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Subaqueous soils : a resource inventory protocol
Les sols subaquatiques : une méthode pour inventorierleurs ressources

DEMAS George (1), **RABENHORST Martin** (2)

(1) USDA-Natural Resources Cons. Serv., 304 Commerce St., Snow Hill, MD 21863, USA
(2) Univ. of Maryland, Dept. of Natural Resource Sciences, College Park, MD 20742, USA

Recent technological advances have provided new opportunities to pedologists and soil surveyors involved in research and soil resource inventory projects. The development of geographic information systems (GIS) and global positioning systems (GPS) has had major impacts on pedological research through permitting increased accuracy in documenting site locations and attributes, and by providing the ability to electronically analyze soil-landscape relationships (Evans and Roth, 1992; Moore et al., 1993; Thompson et al., 1997). These technologies have also affected soil survey methods (Rahman et al., 1997) and soil survey presentation and utilization (Soil Survey Staff, 1993).

Although technological advances have led to benefits in pedological applications, especially in terrain analysis techniques for the identification and characterization of soil-landscape units, these advances and techniques have yet to be applied in subaqueous environments. The characterization and mapping of sediments in shallow water habitats may be critical to efforts to enhance and restore estuarine ecosystems. Prior efforts to evaluate the attributes and distribution of estuarine sediments are not sufficiently detailed for ecological work. The main limitations to better sediment inventories are the absence of a well defined taxonomic system and an adequate mapping protocol.

While interest in shallow water (<3 m) environments has sharply increased due to the degradation of many estuarine systems throughout the world, the sediments which support submersed macrophytes have generally been neglected by pedologists and those working in soil survey programs. The reasons for this may be the relative lack of pedological experience in shallow water habitats and also the inherent difficulties associated with the examination of sediments in permanently submersed environments.

Some pedologists may be uncomfortable with extending soil survey activities into areas permanently submersed by shallow water. Nevertheless, the rationale has been clearly outlined for the inclusion of sediments from shallow water environments within the concept and definition of soil (Demas, 1993) and pedological evidence has demonstrated that sediments under shallow water are soil, (including their support of such rooted, flowering submersed vegetation as *Zostera marina* and *Ruppia maritima*, and the development of diagnostic pedogenetic horizons) (Demas et al, 1996.)

There are several problems associated with pedological analysis of subaqueous environments, one of which is the relative imprecision in documenting locations of collected data. An additional problem encountered when working in subaqueous environments is the lack of detailed bathymetric data. Published bathymetric maps, in many cases, are produced from widely spaced data representing between 25 to 5,000 ha per sounding (Wells et al., 1994; Ryan, 1953; Folger, 1972). In contrast, terrain analysis in terrestrial settings have relied on elevation data typically representing <1 ha per measurement (Rebertus, 1989; Thompson et al., 1997). In shallow water environments, collection of bathymetric data are further complicated by tidal fluctuations. The objectives of this study were: (i) to utilize available technological instrumentation to obtain subaqueous terrain data; and (ii) to develop a protocol for the identification of subaqueous soil-landscape units.

Materials and Methods

The site selected for this study was a 1,300 ha portion of Sinepuxent Bay, Maryland (Fig. 1). Sinepuxent Bay is a coastal estuary bounded to the east by the Assateague Island barrier system and to the west by the Worcester County mainland. The bay is generally shallow (<5 m) and has a relatively small tidal range of 0.5-0.75 m (U.S. Dept. of Interior, unpublished data). It is connected to the Atlantic Ocean by the Ocean City inlet 9 km to the north and by the Chincoteague inlet 45 km to the south.

