Detecting Wetland Fire Occurrence in the Sacramento-San Joaquin Delta Through Charcoal in Peat Soils

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ABSTRACT

The Sacramento- San Joaquin Delta is the largest estuary in the United States west of the Mississippi river, despite the depletion of most of its wetland through the past century. As a result of said depletion, determining effective wetland management strategies to preserve and restore the Delta is crucial and has brought upon questions whether prescribed burning has ever been a crucial portion of the Delta's history. Through the analysis of charcoal in a soil core at Dutch Slough, it is assumed that human history of prescribed burnings by Native Americans and early European settlers could be discovered, and the efficiency of prescribed burning could be determined. Results of this study proved inconclusive due to the lack of evidence to determine a strong correlation between fires and several soil characteristics due to lack of historical records of fires, uncertainty regarding amount of charcoal to indicate a past fire, and inability to date soil core. This study could be viewed as a starting point for further investigation into the presence of prescribed fires in the Delta.

KEYWORDS

Accretion, Cover Burns, Impoundment, Prescribed Burning, Organic Matter

INTRODUCTION

The Sacramento-San Joaquin Delta's wetland ecosystems have been severely depleted by 98% (Drexler et al. 2018) due to the construction of 1,100 miles of levees, which transformed 700,000 acres of the Delta's peat soil into farmland (Hanak et al. 2018) beginning in the early 1900's. Historically, the high runoff of sediment and high plant productivity led to the formation of peat soils in this delta which have acted as a huge carbon sink. Despite peatlands only covering 3% of earth's surface, they contain around 30% of the Earth's soil organic carbon (Heinemeyer et al. 2018). The depletion of 98% of the peatlands in the Delta released about ~ 83-100 Tg C into the atmosphere and the remaining portions of the Delta retained about 67-110 Tg C (Drexler et al. 2018). With tremendous amounts of carbon being stored within peat, the urgency to restore much of these peatlands has grown tremendously in California due to the increasing severity of climate change and global warming. Recent restoration efforts by California EcoRestore has led to the restoration of 30,000 acres in the Delta as of 2020 which is about 1% of the original, undisturbed Sacramento-San Joaquin Delta (CDWR, 2021). Additionally, the restoration of the Delta's wetland ecosystems can promote biodiversity, flood control, and filtering of pollutants so it is important to manage wetland ecosystems effectively (Heinemeyer et al. 2018).

Emergent wetland management techniques include prescribed burning, vertical accretion management, water-level management, and salinity management (Gray et al. 2013). However, prescribed burning is not a common practice in California because wetlands have historically been drained and developed into agricultural lands (Gray et al. 2013). Prescribed burning has been more or less an afterthought in terms of management and should be given more of an emphasis considering it can increase the productivity of wetland ecosystems that have not been converted into pastures (Venne et al. 2016). Since wetlands in California maintain steady water levels, cover burns would be the optimal prescribed fire to use in this ecosystem (Gray et al. 2013). Cover burns can remove overgrowth of thatch that can block new shoots from sprouting which lowers the overall productivity of the ecosystem (Glenn et al. 2013). Cover burns were mostly prescribed in the winter, to increase vegetation for wildlife (Gray et al. 2013). It is important to note that fires are only beneficial to wetlands if they are not dried out because soil will become combusted and vegetation destroyed in a dried out wetland (Venne et al. 2016).

The Sacramento-San Joaquin Delta wetlands involved in this study are not dried out so they are not prone to fire. Even then, fires are uncommon in this area as the only other source of natural fire would be lightning strikes, which much of California's wetland ecosystems lack the instability for (Gray et al. 2013). Fires in the Delta's history are likely attributed to human activities such as prescribed burning from early European settlers or Native Americans (Hankins 2013). Unfortunately, after the elimination of Native American sovereignty after the Gold Rush in the mid-1800s, much of the Bay Area Native Americans' lands, cultures, and ecosystem management practices were lost or restricted (Hyer and Trafzer, 1999). Consequently, throughout the 1900s, several wetlands were being drained for agriculture, thus becoming damaged by these same settlers (Lemly et al, 2000). However, it is most probable that Native Americans are responsible for past burns because they have historically used prescribed burning in order to clear paths, manipulate vegetation to grow certain plants faster, agriculture, and spiritual purposes (Hankins 2013). Without land to steward, many Native techniques for sustainability have become harder to access, given that they are less practiced, prohibited, and erased by colonizers—especially via fire suppression (Kimmerer and Lake, 2001). Therefore, it is important to investigate how Native Americans engaged in fire practices and how we can use them as a tool to shape our current ecosystems. This history of Native American fires, natural fires, or other sources of fire in the Delta could be reconstructed through the discovery of charcoal in the Delta's peatland soils.

