2 shows the location of all pits. Soil profiles were described and sampled. Grab samples and Uhland cores (75 mm in diameter x 75 mm in height) for laboratory analysis were taken from each horizon.

Three reference bays were selected in Bladen County, North Carolina based on their similarity of soils to Juniper Bay, lack of drainage or agricultural applications, and ownership cooperation. The bays selected were Charlie Long-Millpond Bay (34^{o}46’00”N 78^{o}33’30”E) and Tatum Millpond Bay (34^{o}43’00”N 78^{o}33’00”E), both located in the Bladen Lakes State Park and Causeway Bay (34^{o}39’45”N 78^{o}25’45”E) which is located 10 km N of White Lake, N.C. A trail from the rim of each bay to the center was cut through the vegetation (Fig 6.3).

The general soil types found in Juniper Bay were also found in all three natural bays, mineral, histic, and organic. Plots were marked off and numbered at 50 m intervals along the transects. Plots were then randomly selected in each soil to be sampled. There were a total of eight sampling plots in each reference bay, two in both the mineral and histic soils and four in the organic soil. The soil profile in the selected plot was described using a McCauley peat sampler and an open bucket auger. Grab samples were gathered and placed in plastic bags for laboratory analysis. The McCauley auger was also used to take undisturbed samples to determine bulk density and porosity (Soil Survey Staff, 1993). Due to the high water table (10 cm below the surface) we were unable to dig a pit or obtain Uhland core samples.

Grab samples from Juniper Bay and the reference bays were dried and ground with an electric grinder to pass through a 2 mm mesh sieve. Percent organic carbon and total nitrogen were determined through dry combustion with a Perkin-Elmer PE2400 CHN Elemental Analyzer (Culmo, 1988). Uhland cores from Juniper bay were used to determine saturated hydraulic conductivity, soil moisture release curves, bulk density, and porosity. Ten-cm undisturbed samples taken with the McCauley peat sampler from the reference bays were used to determine porosity and bulk density. Disturbed samples from all horizons were placed in pressure plates to determine water content at -1 and -15 bars in samples from Juniper bay, and -1/3 and -15 bars in samples from the reference bays. Available water was the difference in water content at -1/3 and -15 bars and porosity was calculated from the difference between saturation and oven dry.

Soil types, organic, histic, and mineral, were analyzed separately using the SAS procedure PROC MIXED (SAS, 2000), with an AR(1) covariance structure. There were two locations in the organic soil at Juniper Bay that had been drained 15 and 20 years, and 4 locations that had been drained for 30 years. There were three locations in the histic soil at Juniper Bay that had been drained 15 and 20 years. There were five locations in the mineral soils at Juniper Bay that had been drained 20 years, and four locations that had been drained for 30 years. Each location had paired pits with one located at the crest of the field and one near the ditch. Horizons varied depending on location and pit and were evaluated as a spatially repeated measure. The data were not balanced so LSMEANS were used to obtain estimated means. Comparisons among crest and near ditch pits were made with $p>0.1$ being significant.

The comparisons between the reference bays and Juniper bay were analyzed separately depending on, soil type: (organic, histic, and mineral), using the SAS procedure PROC MIXED (SAS, 2000), with an AR(1) covariance structure. Data from the crest locations in Juniper Bay were used in this analysis after determining that differences in crest and ditch locations were minimal. Organic, histic, and mineral soils were combined across the three reference bays, resulting in 12 organic, six histic, and six mineral locations. Horizons varied depending on location and pit and were evaluated as a spatially repeated measure. The reference Carolina bays were considered random variables so results could be inferred to other natural bays. Soils from the reference bays were considered as time zero so comparisons could be made as to the effects of time since drainage. The data were not balanced so LSMEANS were used to obtain estimated means. Comparisons among Juniper Bay and the reference bays and time since drainage were made with $p>0.1$ being significant.

RESULTS AND DISCUSSION

Organic Soils

JUNIPER BAY VS. REFERENCE BAYS

A typical description of organic soil profiles at the reference bays and a typical profile or organic soil in Juniper Bay are given in Table 6.1. Reference bay soils included Oi and Oe horizons, which have been recognized in other Carolina bays with natural vegetation (Stager and Cahoon, 1987). The Oi horizon is a fibric woody peat layer about 20 cm thick that is composed of plant debris and roots. The Oe horizon is a hemic or mucky peat layer that is massive and often contains organic bodies and extended to 50 cm. These two layers are not present in Juniper Bay and were probably removed, and burned during clearing of the land and mixed in subsequent cultivation. The organic soil at Juniper Bay has a surface horizon Oap that is sapric material or muck that has a strong to moderate fine granular to subangular blocky structure. The Oa horizons in the reference bays are composed of sapric material with massive structure and can extend from 40 to 180cm deep. The Oa horizons in Juniper Bay have sub-angular blocky to prismatic, and occasionally massive structure. Structural difference between Juniper Bay and the reference bays are interpreted to be a result of drainage and tillage. Similar changes in structure were described by Lee and Manoch (1974) in which organic soils become granular or subangular blocky in structure in the surface horizons; subsurface horizons become prismatic with secondary blocky characteristics following drainage and massive structure results when the soil becomes saturated. This structure change should increase saturated hydraulic conductivity. Oa horizons extend to depths of 40 and 70 cm below the surface, much shallower than comparable locations in the reference bays. The thinner organic horizons in Juniper Bay are a result of clearing activities and subsidence that, has been estimated to be between 75 and 86 cm in Juniper Bay (Chapter 3). Reported thickness of the organic layers in Carolina bays vary from 1 cm (Newman and Schalles, 1990) to 4.6 m (Shariz and Gibbons, 1982). There is a thick (25 cm) transitional horizon from organic material to mineral material at the reference bays and the C horizons tend to be sandy loam or sand, while at Juniper Bay the transition is a clear boundary and the C horizons are loamy sand to sandy clay loam. Saunders and Brown (1992) stated that the subsoil type in Carolina bays are related to their geomorphic surfaces, and could account for the differences in the C horizon material.

The colors of the organic soils at Juniper bay were black to dark brown (10YR) with an occasional redder hue (7.5YR) but were black at the reference bays (N 2.5/0). Dolman and Buol (1967) found in organic soils of the Tidewater region of North Carolina in which deeper less oxidized organic horizons tended to be a dark reddish brown (5YR 2/2) while shallower more oxidized organic horizons tended to be black (10YR 2/1) to very dark brown (10YR 2/2). Lee and Manoch (1974) found in a the organic soils of a Wisconsin marsh there was a change in color from a dark reddish brown to a black color after 50 years of drainage. However, the difference in color maybe a result of different soil environments. Lilly (1981) indicates that the dark reddish color of deep organic soils of North Carolina are preserved by being kept continuously anaerobic, while the areas with black organic soils have experienced some oxidization. This suggests that deeper horizons in Juniper Bay's organic soils remained anaerobic for longer periods and the reference bays formed under anaerobic conditions that fluctuated.

Charcoal fragments were found in several of the profiles in Juniper Bay, but were not seen in the reference bays suggesting that fire may have played a role in the development of the soils at Juniper Bay. However, the profile sites described in the reference bays were limited in size and may not have provided adequate information for such a discovery. There have been other studies of Carolina bays that have found evidence of fire in the soil profiles (Cohen et al., 1999). Profile descriptions of all organic soils of Juniper Bay and the reference bays can be found in Appendix F.

LSMEANS estimates comparing physical characteristics of organic soils at Juniper Bay to the reference bays are in Table 6.2. There was a significant difference between Juniper Bay and the reference bays in available water. In the surface 20 cm of Juniper Bay and the reference bays there was the same amount of available water, 0.27 and 0.30 cm^3 cm^{-3}. Estimated (-1/3 to -15 bar) available water in the reference bays remained constant through the profile at 0.30 cm^3 cm^{-3}. Available water contents in Juniper Bay increase to 0.50 cm^3 cm^{-3} at 54 cm and then decreased to levels found in reference bays at 87 cm. Histosols have an extremely high water holding capacity and much of it is in the larger pores (gravitational) or in micropores that is unavailable for plant growth (Boelter and Blake, 1964). Fibric soils, like those in the reference bays, have large pores and relatively high saturated hydraulic conductivities, while sapric soils have more micropores and have hydraulic conductivities lower than clay-textured sediment (Boelter, 1965). Despite the ability to hold large amounts of water, drained organic soils may dry out quickly and be prone to drought (Lilly, 1981). In addition, water in the small pores in the underlying undeveloped organic soil will not move by capillary conductivity to the larger pores in the developed surface soil, i.e. no recharge from underlying soil resulting in droughty conditions near the surface (Lilly, 1981). Although not significant, there were trends in particle size, bulk density and porosity. There tended to be less sand and clay through the profile in the reference bays. These trends are probably a result of the geomorphic surface on which they occur (Saunders and Brown, 1992) or deposition from the surrounding landscape (Preston and Brown, 1964). Bulk density tended to be higher at Juniper Bay and ranged from 0.48 to 1.23 g cm^{-3} compared to 0.29 to 0.96 g cm^{-3} at the reference bays. Conversely porosity tended to be higher at Juniper Bay.

