





**VERTICAL STRATIFICATION OF SOIL ORGANIC CARBON
UNDER DIFFERENT VEGETATION TYPES IN THE
KARAVASTA LAGOON (ALBANIA)**

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DOI: <https://doi.org/10.51193/IJAER.2025.11509>

Received: 19 Sep. 2025 / Accepted: 29 Sep. 2025 / Published: 01 Oct. 2025

ABSTRACT

Vegetated coastal wetlands are considered a nature-based climate mitigation solution, since they can capture and store organic carbon for centuries to millennia. It is necessary to quantify the amount of stored organic carbon to calculate their sequestration capacity and include them in the context of international climate agreements. In this study, the distribution of organic carbon in the soils of Karavasta Lagoon was determined. The carbon stock of different vegetation types was compared while taking into account abiotic environmental variables that could influence their storage potential. Twenty-six points were sampled, up to a depth of 20 cm, dividing them into depth intervals of 0–5 cm, 5–10 cm and 10–20 cm and measuring pH, EC, carbonates, and LOI for each depth. Total organic carbon (TOC) content was calculated by applying a conversion factor of 0.71 ($TOC = 0.71 \times LOI$). Furthermore, different types of vegetation were mapped to overlap them with the chemical-physical characteristics of the sampling points. The results indicate that organic carbon concentrations are relatively uniform across vegetation types: halophytic vegetation, wooded dunes with *Pinus* species, and abandoned agricultural land. They show a clear decrease with depth, from 33.35 g/kg in the surface layer to 15.78 g/kg at 20 cm. On average, the sampled soils have a SOC density of 0.03 g cm⁻³ and a SOC stock of 55.02 ± 20.55 Mg C ha⁻¹ within the top 20 cm, highlighting the role of the Karavasta Lagoon as an important blue carbon system in the context of climate change mitigation.

Keywords: Soil organic matter, Vegetated coastal wetland, Floristic composition, Land use impact, Blue carbon, Karavasta Lagoon.

1. INTRODUCTION

Anthropogenic activities are directly or indirectly influencing the cycles of elements by changing their equilibrium and distribution in the lithosphere, atmosphere and hydrosphere. In this way the life forms in the biosphere are facing dramatic consequences from human-driven changes. In particular, changes in the carbon cycle have changed the flow of this element, transferring it from its larger deposit, in the lithosphere, to its smaller one, in the atmosphere. The amount of carbon released into the atmosphere is such that it has grown by nearly half the carbon composition of the atmosphere, from 278 parts per million (ppm) in 1750 [1] to approximately 419 ppm in 2023 [2]. Given this issue, one of the nature-based climate mitigation measures is to increase the flow of carbon from the atmosphere to the lithosphere through the vegetated coastal wetlands. Thanks to their high productivity and, above all, anaerobic conditions, coastal wetlands slow down the decomposition of organic carbon, reducing the release of CO₂ into the atmosphere, and storing carbon for centuries to millennia [3]. Thanks to their vegetation structure, these ecosystems can accumulate not only autochthonous organic carbon (produced via photosynthesis) but also allochthonous organic carbon (derived from rivers and oceans). Since the role of vegetation is one of the most important factors, we will focus this study on the relationship between vegetation and stored organic carbon.

The term blue carbon is the organic carbon that is captured and stored by the oceans and coastal ecosystems, particularly by vegetated coastal ecosystems [4]. The interest in this research area has increased significantly, especially following the recognition of their role in climate change mitigation and adaptation [4]. In this context, the Mediterranean region as a whole and Albania in particular are still understudied. Given the high number and large surface area of wetlands along the Albanian coast, many of which are part of important international conventions, such as Ramsar Convention [5], these ecosystems need to be investigated and studied.

In addition to the many ecosystem services provided by coastal wetlands (water regulation and supply, erosion control, waste treatment, nutrient cycling, pollution management, and biodiversity enhancement), one of the main ones is carbon sequestration [6]. This study aims to quantify the distribution of organic carbon in relation to the depth of the Karavasata Lagoon soils, in order to demonstrate their importance in terms of climate change mitigation, acting as a CO₂ reservoir and mitigating its effects in the atmosphere.

The research was performed on belowground organic carbon, because most of the aboveground plant material is not sequestered in the long term and, more importantly, because the belowground sedimentary reservoir contains most of the carbon stock [7].

The objectives were to determine the distribution of organic carbon along the soil profile, to compare the carbon stocks of different vegetation types and to understand the physicochemical

factors that could affect their carbon storage potential. Taking into account the ecological and international importance of Karavasta Lagoon, this research is crucial. In this context, our study aims to: (1) quantify blue carbon stocks and their spatial distribution with depth; (2) compare the carbon stocks of different vegetation types; and (3) determine which abiotic factors might influence their carbon storage potential.

Based on the experience of studying other wetlands on the Albanian coast, we hypothesize: 1) the Lagoon of Karavasta is a significant organic carbon stock, 2) the highest carbon stocks are found in halophytic vegetation, 3) most of the carbon is found in the surface depth, between 0 and 5 cm.

The amount of organic carbon calculated in this study constitutes valuable information for the context of climate change mitigation through nature-based solutions, which can be incorporated into reports regarding international climate agreements (such as, Nationally Determined Contributions and National Communications).

2. MATERIALS AND METHOD

2.1 Study Area

The Karavasta Lagoon is one of the most diverse ecosystems in Albania. Located on the central coast of the Adriatic Sea, it is positioned between the two mouths of the Shkumbin and Seman rivers, to its north and south, respectively. The sediment flows from both rivers render this area one of the most dynamic along the coastline [8]. While the lagoon area is characterized by alluvial and swampy soil, the mountainous area next to it consists of weathered rock formations [9, 10]. The sediments are composed of sand and clay throughout the lagoon [11].

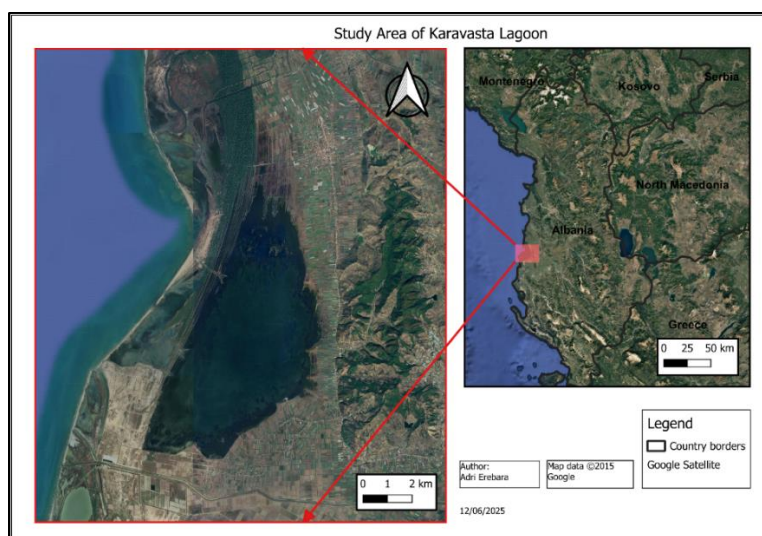


Figure 1: Karavasta Lagoon, the area where the study is centered (map data: Google Earth, QGIS, 3.34.7-Prizren)

A pine forest belt separates the lagoon from the Adriatic Sea in its western part, while in the east it is bordered by the Myzeqe canal and agricultural land. The Karavasta Lagoon spans an area of 4,600 hectares, measuring 15.4 kilometers in length and 4.1 kilometers in width. Furthermore, as a highly dynamic ecosystem, it is susceptible to several natural influences as well as heavy agricultural activity in its proximity. Its considerable extent and geographic position make it subject to a variety of natural influences, as well as pressures from intensive agricultural activity in the surrounding area. The Vahuti Channel, 700 m long and 0.75 m deep, connects the Karavasta Lagoon to the sea [11].