My main goal is to investigate the charcoal record in wetland peat soils to indicate fire events in Dutch Slough's history. In order to do this, I will look at: (1) what depths are there charcoal concentrations through a Dutch Slough Core, (2) how do soil characteristics change with depth, and (3) do any of the soil characteristics correlate with charcoal in the soil?

METHODS

Study Site

Dutch Slough is a wetland located in Oakley, California as part of the Sacramento-San Joaquin Delta in Northern California. It is formed at the confluence of the San Joaquin River and Sacramento River and the delta is considered one of the largest freshwater tidal estuaries in the western United States. The delta has a mediterranean climate with hot, dry summers and occasionally wet winters. Average annual temperatures range from 8.8 degrees Celsius to 22 degrees Celsius and average annual precipitation ranges from 8 cm to about 144 cm. Dutch Slough is an impounded wetland that has recently been restored as part of a California Ecostore Initiative to restore 30,000 acres of wetlands in California. Originally, the pastured land was supposed to turn into housing development. Dutch Slough became impounded around the beginning of the 1900's. However, the area where the soil core was extracted for this study was never disturbed by any agricultural or other processes. Species that reside in these wetlands include tule reeds and cattails such as *Scirpus ssp,Typha ssp,* and rushes and sedges (*Juncus ssp., carex ssp., cyperus ssp.*). There have been a few invasive species in the area, including Brazilian water weed (Egeria densa), giant reed (Arundo donax), fennel (Foeniculum vulgare), and the yellow starthistle (Centaurea solstitialis). Elevations at Dutch Slough range from 6 feet below sea level to 6 feet above sea level. The higher elevations of the wetland supports trees and shrubs such as cottonwood, buckeye and alder trees.

Soil Core Collection

A 1m peat soil core was extracted from Dutch Slough using a steel corer. The core was taken from a previously impounded area of the wetland but was never used for its original agricultural purposes. The core was sliced vertically into 2 cm samples. One cubic centimeter subsamples of those slices were extracted for dry bulk density and loss on ignition calculations.

Removal of Organic Matter and Sieving

In order to prepare the 2 cm thick samples for sieving, samples were placed into mason jars to later undergo a hydrogen peroxide treatment that would reduce the amount of organic matter that blocks the charcoal during identification. First, 60 ml of 30% hydrogen peroxide (Tilings-Range. 2019) was added to each sample in order to prevent the loss of any sample core to excess chemical reactions. Secondly, 20 ml of 30% hydrogen peroxide was added every 20 minutes to the samples, followed by deionized water whenever samples exhibited bubbles/foam in order to cool the sample down. These samples were then left in a fume hood for 48 hours to let the reaction come to completion.

Samples were then placed into an ultrasonic cleaner to eliminate clumps of soil and separate any fine soils from any organic matter still left in the samples. Afterwards, samples were then sieved through a 2ml sieve and a 250 µm sieve because it is within this range that charcoal particles are the most visible. Sieved samples were then placed into a 6 cm by 6 cm petri dish in preparation for charcoal counting.

Charcoal Count

Charcoal particles were counted by each 1 cm^2 square on the petri dish square to make counting more organized, accurate and efficient. Charcoal particles are characterized by a jagged appearance, black color, circular patterns throughout the particle, and a shattering effect when smashed (Enache and Cumming 2006). Particles with these traits were then considered for the count.

Dry Bulk Density, Water Content %, and Loss on Ignition % (Organic Matter)

The 1 cm^3 subsamples were weighed to determine wet weight, placed into a furnace at 60 ºC for 2 days, and then weighed for their dry weight to determine dry bulk density. To estimate organic content in the soil slices, the samples were then placed in crucibles, weighed, heated in a furnace once more for 5 hours at 550 ºC, and finally weighed again after most of the organic matter was converted to carbon dioxide (Heiri et al. 2001).

Spearman Rank Correlation

In order to determine a pattern or correlation between charcoal and any of the other soil characteristics, a Spearman Rank correlation will be applied using the following formula:

$$\rho = \frac{\frac{1}{n}\sum_{i=1}^{n}\left(R(x_i) - \overline{R(x)}\right)\cdot\left(R(y_i) - \overline{R(y)}\right)}{\sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}\left(R(x_i) - \overline{R(x)}\right)^2\right)\cdot\left(\frac{1}{n}\sum_{i=1}^{n}\left(R(y_i) - \overline{R(y)}\right)^2\right)}}$$

This formula involves ranking categories of data and comparing each ranking of two different variables with each other. Although there is a more simplistic version of this formula, it cannot be used as that requires no duplicate ranks. Charcoal concentration and the given soil characteristic will be graphed using a scatter plot and will provide a visual representation for any noticeable trends.