It is unfortunate that we were unable to obtain saturated hydraulic conductivity (K_{sat}) measurements in the reference bays. We would have expected higher K_{sat} values in the Oi and Oe horizons and lower K_{sat} values in the Oa horizons in the reference bays than at Juniper Bay. Unrippened organic material K_{sat} values of 0.002 to 0.19 cm hr^{-1} and 15-37 cm hr^{-1} for a ripened layer (Skaggs and Barnes, 1976). Chason and Siegel (1986) found that the K_{sat} of decomposed peat can range from 0.1 to 8.0 m day^{-1}, with the large K_{sat} values caused by discontinuous zones of buried wood and other structural features that can enhance or obstruct water flow. In the upper layers of undisturbed peat, K_{sat} can be as high as 30 m d^{-1} (Ingram 1967). The K_{sat} of geologic materials of low permeability (sapric material with massive structure) is scale dependent: the greater the size of the flow system, the greater the permeability because of the increased likelihood of large conduits like roots (Neuzil, 1986).

TIME IN AGRICULTURAL PRODUCTION

There were significant differences in bulk density due to time since drainage began in the organic soils (Fig. 6.4). Bulk density in organic soils tends to increase with subsidence and decomposition (Boelter, 1965) and values will vary according to the amount of mineral material and the type of vegetation. Bulk density also increases as traffic of agricultural equipment compacts soil layers near the surface. Bulk density of Juniper Bay organic soils were consistently higher than the reference bays organic soils and are similar to findings by

Ewing et al. (2003) that showed bulk density in a drained Carolina bay is higher than that of an undrained Carolina bay. Bulk density at the surfaces of the reference bays was lowest at the surface and increased with depth. Bulk density in the upper 50 cm was similar for all times since drainage of Juniper Bay to a depth of 100 cm. Below 100 cm bulk density was different among times of drainage due to different types of mineral material in the C horizons. Bulk density was higher in the surface 20 cm of Juniper Bay and decreased at 50 cm depth, because of mineral material from ditch spoil, subsidence, and tillage. The increase in bulk density below 50 cm in Juniper Bay is due to increases of mineral material as the soil changes from organic to mineral. Although not significant, porosity tended to be the inverse of bulk density throughout the profile, when bulk density increased porosity decreased, and vice versa. LSMEANS estimates for time of drainage in organic soils can be found in Appendix B.1.

CREST VS. DITCH

Profiles of organic soils located at the crest and edge of the field varied because of better drainage and addition of ditch spoil next to the ditch. Figure 6.5 provides an illustration of the soil at the crest and ditch at location 16, and Table 6.3 includes the associated profile descriptions. The Oap horizon at the ditch is 24 cm deep and only 11 cm deep at the crest, and both have the same strong medium granular structure. However, in the Oa1 and Oa2 horizons the structure is massive at the crest while at the ditch there is weak to moderate very coarse prismatic to sub-angular blocky structure, which indicates greater profile development. Both profiles have a dense or cemented layer between 100 and 110 cm. This is a characteristic of Carolina bays that has been described by others (Thom, 1970, and Wright et al., 2000), and indicates an accumulation of silica or humate material. There is a

2Bh horizon at the ditch that is not present at the crest. This may be a result of the increased movement of water, and associated organic material, through the soil around the ditch with the illuvial organic material accumulating in this horizon.

LSMEANS estimates comparing the crest and ditch locations in the organic soils can be found in Table 6.4. There was a significant difference in bulk density and total pores between the crest and ditch in the organic soils. Bulk density near the ditch was 0.16 to 0.46 g cm^{-1} higher in the upper 70 cm, and can be attributed to the higher amounts of sand deposited from maintaining the ditches. Bulk density for both areas decreased from the surface to 50 cm, and then increased. Porosity was higher throughout the profile at the crest compared to the ditch as a result of the lower bulk density. Particle size, saturated hydraulic conductivity, and available water were not found to be significantly different between the crest and ditch location.

<u>Histic Soils</u>

JUNIPER BAY VS. REFERENCE BAYS

A typical description of histic soil profiles at the reference bays and a typical profile or histic soil in Juniper Bay is given in Table 6.5. The histic soils tend to form a ring around areas of organic soils in both Juniper Bay and the reference bays. The reference bays usually has an Oi or Oe horizon of woody peat that consists of accumulated plant debris and roots, with an Oa horizon of massive sapric muck extending to less than 40 cm depth. Below this is an OC horizon where the organic material changes to mineral material, and then a C horizon that is usually sand. There are no Oi or Oe horizons in the histic soils at Juniper Bay. They have Ap horizons with organically coated sand grains, with an underlying Oa horizon that extends to approximately 40 cm and tends to have granular to sub-angular blocky structure.

The structure in the Oa horizon is due to agricultural practices and subsidence processes. There is a clear transition in Juniper Bay to mineral material that is usually sand or loamy sand. The color of the C horizon in Juniper Bay tends to be lighter in color (10YR 6/4) than in the reference bays (10YR 2/2), and is a result of local geomorphic surfaces (Saunders and Brown, 1992). Profile descriptions of all histic soils of Juniper Bay and the reference bays can be found in appendix F.

LSMEANS estimates comparing physical properties of the histic soils at Juniper Bay and the reference bays are in Table 6.6. There was a significant difference in available water and clay between Juniper Bay and the reference bays. Juniper Bay tended to have 0.1 to 0.3 cm^3 cm^{-3} more available water than the reference bays. The higher amount of clay in Juniper Bay, approximately 8 to 25% higher through the profile, can result in higher amounts of available water. In addition, there is the potential that the organic horizons at the reference bays may contain a greater portion of macropores reducing the amount of available water. There were no significant difference between Juniper Bay and the reference bays in percent sand, bulk density and porosity.

TIME IN AGRICULTURAL PRODUCTION

There was a significant time since drainage effect on particle size and available water (Fig. 6.6). Sand ranged from 72.9% at 32 cm and increased with depth to 92.9% at 119 cm at time zero. After 15 years sand content ranged from 78.7 to 63.4% and 47.2 to 94.2% after 20 years. Clay content was the lowest at time zero ranging from 7.2 to 2.8%. After 15 years of drainage clay content ranged from 30.5% in the C horizon to 21.2% at the surface, and after 20 years it ranged from 3.6 to 42.4%. Although the differences in particle size are correlated with time in agriculture, we feel that the difference are more an effect of the depositional environment. Available water was similar in the upper 20 cm for time zero and 15 years since drainage, 0.37 and 0.33 $cm^3\ cm^{-3}$ respectively, but lower 20 years since drainage, 0.21 $cm^3\ cm^{-3}$. All available water contents increased as depth increased to 32 cm, however time zero and 20 years were similar, 0.42 and 0.43 $cm^3\ cm^{-3}$ respectively and 15 year was higher at 0.65 $cm^3\ cm^{-3}$. Below 32 cm, at time zero available water decreased and remained around 0.17 $cm^3\ cm^{-3}$ through the rest of the profile. The 15 years since drainage decreased to 0.11 $cm^3\ cm^{-3}$ by 85 cm and then increased to 0.22 $cm^3\ cm^{-3}$ at 104 cm. The area drained for 20 years increased to 0.54 $cm^3\ cm^{-}$at 77cm, then decreased to 0.25 $cm^3\ cm^{-3}$ at 122 cm. LSMEANS estimates for time since drainage for all variables are in Appendix B.2.

CREST VS. DITCH

There are some visual differences between soil profiles located at the crest and the ditch through the histic soils. Figure 6.7 provides an illustration of the soil at the crest and ditch at location 11, and Table 6.7 is the associated profile descriptions. There was an Oap horizon at the surface of the crest location with strong medium granular structure, while the ditch location had an Ap horizon with a weak fine granular structure. This suggests that either the organic soil has decomposed to a point that it is no longer organic, or that mineral material from the ditch has been mixed in. The Oa horizon at the ditch extends to a depth of 23 cm, while at the crest it extends to a depth of 34 cm, again indicating a loss of organic material from the surface, from oxidization or land shaping that removed material from near the ditches and deposited in the crest. The more defined structure in the OA horizon at the ditch, weak medium sub-angular blocky, compared to the weak coarse prismatic at the crest, indicates drier conditions which results in the formation of better structure in organic soils (Lee and Manoch, 1974). There are some locations in the histic soils where it is histic at the center of the ditch, but is closer to “mineral” near the ditch. Also there are locations near the ditch in which the surface horizon has been influenced by spoil form the ditch maintenance. All organic and histic soils in Juniper Bay, if cultivated long enough, will become mineral soils with dark surface horizons due to the inevitable natural loss of organic matter through oxidization (Lilly, 1981), and this may be the case in the histic soils of Juniper Bay.

There were no physical differences between the crest and ditch positions in the histic soils. LSMEANS estimates for the physical properties of the histic soil can be found in Table 6.8. However, saturated hydraulic conductivity tended to be higher in soils at the ditch, probably due to increased soil structure.

Mineral Soils

JUNIPER BAY VS. REFERENCE BAYS

Mineral soils in the reference bays and Juniper Bay were relatively similar (Table 6.9) with differences in the surface horizon being a result of agricultural activities. The mineral soils at the reference bays had a thin (10 cm) Oi horizon consisting of plant debris and roots, which are not present in Juniper Bay. Below this is an A horizon with weak granular structure. A thick (20 cm) E horizon is next, followed by several spodic horizons. There were a few locations in the reference bays that had an E’ and Bh’ horizons. The mineral soils in Juniper Bay had a dark Ap horizon with organically coated sand grains and weak granular structure. There was a thick (20 cm) E horizon, which sometimes was mixed with the Ap horizon, followed by several Bh horizons. There were also C horizons at the bottom of some mineral soil profiles that consisted of sand or cemented sandy clay loam similar to what was described by Ingram et al., (1957), Stager and Cahoon (1987), and Lide et al., (1995). Profile descriptions of all mineral soils of Juniper Bay and the reference bays can be found in Appendix F.

