Resolution of sedimentation rates in impacted coastal environments using ^{137}Cs and ^{210}Pb markers: Dog River and Fowl River embayments

J.M. Sanders[1], D.W. Haywick[2], and M.L. Fearn[2]
[1]Department of Physics and [2]Department of Earth Sciences
University of South Alabama

Introduction

Excessive sedimentation associated with urban sprawl and poor land development practices is a major issue along much of the Alabama Gulf Coast including Mobile's Dog River. Property owners complain about shallow mud-choked channels, city dredges struggle to keep flood channels open to handle flood flows, benthic fauna are smothered beneath blankets of mud associated with heavy rainfall events, and light penetration and water temperatures are affected by suspended sediments. While sediment in Dog River is commonly considered to be a significant problem, there is a dearth of hard data that documents the actual change in sedimentation rates covering the years of Mobile's growth. Radioisotopic dating offers a means of providing sedimentation data that will allow city planners, land managers, and environmental groups to understand and deal with the long term consequences of their actions.

The rate of sedimentation and the change in rate of sedimentation are two of the most important parameters by which to interpret the depositional history and health of coastal environments. Sedimentation rates have traditionally been estimated by using sediment traps or through various biological (e.g., pollen, diatoms, wood) and physical markers (e.g., chronostratigraphic horizons such as volcanic ash beds). More recently, short-lived radioactive markers such as ^{210}Pb and ^{137}Cs have been used. The object of this research was to determine the average rate of sedimentation over the least 50 years at various points in two southern Alabama coastal embayments, Dog River and Fowl River, by using ^{137}Cs and ^{210}Pb dating. Portions of Dog River have been heavily impacted by run-off sediment due to its headwaters being affected by Mobile's urban sprawl. Fowl River has been much less impacted as most of its drainage is derived from non-developed areas in southern Mobile County. The proposed dating techniques allowed sedimentation rates to be determined for each river and for different tributaries within a watershed to investigate the effects of development on sedimentation in the two river systems. Cores were also be extracted from Big Creek Lake (also known as Converse Reservoir), a reservoir which was filled between 1950 and 1955 to serve as the water supply for the City of Mobile. Although it is a completely different environment to the two embayments to be studied, the cores from the lake served as references by which to evaluate the nature of the ^{137}Cs and ^{210}Pb flux in the Mobile area.

The age of the sediments were determined by detection of gamma-rays emitted from ^{137}Cs fallout. Since ^{137}Cs fallout was produced primarily during a ten-year period when large nuclear weapons were tested in the atmosphere, its presence or absence in sediment serves to identify the stratum as having been deposited prior to, during, or after the era of widespread atmospheric testing[1, 2]. The ^{137}Cs content was determined through gamma-ray spectrometry using a high-purity germanium detector. Such a detector provides a spectrum which reveals gamma rays emitted by a wide variety of radionuclides. The use of gamma-ray spectrometry to determine the ^{137}Cs content has the advantage that it is non-destructive, so samples from the core may be examined further for chemical composition, grain size distribution, and the like.

The use of ^{210}Pb to analyze sedimentation in lakes, estuaries, and coastal marine environments is a well-established technique which relies on the flux of ^{210}Pb from the decay of atmospheric ^{222}Rn, and it is capable of dating sediments extending back over several decades[3]. It can therefore supplement and extend the ^{137}Cs results. However, accurate dating of sediment through gamma-ray analysis requires accurate calibration of the efficiency of the gamma-ray spectrometer and careful assessment of the absorption of the gamma-rays by the sample[4, 5, 6]. Due to these complications, the analysis of ^{210}Pb during this project period was not completed. At the time of this Final Report, we are continuing to re-analyze our samples for ^{210}Pb, and it is expected that future publications will report the results of the ^{210}Pb analysis. The remainder of this report will focus solely on the more straight-forward ^{137}Cs results.

Sampling and Analytical Methods

Sampling Strategy and Methods

Dog River's three tributaries (see Figure 1) have been affected differently by the growth of Mobile. Because the city has grown into each watershed at a different time, chronological comparisons among the three will be useful. The Eslava Creek watershed was largely settled before 1963 with most growth occurring from 1940 to 1960. We hypothesized that the highest sedimentation rates (upstream of Moore Creek) likely occurred in close association with the construction of I-65 in early 1960s. The Halls Mill Creek watershed has been more heavily impacted since 1963. The Rabbit Creek watershed has been the least affected by development, but it has recently fallen victim to development in the Tillmans Corner/Theodore area. The Halls Mill Creek and Rabbit Creek watersheds differ in size and in percentage of hilly erodible land, which would affect the amount of sediment each tributary receives.