RESULTS

Charcoal Count

Charcoal was found in several portions of the Dutch Slough soil core. Charcoal concentrations ranged from 0 particles/cm^3 in several instances to only 4.63 particles/cm^3 at the 78th centimeter (Figure 1). The 78th centimeter depth is a huge outlier compared to the rest of the depths in the core as the next highest concentration is 78 particles/cm^3**.** 87% of the samples from depths 0 - 32 cm have charcoal signals that range from 0.027582 g/cm^3 to 0.313484 g/cm^3 (Figure 1). From the depths of 34 cm - 44 cm, no charcoal particles were found in five of the six samples found there. Below 44 cm, there are charcoal particles found in every sample except for the 86th sample. The concentrations in this portion of the core are much higher than in the other two portions of the core. The average concentration for the 100 cm core is 0.319937 g/cm^3. The average measured from 44 cm to 100 cm is 0.51628 g/cm^3 which is significantly higher than the core as a whole. There is no distinct overall trend as depth in the soil increases.

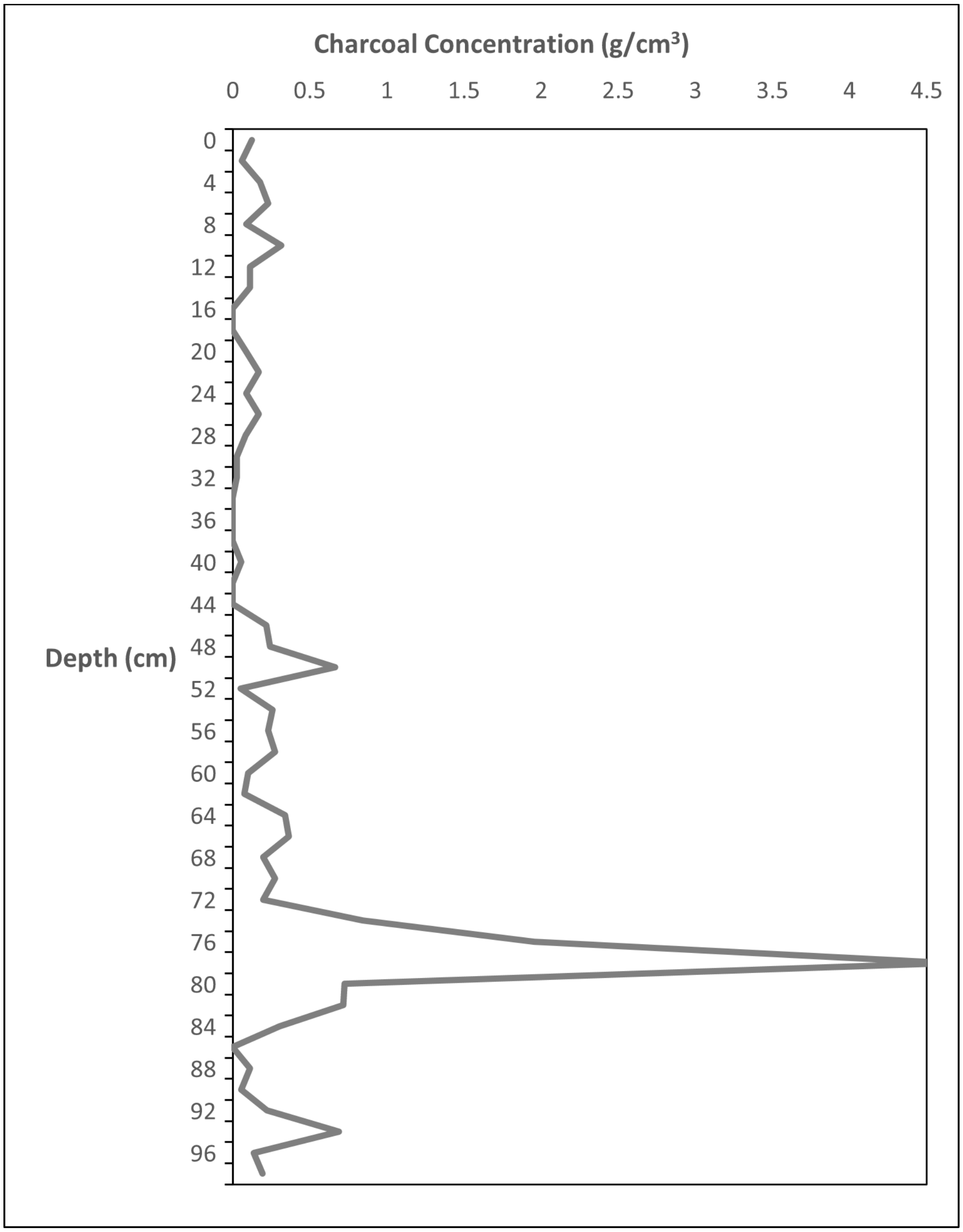

Figure 1. Distribution of Charcoal concentration down the depth of a Dutch Slough Soil Core.