There were no significant differences in particle size between the mineral soils at Juniper Bay and reference bays (Table 6.10). We were unable to obtain undisturbed samples from the reference bays to determine bulk density, porosity and available water. However bulk density at Juniper Bay ranged from 1.09 g cm^{-3} at the surface and increased to 1.63 g cm^{-3} at 126 cm, porosity ranged from 0.42 to 0.52 cm^3 cm^{-3}, and available water ranged from 0.27 to 0.18 cm^3 cm^{-3}.

TIME IN AGRICULTURAL PRODUCTION

We were unable to take intact samples in the reference bays to determine bulk density, porosity, and available water. The areas at Juniper Bay drained for 30 years had an available water of 0.23 cm^3 cm^{-3} in the surface 10 cm, increased to 0.35 cm^3 cm^{-3} at 23 cm, then decreased to 0.18 cm^3 cm^{-3} at 57 cm, and then remained close to the values found in the 20 year areas (Fig. 6.8). Bulk densities in mineral soils at Juniper Bay were similar after 20 and 30 years of drainage. LSMEANS estimates comparing time since drainage of histic soils are in the Appendix B.3.

CREST VS. DITCH

There are visual differences between soil profiles located at the crest and the ditch. Figure 6.9 provides an illustration of the soil at the two locations, and Table 6.11 is the associated profile description of location three. The Ap horizon is approximately the same thickness and color at both locations, however, there is 10% less organically coated sand grains at the ditch. It appeared that some of the surface material might be from ditch maintenance, and is more evident at other locations (see appendix E). There is an AE horizon at the ditch that is a result of tillage. Such a mixing of A and E horizons occurred at several locations at both the crest and ditch in the mineral soils. The E horizon is 4 cm thicker at the ditch, and the Bhir horizons extend deeper into the profile. There was defined structure in the surface 22 cm at the ditch but only the surface 12 cm at the crest. There was a sulfur smell associated with the lowest horizon indicating reduced conditions.

There was a significant difference in the particle size between the crest and ditch positions in the mineral soil (Table 6.12). There was more than 85% sand throughout the profile in both positions. The crest had 3% more sand in the surface 15 cm, approximately the same at 30 cm and the crest had 7.5% more at 50 cm, and approximately the same for the remainder of the profile, increasing with depth to 95% sand at 125 cm. There was 2 to 6% more clay in the surface 50 cm at the ditch position than the crest. Below 50 cm clay content was similar, approximately 3%, for the rest of the profile. There were no significant differences between the crest and ditch for bulk density, porosity, available water, or saturated hydraulic conductivity (Table 6.12). However , there was a trend for saturated hydraulic conductivity to be higher near the ditch and for available water to be lower. This trend probably reflects the increased development of structure and the associated increase in macropores.

CONCLUSIONS

The organic soils in Juniper bay have undergone the most change since drainage began. There were some differences between crest and ditch locations, however they are relatively small compared to the differences between Juniper Bay and the reference bays. Preparing Juniper Bay for agricultural production resulted in the removal of surface organic horizons Oi and Oe. The remaining organic soil is thinner due to subsidence and has developed granular structure at the surface due to tillage and desiccation. The loss of the surface horizons and the development of structure have increased saturated hydraulic conductivity and plant available water. Bulk density has increased since drainage and indicated that the process of oxidation is still ongoing. Restoration efforts may be hampered or influenced by the change in hydraulic properties. For example, restoring the water table to pre-drainage levels might result in a water table that is above the soil surface forming a pond. The pre-drainage sapric Oa horizon, which originally had massive structure, perched water because of an extremely low K_{sat}. After drainage the sapric material develops structure that allow water to move through the profile increasing K_{sat}. Although there were differences in particle size properties in the organic soils, we feel that there is not a large enough difference to influence restoration efforts. The dense layer found beneath the organic soils in Juniper Bay was not encountered in the reference bays. This layer was either deeper in the profile at the reference bays or has formed since drainage at Juniper Bay and is now acting as an aquitard.

Histic soils at Juniper bay were lacking an Oi and Oe horizons and have greater structure development. Other physical properties were similar enough between Juniper Bay and the reference bays and should not affect hydraulic properties. However, some histic areas in Juniper Bay show indications that they may have once been organic soils and have subsided resulting in a organic layer grouped as histic. This may result in water tables above the soil surface if hydrology is returned to the pre-drained levels. The effects of ditch maintenance were most evident in the histic soils with an Ap horizon over an Oa horizon at the ditch locations. There were also indications of better structure at the ditch indicating better drainage. Difference between the ditch and crest and differences in particle size data are not enough to justify different management practices.

Mineral soils at all locations were well developed with some differences. These differences include a thin Oi horizon at the reference bays and a thicker Ap horizon and deeper E horizon as a result of the addition of ditch spoil at Juniper Bay. The E horizon was thicker at the ditch compared to the crest and the Bh horizons extended deeper into the profile indicating better water movement through the profile. Soil structure was more developed at Juniper Bay. There is little to indicate that the physical properties of the mineral soils in Juniper Bay are different than those of the reference bays, and both should behave similarly under the same hydraulic conditions. Differences in sand silt and clay content are relatively small and could be attributed to the depositional environments at the time of formation. Areas of Juniper Bay that are now mineral soils may have had histic epipedons prior to drainage and may result in water tables above the soil surface if hydrology is returned to the pre-drained levels.

The restoration of Juniper Bay soils to those typically found in natural undrained Carolina bay wetlands can be achieved decades if not centuries. The mineral soils are similar enough already, however, the mineral soils may not support hydrophytic vegetation as well as the histic and organic soils because of the higher K_{sat} and lower available water. Histic soils would require some time to accumulate organic debris to form an Oi and Oe horizons. The organic soils would require a great deal of time possibly centuries, to be restored to natural conditions, due to the large amounts of organic material that has been lost since drainage.

REFERENCES

Bliley, D.J. and D.A. Burney. 1988. Late Pleistocene climatic factors in the genesis of a Carolina Bay. Southeast. Geo. 29:83-101.

Boelter, D.H. 1965. Hydraulic conductivity of peats. Soil Sci. 100:227-231.

Boelter, D.H. and G.R. Blake. 1964. Importance of volumetric expression of water contents of organic soils. Soil Sci.Soc Am . Proc. 28:176-178.

Chason, D.B. and D.I. Siegel. 1986. Hydraulic conductivity and related physical properties of peat, Lost River peatland, northern Minnesota. Soil Sci. 42:91-99.

Clean Water Act Section 404. 1977. [33 USC 1344]

Cohen, A.D., C.P.Gage, W.S. Moore, and R.S. VanPelt. 1999. Combining organic petography and palynology to assess anthropogenic impacts on peatlands Part 2. An example from a Carolina Bay wetland at the Savannah River Site in South Carolina. Int. J. Coal Geo. 39:47-95.

Crozer, C. 2000. Fertilizer and lime management. North Carolina Corn Production Guide. North Carolina Cooperative Extension Service, North Carolina State University: Raleigh, N.C.

Culmo, R.F. 1988. Principle of Operation – The Perkin-Elmer PE 2400 CHN Elemental Analyzer. Perkin Elmer Corp. Norwalk, CT.

Dolman, J.D. and S.W. Buol. 1967. A study of organic soils in the Tidewater region of North Carolina. North Carolina Agric. Exp. Stn. Tech. Bull. 181.

Ewing, J.M, M.J. Vepraskas, and C.W. Zanner. 2003. Agricultural Impacts on Soils in a Drained Carolina Bay. Soil Science Society of North Carolina meeting abstracts (in press), 2003.

Ewrin, K.L. 1991. An Evaluation of Wetland Mitigation in the Southeast. *In* J.A. Kusler and M.E. Kentula, (eds). p. 233-265. Wetland Creation and Restoration. Island Press, Washington DC.

Gallihugh, J.L. and J.D. Rogner. 1998. Wetland Mitigation and 404 Permit Compliance Study, Vol. I. U.S. Fish and Wildlife Service, Region III, Burlington, IL, and U.S. Environmental Protection Agency, Region V, Chicago. 161pp.

Grant C. 1945. A biological explanation of the Carolina Bays. The Scientific Monthly. 61:443-450.

Ingram, H.A.P. 1967. Problems of hydrology and plant distributions in mires. J. Ecol. 55:711-724.

Ingram, R. L. and M. Robinson. 1957. Clay minerals of some Carolina Bay sediments. J. Mitchell Soc. N. C. Acad. of Sci. Proc. 73:241.

Johnson, D.W. 1942. Origin of the Carolina Bays. Columbia University Press.

Johnson. D.W. 1936. Origin of the Supposed Meteorite Scars of the Carolina. Science. 84:15-18.

Lee, G.B. and B. Manoch. 1974. Macromorphology and Micromorphology of a Wisconsin Saprist. *In* M. Stelly and R.C. Dinauer, (eds.) Histosols Their Characteristics, Classification and Use. SSSA pub 6. Soil Sci. Soc. Am. Madison, Wisconsin.

LeGrand, H. E. 1953. Streamlining of the Carolina Bays. J. Geol. 61:263-274.

Lide, R. F., V.G. Meentemeyer, J. E. Pinder III, and L.M. Beatty. 1995. Hydrology of a Carolina Bay located on the upper coastal plain of Western South Carolina. Wetlands. 15:47-57.

Lilly, J.P., 1981. The Blackland Soils of North Carolina: Their Characteristics and Management for Agriculture. p.27-33. North Carolina Ag. Res. Tech Bul. No. 270.