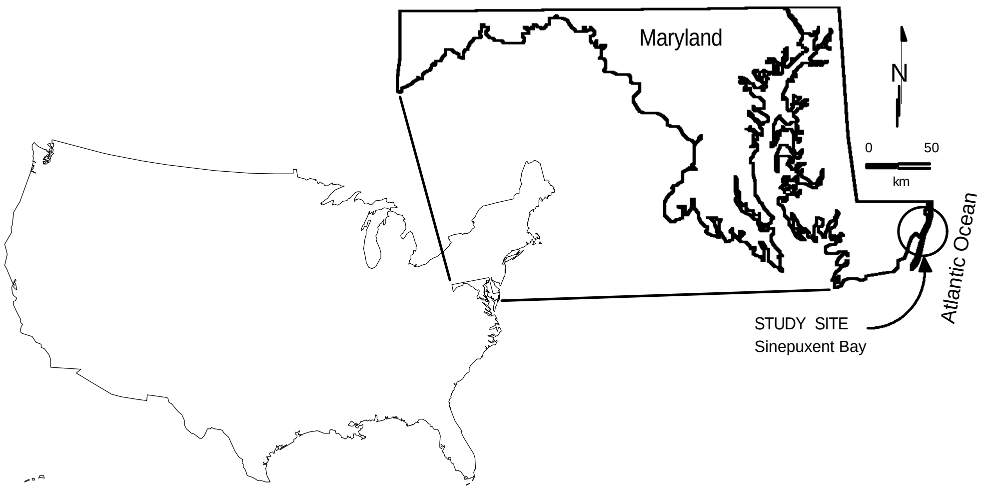

Figure 1. The study site is located in Sinepuxent Bay, Maryland, along the mid-Atlantic coastline of the USA, behind the Assateague Island barrier system.

A Raytheon DE-719C marine research fathometer used for the collection of bathymetric data was equipped with an Odum Digitrace unit to accommodate digital output of the data. The fathometer, which was mounted on a 6 m boat equipped with a 50 horsepower outboard motor, was calibrated each day prior to collecting data and was checked periodically throughout the day. Accuracy of the calibrated unit was within 1 dm. A Rockwell PLGR+ PPS GPS unit was utilized to obtain latitude and longitude of specific locations. Each day, prior to collection of data, the unit was allowed to download the "almanac," a process required to ensure operation at maximum accuracy. All data were collected when the unit had a Figure of Merit (FOM) value of 1, indicating that the unit was operating at an accuracy level of within 1 m in the unobstructed areas of the study site (Rockwell Corp. Staff, 1994). The GPS unit and fathometer were both connected through serial ports of a laptop computer running Geolink XDS software (GeoResearch Inc. Staff, 1994) which provides the capability of simultaneously recording the time of day, real time GPS location, and fathometer soundings. Data were collected using a boat speed of approximately 7 kilometers per hour, while soundings/locations were recorded every 5 seconds (approximately 10 m apart.) A Remote Data Systems WL40 digital Tide Gauge was installed on a dock piling at the north end of the site to record tidal measurements every 10 minutes. At the end of each day, the tide data were downloaded for later analyses. The tide gauge was calibrated with respect to Mean Sea Level (MSL) through survey linked to USGS benchmark located nearby. These data were later used to normalize all fathometer soundings to MSL.

Bathymetric surveys were made during the Spring of 1996. The survey consisted of cross sections, "edge" surveys, and main channel surveys. The mainland and barrier island edges were hand digitized and labeled as 0 MSL prior to combining and manipulation of the bathymetric data. A bathymetric map of the site was created using the Surfer6 contouring software package (Keckler, 1995). All location data was converted to decimal degrees and "duplicates" were edited out. This was required due to the tendency of the software to average points located too close together. The normalized fathometer data and location data were converted to a text file and then imported into the contouring package. The map developed was based on the Kriging method (Odeh et al., 1992, Keckler, 1995) with a 100 by 100 node capacity. Pedons at selected locations were sampled by using a MacCauley sampler, a vibracorer, or a standard bucket auger. The soils were described using standard methods of the USDA-NRCS (Soil Survey Staff, 1993) and were classified according to *Soil Taxonomy* (Soil Survey Staff, 1996.)