Dry Bulk Density, Water Content %, and Loss On Ignition %

Overall, dry bulk density fluctuates down the soil core and has an overall negative trend as depth increases (Figure 2). The maximum density is seen at 14 cm of 0.924 cm and afterwards dry bulk density decreases overall. A huge decrease in dry bulk density is seen at the 30 cm mark and other considerable decreases are observed at 36 cm and 40 cm (Figure 2). It appears that at 64 cm was when dry bulk density first increased chronologically.

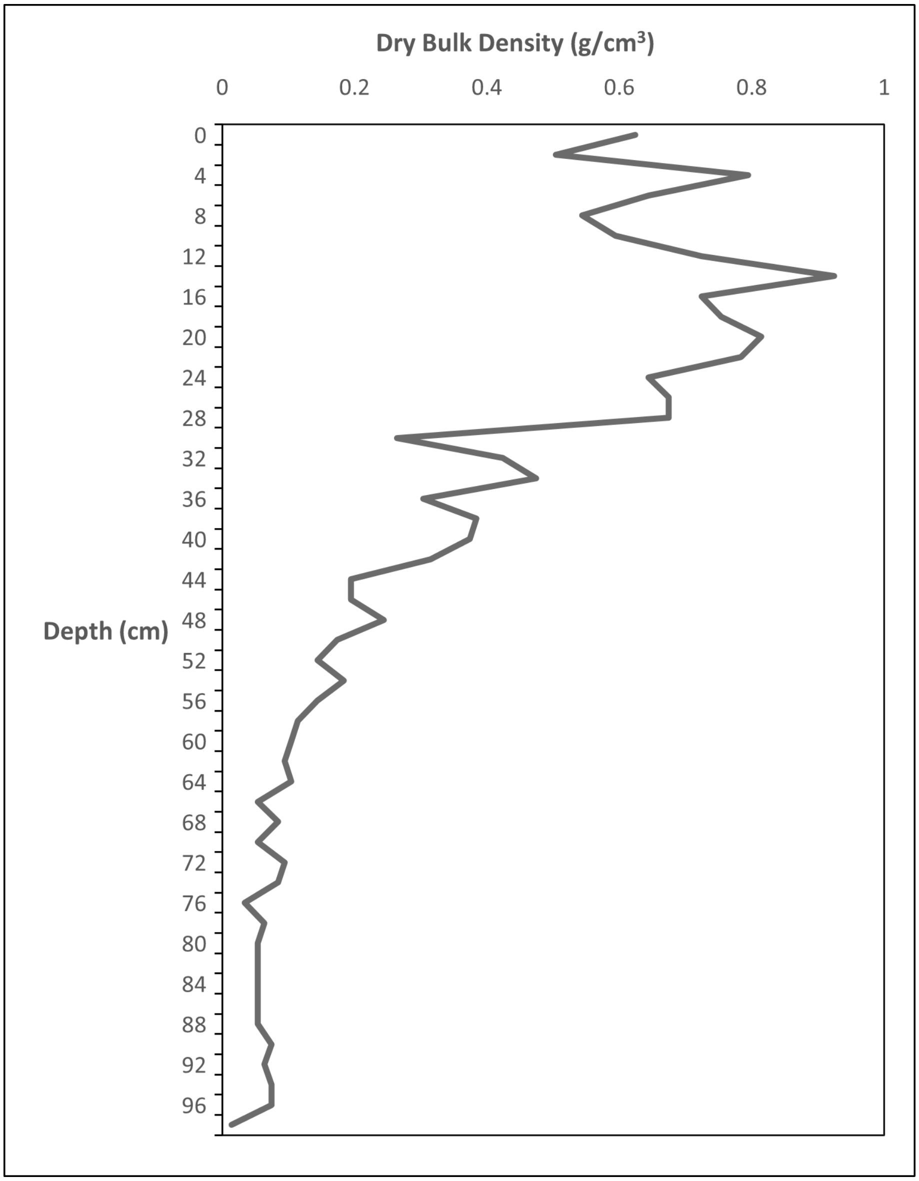

Figure 2. Distribution of Dry Bulk Density down the depth of a Dutch Slough Soil Core.

Water content percentage and loss on ignition tend to follow similar patterns down the soil core (Figure 3). Both graphs have an initial decrease from the top of the core and begin to increase in the 28 cm to 44 cm range. It is important to note that the loss on ignition graph has a dramatic increase at the 40 cm mark. Loss ignition has a fluctuating pattern after the 56 cm mark and constantly increases and increases down to 100 cm while water content percentage stays relatively constant. Overall, the water content and loss on ignition increase down the soil core.