Lilly, J.P. and Baird. 1993. North Carolina Cooperative Extension Service Pub. AG 439-17. North Carolina State University: Raleigh, N.C.

Neuzil, C. 1986. Groundwater flow in low-permeability environments. Water Resources Research. 22:1163-1197.

Newman, C.M. and J. F. Schalles. 1990. The water chemistry of Carolina bays: A regional survey. Arch. Hydrobiol. 118:147-168.

Nifong, T.D. 1998. An ecosystem analysis of Carolina Bays in the Coastal Plain of the Carolinas. Ph.D. Dissertation. University of North Carolina, Chapel Hill.

Odum, H. T. 1952. The Carolina Bays and a Pleistocene weather map. Am. J. Sci. 250:263-270.

Preston, C.D. and C.Q. Brown. 1964. Geologic section along a Carolina Bay, Sumter County, South Carolina. Southeast. Geol. 6:21-29.

Prouty, W.F. 1952. Carolina Bays and their Origin. Geo. Soc. Am. Bull. 63:167-224.

SAS Institute Inc. 2000. The SAS system for Windows. Release 8.2. SAS Inst., Cary, NC.

Saunders, C.L. and C.Q. Brown. 1992. Substrate variability and internal sediments and sediment textural gradients in three Carolina bays, south-central coastal plain, North Carolina. 41st Southeast GSA Meetings Abstracts. 24:62-63.

Schafale, M.P. and A.S. Weakley. 1990. Classification of the Natural Communities of North Carolina: Third Approximation. p. 205-217. North Carolina Natural Heritage Program, Division of Parks and Recreation, Department of Environment, Health and Natural Resources. Raleigh, NC.

Sharitz, R.R. and J.W. Gibbons. 1982. The ecology of southeastern shrub bogs (pocosins) and Carolina Bays: A community profile. Fish and Wildlife Service.

Skaggs, R.W. and J.S. Barnes. 1976. Drainage and water table control on colloidal muck soils. Am .Soc. Agric. Eng. Annual meeting, Paper No. 76-2041.

Soil Survey Division Staff, 1993. Soil Survey Manual. United States Department of Agriculture, Washington D.C.

Stager, J.L. and L.B. Cahoon. 1987. The age and tropic history of Lake Waccamaw, North Carolina. J. Elisha Mitchell Sci. Soc. 103:1-13.

Thom, B.G. 1970. Carolina Bays in Horry and Marion Counties, South Carolina. Geo. Soc. Am. Bull. 81:783-814.

US Army Corps of Engineers. 2002. Regulatory Guidance Letter No. 02-2.

Weakley, A.S. and S.K. Scott. 1982. Natural features summary and preserve design for Carolina Bays in Bladen and Cumberland Counties, NC. Unpublished report to NC Natural Heritage Program, The Nature Conservancy, and Earthlines, Inc., Raleigh, NC.

Wilson, K.A. and W.J. Mitsch. 1996. Functional assessment of five wetlands constructed to mitigate wetland loss in Ohio, USA. Wetlands 16:436-451.

Wright, E., T. Carter, R. Leeson, S. Forman, L. Abrams, and S. Harris. 2000. Stratigraphy of two-overlapping Carolina Bays, Horry County, South Carolina. GSA proc. 32:84.

Table 6.1. Example profile descriptions of organic soils from the reference bays and Juniper Bay.

Horizon	Depth	Description
		Reference bay
Oi	0-20	Black (10YR 2/1) fibric to hemic muck that is part of the root mat; weak coarse platy structure from layering of plant debris; gradual boundary.
Oe	20-50	Very dark brown (10YR 2/2) hemic muck; massive structure with many organic bodies 0.5 to 1.0 cm in diameter; gradual boundary.
Oa	50-85	Black (10YR 2/1) sapric muck; massive structure; gradual boundary.
OC	85-110	Very dark brown (10YR 2/2) mucky loam to mucky sandy loam; massive structure; gradual boundary.
2C1	110-140	Very dark brown (10YR 2/2) sandy loam; massive structure; gradual boundary.
2C2	140-180	Dark gray (10YR 4/1) sand; single grain structure.
		Juniper Bay: JB10C
Ap	0-10	Very dark brown (10YR 2/2) sandy loam; moderate medium (3mm) granular structure; abrupt boundary.
Oa	10-20	Black (N 2.5/0) sapric material; moderate fine (2mm) granular to sub-angular blocky structure; abrupt boundary.
OA1	20-51	Black (10YR 2/1) mucky silt loam, weak very coarse (20cm) prismatic structure; clear boundary.
OA2	51-61	Very dark brown (10YR 2/2) mucky silt loam with 25% black (N 2.5/0) charcoal; weak coarse (10cm) prismatic structure.
OA3	61-68	Dark brown (10YR 3/3) mucky fine sandy loam; very weak coarse (10cm) prismatic structure; clear boundary.
Bw	68-107	Yellowish brown (10YR 5/4) very fine sandy clay loam; weak very coarse (20cm) platy to moderate medium (5cm) sub-angular blocky structure; clear boundary.
C	107-120	Light brownish yellow (10YR 6/2) sandy clay loam; strong medium (1cm) angular blocky structure; faint reaction to α,α'-dipyridyl.

Table 6.2. Comparison of physical properties of organic soils in Juniper Bay and Reference bays.

Horizon[t]	Depth	Sand	Clay	Bulk Density	Porosity	Plant Available Water*
	(cm)	-------- (%)	-------	(g cm^{-3})	(cm cm^{-3})	(cm cm^{-3})
				Juniper Bay		
1	15	57.5	26.4	0.70	0.60	0.27
2	32	53.8	30.0	0.52	0.64	0.46
3	54	57.1	27.8	0.48	0.67	0.50
4	75	59.5	22.2	0.85	0.62	0.42
5	87	71.1	11.8	1.20	0.58	0.30
6	108	---	---	---	---	---
Error	Error	14.8	6.7	0.17	0.14	0.07
				Reference Bays		
1	19	---	---	---	---	0.30
2	48	40.5	16.2	0.29	0.62	0.29
3	88	44.4	13.6	0.35	0.66	0.26
4	123	55.7	12.0	0.64	0.58	0.27
5	148	53.5	12.9	0.74	0.60	0.32
6	171	63.8	11.2	0.96	0.52	0.19
Error		10.9	4.5	0.15	0.09	0.05

* significant at p>0.1 (---) data not available. [t] Horizons were different between Juniper bay and reference bays and are numbered here to indicate the presence of a distinct horizon.

Table 6.3. Profile descriptions of crest (C) and ditch (D) in an organic soil at Juniper Bay.

Horizon	Depth	Matrix	Texture	Structure	OC	Comments
	(cm)				(%)	
			JB16C			
Oap	0-11	N 2.5/0	sm	Strong Medium Granular	26.2	
OA1	11-31	10YR 2/2	sm	Massive	52.5	10% wood fragments 10% charcoal
OA2	31-52	10YR 2/2	sm	Massive	27.9	10% wood fragments 10% charcoal
2Bw	52-61	5YR 3/3	SL	Moderate Coarse Prismatic	5.5	
2BC	61-78	10YR 5/4	LS	Massive	0.5	10% wood fragments 40% 2.5Y 8/1 depletions
2C1	78-100	10YR 6/4	LS	Massive	0.3	5% wood fragments
2C2	100+	10YR 4/1	LS	Single Grain	0.3	Dense; reacts to alpha, alpha
			JB16D			
Oap	0-24	N2.5/0	sm	Strong Moderate Granular	13.4	
OA1	24-41	10YR 2/2	sm	Moderate Very Coarse Subangular Blocky	31.9	20% wood fragments
OA2	41-59	10YR 2/1	sm	Weak Very Coarse Prismatic	19.6	10% wood fragments
2Bw	59-74	10YR 5/4	SL	Very Weak Coarse Subangular Blocky	1.5	20% 10YR 8/2 depletions
2BC	74-110	10YR 6/4	LS	Massive	0.5	10% 10YR 8/2 depletions, slightly brittle
2Bh	110-130	10YR 2/1	SL	Massive	0.5	Cemented, brittle and firm

sm = sapric material, LS = loamy sand, SiL = Silt loam, SL = Sandy loam, mSL = mucky sandy loam

Table 6.4. Crest vs. Ditch comparison of physical properties of the organic soil in Juniper Bay.

Horizon	Depth	Sand	Clay	Bulk Density*	Ksat	Porosity*	Plant Available Water
	(cm)	-------- (%)	-------	(g cm^{-3})	(cm hr^{-1})	(cm cm^{-3})	(cm cm^{-3})
				<u>Crest</u>			
Oap	15	56.4	27.3	0.69	10.35	0.61	0.17
OA1	32	53.8	30.0	0.53	6.76	0.62	0.35
OA2	52	57.1	27.7	0.47	5.41	0.67	0.41
Bw	74	59.5	22.2	0.83	7.48	0.65	0.33
BC	88	71.1	11.8	1.16	1.49	0.61	0.20
C	110	---	---	---	---	---	---
Error	3	13.8	6.5	0.10	3.20	0.04	0.07
				<u>Ditch</u>			
Oap	15	70.0	17.7	0.85	7.13	0.60	0.15
OA1	32	66.7	18.5	0.69	10.17	0.65	0.26
OA2	48	70.2	17.3	0.87	4.43	0.59	0.24
Bw	66	72.2	13.7	1.29	2.62	0.46	0.34
BC	92	72.4	14.2	1.23	3.22	0.47	0.20
C	107	79.4	10.7	1.61	2.37	0.52	0.47
Error	3	13.8	6.5	0.10	3.20	0.04	0.07

* significant at p>0.1 (---) data not available.