According to the Ramsar Convention [12], the Karavasta Lagoon and Divjaka Park are wetlands of international importance. They were formally included in the "List of Wetlands of International Importance" [13]. This categorization acknowledges their vital function as habitats for waterfowl species. According to the IUCN, it falls under Category II and is currently also known as Divjakë-Karavasta National Park (<http://akzm.gov.al/>).

The climate in the lagoon is Mediterranean, mild, and humid. In the winter, the average monthly temperature is 12 °C, while in the summer, it is 24 °C. It has an average annual temperature of 19.8 °C and receives between 950 and 1,200 mm of precipitation annually, spread out across 85 to 100 days. During the winter months, the region is known for its frequent and powerful winds [8].

The wind blows primarily in two directions: northwest in the spring and summer and southeast in the fall and winter. The typical wind speed ranges from 2.5 to 3.3 meters per second [9]. Like other Mediterranean coastal lagoons, the lagoon experiences a water shortage during the summer months due to low rainfall and approximately 150 mm of evaporation each month, making it subject to seasonal climate fluctuations [9]. The hydrochemical regime of the lagoon is determined by the amount of water exchange with the sea as well as the local climate and hydrological performance.

2.2 Sampling and Processing

Soil sampling was carried out in Karavasta Lagoon during the period between December 2024 and January 2025, as described in the protocols of Colombo and Miano [14]. Soils were sampled in different parts of the lagoon, across different vegetation types, in order to cover the whole area and be representative of the lagoon. A total of 26 samples were collected in different areas, within the borders and inside the lagoon.

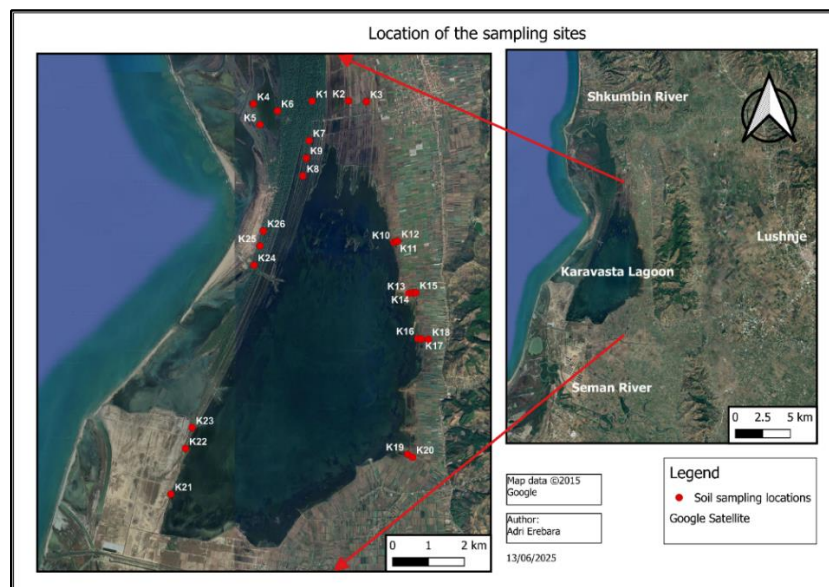


Figure 2: Geographical location of the Lagoon of Karavasta and position of the sampling sites (map data: Google Earth, QGIS, 3.34.7-Prizren)

The samples were sealed with plastic film, placed in a refrigerator at 4 °C to avoid altering the properties of the samples, and transported to the Laboratory of Agroenvironment and Ecology at the Agricultural University of Tirana. They were dried at room temperature, cut into sections of 0–5 cm, 5–10 cm and 10–20 cm depth, ground and sieved through a 2 mm sieve, so as to separate the coarse matrix. Consequently, they were prepared for physicochemical analysis.

Soil physical-chemical analysis

To measure the **pH** of our soils, a suspension was prepared consisting of deionized water and soil, in a ratio of 1:2.5 (w/v). The suspension was then measured using a pH meter (Sartorius PB-11). To measure the **electrical conductivity** (EC) the same ratio was used to prepare the suspension and the reading was taken using the instrument WTW InoLab Cond 720. On the other hand, the dry **bulk density** (BD) was measured on undisturbed soil samples with known volume, after they were oven-dried at 105 °C for 48 hours.

The organic matter content was determined by calculating the **loss-on-ignition** (LOI), where the soil samples were weighed after oven-drying at 105 °C for 24 hours and after incineration at 450 °C for 4 hours. The weight differential between 105 °C and 450 °C, divided by the weight at 105 °C, represents the proportion of organic matter [15].

The **total carbonate** (TC) content in the soil was determined in a Dietrich-Fruehling calcimeter by acid solubilization, adding hydrochloric acid (1:1 v/v), and measuring the amount of CO₂

produced by the dissolution, which is linearly related to the amount of carbonate present in the sample [14].

Total Organic Carbon (TOC) content was predicted by applying a conversion factor to the values of LOI. As direct elemental analysis was not feasible for all samples, we used a coefficient derived from a study conducted in the Kune-Vain Lagoon, an Albanian coastal wetland with similar environmental conditions and soil characteristics to our study site [16]. This approach follows the common practice of establishing a relationship between % LOI and % organic carbon, typically validated through parallel analysis of all samples using an elemental analyzer, as was done in the Kune-Vain study. This was achieved through the use of elemental analysis, on the basis of which it was possible to establish a reliable relationship between % LOI and % organic carbon for all samples. A well-known and widely used alternative method of estimating TOC from LOI data is used in cases where direct analysis is limited [17]. In this study, the coefficient is 0.71 ($TOC = 0.71 \times LOI$). From TOC values Soil Organic Carbon was obtained (SOC). from LOI data

Soil Organic Carbon Density and **Soil Organic Carbon Stock** were calculated through the bulk density (BD) reported for the entire soil sampled by Erebara et al. [16], since in this study BD values were not measured for each individual soil layer. For each sampling point, two soil samples were taken, the BD was measured and the average of the two samples was used for subsequent calculations. To calculate soil organic carbon (SOC) density, the average SOC value for the whole sample was multiplied by the bulk density. Further, the SOC values, originally expressed in $g\ kg^{-1}$, were transformed into a mass fraction ($g\ g^{-1}$) by dividing by 1000. Using the following formula to determine the SOC density in g/cm^3 [18]:

$$SOC\ density\ (g/cm^3) = BD\ (g/cm^3) \times \frac{SOC\ (g/kg)}{1000}$$

The SOC density was then multiplied by the mean thickness (cm) of the two soil samples and a factor of 10 to convert units to determine the SOC stock ($Mg\ C\ ha^{-1}$):

$$SOC\ stock\ (Mg\ C/ha) = SOC\ density\ (g/cm^3) \times Layer\ thickness\ (cm) \times 10$$

2.3 Floristic Survey

An identification of the flora in the sampled areas of the Lagoon of Karavasta was conducted, detailing the habitats and their corresponding plant species. These ecosystems are classified taking into account the various plant communities that compose them and cover the land. The observations have identified some plant communities, among which are the 2270 Wooded dunes with *Pinus pinea* and/or *Pinus pinaster*, as well as various types of halophytic vegetation, which include habitats 1310 *Salicornia* and other annuals colonizing mud and sand, 1410 Mediterranean

salt meadows (*Juncetalia maritimi*), and 1420 Mediterranean and thermo-Atlantic halophilous scrubs.