Coring sites in Dog River were chosen to sample these varied portions of the watershed. Site A (core DRA1) was in the main channel near the mouth of the river. Site B (core DRB1) was also in the channel near the mouths of Rabbit Creek and Halls Mill Creek. Site C (core DRC1) was in the channel near the mouth of Moores Creek. Site D (core DRD3) was in the upper part of the river (Eslava Creek). Sites E (Core DRE1, Rabbit Creek) and F (core DRF1, Halls Mill Creek) sampled the tributaries to the river. In order to avoid coring through disturbed sediments, the sites were selected after careful attention was given to possible dredging by government agencies or private landowners as well as to rerouting of flow by drainage projects.

Fowl River (see Figure 2) is a coastal plain stream comparable to Dog River, but with a relatively undeveloped watershed. The three sites chosen were near the mouth (site A, core FRA1) and well up-stream of the mouth (site B, core FRB1, and site C, core FRC1). It was expected that Fowl River cores could be used to establish "normal" sedimentation rates.

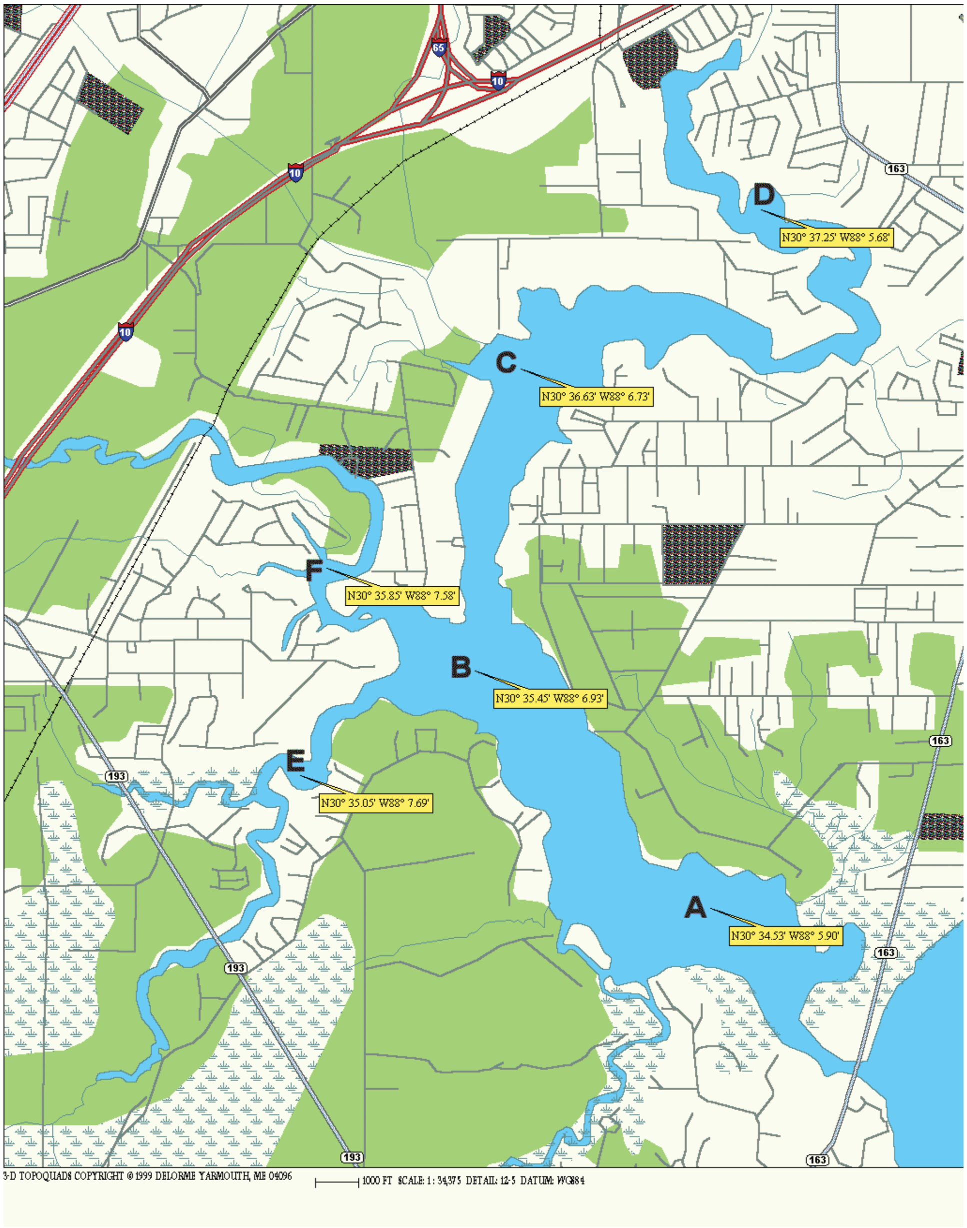


Figure 1: Dog River watershed showing the core sampling sites.

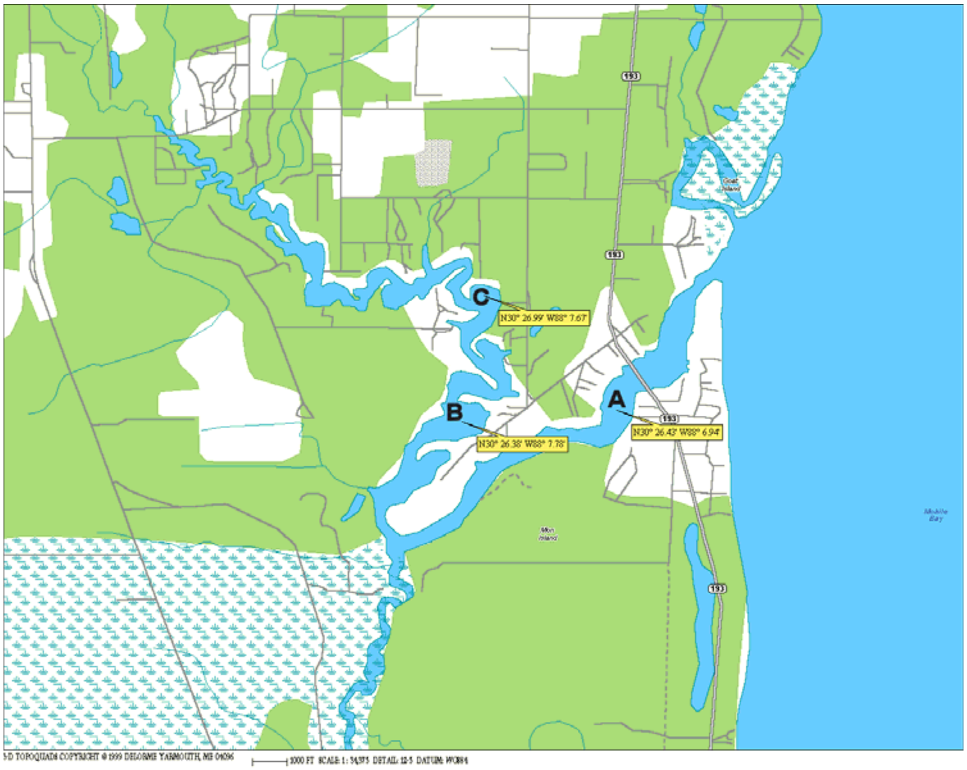
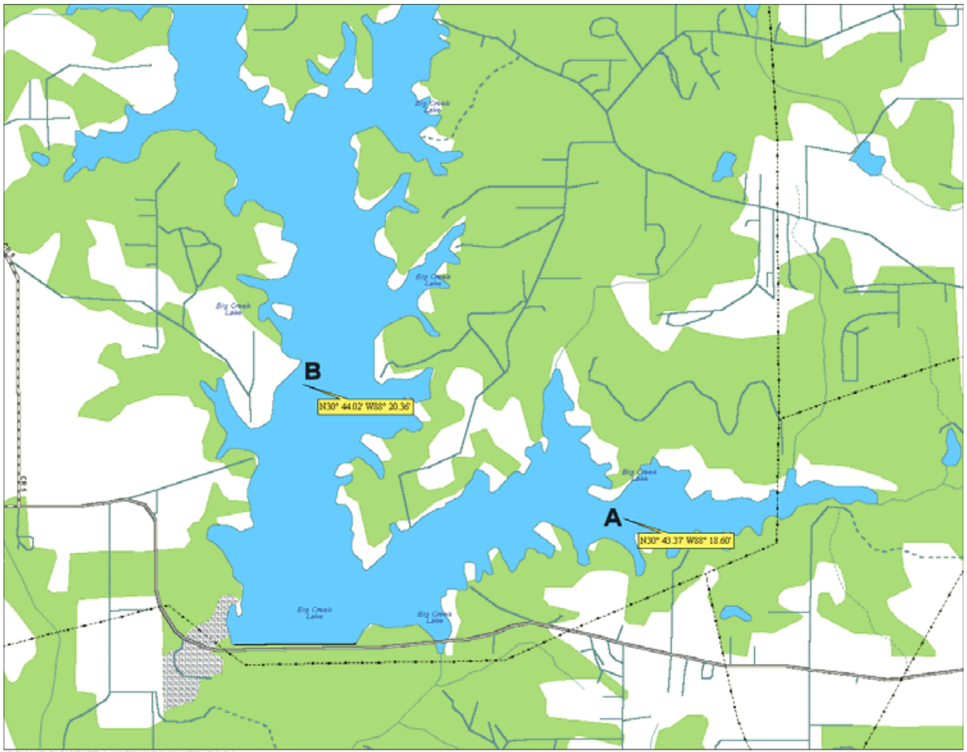


