Comparative analysis of organic matter and carbonate mineral distribution in shallow water surface sediments off the forested Kalande and deforested Ngelwa watersheds entering Lake Tanganyika, Tanzania

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Introduction
The impacts of watershed deforestation on lacustrine environments can dramatically affect the productivity of the littoral zone and strongly influence sedimentation rates. Many watersheds flowing into Lake Tanganyika (3°18'-8°47'S, 29°05' - 31°18'E) from northern Kigoma region, Tanzania are currently experiencing the effects of deforestation to accommodate high human population densities and increasing cultivation of cassava and other crops (O'Reilly et al., 2005). These disturbed watersheds exist in stark contrast to protected watersheds located within nearby Gombe Stream National Park, where human impact has recently been more tightly controlled. Differences between forested and deforested watersheds are manifested by major increases in sediment accumulation rates in the latter (Cohen et al., 2005a) and related differences in organic matter type and carbonate concentrations within near shore sediment deposits.

Organic matter (OM) abundance can be used as a measure of benthic secondary productivity, terrestrial/aquatic productivity and organic matter flux in lake systems (Palacios-Fest et al., 2005). Patterns of OM distribution in sediments can be compared across similarly sized watersheds with different land use histories to understand disturbance impacts on lake productivity and health. Carbonate mineral (CM) distribution is similarly helpful in comparing biogenic (shell material) and authigenic (commonly aragonite) carbonate abundance patterns in sediments. Smear slide analysis of fine-grained sediments may help to delineate organic matter type distribution within the watersheds.

This is a preliminary study focusing on organic matter and carbonate material being deposited into the shallow lake waters near the mouth of the forested Kalande watershed and the deforested Ngelwa watershed. It is expected that water depth will influence the organic and carbonate content of the stream deposits by winnowing material in deeper water locations. It is expected that organic matter will be more prevalent in the Kalande deposits overall, as terrigenous material is readily washed in and primary productivity is not overwhelmed by increased sedimentation rates (such as those present in the Ngelwa watershed). Shell material is expected to control the % CM in both watersheds. Water depth for all deposits in this study is shallow and the small grain size of aragonite is not readily preserved in higher energy, shallow water systems. While obviously applicable to current lake management and land use issues affecting Lake Tanganyika, this study can further be used as a framework to think about changes in organic matter as an indicator in paleoclimatic studies of lake systems.

Study Area
Lake Tanganyika is the largest and deepest lake of the East African Rift Valley, reaching a maximum depth of 1470 m across its three half-graben basins. In the Kigoma Basin, local depth maximum reaches 1200 m (Scholz et al., 2003). The Kalande and Ngelwa streams erode through local Quaternary sediments and Kigoma Quartzite bedrock (Strickler, this volume). Kalande stream drains a ~1.7 km^2 watershed located within Gombe Stream National Park, which is controlled for deforestation, cultivation and natural burning cycles. Local flora includes oil palms, as well as evergreen and dry forests, contributing terrestrial organic matter to the system (Bygott, 1992). Ngelwa stream is located south of Gombe, draining a ~1.6 km^2 watershed north of Mtanga village. Deforestation due to population concentration has resulted in much sparser vegetation within the Ngelwa watershed, and therefore the bedrock geology is much more readily exposed.

Methods
Field Methods
Shallow water grab samples were collected aboard the R/V *Echo* on July 15, 18, and 29, 2006. Sampling for this study occurred along two transects, one from the mouth of Kalande stream (NP06-DT4) and one from the mouth of Ngelwa stream (NP06-DT3), below a water depth of 60 m (sediments collected at water depths > 60 m are dealt with in Magazi, this volume). Water depth at each site was measured with a Lawrence echosounder. Location was determined with a Garmin GPS device. Collected sediment was stored and transported in Whirl-paks.