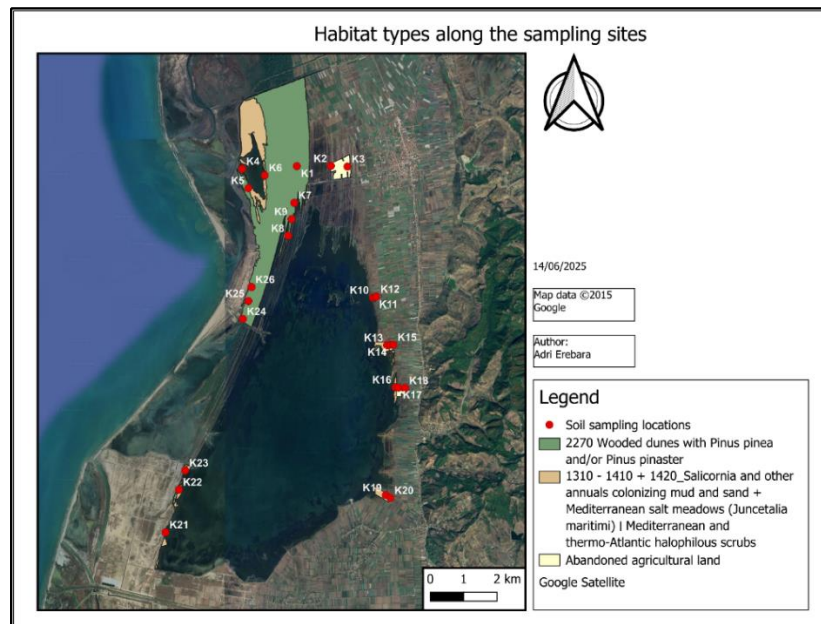


Figure 3: Map of habitats along the sampling areas in the Lagoon of Karavasta (map data: Google Earth, QGIS, 3.34.7-Prizren)

Halophytic Vegetation

Halophilous vegetation flourishes in areas of high salinity, especially near saline waters, where it is predominantly dominated by:

- These associations are dominated by species of the genus *Arthrocnemum* (Order: Salicornietalia). The dominant species in these associations are: *Arthrocnemum fruticosum*, *A. perenne*, *A. glaucum*, *Salicornia europaea*, *Limonium vulgare*, *Inula crithmoides*, *Halimione portulacoides*, *Artemisia coerulescens*, etc.

Moving away from the shores of the lagoon, plant communities transition from halophytic areas to those dominated by *Juncus*, and subsequently to associations dominated by *Tamarix* species (e.g., *Tamarix dalmatica*, *T. hampeana*) in less saline areas.

- These associations, where the dominant species are *Juncus maritimus* and *Juncus acutus*, are spread widely around the lagoon areas. They form a continuous band, often alternating with *Arthrocnemum*-dominated plant associations. Accompanying species in the dominant type include: *Phragmites australis*, *Schoenus nigricans*, *Carex extensa*, *Aeluropus littoralis*, *Arthrocnemum perenne*, etc.

This area is classified into three distinct habitat types under Natura 2000, each characterized by different associations: 1310 *Salicornia* and other annuals colonizing mud and sand, 1410 Mediterranean salt meadows (*Juncetalia maritimi*), and 1420 Mediterranean and thermo-Atlantic halophilous scrubs. They are primarily located at sampling points K4, K5, K6, K13, K16, K19 and K21.



Figure 4: Presence of the habitat 1410 with meadows of *Juncus* speies



Figure 5: Occurrence the habitat type Natura 2000 1310, with *Salicornia*

Wooded Dunes with Pinus pinea and/or Pinus pinaster

Mediterranean coniferous forests in the area are mainly dominated by Aleppo pine (*Pinus halepensis*), with a significant presence of stone pine (*Pinus pinea*), a valuable species well-adapted to coastal sandy soils. In depressions within the forest, other tree species such as *Ulmus minor*, *Fraxinus angustifolia*, *Quercus robur*, *Populus alba*, and *Alnus glutinosa* can also be found. These forests represent habitat type 2270* (Wooded Dunes with *Pinus pinea* and/or *Pinus pinaster*) and are associated with the sampling points K1, K7, K8, K9, K22, K23, K24, K25, K26.



Figure 6: Pine forest dunes of the 2270 habitat type Natura 2000



Figure 7: *Pinus halepensis* and *P. pinea* are found in the pine forest



Figure 8: Agricultural land recently abandoned showing evidence of previous farming



Figure 9: A crop land that has been abandoned but still has agricultural infrastructure (irrigation channels)

Abandoned agricultural land

In some areas, such as the sampled points on the eastern border of the lagoon K2, K3, K10, K11, K12, K14, K15, K17, K18, and K20, we have the presence of abandoned agricultural fields, which present a mix of plant species. Their state shows signs of past cultivations and the gradual recovery through spontaneous vegetation. The vegetation includes ruderal and pioneer species, demonstrating that a secondary ecological succession is taking place.

Table 1: Vegetation Types and Associated Sampling Points in Kune-Vaini Lagoon

Habitat Type	Sampling Points
Halophytic Vegetation	K4, K5, K6, K13, K16, K19, K21
Wooded Dunes with Pinus species	K1, K7, K8, K9, K22, K23, K24, K25, K26
Abandoned agricultural land	K2, K3, K10, K11, K12, K14, K15, K17, K18, K20

2.4 Mapping Spatial Distribution of Organic Carbon and Related Soil Properties

Using spatial analysis in QGIS (v. 3.34.7) we mapped the distribution of soil parameters at the sampling sites. By visualizing the distribution of the values of the various parameters along the depth of the soil, we can analyze their distribution in the soil profile of the lagoon. In this way we have an overview of the spatial distribution of organic carbon accumulation in the Karavasta Lagoon. Furthermore, we can integrate this distribution with key environmental factors and the type of habitat/vegetation present. This method provides an understanding of the spatial distribution of carbon storage in the Karavasta Lagoon.

3. RESULTS AND DISCUSSION

Vertical Distribution of Soil Organic Carbon

Soil Organic Carbon values, obtained from TOC estimated using LOI via a conversion coefficient, showed a clear vertical decline from the surface (0–5 cm) to the depth (10–20 cm). In the surface layer we find the highest concentration, with a range from 10.99 g/kg (K21) to 84.84 g/kg (K16) and with an average of 33.35 g/kg. The lower layer (5–10 cm) exhibits decreasing SOC values compared to the surface layer, ranging from around 6 g/kg (K26) up to 47.48 g/kg (K16), with an average of 18.31 g/kg. This vertical decline continues with the 10–20 cm layer (average of 15.78 g/kg), which has as minimum values 4.76 g/kg (K22), but still reaching 0.33 g/kg (K20). There are several exceptions to this SOC decrease with depth, such as samples K2, K3, K18, K19, and K20, where the deeper layers maintain comparatively high levels.