Results and Discussion

Over 23,000 geo-referenced and normalized fathometer soundings were collected within the 1,275 ha study area, which corresponds to approximately 0.06 ha/sounding. The most detailed bathymetric map of the site prior to this study was based on 51 depth soundings, or approximately 25 ha/sounding (Wells et al., 1996.) The bathymetric map produced in this study was sufficiently detailed to permit analyses of slope gradients, concavity, convexity, in addition to documenting actual elevation (bathymetry). This represented a significant step in the attempt to understand the nature of subaqueous landforms and their distribution. Utilizing this initial approach to terrain analysis, 11 possible subaqueous landscape units were identified (Fig. 2). Further consideration of geomorphic attributes and the use of infrared photography later resulted in the combination of some units due to their overall similarities.

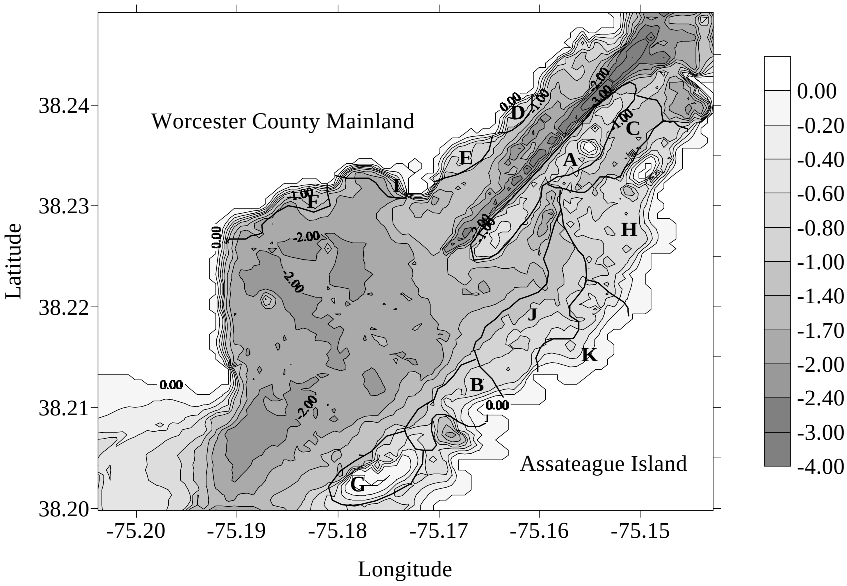

Figure2. Bathymetric map of the study area showing subaqueous landscape units (A through K). In most of the study area the water is <2.5 m deep.

The subaqueous landscape units in Fig. 2 can be understood as representing 6 distinct subaqueous landforms. The first landform (landscape unit A) is a shallow dredge shoal (running NE-SW in mid-bay), appears to have been created sometime in the late 1930's or early 1940's (based on examination of USDA-NRCS 1938 and 1952 aerial photography). Water depth in this unit ranges from 0.1-0.5 m and slopes are <0.8%. A second landform is the extremely shallow and sandy curvilinear areas adjacent to the barrier island tidal marshes. These are subaqueous overwash fans derived from barrier island washover events (landscape units B and K). Water depths range from 0.1-0.6 m and slopes are <0.5% and very gradual. Adjacent to the Worcester County mainland in the northern half of the site, a third landform was identified which is representative of two shallow, eroded coves (landscape units D and E) where the water depth ranges from 0.1-0.9 m. Slope in this unit is 0.3-1.0%, but the length of slope is significantly less than that encountered in the barrier island overwash unit. A fourth landform representative of silty deep water coves adjacent to eroding mainland tidal marshes was identified in the southern half of the study site (landscape units F and I). Water depth of this unit ranges from 1.2-2.0 m with a slope of 0.3-0.8%. A fifth landform is representative of the gently sloping transitional areas between the barrier island overwash dominated units and the dredge shoal and very deep central plain in the southern half of the site (landscape units C, G, and J). Water depth in this unit ranges from 0.6-1.5 m and slope configuration is generally concave. The sixth landform (landscape unit H) is a shallow area where washover events have had much less impact. Buried marshes are commonly within 1 m of the surface. Water depth ranges from 0.2-0.9 m and slopes range from 0.2-0.7%