Lab Methods
Organic matter and carbonate mineral abundance of collected grab samples was determined using loss-on-ignition methods. Ceramic crucibles were washed, dried and pre-combusted at 900º C in a Neycraft muffle furnace to clean them. Each grab sample was mixed to homogenize the sediment before sub-sampling. Approximately 5 g of sediment was added to each pre-weighed crucible, weighed using an Explorer Ohaus balance, and heated at 60º C in a Rave drying oven overnight to remove water. Once dry, samples were weighed, heated in the muffle furnace to 550º C for 2 hours to remove organic matter and then reweighed. Samples were combusted once more at 900º C for two hours to remove inorganic carbonate mineral (shell material or authigenic carbonate/aragonite crystals). The final weight of each sample was then measured. Total organic matter and carbonate mineral percentages were then calculated from sample post-combustion weight loss.

Due to the coarse grain size of shallow water surface sediments off these watersheds, the coarse fraction of sieved grab sample sediment was also macroscopically observed to determine relative abundances of shell material (biogenic carbonate). Shell material occurrence in a given sample was estimated and measurements of the largest shell observed were recorded. Given the shallow depth of all grab samples used in this study, shell material is thought to be the major contributor of CM in collected sediments. Aragonite rosettes were not observed in the shallow water sample smear slides, supporting this hypothesis. Macrofloral constituents were also observed in the coarse fraction.

Each grab sample was also sub-sampled to create smear slides. A small amount of sediment was prepared using a U.S. standard 63 micron-sized sieve to separate out the fine-grain fraction for further analysis. After settling, sediment from this fraction was pipetted onto a clean glass microscope slide. Slides were placed in the drying oven for ten minutes before three drops of Norland mounting medium and a plastic cover slip were placed over the sediment. The mounting medium was allowed to cure under UV exposure for ten minutes. Slides were viewed through a Leica CME optical microscope at 40x magnification to characterize organic matter constituents. Abundance estimates of organic matter constituents, when possible, were made by establishing the absolute percentage of a field of view covered by the variable to be measured, averaged between five fields of view (Jimenez, 2005).

Statistical Analyses
The computer program JUMP was used to perform statistical analyses of the % OM within collected grab samples. % OM was analyzed using an ANOVA model to ascertain which variables, if any, significantly contributed to the difference between streams. Plots of depth vs. % OM and depth vs. % CM were regressed, and r^2 correlations and p-values calculated to understand the strength of any correlations. Due to the small sample size and limited time for replication, a significance level of 0.1 was applied to all statistical analyses.

Results and Interpretation
In order to elucidate the influence of watershed disturbance on organic matter and carbonate mineral distribution in shallow water surface sediments, two data sets were compiled consisting of eight grab samples taken from each stream transect at comparable water depths. Correlation analyses (regression and probability) were performed using these data sets to determine relationships between organic matter and carbonate mineral abundance and either water depth of sediments or distance from stream mouth. These relationships can be compared across the watersheds. Further analysis (ANOVA modeling) was performed on a slightly larger data set (n=36) to statistically compare organic matter abundance as it differs between watersheds.

Organic matter in the Ngelwa watershed is minimally correlated with depth, whereas the Kalande stream deposits showed no discernable relationship. Deposits for the deforested Ngelwa transect had an r^2 value of 0.4913, and was statistically significant in its difference from a zero-slope line with a p-value of 0.0528, at a significance level of 0.1 (Figure 1). This is in contrast with past Nyanza project findings (Jimenez, 2005), which suggested that percent organic matter is a robust indicator of depth. The difference in findings is likely due to differences between the input system for streams in this study and those of the Luiche Platform and TAFIRI Bay where the previous study took place. Both the gentle slope and high volume input of the Luiche Platform (Smith, 2005) and the lack of major sediment input in TAFIRI Bay are considerably different conditions than the streams considered in this study. Astley (this volume) shows that shallow water grab samples were collected along a steeply sloping profile which may influence the distribution of organic matter. Values for the Kalande watershed relationship may have been complicated due to increased terrigenous material input to the area. Leaves, grasses and roots enter the stream and are deposited in shallow water sites, most likely due to their relatively large size. This would explain the relative peaks of organic matter concentrated around 15 – 20 m water depth in Kalande sites and could influence the non-linear relationship in that watershed. Also, the value of percent organic matter as a depth indicator may somewhat rely on comparisons between shallow- and deep-water deposits and was therefore less helpful in a more spatially limited study.