Table 6.5. Example profile descriptions of soils with histic epipedons from the Reference bays and Juniper Bay.

Horizon	Depth	Description
	(cm)	**Reference bay**
Oi	0-15	Very dark brown (10YR 2/1) hemic material; weak medium platy structure; clear boundary; root mat.
Oa	15-36	Black (N 2.5/0) sapric material; massive structure; clear boundary.
OC	36-65	Black (N 2.5/0) sandy loam; massive structure; gradual boundary.
C	65-100	Very dark brown (10YR 2/2) sand; single grain structure.
		Juniper Bay: JB61C
Ap	0-22	Black (N 2.5/0) mucky sandy loam with 60% organically coated sand grains; moderate medium granular structure; clear boundary.
Oa	22-36	Very dark brown (10YR 2/2) sapric material; strong coarse granular structure; clear boundary.
Bw	36-56	Dark brown (10YR 3/3) sandy loam with 2% gray (10YR 6/1) sand; weak medium sub-angular blocky structure; clear boundary.
BC	56-74	Dark yellowish brown (10YR 4/6) loamy sand with 2% gray (10YR 6/1) sand; weak medium sub-angular blocky structure; gradual boundary.
C	74-108	Brownish yellow (10YR 6/6) with 2% gray (10YR 6/1) sand; single grain structure.

Table 6.6. Comparison of physical properties in soils with histic epipedons between Juniper Bay and Reference bays.

Horizon [t]	Depth	Sand	Clay*	Bulk Density	Porosity	Plant Available Water*
	(cm)	-------- (%)	-------	(g cm^{-3})	(cm cm^{-3})	(cm cm^{-3})
				Juniper Bay		
1	18	70.9	22.0	0.84	0.66	0.27
2	30	57.4	32.0	0.63	0.62	0.54
3	51	64.4	28.6	1.16	0.56	0.41
4	65	81.8	13.7	1.32	0.48	0.46
5	95	82.4	10.4	1.73	0.32	0.22
6	112	75.9	19.6	1.67	0.40	0.23
Error	4.6	8.5	5.6	0.07	0.05	0.13
				Reference Bays		
1	16	---	---	---	---	---
2	32	72.9	7.2	0.6	0.62	0.44
3	56	85.9	3.2	0.61	0.61	0.18
4	82	91.1	2.8	0.47	0.37	0.19
5	118	92.9	2.8	---	---	---
Error	4.4	5.4	3.7	0.11	0.07	0.10

* significant at p>0.1 (---) data not available. [t] Horizons were different between Juniper bay and reference bays and are numbered here to indicate the presence of a distinct horizon.

Table 6.7. Profile descriptions of crest (C) and ditch (D) in a histic soil at Juniper Bay.

Horizon	Depth	Matrix	Texture	Structure	OC	Comments
	cm				%	
			JB11C			
Oap	0-18	N 2.5/0	sm	Strong Medium Granular	46.4	
OA	18-34	10YR 2/2	sm	Weak Coarse Prismatic	48.8	5% wood fragments
Bw	34-57	10YR 2/2	SiL	Weak Medium Prismatic	6.1	
2BC	57-67	10YR 6/4	LS	Single Grain	0.6	15% 10YR 8/1 depletions
2C1	67-90	10YR 7/6	LS	Single Grain	0.1	20% 10YR 8/1 depletions
2C2	90-110	10YR 6/4	LS	Single Grain	0.2	
			JB11D			
Ap	0-10	N2.5/0	SL	Weak Fine Granular	5.2	90% organic coatings
OA	10-23	N2.5/0	mSL	Weak Medium Subangular Blocky	12.6	80% organic coatings
Bw1	23-39	10YR 2/2	SL	Weak Fine Prismatic	2.7	20% 10YR 8/1 depletions
Bw2	39-59	10YR 3/4	SL	Very Weak Medium Prismatic	1.0	30% 10YR 8/2 depletions
BC	59-92	10YR 6/6	LS	Single Grain	0.3	
C1	92-111	10YR 5/2	LS	Massive	0.3	1-2cm bands of 10YR 3/1
C2	111-120	10YR 2/1	SL	Massive	0.8	Sulfur smell

sm = sapric material, LS = loamy sand, SiL = Silt loam, SL = Sandy loam, mSL = mucky sandy loam

Table 6.8. Crest vs. Ditch comparison of physical properties of soils with histic epidedons in Juniper Bay.

Horizon	Depth	Sand	Clay	Bulk Density	Ksat	Porosity	Plant Available Water
	(cm)	-------- (%) -------		(g cm^{-3})	(cm hr^{-1})	(cm cm^{-3})	(cm cm^{-3})
				Crest			
Oap	17	70.9	22.0	0.82	9.29	0.06	0.19
OA	30	57.4	31.9	0.65	4.39	0.64	0.42
Bw	52	64.4	28.6	1.15	3.22	0.56	0.34
BC	70	81.8	13.7	1.36	2.23	0.47	0.36
C1	97	82.4	10.4	1.67	2.88	0.35	0.16
C2	111	75.9	19.6	1.70	1.33	0.34	0.13
Error		7.56	6.90	0.11	3.10	0.07	0.10
				Ditch			
Oap	15	74.8	19.5	0.89	17.16	0.36	0.14
OA	30	66.9	22.1	0.65	10.56	0.73	0.16
Bw	45	77.6	15.2	1.06	5.44	0.57	0.18
BC	66	79.4	13.6	1.40	5.37	0.35	0.45
C1	85	82.6	14.7	1.60	2.06	0.31	0.11
C2	99	79.1	16.9	1.76	0.03	0.40	0.15
Error		7.56	6.90	0.11	2.8	0.07	0.10

* significant at p>0.1

Table 6.9. Example profile descriptions of mineral soils in reference bays and Juniper Bay.

Horizon	**Depth**	**Description**
	(cm)	**Reference bay**
Oi	0-10	Brown (7.5YR 3/4) fibric organic material, root mat and leaf litter; weak medium platy structure; clear boundary.
A	10-20	Black (10YR 2/1) sandy loam; weak fine granular structure; clear boundary.
E	20-40	Gray (10YR 6/1) sand; single grain structure; clear boundary.
Bh1	40-70	Black (10YR 2/1) sandy loam; weak medium sub-angular blocky structure; clear boundary.
Bh2	70-100	Very dark grayish brown (10YR 3/2) loamy sand; weak coarse sub-angular blocky structure.
		Juniper Bay: JB17C
Ap	0-20	Black (10YR 2/1) loamy sand with 95% organically coated sand grains; weak medium (2-5mm) granular structure; abrupt
E	20-47	20-47cm. Gray (N 6/0) loamy sand with 12% A horizon material in root channels; single grain structure; clear boundary.
Bhir1	47-70	Very dark brown (10YR 2/2) sandy loam with 25% E material in upper half of horizon; massive structure; clear boundary.
Bhir2	70-92	Black (10YR 2/1) and dark brown (10YR 3/3) sandy loam in alternating layers 2-7cm thick; massive structure; abrupt boundary.
Bh	92-120	Black (10YR 2/1) sandy loam with 10% gray (10YR 6/1) sandy grains; massive structure; firm and slightly brittle.

Table 6.10. Comparison of physical properties of mineral soils between Juniper Bay and Reference bays.

Horizon [t]	Depth	Sand	Clay	Bulk Density	Porosity	Plant Available Water
	(cm)	-------- (%)	-------	(g cm^{-3})	(cm cm^{-3})	(cm cm^{-3})
				Juniper Bay		
1	10	90.9	7.4	1.09	0.48	0.23
2	27	88.1	5.1	1.32	0.46	0.26
3	44	93.8	3.1	1.45	0.49	0.26
4	62	93.2	3.7	1.49	0.52	0.20
5	85	94.5	4.3	1.55	0.49	0.23
6	101	95.7	2.5	1.59	0.43	0.17
7	126	95.9	2.7	1.63	0.43	0.18
Error	7	3.5	1.1	0.04	0.06	0.07
				Reference Bays		
1	10	82.7	4.1	---	---	---
2	22	85.7	3.3	---	---	---
3	52	96.4	1.2	---	---	---
4	82	90.4	4.2	---	---	---
Error	6	2.6	0.8	---	---	---

* significant at p>0.1 (---) data not available. [t] Horizons were different between Juniper bay and reference bays and are numbered here to indicate the presence of a distinct horizon.

Table 6.11. Profile descriptions of crest and ditch in a mineral soil at Juniper Bay.

Horizon	Depth	Matrix	Texture	Structure	OC	Comments
	cm				%	
JB03C						
Ap	0-12	N 2.5/0	LS	Moderate Fine Granular	3.3	90% coated sands
E	12-26	5YR 7/1	LS	Single Grain	0.2	25% Ap material mixed in
Bhir	26-42	5YR 3/1	LS	Massive	1.1	
Bir	42-61	10YR 6/3	LS	Single Grain	1.2	
B'hir	61-75	10YR 5/2	LS	Single Grain	0.4	Accumulation organic material
C	75-85+	10YR5/2	LS	Single Grain	0.9	Sulfur smell
JB03D						
Ap	0-15	N 2.5/0	LS	Moderate Fine Granular	2.3	80% coatings
A/E	15-22	N 2.5/0 2.5Y 7/1	LS	Weak Fine Subangular Blocky	1.7	Mixed Ap and E horizons
E	22-40	2.5Y 7/1	LS	Single Grain	0.1	
Bhir1	40-54	10YR 3/2	LS	Massive	0.8	2 cm bands of 10YR 2/1
Bhir2	57-70	10YR 3/3	LS	Massive	0.8	
Bhir3	70-84	10YR 3/3	LS	Massive	1.5	25% 10YR 2/1 weakly cemented LS
Bhir4	84-100	10YR 2/2	LS	Massive	2.1	Sulfur smell

LS = loamy sand

Table 6.12. Crest vs. Ditch comparison of physical properties of the mineral soils in Juniper Bay.