Examination of pedons from numerous locations from the various landscape units demonstrated that each of the six major landforms had distinct soil characteristics. A description of a profile representative of the deep water mainland coves (units F and I) is shown in Table 1. This soil is dominated by fine textured, sulfidic, high n-value materials which are underlain by a buried organic soil (former marsh surface) and can be classified as a fine-silty, mixed, mesic Thapto-histic Sulfaquent (Soil Survey Staff, 1996). In contrast, the representative profile for the overwash fans (units B and K) (Table 2) is predominantly dense sand with calcareous shell fragments, which is underlain by a slightly finer buried soil surface. This soil can be classified as a siliceous, mesic Typic Psammaquent

Table 1. Modal profile description of deep water mainland cove landform (units F & I).

Horizon	Depth (cm)	Description
A	0-18	Dark greenish gray (10Y 3/1) silt loam; massive; friable, slightly sticky, slightly plastic; n-value greater than 1.0, material flows easily between fingers when squeezed; 30 percent light olive brown (2.5Y 5/3) organic fragments; slightly alkaline; saline; clear smooth boundary.
Cg1	18-85	Dark greenish gray (10Y 3/1) silty clay loam; massive; firm, slightly sticky, slightly plastic; n-value greater than 1.0, material flows easily between fingers when squeezed; slightly alkaline; saline; abrupt wavy boudary.
Oeb	85-135	Dark brown (7.5YR 3/2) mucky peat; hemic soil material, fiber content is one-third the soil volume after rubbing; 70 percent silt loam mineral material; slightly alkaline; saline; clear smooth boundary.
Oab	135-150	Very dark brown (10YR 2/2) muck; sapric soil material, fiber content is one-tenth the soil volume after rubbing; 60 percent silt loam mineral material; slightly alkaline; saline.

Conclusions

The significance of is study is twofold. First, the approach demonstrates that available technology can be utilized to develop a more highly detailed, accurate, and useful bathymetric map than has been previously available for sediment studies (Folger 1972; Katuna and Ingram, 1974; Ryan, 1953; Wells et al., 1994; Wells et al., 1996). Second, and of greater pedological importance, the level of bathymetric detail is sufficient to permit subaqueous terrain analysis including the identification and delineation of subaqueous landforms. This protocol can provide a basis from which the examination of sediment-landscape relationships can be extended into pedological, ecological, and environmental research and applications.

Table 2. Modal profile description for overwash fan landform (units B and K).

Horizon	Depth (cm)	Description
A	0-3	Olive (5Y 4/3) sand; single grain; loose; slightly alkaline; saline; abrupt smooth boundary.
C1	3-25	Black (N 2/) sand; few medium distinct olive gray (5Y 5/2) mottles; massive; firm; slightly alkaline; saline; gradual smooth boundary.
Cg1	25-47	Dark greenish gray (5GY 3/1) sand; massive; firm; 2 percent shell fragments; slightly alkaline; saline; gradual smooth boundary.
Cg2	47-58	Very dark gray (5Y 3/1) sand; massive; firm; slightly alkaline; saline; clear smooth boundary.
Cg3	58-95	Dark greenish gray (5GY 3/1) sand; massive; firm; 1 percent shell fragments; slightly alkaline; saline; abrupt wavy boundary.
2ACb	95-110	Very dark gray (5Y 3/1) fine sand; massive; firm; 10 percent dark brown (7.5YR 3/2) organic fragments; 20 percent shell fragments; slightly alkaline; saline.