Organic matter concentrations were higher in the Kalande samples than the Ngelwa samples, both macroscopically, in smear slides and through loss-on-ignition analysis. Organic matter percentages in the Ngelwa data set ranged from 1.8601 to 3.1362, with an average value of 2.5365; percentages in the Kalande data set ranged from 1.9756 to 4.3870, with an average of 2.7825. The minimum, maximum and mean values were larger in the Kalande deposits and comparisons between samples at comparable water depths show that the Kalande forested watershed deposits have higher organic matter concentrations than the Ngelwa deforested watershed deposits (Figure 3). Aqueous organic matter was consistently the dominant organic component in all grab samples, with a value between 80 – 95 percent. Terrigenous organic matter was slightly more prevalent in Kalande (with the notable exception of 10 percent terrigenous content at the 15 m sample in Ngelwa). There is no obvious patter between depth and organic material type deposited.

Carbonate mineral distribution was not effectively predicted by depth in shallow water settings (Figure 2). Abundance of shell material in the coarse sediment fraction was determined qualitatively by macroscopic observation of occurrence in grab sample material. Shells were present in all Ngelwa grab samples excluding one taken at the stream mouth. Shells were rare (< 5%) in the very shallow (5.9 m) and deep (50.5 m) grabs, but remained common to abundant (5 - >15%) between 11 and 45.5 m water depth. The Ngelwa data set for carbonate mineral abundance ranged from 2.2095 to 6.2007, with an average of 3.3676. This is in stark contrast to samples off the Kalande watershed. Shells were macroscopically rare at 12.1 and 18.3 m water depth while macroscopically absent from all other Kalande grab samples. The Kalande data set ranged from 0.5961 to 3.6343, with an average of 1.6045. (Figure 4)

Abundance of carbonate mineral did not decline with depth as hypothesized, suggesting that depth is not the limiting factor in carbonate mineral distribution in either watershed. The abundance of shell material concentrated in the deforested deposits raises interesting questions about macrofaunal response to watershed disturbance. It is possible that the bivalves and gastropods found in the Ngelwa deposits prefer the coarser substrates found there to the finer sediments off the Kalande Stream (Moreno, this volume). Cohen et al. (2005b) also reports that there are clear associations of particular taxa with high disturbance levels, which may be a factor here. Further description of the fauna found in these deposits would shed light on this possible explanatory relationship.

The pattern of organic matter distribution was not well explained by an ANOVA model taking into account only water depth and stream differences (p-value = 0.5941, F-ratio = 0.5421, df = 2). When variables were considered individually, neither depth nor stream were significant predictors of organic matter difference between samples. Carbonate mineral distribution, however, was well explained by an ANOVA model (p-value = 0.0222, F-ratio = 5.1749, df = 2). Depth was not a significant contributor to differences between samples. Which stream the grab sample was from, however, significantly (at a significance level of 0.01) contributed to the difference in %CM found in the collected grab samples (p-value = 0.0085, F-ratio = 9.5974, df = 1).

Conclusions

Increased sediment accumulation due to increased erosion is a far-reaching consequence of watershed disturbance. This is of particular concern along the northern reaches of the lake, where deforestation rates are as high as 100% in some areas (Cohen, et al., 2005a). While this study is limited, the results show that there is a tangible response by watersheds due to anthropogenic activity. Statistically, land use history is the most influential variable in organic matter and carbonate mineral distribution in shallow water sediments off small watersheds entering Lake Tanganyika. Organic matter distribution is complicated in steeply sloping depositional environments with intense terrigenous inputs.

Organic matter is more prevalent in the Kalande deposits due to macrofloral availability; deforestation in the Ngelwa watershed has increased sediment accumulation rates and clastics overwhelm organic inputs from the stream.

It is important, for the long-term viability of these near shore ecosystems, to recognize these natural responses to disturbance and work to minimize the negative impacts.