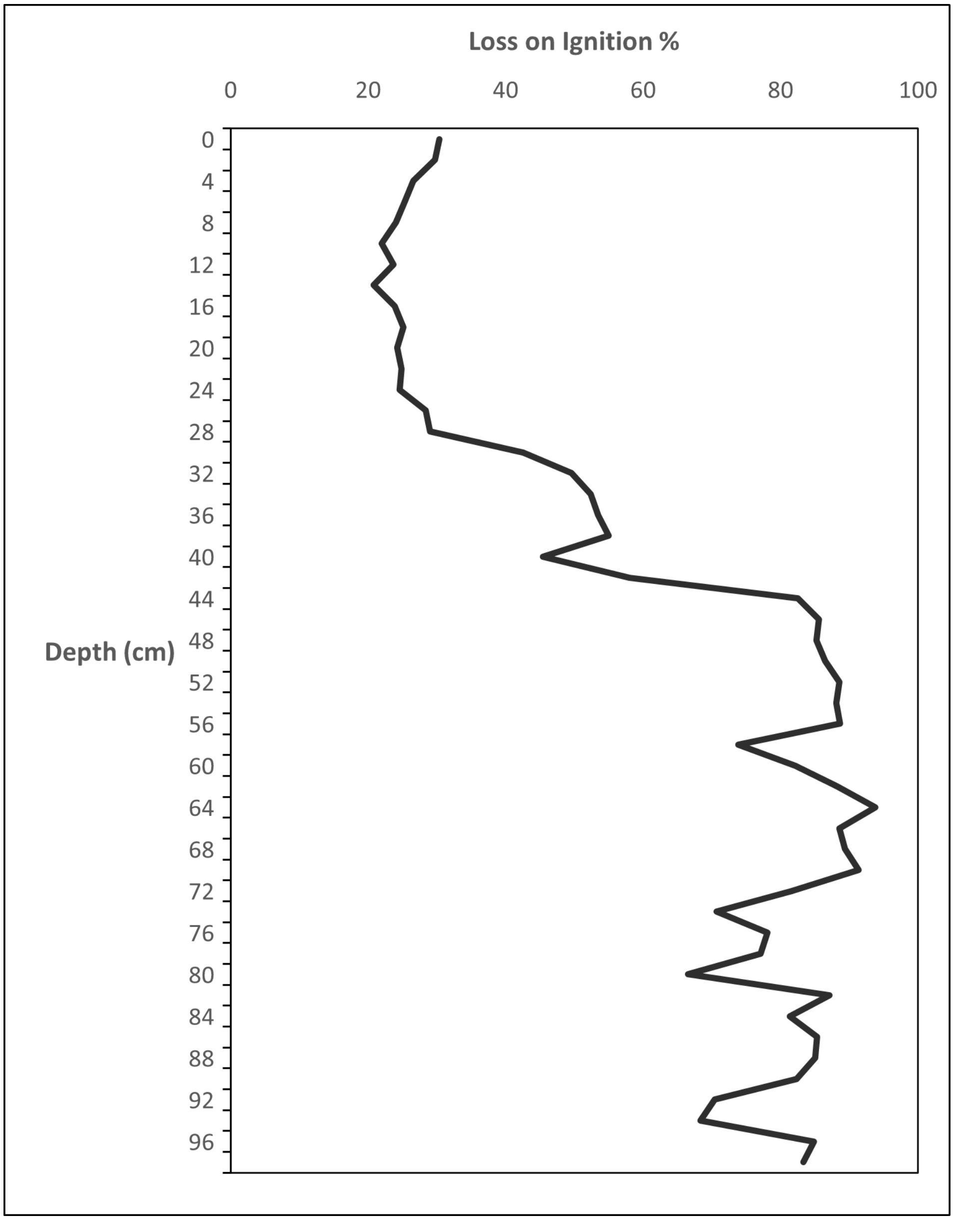

Figure 3. Distribution of Loss on Ignition % down the depth of a Dutch Slough Soil Core.

Spearman Rank Correlation

There was a weak correlation between charcoal concentration and loss on ignition % (organic matter) because the Spearman Rank coefficient was ρ = 0.326678 (Figure 4). The relationship between charcoal concentration and dry bulk density was stronger as ρ = -0.46603 and could be considered a moderate correlation (Figure 5). Water content % and charcoal concentration also had a moderate correlation as ρ = 0.444232 (Figure 6).