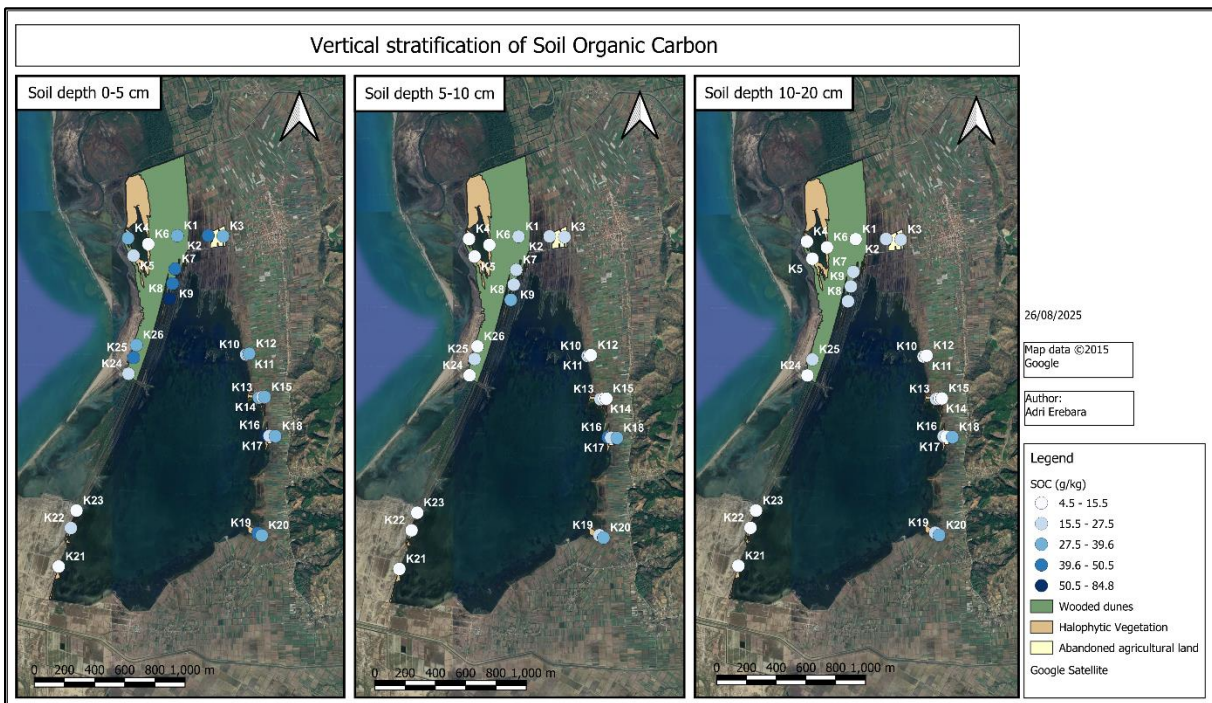


Figure 10: Vertical stratification of Soil Organic Carbon in Karavasta Lagoon (map data: Google Earth, QGIS, 3.34.7-Prizren)

Overall, there is spatial variability with contrasting values, although some samples, such as K7, K8, K9, K19, K25, exhibit intermediate carbon storage potential values (>40 g/kg at the surface). And also higher levels of SOC, such as K16 (0–5 cm = 84.8 g/kg; 5–10 cm = 47.5 g/kg), which shows a layer rich in organic matter. Additionally, sample K16 (0–5 cm = 84.8 g/kg; 5–10 cm = 47.5 g/kg) indicates a layer with higher amounts of SOC.

In order to evaluate the soil's capacity to store carbon, we calculated the soil organic carbon density and stock. The SOC density in the sampled soils ranged from 0.01 to 0.05 g cm⁻³, with an average of 0.03 g cm⁻³. Furthermore, SOC content ranged from 25.70 to 93.31 Mg C ha⁻¹, with an average of 55.02 ± 20.55 Mg C ha⁻¹. These results are consistent with the global dataset of SOC in tidal marshes compiled by Maxwell et al. [17], who reported SOC stocks of 79.2 ± 38.1 Mg SOC ha⁻¹ in the top 30 cm. Although our SOC stocks are slightly lower due to the reduced sampling depth (20 cm), they are still within the reported range, demonstrating the carbon storage potential of these ecosystems. This affirms the relevance of our data within global efforts to mitigate climate change through the assessment and conservation of blue carbon in vegetated coastal wetland ecosystems.

Organic Carbon Accumulation Across Habitat Types

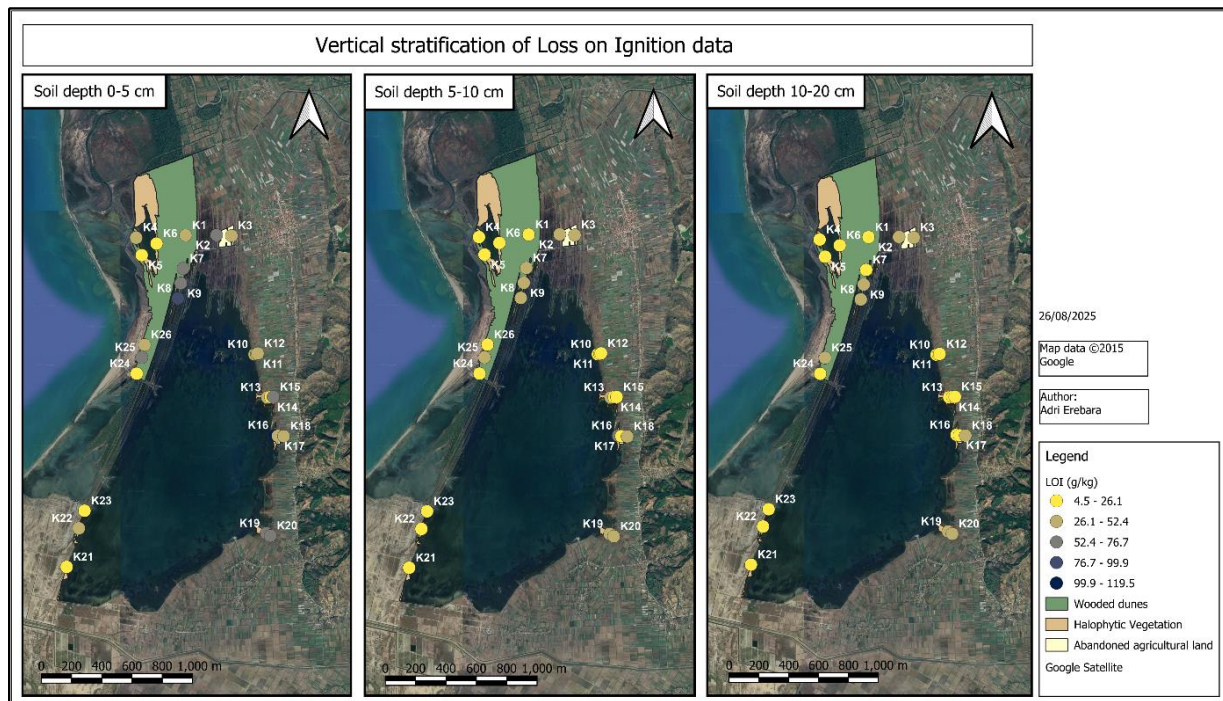
In halophytic vegetation, SOC data show a marked decrease in concentrations with increasing soil depth. The surface layer (0–5 cm) shows the highest values, ranging from 10.99 g/kg (K21) to 84.84 g/kg (K16), and a mean of 34.77 g/kg. Most of the samples have a clear decline in SOC in the 5–10 cm layer, with a mean of 19.55 g/kg and a range from 7.18 to 47.48 g/kg. In the deeper layers (10–20 cm), we note a further decrease, with an average of 16.11 and a range from 4.87 to 24.35 g/kg, although in some samples, such as K13, K16, and K19, we find relatively high values even in the deeper layers.

In wooded dunes, SOC concentrations follow the same vertical trend, with higher amounts in the surface layer (0–5 cm), with a mean of 33.35 g/kg and a wide range between 12.20 and 63.35 g/kg. Values decline progressively with depth, with a mean value of 18.31 g/kg in the 5–10 cm layer and 15.78 g/kg at the 10–20 cm layer. The range also decreases slightly with depth, ranging from 5.57 to 27.54 g/kg at 5–10 cm and from 4.76 to 24.33 g/kg at 10–20 cm.