Future Work

Further comparisons of organic matter and carbonate abundances between comparable forested and deforested watersheds entering Lake Tanganyika would make the results of this type of study more robust. More work could be done to assess how other variables, such as distance of sample site from stream mouth, affect organic matter and carbonate mineral distribution in these watersheds. Statistical analysis of carbonate mineral abundance between the two watersheds would be helpful in more clearly understanding biogenic contributions to the carbon budget in the area. A higher resolution study of the near shore environments off these streams would allow for a clearer picture of the impacts of increased sediment accumulation and perhaps provide a threshold between nutrient addition and productivity choking in these streams. Also, comparisons of these characteristics through time in sediment cores would increase understanding about deforestation/land use cycles and their effect on productivity and sedimentation in the lake.

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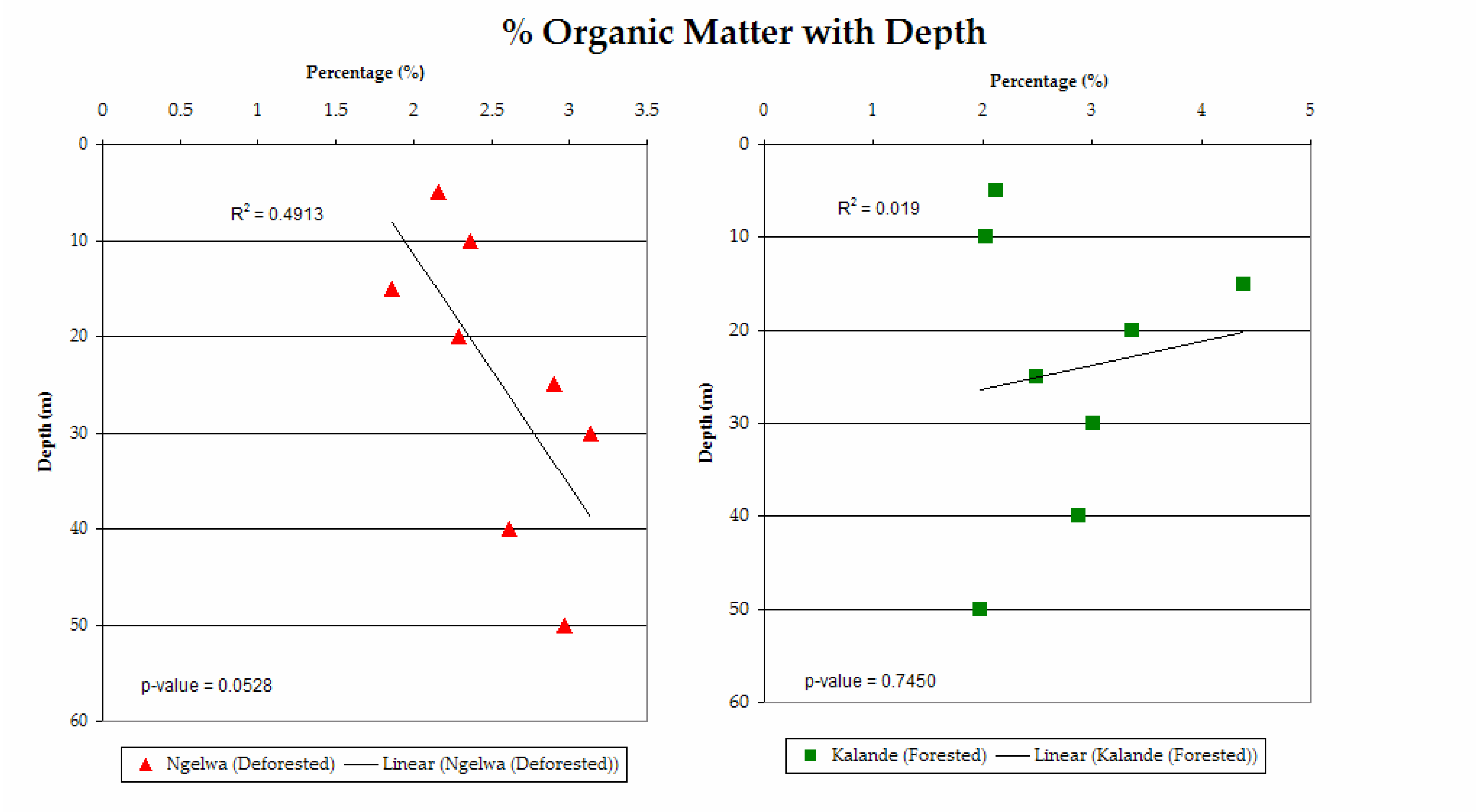