Figure 2: Fowl River watershed showing the core sampling sites.

Cores (CVA1 and CVB1) taken from Converse Reservoir (see Figure 3), Mobile's municipal water supply reservoir impounded in the early 1950s, were used to provide a comparison between the sedimentation rate in lacustrine and riverine environments.

Cores of sediment were obtained using a modified Livingston piston corer which consists of a 2 m section of 5 cm diameter PVC pipe secured to rigid galvanized pipe. This device has been used successfully to study analogous coastal environments in coastal lakes and estuaries along the northern Gulf of Mexico[7] and is appropriate for our study as it causes minimal disturbance to bottom sediments. The corer was pushed down by hand from between two boats tied side by side. The cores were approximately 1.2 meters in length which was expected to adequately cover the time interval resolvable via ^{137}Cs and ^{210}Pb dating. Archival duplicate cores were taken at each site. The cores were capped on site and placed in cold storage prior to sampling. The cores were extruded from the PVC pipe in 2-cm slices, except for the Converse Reservoir cores which were sampled in 1-cm slices. The samples were placed in 8-cm diameter polystyrene jars and allowed to air-dry prior to gamma-ray analysis. When dry, the sediment samples were approximately 0.5 to 1-cm thick and covered the bottom of the sample jars.

In the case of four cores (DRB1, DRF1, FRA1, and FRC1), the sediment was found to have partially dried and shrunk in the PVC pipe prior to extrusion. The extruded length of the sediment was therefore shorter than the original length. The extruded sample depths



3-D TOPOQUADS COPYRIGHT © 1999 DELORME YARMOUTH, ME 04096 1000 FT SCALE: 1 : 34,375 DETAIL: 12-5 DATUM: WGS84

Figure 3: Converse Reservoir (Big Creek Lake) showing the core sampling sites.

associated with these cores were multiplied by the ratio of the original length to the extruded length in order that the resulting adjusted depths would correspond to the samples' original positions in the core. The correction to the sample depths for these cores averaged 12%.

Gamma-ray Analysis

The dried samples were analyzed by a 35% efficiency, coaxial, N-type, high-purity germanium (HPGe) gamma-ray detector (Princeton Gamma-Tech NIGC35210). The detector employed a low-background "J"-style cryostat neck with remote preamplifier, and the detector itself was provided with a low-background Z-graded shield. Signals from the detector were amplified and sent to a multichannel analyzer (Princeton Gamma-Tech System 8008G) which provided a display for the computer. A typical gamma-ray spectrum in the region of the 662-keV ^{137}Cs peak is given in Figure 4 for two samples from one of the Dog River cores. The counts in the 662-keV peak of ^{137}Cs, after subtraction of background counts obtained with an empty sample jar, provided the relative ^{137}Cs activity for each sample. The relative ^{137}Cs activity was plotted as a function of depth to provide a profile for each core.