Finally, SOC concentrations in abandoned agricultural lands continue to indicate vertical stratification, although with a less pronounced decrease. The surface layer (0–5 cm) contains the highest amounts of SOC among the three vegetation types, with a mean of 36.41 g/kg and a range of 15.65–42.46 g/kg. At 5–10 cm, the mean SOC is 20.54 g/kg, with values ranging from 7.86 to 32.91 g/kg, while at 10–20 cm the mean is 17.41 g/kg, with a range of 6.86 to 30.33 g/kg. In particular, in samples K18 and K20, SOC concentrations at 10–20 cm are comparable to those in the uppermost layers, reflecting the legacy of past agricultural practices. Among vegetation types, SOC concentrations were quite similar, with abandoned agricultural land showing slightly higher values.

Spatial Distribution of Loss on Ignition

The LOI values show extremely high variability, with values ranging from 6.7 to 119.5 g/kg. Generally, the vertical distribution indicates a decline in organic matter with increasing depth, characterized by accumulation in the surface layer and progressive decomposition in deeper ones. Exceptions include some samples (K3, K18, K20, K23) that exhibit relatively uniform values with depth. In certain samples, we encounter very high surface values, as observed in K7 (0–5)=67 g/kg, K8 (0–5)=89.2 g/kg, K16 (0–5)=119.5 g/kg, highlighting hotspots of organic matter accumulation.



**Figure 11: Vertical variation of Loss on Ignition data in Karavasta Lagoon
(map data: Google Earth, QGIS, 3.34.7-Prizren)**

R^2 analysis (coefficient of determination) also supports the vertical distribution with depth, as organic matter values show a stronger relationship between adjacent layers ($R^2 = 0.66$ between 0–5 and 5–10 cm; $R^2=0.61$ for 5–10 and 10–20 cm), in contrast to those that are more distant ($R^2=0.33$ between 0–5 and 10–20 cm). The same values of R^2 were found for the SOC, since its values come from LOI.

Soil samples in halophytic vegetation show a surface layer (0–5 cm) of high organic content (mean 49 g/kg), which generally decreases with depth (5–10 cm layer mean 27.5 g/kg and 10–20 cm layer mean 22.7 g/kg). With some samples in the surface layer of 0–5 cm, such as K16=119.5 g/kg and K19=69.9 g/kg, acting as reservoirs of blue carbon sequestration in the wetland. Wooded dunes also show a maximum LOI value in the 0–5 cm layer (mean 47 g/kg), ranging from 17.2 (K23) to 89.2 g/kg (K8), followed by a clear decline with depth (5–10 cm layer mean 25.8 g/kg and 10–20 cm layer mean 22.2 g/kg). This is probably due to the mineralization and dilution of accumulated organic matter in sandy substrates. The majority of sites contain high amounts of organic matter, while some sites, such as K23 and K24, have lower amounts, which indicates high spatial variability in this vegetation type.

The range of organic matter values is narrower in samples taken from abandoned agricultural land. They have a high content at depths of 0–5 cm, ranging from 22 to 59 g/kg (mean 51.3 g/kg).

Generally, this value decreases with depth (5–10 cm layer mean 28.9 g/kg and 10–20 cm layer mean 24.5 g/kg), with the exception of some cases (such as K3, K18, and K20), which remain with a relatively high content even in the deeper layers, likely reflecting the effects of agricultural practices, such as plowing. In this way, abandoned agricultural lands retain a substantial reserve of organic matter in the soil.

Vertical Distribution of Carbonates

Carbonate dynamics at the sampling points show a clear increase with increasing depth, although their values are very varied, from 0.92 to 47.4 g/kg. Their vertical distribution initially shows a high quantity in the 0–5 cm layer (average 10.83 g/kg), which increases in the 5–10 cm depth (average 12.98 g/kg) to have a further slight increase in the deeper layer of 10–20 cm (average 13.91 g/kg).

The application of the coefficient of determination showed a strong relationship between the 0–5 cm and 5–10 cm horizons ($R^2 = 0.78$), suggesting that the carbonate content remained relatively stable between these depths. While for the other layers it showed a lower relationship ($R^2 = 0.51$ for 5–10 and 10–20 cm and $R^2 = 0.39$ for 0–5 and 10–20), indicating that the accumulation of carbonates at depth is less associated with the surface content.

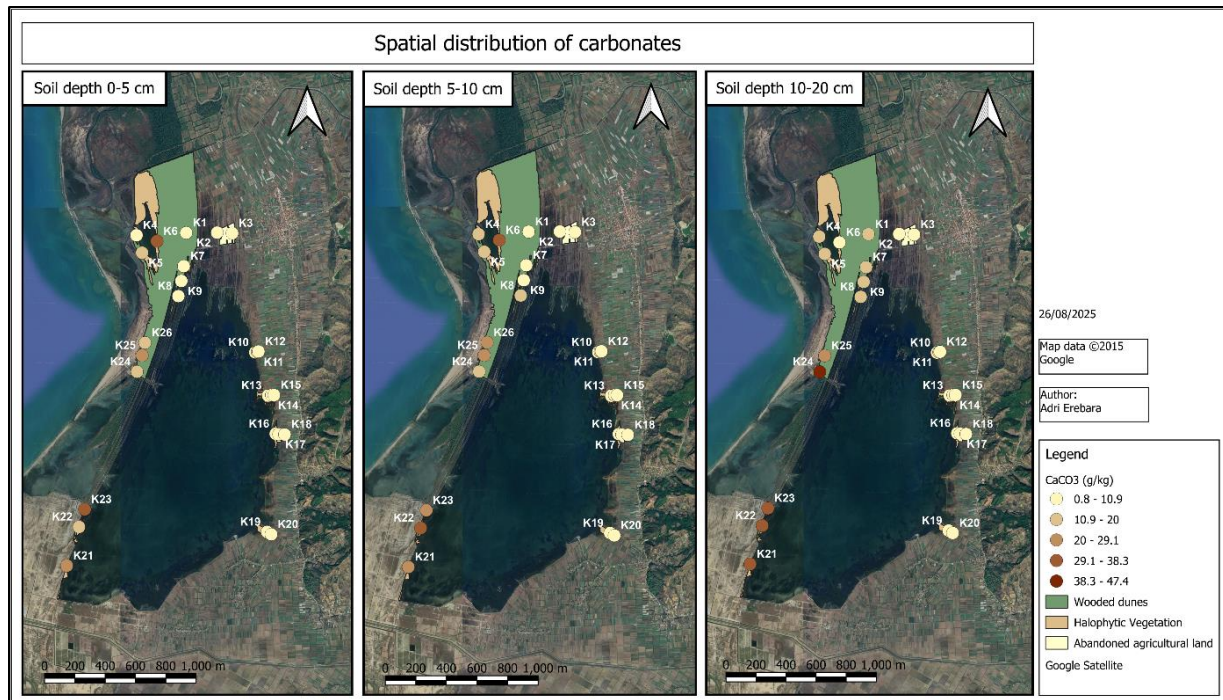


Figure 12: Spatial distribution of the CaCO_3 in the soil depth of Karavasta Lagoon (map data: Google Earth, QGIS, 3.34.7-Prizren)

Soils with halophytic vegetation generally show medium carbonate values (between 6 and 16 g/kg), with the exception of particularly high values in K6 (up to 33 g/kg) and K21 (on average 29 g/kg). There are differences in the vertical distribution patterns with depth, with some samples indicating accumulation at depth (K4 and K5) and others remaining uniform.