Figure 1. Correlation of organic matter distribution with depth is poor in both the Kalande and Ngelwa watershed deposits, suggesting that depth is not a robust indicator of organic matter abundance in shallow water systems.

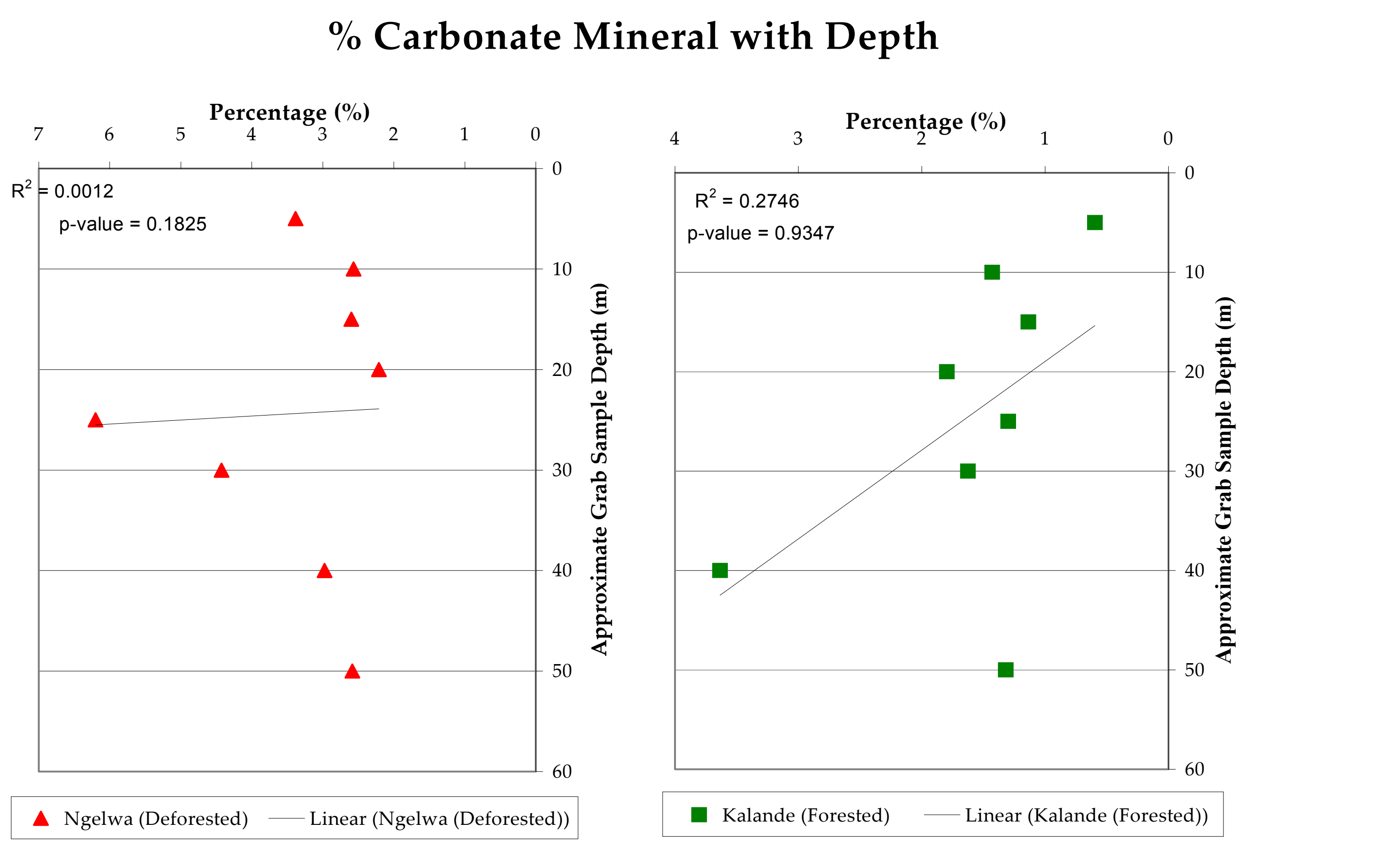

Figure 2. Correlation of carbonate mineral distribution with depth is poor in both the Kalande and Ngelwa watershed deposits.