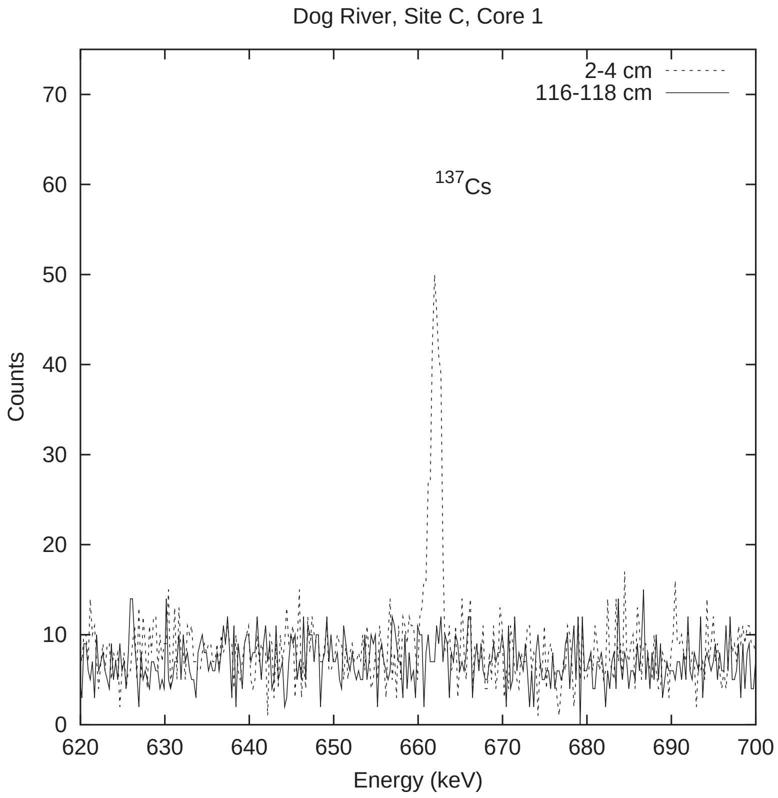


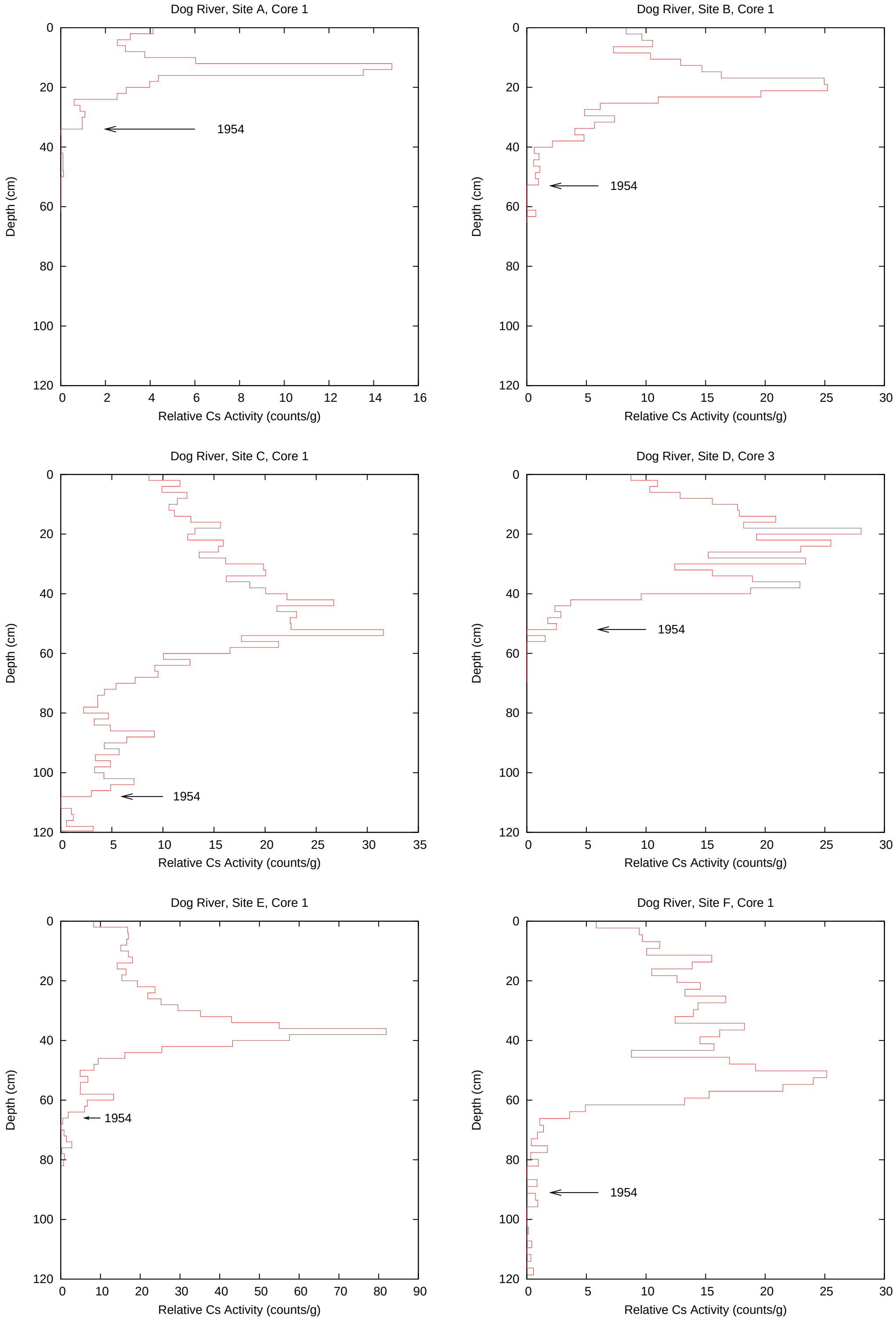
Figure 4: Gamma-ray spectra in the region of the 662-keV peak of ^{137}Cs. The dashed line is the spectrum for a sample at depth 2- to 4-cm, while the solid line is the spectrum for a sample at depth 116- to 118-cm.

Grain Size Analysis

After gamma-ray analysis, samples from two of the Dog River Cores (DRC1 and DRF1) were processed for grain size analysis using the pipette and sieve method as outlined in Coventry and Fett[8]. As ^{137}Cs preferentially binds to micaceous sediments, resolution of grain size characteristics of each sample is both necessary and desirable in order to evaluate the isotopic signatures of the cores[9]. For each sample, five to 20 g dried sediment fractions were weighed, disaggregated, and transferred into hydrometer jars to which 1000 ml of distilled water was added. Following agitation, 10 ml aliquots were extracted at a specific depth at timed intervals according to Stoke's Law (corrected for temperature). Percent silt and percent clay were determined by weighing the sediment content of these aliquots as collected on pre-weighed filter papers.

Results and Conclusions

Profiles of ^{137}Cs activity as a function of sample depth are given in Figures 5 and 6. On each figure is an arrow indicating the lowest depth at which ^{137}Cs is reliably found– this was taken to be the 1954 horizon.


Dog River, Site A, Core 1

Dog River, Site B, Core 1

Dog River, Site C, Core 1

Dog River, Site D, Core 3

Dog River, Site E, Core 1

Dog River, Site F, Core 1

Figure 5: Relative ^{137}Cs activity profiles for cores taken from Dog River.