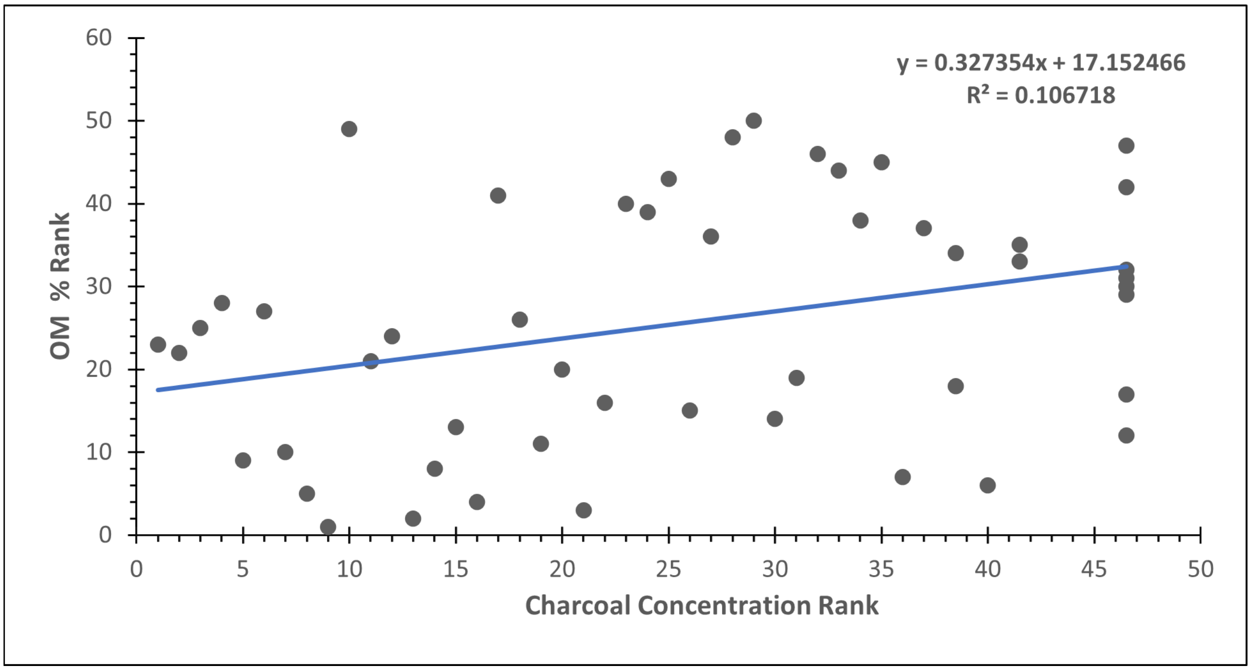

Figure 4: Spearman Rank Correlation between Charcoal Concentration and Organic Matter %

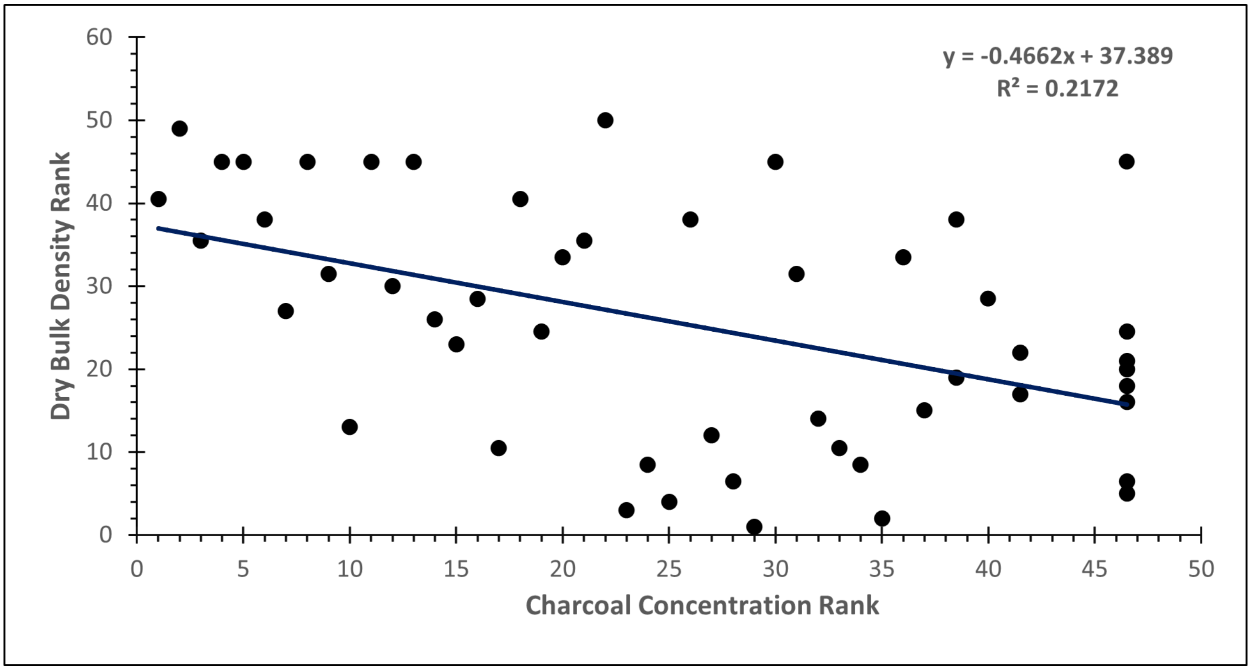

Figure 5: Spearman Rank Correlation between Charcoal Concentration and Dry Bulk Density