Bibliography

Demas, G.P. 1993. Submerged soils: a new frontier in soil survey. Soil Survey Horizons 34:44-46.

Demas , G.P., M.C. Rabenhorst, and J.C. Stevenson. 1996. Subaqueous soils: a pedological approach to the study of shallow water habitats. Estuaries 19:229-237.

Evans, C.V. and D.C. Roth. 1992. Conceptual and statistical modes to characterize soil materials, landforms, and processes. Soil Sci. Soc. Amer. J. 56:214-219.

Folger, D.W. 1972. Characteristics of estuarine sediments of the U. S. Geol. Surv. Prof. Pap. 742. U. S. Dept. Inter., Washington, D.C.

GeoResearch, Inc. Staff. 1995. Geolink/PLGR PPS+ GPS/GIS Mapping System XDS Manual. GeoResearch, Inc., Billings, Montana.

Moore, I.D., P.E. Gessler, G.A. Neilson, and G.A. Peterson. 1993. Soil attribute prediction using terrain analysis. Soil Sci. Soc. Amer. J. 57:443-452.

Katuna, M.P. and R.L. Ingram. 1974. Sedimentary structures of a modern lagoonal environment: Pamlico Sound, North Carolina. Sea Grant Publication UNC-SG-74-14, Univ.of North Carolina, Chapel Hill.

Keckler, D. 1995. SURFER for Windows user's guide. Golden Software, Inc., Golden, Colorado.

Moore, I.D., P.E. Gessler, G.A. Neilson, and G.A. Peterson. 1993. Soil attribute prediction using terrain analysis. Soil Sci. Soc. Amer. J. 57:443-452.

Odeh, I.A.O., A.B. McBratney, and D.J. Chittleborough. 1992. Fuzzy-c-means and Kriging for mapping soil as a continuous system. Soil Sci. Soc. Amer. J. 56:1848-1854.

Rahman, S., L.C. Munn, G.F. Vance, and C. Arneson. 1997. Wyoming Rocky Mountain forest soils: mapping using an ARC/INFO geographic information system Soil Sci. Soc. Amer. J. 61:1730-1737.

Rebertus, R.A., J.A. Doolittle, and R.L. Hall. 1989. Landform and stratigraphic influences on variability of loess thickness in northern Delaware. Soil Sci. Soc. Amer. J. 53:843-847.

Rockwell Corp. Staff. 1994. Operations and maintenance manual: Precision Lightweight GPS Receiver (PLGR+). Rockwell International Corporation, Cedar Rapids, Iowa.

Ryan, J.D. 1953. The sediments of Chesapeake Bay. Maryland Board of Nat. Res.-Dept. Geol., Mines and Wat. Res. Bull. 12. Baltimore, Maryland.

Soil Survey Staff. 1993. Soil Survey Manual. United States Dept. Agric.-Soil Conserv. Serv. Agric. Handbook 18. Washington, D.C

Soil Survey Staff. 1996. Keys to Soil Taxonomy. Seventh edition. USDA-Natural Resources Conservation Service, Washington, D.C.

Thompson, J.A., J.C. Bell, and C.A. Butler. 1997. Quantitative soil-landscape modeling for estimating the areal extent of hydromorphic soils. Soil Sci. Soc. Amer. J. 61:971-980.

Wells, D.V., R.D. Conkwright, J.M. Hill, and M.J. Park. 1994. The surficial sediments of Assawoman Bay and Isle of Wight Bay in Maryland: physical and chemical characteristics. Coastal and Estuar. Geol. File Rept. No. 94-2, Maryland Geol. Surv., Baltimore, Maryland.

Wells, D.V., R.D. Conkwright, R. Gast, J.M. Hill, and M.J. Park. 1996. The shallow sediments of Newport Bay and Sinepuxent Bay in Maryland: physical and chemical characteristics. Coastal and Estuar. Geol. File Rept. No. 96-2, Maryland Geol. Surv., Baltimore, Maryland.

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