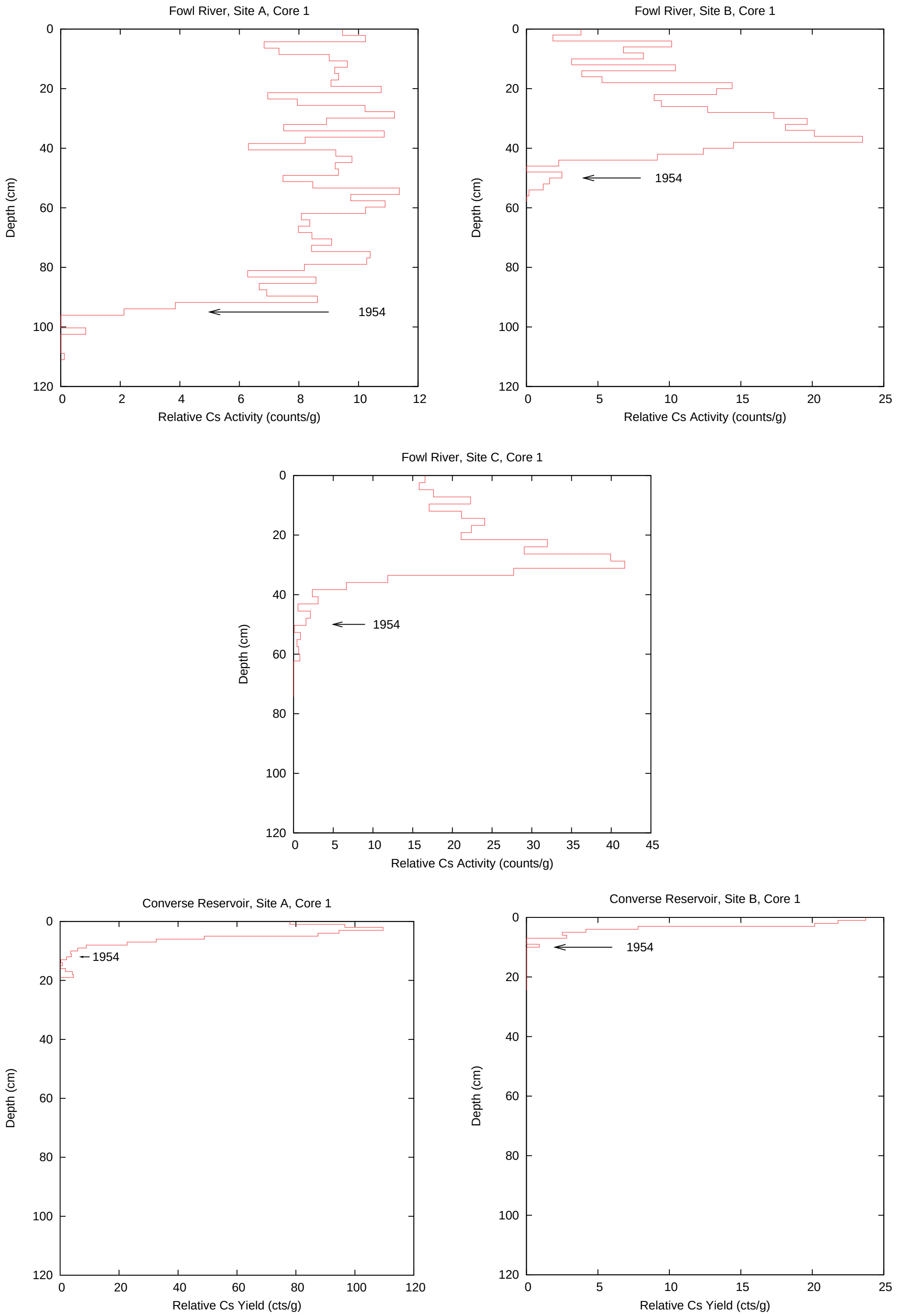


Figure 6: Relative ^{137}Cs activity profiles for cores taken from Fowl River and Converse Reservoir.