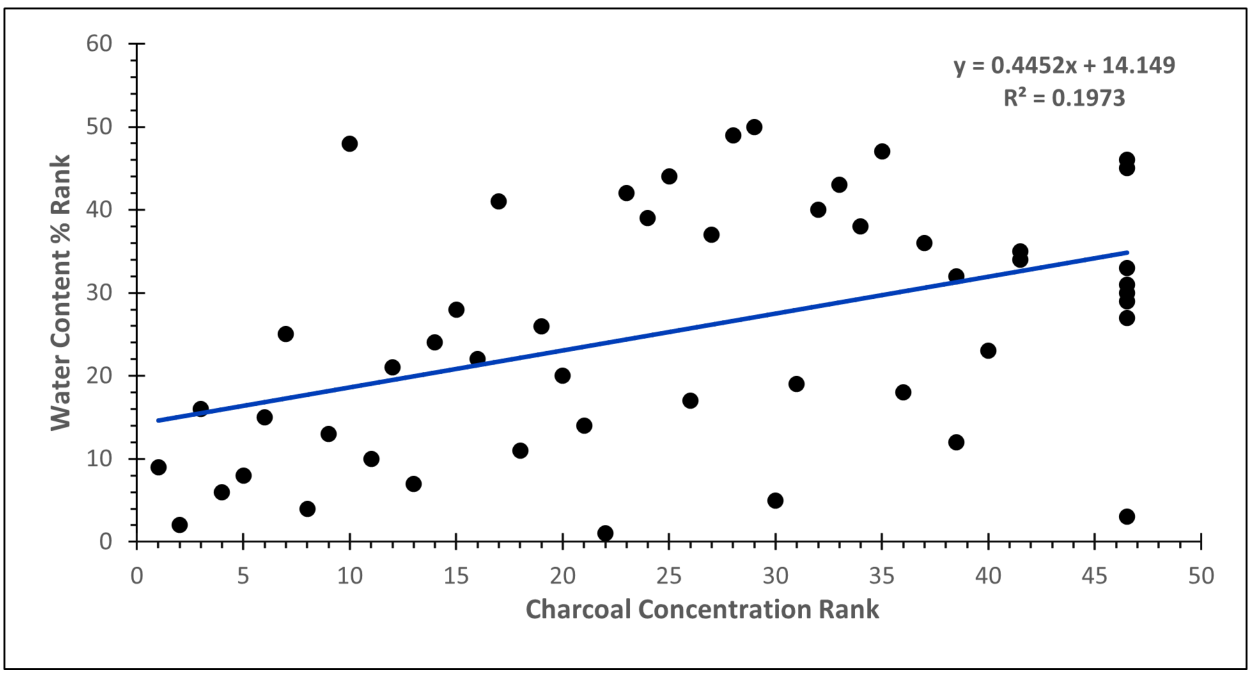

Figure 6: Spearman Rank Correlation between Charcoal Concentration and Water Content %

DISCUSSION

Charcoal Findings

The charcoal found in Dutch Slough indicates that there was fire activity in its history. The amount of charcoal found 78 cm deep is a strong indicator and it should be further investigated whether what size of a signal is representative of a fire event or if we can consider smaller signals/concentrations as fire events. Soils can still contain charcoal without burning and this could be due in part to aerial movement of charcoal particles during nearby fires events with huge smoke plumes (Pisaric 2002). Between depths 0 - 32 centimeters, the concentrations of charcoal were smaller than the median and mean charcoal concentrations inferring that nearby fire events led to those charcoal deposits because there are no known recorded fires in Dutch Slough. The majority of samples in depths 34 - 44 centimeters contained no charcoal particles and this could be due to the impoundment that happened at Dutch Slough in the beginning of the 1900's (Herbold n.d.). This event is seen at the same depths in the other soil characteristics of the soil core. The lack of charcoal activity could be a result of the change in behavior of several human activities such as the fire suppression movements that began in the early 1900's (Folweiler 1938). This could have contributed to a lack of aerial carbon transport as nearby forest ecosystems weren't being allowed to burn and charcoal to travel.

Charcoal particles that ranged from 250 µm - 2ml were the only particles of this size that were observed. In other studies, charcoal has also been found in smaller sizes of 63 µm and 125 µm and would greatly improve the results of this study (Umbanhowar and Mcgrath 1998). Charcoal is very likely to break down into smaller particles in the sieving process since it is very brittle, which could make it more abundant. Including this data would output a much larger dataset and provide a more accurate depiction of charcoal profiles.