Instead, the soils sampled in the wooded dune vegetation show a clear increase in the carbonate content with increasing depth, although their values vary from a minimum of 3.78 g/kg in the 0–5 cm surface layer to a maximum of 47.4 g/kg in the 10–20 cm layer. Lastly, the lowest carbonate values, ranging from 0.9 to 13.3 g/kg, are found in abandoned agricultural soils. Most samples, with the exception of K11, K12, and K14, exhibit a drop in carbonate, most likely as a result of leaching and agricultural practices.

Spatial Distribution of Soil pH

In general, our samples show alkaline pH values, which, however range from moderately basic (7.99) at the depth of 0–5 cm, to values of increasing alkalinity with increasing depth, 8.34 for the depth at 5–10 cm up to a strong alkalinity in the depth of 10–20 cm with a pH of 8.46. This increase in alkalinity may be due to the greater presence of salts as the depth increases, mainly due to the connection and exchanges with sea water or to the presence of fertilizers linked to nearby agricultural activities.

The values of the standard deviation (0.56, 0.56, 0.45 respectively) and the coefficient of variation (6.99%, 6.73%, 5.38% respectively), indicate that the data have a distribution close to the mean and with low variability, indicating a stable pH environment in the studied location.

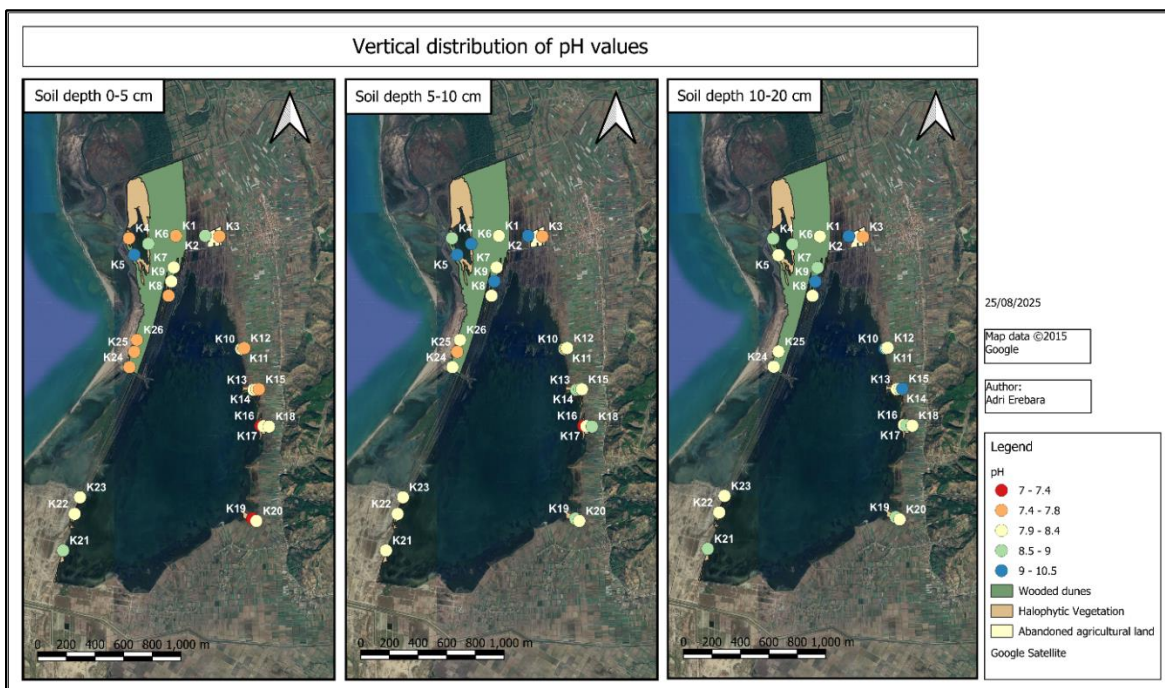


Figure 13: Spatial distribution of pH along the soil depth in Karavasta Lagoon (map data: Google Earth, QGIS, 3.34.7-Prizren)

In soils with halophytic vegetation, pH values follow the tendency of increasing alkalinity with depth, going from moderately alkaline (pH=8.06) to strongly alkaline values (pH=8.58). At the 0–5 cm horizon, pH values indicate neutral to strongly alkaline conditions, with values ranging from 7.21 (K19) up to 9.64 (K5). Overall, the majority of samples are between 8.3 and 8.9, indicating that the halophytic vegetation is characterized by alkaline soils, which are influenced by the surrounding marine environment (samples K5 and K6) or by the use of fertilizers (K13). In the soil depth range 5–10 cm, we note higher values of basicity, which vary between 8.35 and 9.30, indicating strongly alkaline conditions, with the exception of sample K16 (pH=7.11). As regards the depth 10–20 cm, in comparison with the overlying layers it shows uniform alkaline conditions along the samples.

The vegetation of the wooded dunes also shows slightly to moderately alkaline values at a depth of 0–5 cm, with a range of pH values of 7.67-8.19. At a depth of 5–10 cm there is a greater variability in pH, with values between 7.74 and 9.27. The majority of them fall within the moderately alkaline range, confirming the increase in basicity with depth. Similarly, the 10–20 cm layer exhibits a modest increase in alkalinity, predominantly within the moderate range, except for sample K9, which is moderately alkaline (pH=9.17).

In samples taken from abandoned agricultural land, pH values in the 0–5 cm surface layer reflect slightly to strongly alkaline conditions, ranging from 7.43 to 8.89. In the 5–10 cm layer we notice a tendency towards greater alkalinity compared to the surface layer, as the values vary between 7.57 and 9.22. At a depth of 10–20 cm, pH values between 7.62 and 9.42 were recorded, which indicate a slight increase in alkalinity with depth (especially for K10=9.42 and K15=9.18). However, most values range between 8.1 and 8.5, with an average close to 8.41. This variation in data can be correlated with the use of fertilizers during periods of land use for agricultural production.

Spatial Distribution of Electrical Conductivity

Conductivity values, a measure associated with the presence of salts, provide a significant information depending on depth. First, high values of EC are noted in the first depth of 0–5 cm, with an average of 1073 $\mu\text{S}/\text{cm}$, which however decreases to an average of 889 $\mu\text{S}/\text{cm}$ in the subsequent depth of 5–10 cm. To rise sharply in the deep layer of 10–20 cm with an average value of 1376 $\mu\text{S}/\text{cm}$. This vertical trend, exhibiting a decline in the intermediate layer relative to the surface layer, indicates flushing or dilution in the shallow layers. Subsequently, a significant increase in the deeper layer indicates a zone of salt deposition, also affected by groundwater supplies [19].

Furthermore, we compared the data from different depths, where we found a strong relationship between 0–5 and 5–10 cm ($R^2=0.85$) and a weak relationship with the depth 10–20. The depths 5–10 and 10–20 cm were moderately associated ($R^2=0.66$), while 0–5 with 10–20 showed a weak relationship ($R^2=0.48$).