Horizon [t]	Depth	Sand*	Clay*	Bulk Density	Ksat	Porosity	Plant Available Water
	(cm)	------ (%) ------		(g cm^{-3})	(cm hr^{-1})	(cm cm^{-3})	(cm cm^{-3})
			Crest				
1	15	90.8	7.45	1.09	18.4	0.05	0.13
2	31	88	5.21	1.31	15.38	0.46	0.16
3	48	93.7	3.21	1.44	9.97	0.48	0.16
4	67	93.1	3.81	1.48	5.42	0.53	0.10
5	92	94.4	4.31	1.54	5.14	0.49	0.12
6	107	95.3	2.99	1.58	5.64	0.43	0.08
7	122	95.5	3.19	1.61	3.32	0.43	0.08
Error		1.52	1.2	0.05	4.06	0.04	0.03
			Ditch				
1	15	87.7	10.24	1.19	19.01	0.45	0.14
2	32	89.1	8.13	1.27	26.12	0.43	0.11
3	49	85.6	9.34	1.47	21.52	0.35	0.08
4	70	90.7	3.79	1.51	6.71	0.43	0.12
5	89	93.1	4.28	1.49	6.65	0.44	0.13
6	107	94.0	4.18	1.52	4.27	0.39	0.13
7	125	95.1	3.14	1.54	2.7	0.38	0.14
Error		1.52	1.2	0.05	4.06	0.04	0.03

* significant at $p>0.1$ [t] Horizons were different between Juniper bay and reference bays and are numbered here to indicate the presence of a distinct horizon.

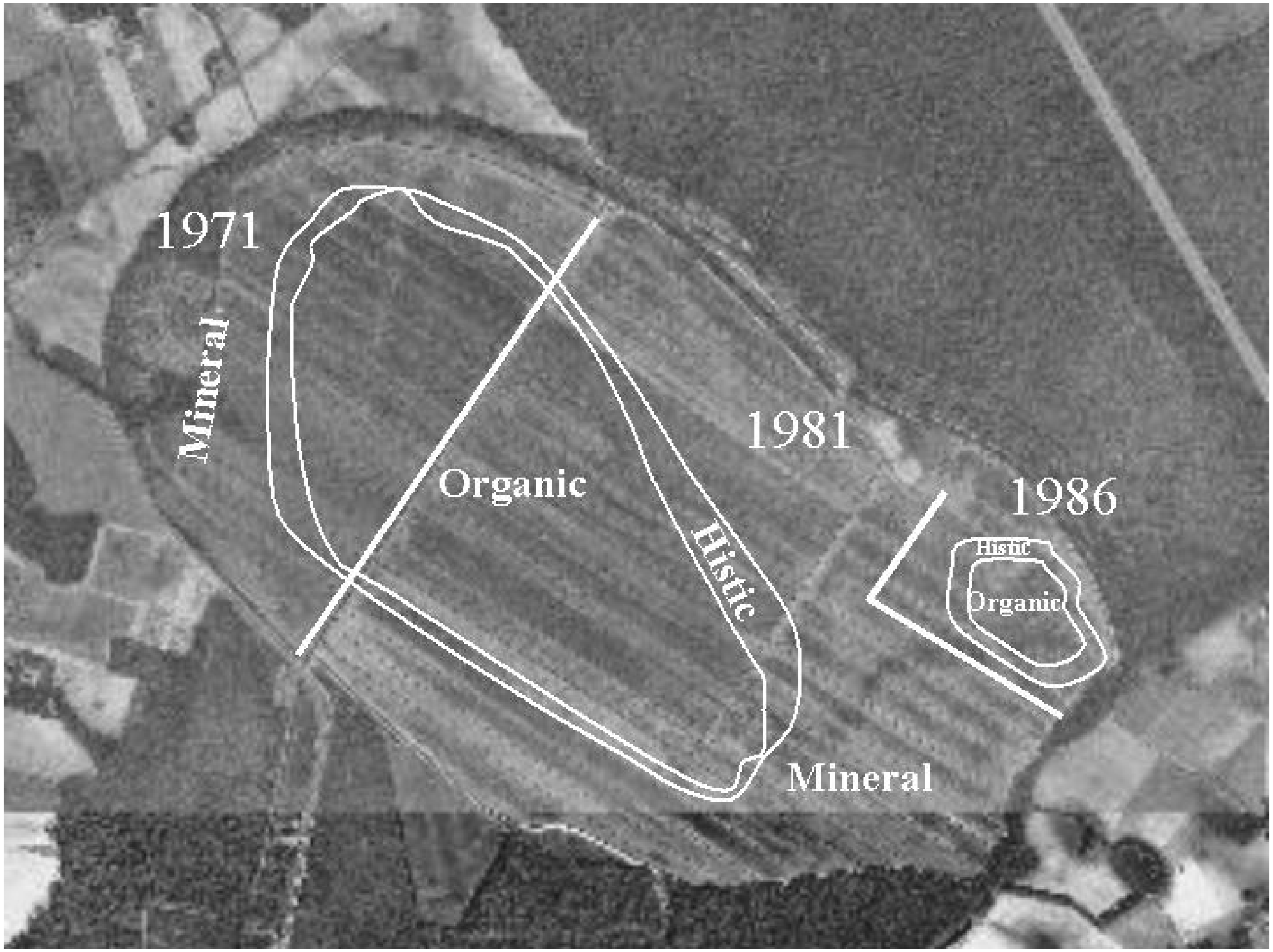


Figure 6.1. Aerial photo of Juniper Bay (2.4 x 1.6 km) showing the time of drainage and areas where organic, histic, and mineral soils are located based on site investigation preformed for the study.

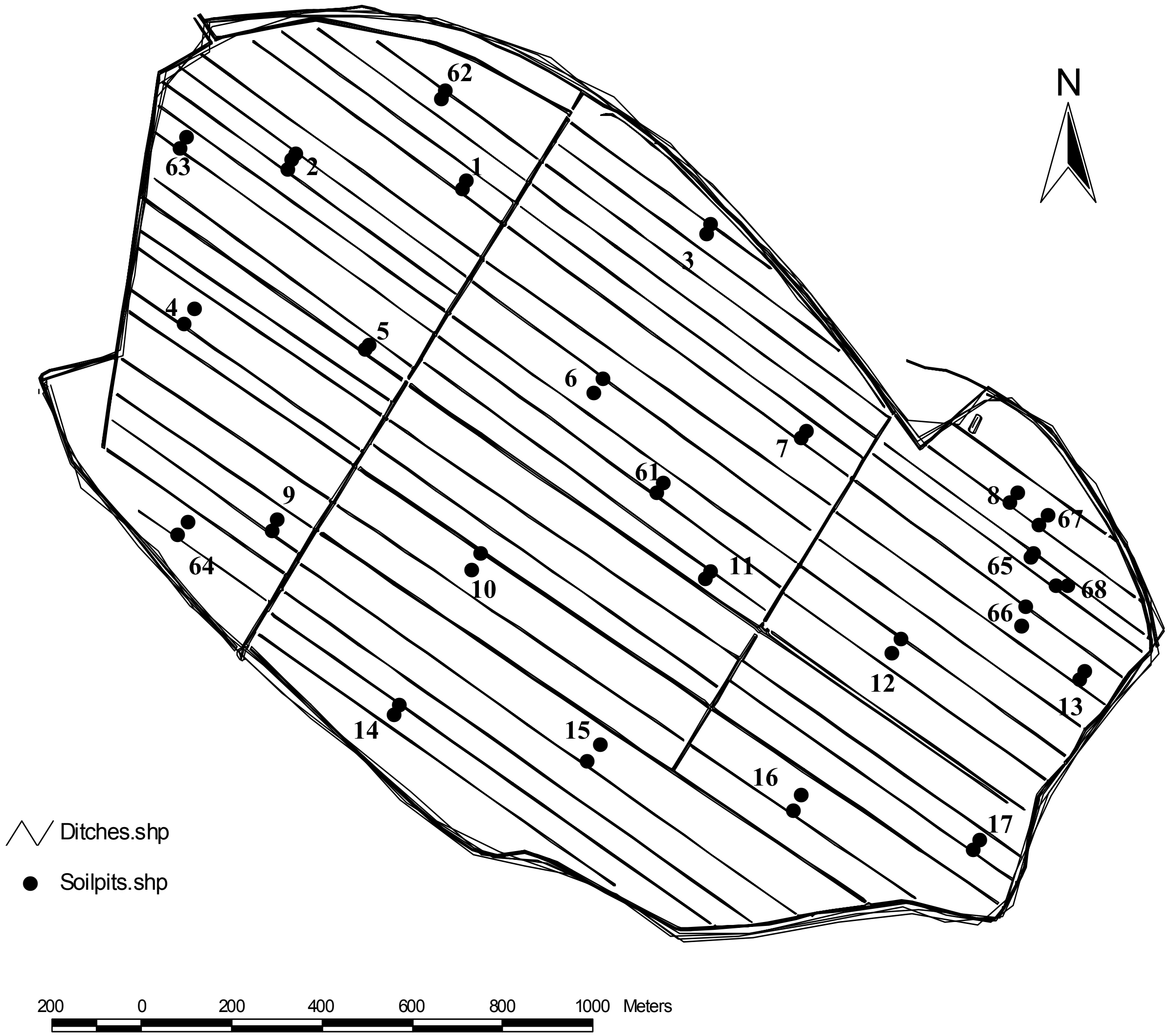
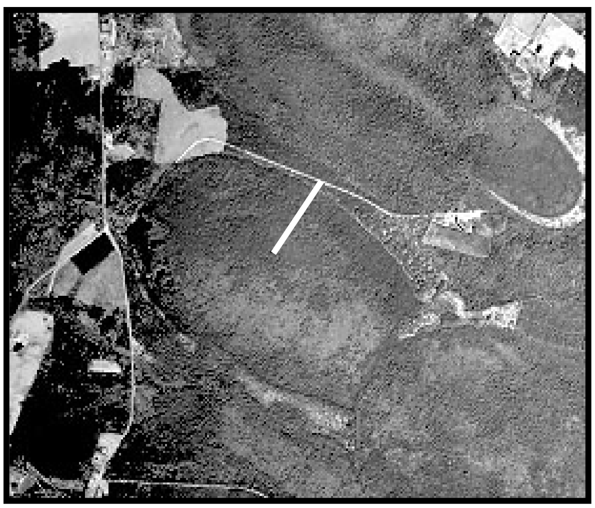
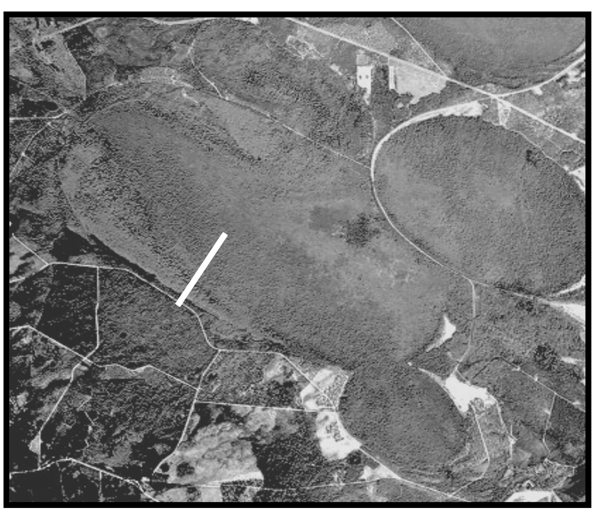