Charcoal with different types of patterns were also discovered throughout the soil core. Different charcoal patterns could be indicative of different types of vegetation or structure of fuel that was burned such as bark, trees, leaves, or formation of temperature (Enache and Cumming 2006). Knowing what types of charcoal are most abundant within a sample can provide a more clear idea of what vegetation Native Americans or early European settlers were trying to get rid of or use. This study did not take into account the amount of the types of charcoal found in each sample due to time restrictions but could be an additional step of this study.

Dry Bulk Density, Water Content %, and Loss on Ignition % (Organic Matter)

The Dutch Slough impoundment event can clearly be seen in the history of dry bulk density, water content %, and loss on ignition %. Around the 44 cm - 50 cm range, all three soil characteristics experience dramatic decreases or increases. It is expected that water content % to decrease as it ascends to the top layers of soil as deeper soils in wetlands are more saturated and compacted. However, the amount it decreased was exaggerated by impoundment as the development of levees around Dutch Slough did not allow for water to enter the ecosystem as much as it used to (Gray et al. 2013). Dry bulk density was able to increase as sediment made up most of the soil's composition. Lastly, loss on ignition % decreased as the plants that relied on the incoming runoff for water and nutrients dried up and the ecosystem was unable to be as productive as it once was. As a result, the organic matter produced decreased. It is important to note that organic matter can vary due to climate conditions such as precipitation, temperature, and solar radiation (Hoogsteen et al. 2015). It would be very useful to have a historical record of these conditions.

Dating

This study loosely uses the carbon dating of a soil core from Brown's island (Drexler et al. 2009) to provide a rough estimation of dating for the Dutch Slough. Brown's island is not an impounded wetland and would therefore, not provide a near similar dating of Dutch Slough since the accretion rates would be higher at Brown's island since it is a tidal wetland. Additionally, they are also located in much different locations and it is more likely that Dutch Slough experienced more human activity and less sediment intake. However, since it is known that Dutch Slough was impounded in the early 1900's, it can be inferred that the 44 cm depth could be dated to around the years 1900 - 1930 as we can see patterns of impoundment at that depth. A depth at 44 cm correlated to the year 1897 at Brown's island. A depth of 64 cm at Brown's island correlates to 1855 and that is around the time European settlers started going to the Bay Area for the Gold Rush (Gutiérrez and Orsi 1998). Before depths of 64 centimeters in dry bulk density, water content %, and loss on ignition %, trends remain relatively constant and start to incrementally change at around the 64 cm mark. This could indicate that humans could have had affected the land in indirect ways such as reducing the amount of water flow in the general Dutch Slough area. A depth of 78 cm at Brown's island, correlates to 1783 and that is when the highest charcoal signal is seen and it could be a result of Native American fire activities. The Spanish were known to have passed the general vicinity of Dutch Slough in the 1700's but it was not until the 1840's that John Marsh settled in Oakley, California that we have guaranteed knowledge of human settlement in the Dutch Slough area (Leighton, 2001). Therefore, it can be assumed that Native Americans or an unlikely lightning strike caused fires during that period.

Spearman Rank Correlation

Charcoal in the soil does not have strong correlations with water content, organic matter, or dry bulk density. It was expected for charcoal and organic matter to have the strongest correlation yet they had the weakest correlation. A possible explanation is that the data isn't representative of a correlation of burning with organic matter. If there was data for when exactly Dutch Slough burned and it was correlated with organic matter, then a more absolute conclusion could be made. It is expected that when the wetlands burn the ecosystem becomes more productive and more organic matter is seen within the soil. Water content and burning seems to be independent during the 78 cm mark as water content remains relatively stable and is likely determined by the amount of runoff and precipitation the land gets. Dry bulk density follows a similar pattern as it remains stable before impoundment and during the 78cm mark where it is assumed burning occurred. Water content and dry bulk density had similar Spearman Rank coefficients and it can be concluded that they do not correlate with burning in wetlands.

Limitations

This study could have been significantly improved with more time and equipment. As mentioned earlier, more time and sieves large enough to prevent overflow could have allowed for less spillage of samples and could have provided smaller sample sizes such as 63 µm and 125 µm sizes. Due to COVID and scheduling conflicts, it was not possible to go to Brown's island and extract soil cores to have a better dating measure. The best improvement would have been to have the resources necessary to carbon date the Dutch Slough soil core in order to determine accurate accretion rates for Dutch Slough and determine when exactly wetlands were burned.

Broader Implications

If these limitations can be overcome, then it would be best if this study could be replicated across several different locations around the Sacramento-San Joaquin Delta to provide a more extensive and holistic understanding of the fire history and fire management by Native Amercians and early European settlers. If we can prove that Native Americans were managing the land using prescribed burning, then it can be inferred that they knew how beneficial these burnings were for the landscape—particularly since Native peoples are connected spiritually with the environment and are considered great conservationists and ecosystem managers. Following their lead, these practices can then be implemented into California's preserved and restored wetlands to build the Delta into the great carbon sink it used to be.

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