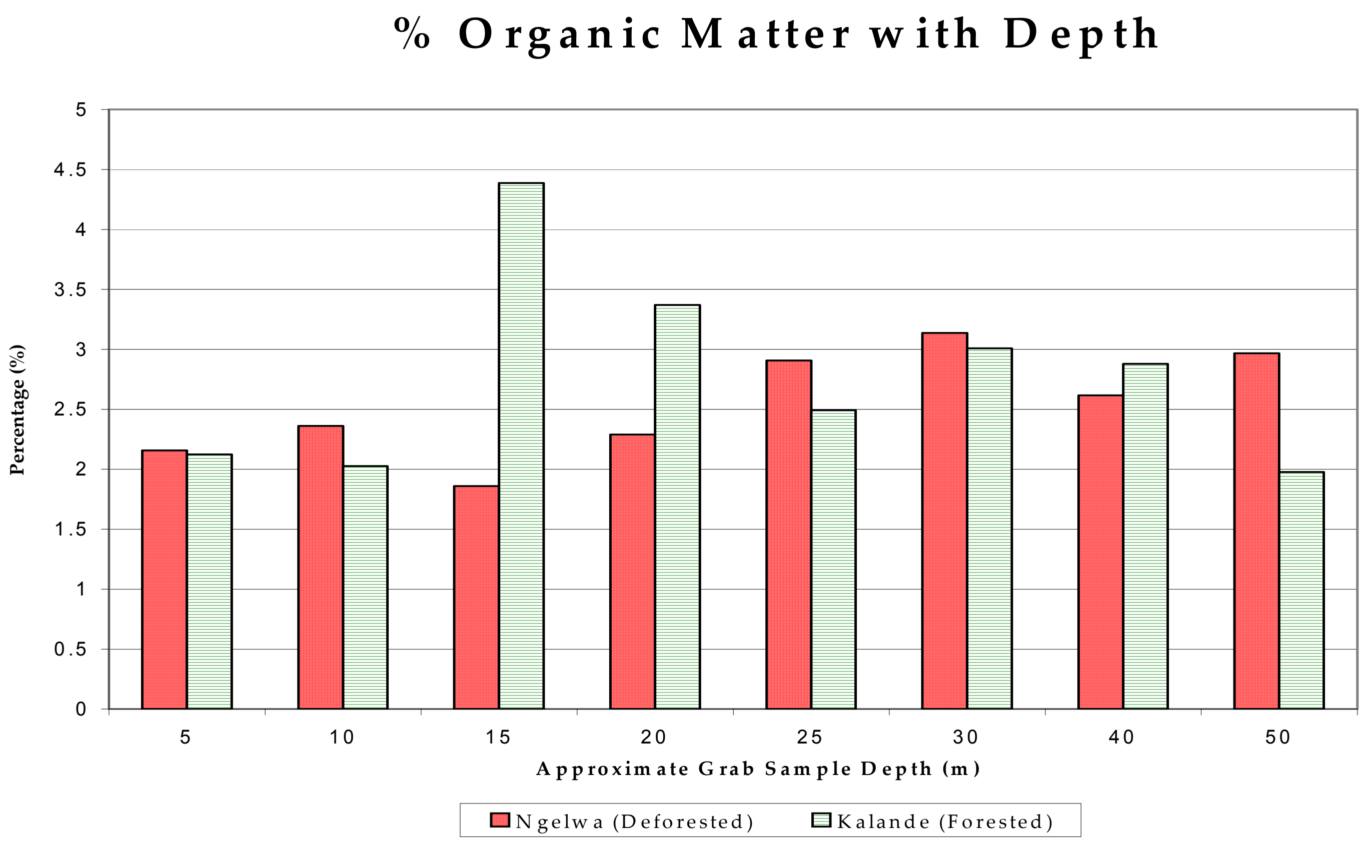

Figure 3. Absolute values of organic matter are larger in Kalande stream deposits taken at comparable water depths due to increased terrigenous input and less rapid sediment accumulation in the forested sites.