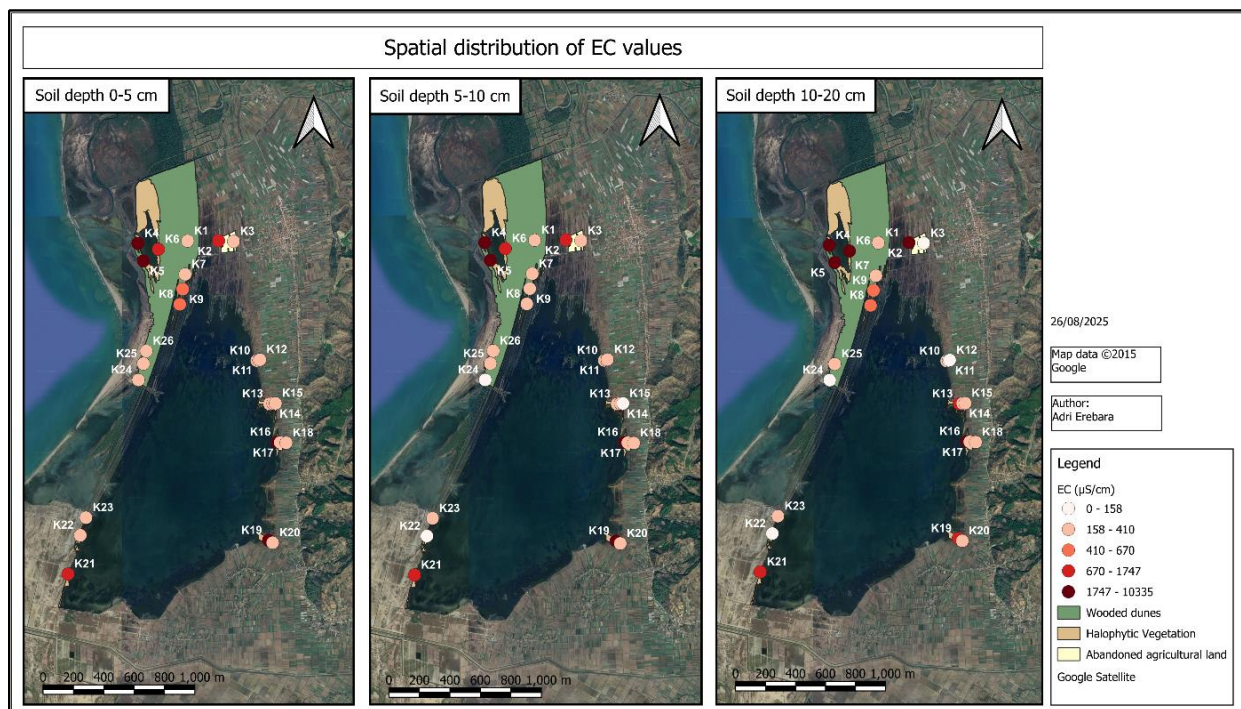


Figure 14: Vertical distribution of the electrical conductivity data in the Karavsta Lagoon soils (map data: Google Earth, QGIS, 3.34.7-Prizren)

In general, halophytic vegetation follows the same trend: high values in the surface layer, a decrease in the 5–10 cm layer, followed by a sharp increase in the 10–20 cm layer. Specifically, however, we note that some samples in the 5–10 cm layer show a slight increase compared to the more superficial layer. At a depth of 0–5 cm, a highly variable trend is observed, ranging from extremely low salinity (363 $\mu\text{S}/\text{cm}$) to very high salinity (10,335 $\mu\text{S}/\text{cm}$). The distribution of electrical conductivity (EC) indicates that higher EC values are located nearer to the coast, while lower EC values are situated further from the shoreline. This behavior is additionally observed in the other depths, so the EC decreases with the greater distance from the coast of the sampling environments. In any case, halophytic vegetation is capable of facing such high EC values.

On the other hand, EC values in the wooded dunes are uniformly low, ranging from 97 $\mu\text{S}/\text{cm}$ to 574 $\mu\text{S}/\text{cm}$. The vertical distribution also has less variation, with a slight decrease in the 5–10 cm layer, but without evidence of salt accumulation in the deeper one. Similarly, abandoned agricultural lands also have generally low values of EC, from 112 $\mu\text{S}/\text{cm}$ to 408 $\mu\text{S}/\text{cm}$, which indicate a non-saline environment. With the exception of sampling point K2, which shows high values (843 $\mu\text{S}/\text{cm}$, 1702 $\mu\text{S}/\text{cm}$, 2701 $\mu\text{S}/\text{cm}$, respectively), probably due to residues of past agricultural practices, the other sites remain low.

4. CONCLUSIONS

This study highlights the vertical stratification of soil organic carbon distribution in different vegetation types within the Karavasta Lagoon. A progressive decrease in SOC concentrations is observed with increasing depth, with the surface layer (0–5 cm) presenting the highest values (mean of 33.35 g/kg) and deeper layers continuously decreasing (5–10 cm = 18.31 g/kg; 10–20 cm=15.78 g/kg). However, in some profiles, such as K2, K3, K8, K16, K18, K19, K20 and K25, high SOC levels have been maintained, due to ecological factors or past land uses. Taking into account the different types of vegetation, the quantities of SOC are relatively similar, with abandoned agricultural lands showing slightly higher values (mean 36.41 g/kg), followed by halophytic vegetation (mean 34.77 g/kg) and wooded dunes (mean 33.35 g/kg).

Calculated SOC density (0.01–0.05 g/cm³) and SOC stocks (25.70–93.31 Mg C ha⁻¹), at 20 cm depth, are within the ranges reported for tidal wetlands globally, although lower than global averages due to the lower sampling depth. Nevertheless, these values confirm the potential for organic carbon storage in the Karavasta Lagoon soils and, at the same time, demonstrate their relevance for climate change mitigation through blue carbon conservation.

The LOI values showed a decreasing trend with depth, ranging from 46.9 g/kg in the 0–5 cm depth, up to 22.22 g/kg in the deepest layer. pH values were alkaline, showing a trend from moderately alkaline in the first depths (pH=7.99-8.34) to strongly strongly alkaline values in the deepest layer (pH=8.45). Electrical conductivity showed high values in the surface layer 0–5 cm (1073 μS/cm), followed by a decrease at 5–10 cm (889 μS/cm) and then an increase again at 10–20 cm (1376 μS/cm). Furthermore, we observed a strong relationship between the upper layers ($R^2=0.85$), indicating uniform dynamics at the surface, and a weak link with deeper soils ($R^2=0.47$). Carbonate concentrations generally have an increase trend with depth, with strong relationship between the first two depths ($R^2 = 0.78$).

5. ACKNOWLEDGEMENTS

We gratefully acknowledge the National Agency for Protected Areas of Albania for their support and collaboration in facilitating this research, with particular thanks to the Administration of Protected Areas in the Fier Region. We also thank our colleagues from the Agro-Environment and Ecology Laboratory at the Agricultural University of Tirana for their valuable assistance with laboratory analyses.

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ANNEX

Table 2: Sampling points, geographical locations and habitat types in Karavsta Lagoon

Sample no.	Sample ID	UTM_WGS84_Zone 34T		Habitat type
		East	North	
1	K1	373229	4539293	Wooded Dunes with Pinus species
2	K2	374248	4539282	Abandoned agricultural land
3	K3	374741	4539253	Abandoned agricultural land
4	K4	371594	4539241	Wooded Dunes with Pinus species
5	K5	371767	4538665	Wooded Dunes with Pinus species
6	K6	372263	4539036	Wooded Dunes with Pinus species
7	K7	373131	4538203	Wooded Dunes with Pinus species
8	K8	372937	4537225	Wooded Dunes with Pinus species
9	K9	373042	4537719	Wooded Dunes with Pinus species
10	K10	375438	4535340	Halophytic vegetation
11	K11	375502	4535355	Abandoned agricultural land
12	K12	375541	4535367	Abandoned agricultural land
13	K13	375836	4533916	Halophytic vegetation
14	K14	375947	4533930	Abandoned agricultural land
15	K15	376029	4533931	Abandoned agricultural land
16	K16	376064	4532663	Halophytic vegetation
17	K17	376163	4532646	Halophytic vegetation
18	K18	376358	4532634	Abandoned agricultural land
19	K19	375726	4529451	Halophytic vegetation
20	K20	375860	4529369	Abandoned agricultural land
21	K21	369106	4528459	Halophytic vegetation
22	K22	369532	4529722	Wooded Dunes with Pinus species
23	K23	369729	4530295	Wooded Dunes with Pinus species
24	K24	371534	4534773	Wooded Dunes with Pinus species
25	K25	371709	4535303	Wooded Dunes with Pinus species
26	K26	371811	4535716	Wooded Dunes with Pinus species