Table 1: Average Accumulation and Sedimentation Rates

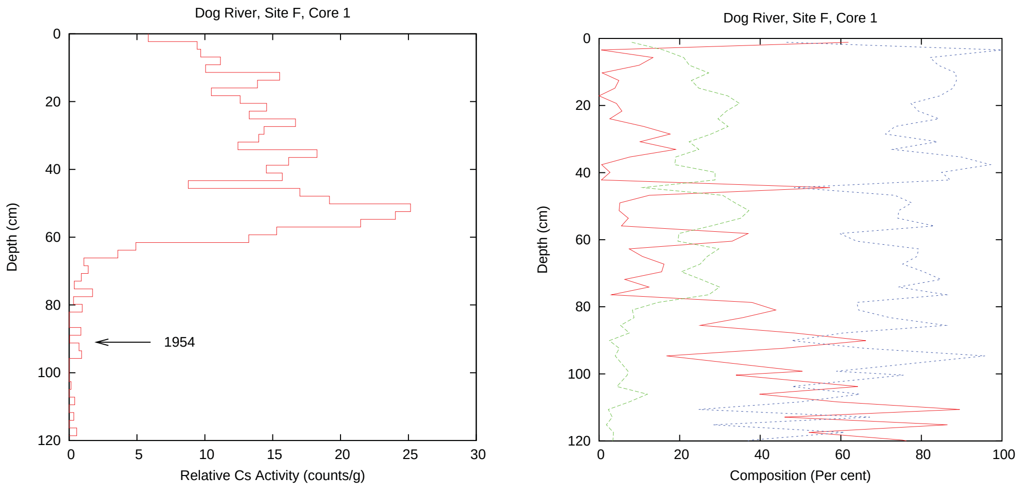
Core	Accumulation Rate (cm yr^{-1})	Sedimentation Rate (g cm^{-2} yr^{-1})
DRA1	0.72 ± 0.04	0.58 ± 0.03
DRB1	1.13 ± 0.04	0.74 ± 0.03
DRC1	2.30 ± 0.04	1.15 ± 0.02
DRD3	1.16 ± 0.04	0.43 ± 0.02
DRE1	1.40 ± 0.04	0.50 ± 0.02
DRF1	1.94 ± 0.08	1.07 ± 0.03
FRA1	2.02 ± 0.04	0.99 ± 0.03
FRB1	1.06 ± 0.04	0.37 ± 0.02
FRC1	1.06 ± 0.04	0.37 ± 0.03
CVA1	0.26 ± 0.02	0.17 ± 0.02
CVB1	0.21 ± 0.02	0.21 ± 0.03

Taking the depth of the 1954 horizon for each core and dividing by the 47 years elapsed yields the average annual rate of accumulation of sediment at each site. These rates are given in Table 1. The average rate of sedimentation was obtained by taking the cumulative dry mass of the samples down to the 1954 horizon, dividing by the area of the core (20.288 cm^2), and dividing by the number of years elapsed since 1954. These rates are also given in Table 1.

A few conclusions may be drawn from the rates displayed in Table 1. Sites DRA1, DRB1, DRD3, and DRE1 appear to be very similar, while DRF1 (Halls Mill Creek) and DRC1 (mouth of Moores Creek) are clearly higher. This confirms the hypothesis that recent development is impacting these creeks to a greater degree than other parts of the watershed which are either undeveloped or were developed significantly before 1954. The two upstream sites in Fowl River (FRB1 and FRC1) have rates that are slightly below the rates for Dog River, which confirms the hypothesis that Fowl River would reflect a low sedimentation rate in the absence of significant development. The high rate for the mouth of Fowl River may indicate the presence of scouring at that location. As expected, the sedimentation rates in the lacustrine environment of Converse Reservoir are noticeably smaller than in the riverine environments.

Results of a grain size analysis for core DRF1 are plotted in Figure 7 which also includes the ^{137}Cs profile for comparison. Of particular interest in the grain size profile is the feature at about 45-cm depth, where the amount of clay and silt relative to sand drops significantly. There is a corresponding drop in the ^{137}Cs activity at this same depth, confirming that ^{137}Cs is preferentially bound to the clay and silt component of the sediment[9]. An analysis of the silt and clay components of the samples showed that organic material comprised about 10% of the fine-grained clay and about 5% of the coarser silt.

Resolving recent (i.e., post-settlement) sedimentation rates in coastal embayments is difficult, yet these data are commonly desired. For example, some property owners along Dog River want the river dredged to maintain it at its “historic” depth. Radioisotope dating analysis on sediment cores has provided a relatively simple and inexpensive method



(a)

(b)

Figure 7: Depth profiles for (a) ^{137}Cs activity and (b) grain size for core DRF1. In (b) the red curve is the percentage of sand, the green line is the percentage of clay, and the blue line is the percentage of silt.

to determine the river depth in 1955-1963 period before most of Mobile's recent growth spurt. Furthermore, this results shown above quantify the degree of sedimentation in different parts of the Dog River and Fowl River watersheds. Consequently, this study has contributed baseline data by which to resolve, monitor, and predict human impact in a coastal embayment. As such, these data can be used for environmental planning by various federal, state, and local management agencies. The current results also provide useful data with which to make comparisons with sedimentation rates in other parts of the Mobile Bay estuary, in particular with Week's Bay and the Mobile River Delta.

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