Figure 6.2. Pit locations at Juniper Bay

a.

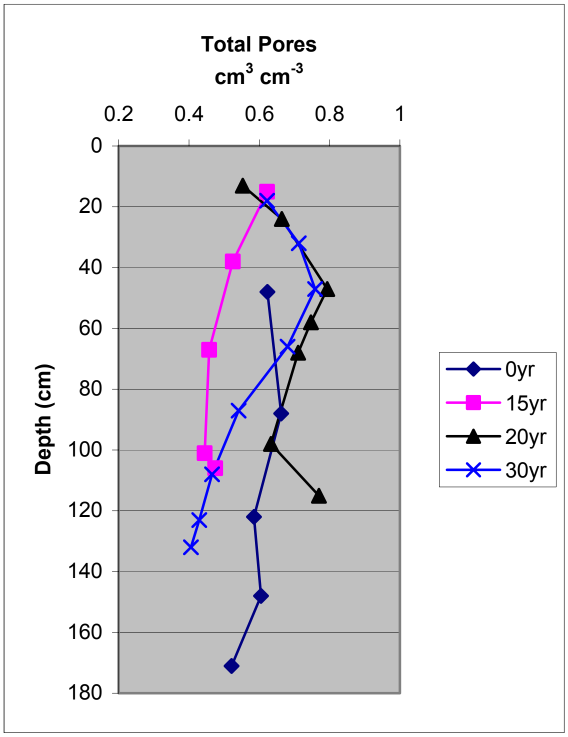


b.

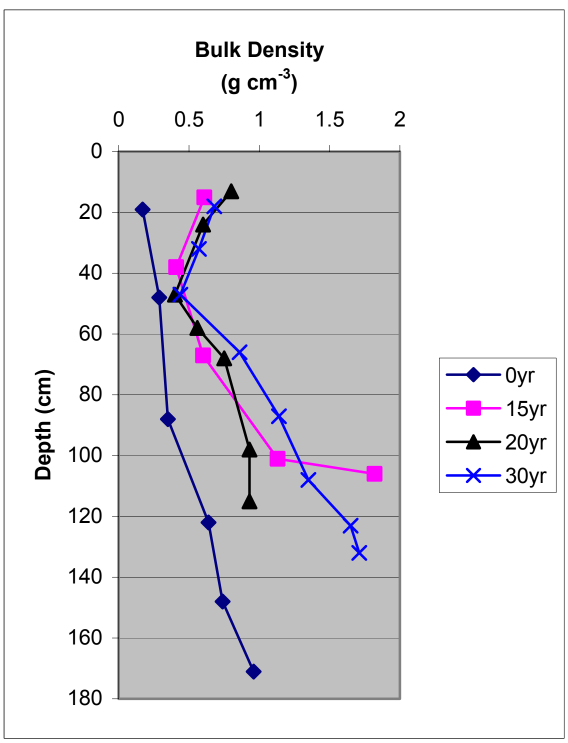


c.

Figure 6.3. Location of transects in (a) Causeway Bay, 1.8 x 1.15km, (b) Charlie Long Millpond Bay, 1.9 x 1.2 km, and (c) Tatum Millpond Bay, 4.4 x 2.2 km.



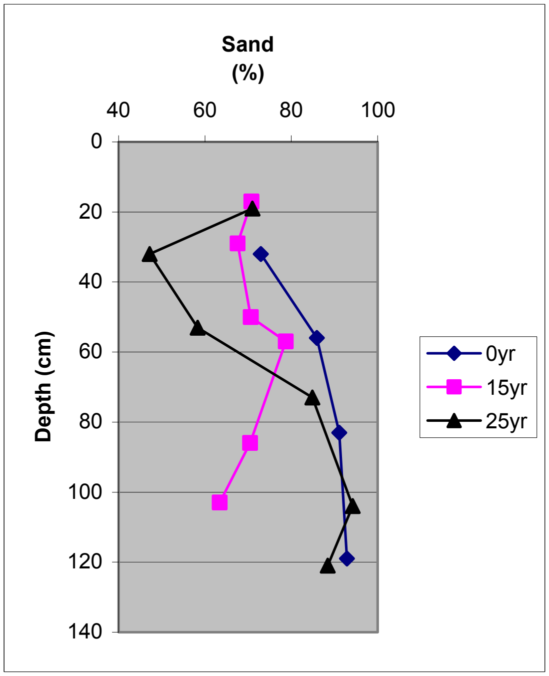
a



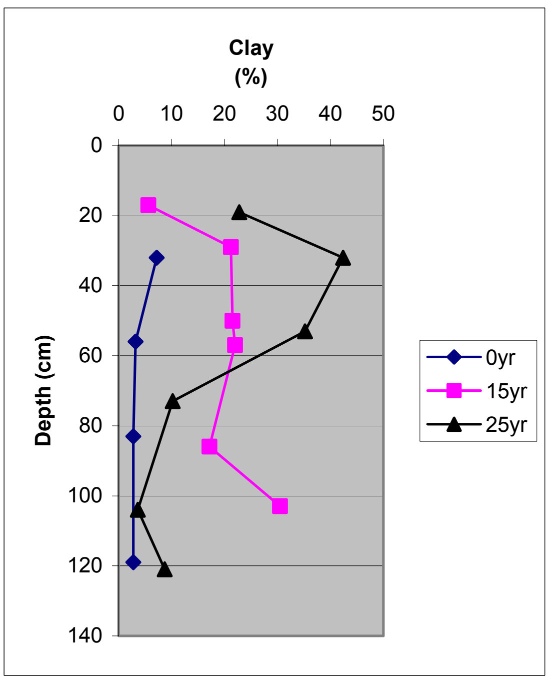
b.

Figure 6.4. Effects of drainage time on total pores (a) and bulk density (b) of an organic soil. Standard deviation is ± 0.1 g cm^{-3}.

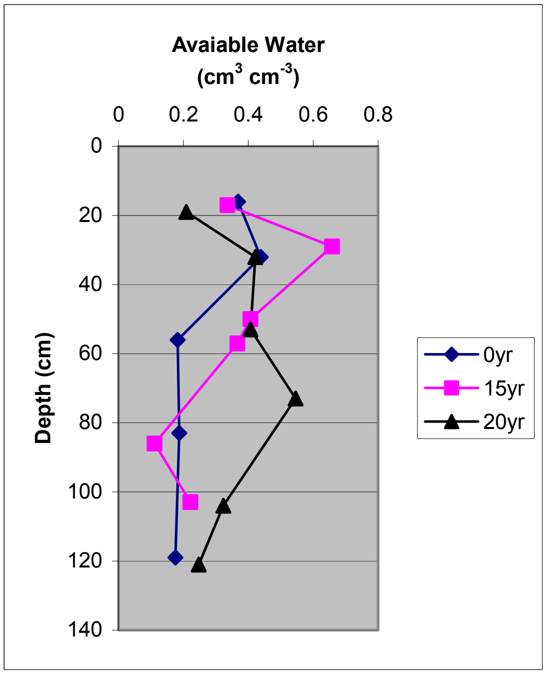
Figure 6.5. Photo comparison of soils at the crest (left) and ditch (right) at location 16 in an organic soil in Juniper Bay. Scale is in cm.