Table 3: Physico-Chemical Soil Parameters at 0–5 cm depth

Sample ID	TOC	LOI 450	CaCO ₃	pH	EC
	g/kg	g/kg	g/kg		μS/cm
K1 (0–5)	30.35	42.75	4.58	7.67	353.00
K2 (0–5)	42.46	59.80	3.75	8.89	843.00
K3 (0–5)	34.55	48.66	0.92	7.43	171.90
K4 (0–5)	34.58	48.70	8.75	7.63	10335.00
K5 (0–5)	18.51	26.07	10.92	9.64	3857.00
K6 (0–5)	12.49	17.58	32.83	8.70	790.00
K7 (0–5)	47.58	67.01	3.79	8.06	297.00
K8 (0–5)	63.35	89.23	9.92	7.66	473.00
K9 (0–5)	40.47	57.01	7.75	8.19	443.00
K10 (0–5)	25.17	35.45	1.50	7.89	217.00
K11 (0–5)	26.54	37.38	12.25	7.81	214.00
K12 (0–5)	29.38	41.38	4.50	7.76	197.70
K13 (0–5)	31.16	43.89	8.92	8.3	363.00
K14 (0–5)	15.65	22.04	10.00	8.02	213.00
K15 (0–5)	39.14	55.13	6.25	7.5	335.00
K16 (0–5)	84.84	119.49	3.58	7.24	2719.00
K17 (0–5)	24.32	34.25	2.58	7.97	221.00
K18 (0–5)	34.09	48.02	6.33	8.24	214.00
K19 (0–5)	49.62	69.88	7.08	7.21	2651.00
K20 (0–5)	37.92	53.41	3.08	8.33	268.00
K21 (0–5)	10.99	15.48	28.33	8.92	1575.00
K22 (0–5)	21.51	30.29	15.42	7.92	187.00
K23 (0–5)	12.20	17.18	30.00	7.9	172.80
K24 (0–5)	18.01	25.37	17.17	7.48	232.00
K25 (0–5)	46.40	65.35	21.25	7.8	273.00
K26 (0–5)	35.89	50.55	20.00	7.66	289.00
Mean	33.35	46.98	10.83	7.99	1073.25
Median	32.63	45.95	8.25	7.90	293.00
Min. value	10.99	15.48	0.92	7.21	171.90
Max. value	84.84	119.49	32.83	9.64	10335.00
Std. Devi.	16.62	23.40	9.02	0.56	2111.90
Coefficient of Variation (%)	49.82	49.82	83.30	6.99	196.78

Table 4: Physico-Chemical Soil Parameters at 5–10 cm depth

Sample ID	TOC	LOI 450	CaCO ₃	pH	EC
	g/kg	g/kg	g/kg		μS/cm
K1 (5–10)	16.10	22.67	8.58	7.92	228.00
K2 (5–10)	22.73	32.01	4.00	9.22	1702.00
K3 (5–10)	24.29	34.21	1.33	7.57	223.00
K4 (5–10)	9.14	12.87	14.83	8.91	5348.00
K5 (5–10)	8.38	11.80	13.83	9.30	3914.00
K6 (5–10)	7.18	10.11	33.50	9.12	1332.00
K7 (5–10)	23.28	32.79	10.38	8.24	258.00
K8 (5–10)	27.54	38.79	17.25	8.07	305.00
K9 (5–10)	22.12	31.15	7.08	9.27	351.00
K10 (5–10)	17.16	24.17	2.63	8.88	252.00
K11 (5–10)	14.11	19.87	12.33	7.79	247.00
K12 (5–10)	15.27	21.51	10.33	7.96	173.70
K13 (5–10)	24.75	34.87	10.25	8.62	202.00
K14 (5–10)	7.86	11.07	9.25	8.56	167.10
K15 (5–10)	15.00	21.13	7.50	7.94	124.40
K16 (5–10)	47.48	66.87	5.42	7.11	2837.00
K17 (5–10)	18.24	25.69	3.33	8.31	312.00
K18 (5–10)	28.81	40.58	6.33	8.57	254.00
K19 (5–10)	24.02	33.83	7.33	8.77	2868.00
K20 (5–10)	32.91	46.36	4.33	8.45	286.00
K21 (5–10)	8.61	12.13	28.75	8.35	891.00
K22 (5–10)	8.12	11.43	33.75	8.12	118.10
K23 (5–10)	13.14	18.50	21.67	8.09	179.50
K24 (5–10)	8.42	11.86	17.50	7.99	153.50
K25 (5–10)	25.97	36.58	22.67	7.74	212.00
K26 (5–10)	5.57	7.84	23.33	7.95	188.40
Mean	18.31	25.80	12.98	8.34	889.49
Median	16.63	23.42	10.29	8.28	253.00
Min. value	5.57	7.84	1.33	7.11	118.10
Max. value	47.48	66.87	33.75	9.30	5348.00
Std. Devi.	9.86	13.89	9.31	0.56	1358.02
Coefficient of Variation (%)	53.85	53.85	71.69	6.73	152.67

Table 5: Physico-Chemical Soil Parameters at 10–20 cm depth

Sample ID	TOC	LOI 450	CaCO ₃	pH	EC
	g/kg	g/kg	g/kg		μS/cm
K1 (10–20)	14.08	19.83	14.67	8.04	233.00
K2 (10–20)	23.10	32.53	3.33	9.05	2701.00
K3 (10–20)	24.93	35.11	1.75	7.62	111.50
K4 (10–20)	7.57	10.66	16.00	8.81	6284.00
K5 (10–20)	4.87	6.86	14.25	7.97	4539.00
K6 (10–20)	12.43	17.51	10.13	8.76	2187.00
K7 (10–20)	16.32	22.98	15.08	8.71	308.00
K8 (10–20)	24.33	34.27	17.92	8.25	427.00
K9 (10–20)	21.33	30.05	12.08	9.18	574.00
K10 (10–20)	14.40	20.28	3.00	9.42	240.00
K11 (10–20)	13.64	19.21	13.33	8.23	140.60
K12 (10–20)	14.04	19.77	9.58	8.29	123.40
K13 (10–20)	18.45	25.99	6.83	8.47	1524.00
K14 (10–20)	6.86	9.66	9.42	8.14	169.80
K15 (10–20)	13.51	19.03	7.25	9.18	301.00
K16 (10–20)	18.40	25.91	5.42	8.38	10014.00
K17 (10–20)	12.09	17.03	5.92	8.54	353.00
K18 (10–17)	29.89	42.10	5.92	8.44	360.00
K19 (10–18)	24.35	34.30	4.25	8.96	1747.00
K20 (10–20)	30.33	42.71	2.58	8.22	408.00
K21 (10–20)	7.22	10.17	29.17	8.52	989.00
K22 (10–20)	4.76	6.71	36.83	8.23	97.00
K23 (10–20)	10.99	15.47	30.42	7.99	197.40
K24 (10–20)	7.43	10.47	47.40	7.91	157.50
K25 (10–20)	19.10	26.91	25.17	8.1	207.00
Mean	15.78	22.22	13.91	8.46	1375.73
Median	14.08	19.83	10.13	8.38	353.00
Min value	4.76	6.71	1.75	7.62	97.00
Max value	30.33	42.71	47.40	9.42	10014.00
Std. Devi.	7.49	10.55	11.64	0.45	2353.27
Coefficient of Variation (%)	47.48	47.48	83.71	5.38	171.06