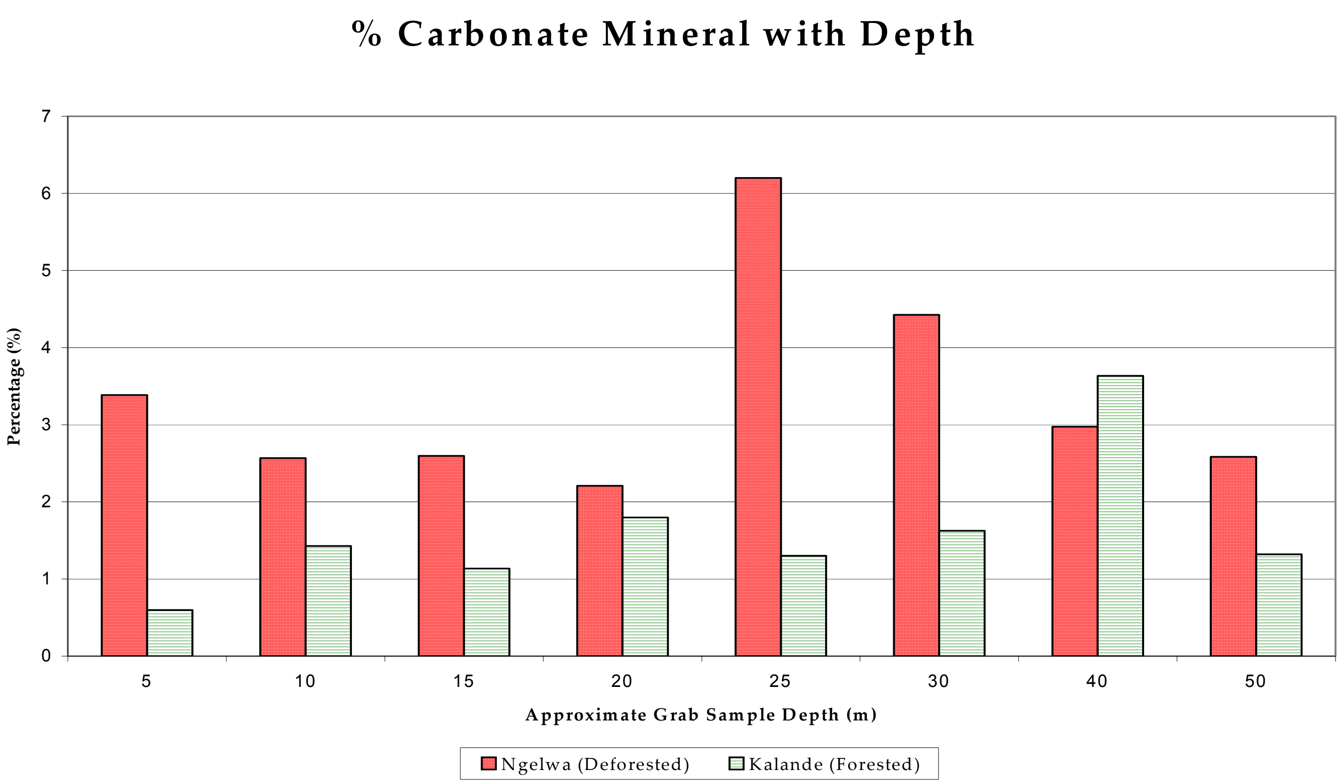

Figure 4. Absolute values of carbonate mineral are larger in Ngelwa stream deposits taken at comparable water depths due to the presence of biogenic carbonate in the form of bivalve and gastropod shells. .