Sand
(%)
40
60
80
100
0
20
40
60
80
100
120
140
Depth (cm)
0yr
15yr
25yr

a


Clay
(%)
0
10
20
30
40
50
0
20
40
60
80
100
120
140
Depth (cm)
0yr
15yr
25yr

b



c

Figure 6.6. Effects of drainage time on sand (a), clay (b), and available water (c) in a histic soil.

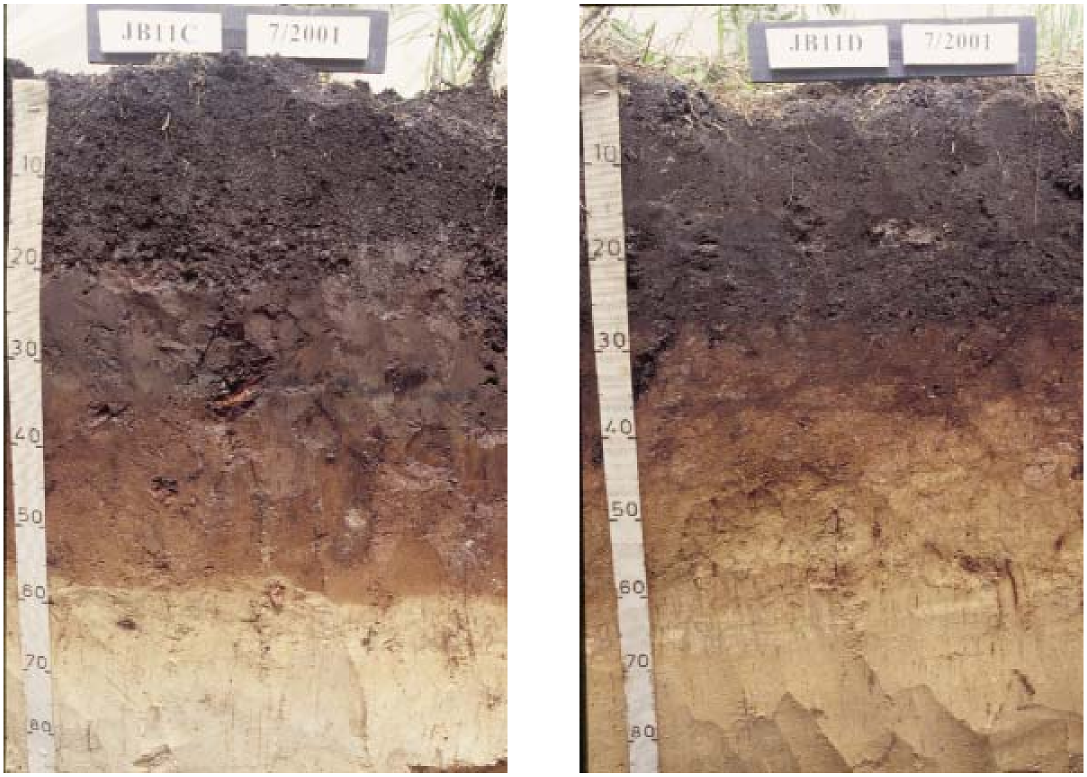
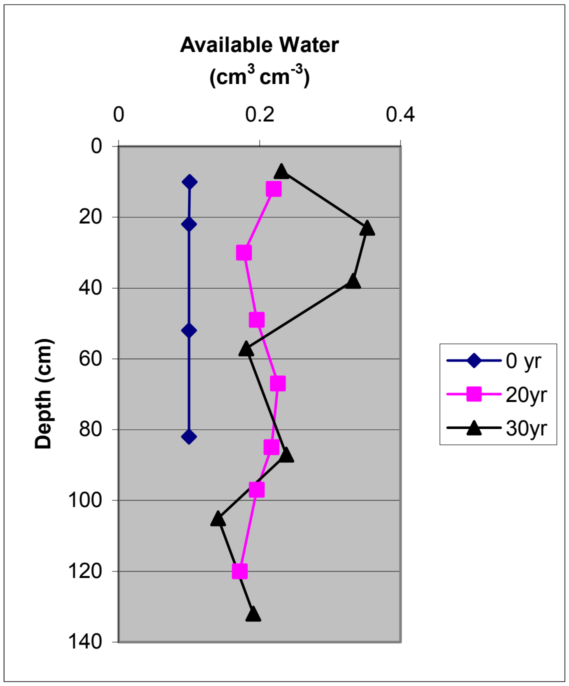
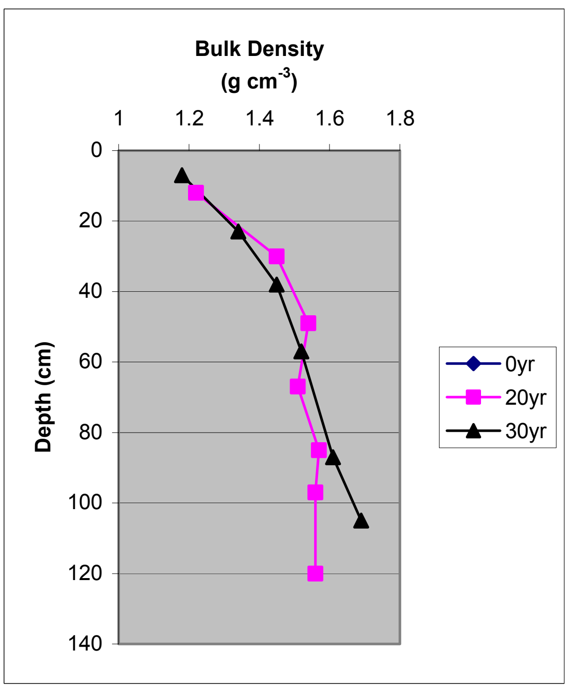


Figure 6.7. Photo comparison of soils at the crest (right) and ditch (left) at location 11 in a soil with a histic epipedon in Juniper Bay. Scale is in cm.



a



b

Figure 6.8. Effects of drainage time on available water (a) and bulk density (b) in a mineral soil.

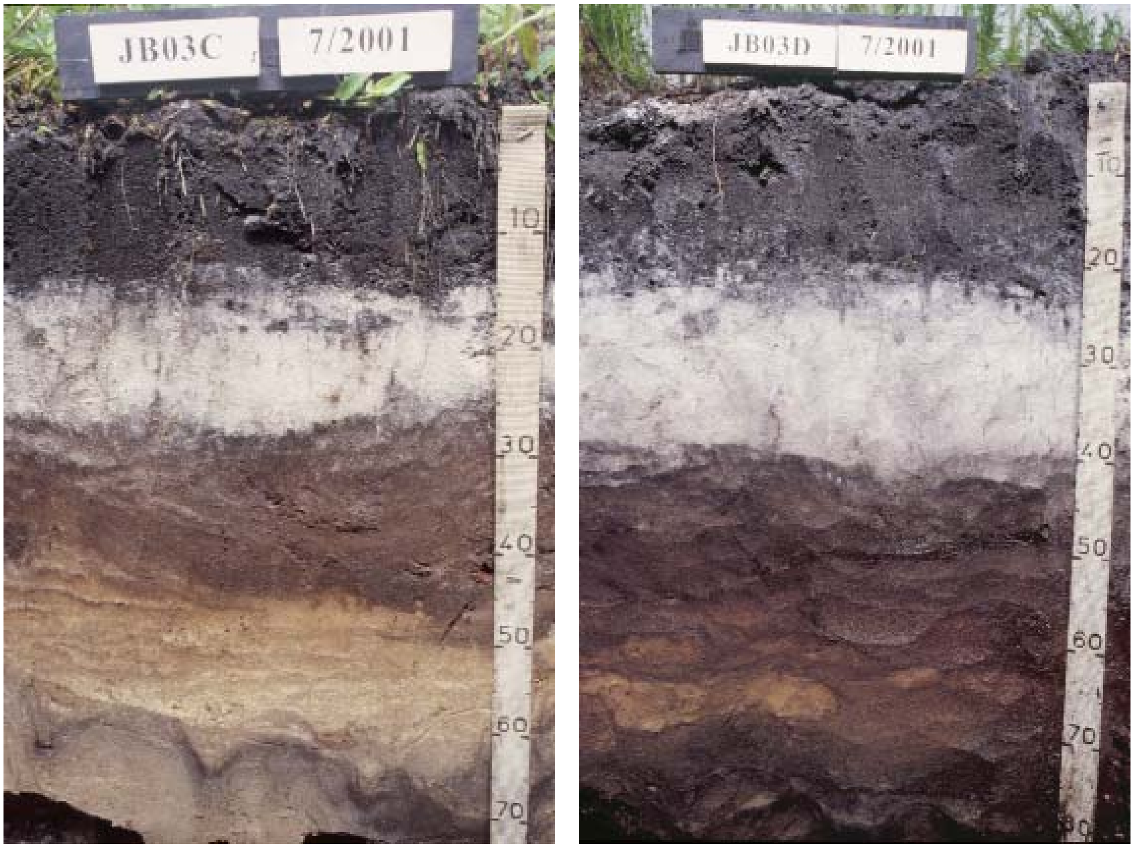


Figure 6.9. Photo comparison of soils at the crest (left) and ditch (right) at location 3 in a mineral soil in Juniper Bay