

Tracking eelgrass loss in estuarine sediments of West  
Falmouth Harbor

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## **Abstract**

Eelgrass (*Zostera Marina*) has been steadily declining from shallow areas of Buzzards Bay, Ma. over the last 35 years. Evidence has shown connections between increasing nutrient pollution and eelgrass decline. Evidence also suggests that boating induced disturbance promotes eelgrass loss. I tested whether trends in sedimentary lignin concentrations and trends in lignin  $\delta^{13}\text{C}$  values reflect recent eelgrass cover change from three sites in West Falmouth Harbor. I also determined whether spatial differences in eutrophication and boat impacts explain why eelgrass has declined from certain parts of West Falmouth Harbor. I found that trends in sedimentary lignin concentration indicate recent eelgrass cover change when the lignin  $\delta^{13}\text{C}$  reflects that of eelgrass. I found no spatial differences in boat impacts between the northern and southern harbor and small spatial differences in nutrient inputs between these two sites. Sedimentary eutrophication indicators did not explain why eelgrass died first in the southern harbor. We conclude that while eutrophication and boating impacts cause eelgrass loss, other environmental factors including water depth and water residence time may determine whether or not a stressor will promote eelgrass loss.

**Key Words:** Eelgrass, lignin, stable isotopes, sedimentary record, nutrient inputs, boating impacts, trace metals.

## **Introduction**

Eelgrass (*Zostera Marina*) is a submerged aquatic vascular plant that grows in shallow marine environments. Eelgrass beds are the foundation of complex food webs

providing protected habitats, breeding grounds, and a substantial carbon-source for many benthic as well as pelagic organisms. Senesced eelgrass leaves contribute substantial amounts of organic matter to the sediments (Vichkovitten and Holmer, 2004) and form a major part of the detrital food pathway in many systems. Annual eelgrass primary production in Buzzard's Bay, Ma accounts for 11% of the total primary production in the bay (Costa, 1988). Many coastal fisheries rely on eelgrass as a breeding ground and nursery for lobsters, crabs, and scallops (Short et al., 1993). Eelgrass beds also stabilize coastal sediments (Gacia and Duarte, 2001), modify currents (Fonseca et al., 1982), trap fine grained suspended particles, and filter toxic metals and nutrient pollution that enter estuaries, especially nitrogen from waste-water (Short and Short, 1984). Because of its sensitivity to nutrient pollution, eelgrass may provide early warning signs for eutrophication and sediment toxicity.

Eelgrass is a rooted plant and thus requires high water clarity to receive sufficient light for photosynthesis. It is sensitive to decreases in incident photosynthetically active radiation (PAR) from phytoplankton blooms and epiphytic macroalgal growth. Under mesocosm experiments simulating different water clarity conditions, eelgrass growth and shoot density declined with reduced light levels (Short, 1987). Nutrient loading is negatively correlated with eelgrass cover (Figure 1). Eelgrass growing in highly polluted waters with low flushing is most threatened and grows only in shallow areas where light can reach the bottom.

Physical human disturbances such as boating activities, mooring, and dock construction can also stimulate eelgrass loss by blocking light, re-suspending sediments in the water column, and physically tearing up eelgrass beds.

Scientists have been documenting major changes in eelgrass cover along the East Coast of the US for the last 100 years. In the 1930s eelgrass communities declined dramatically as a result of infection by a slime mold called the “wasting disease.” More recent declines in eelgrass communities are attributed to decreased light availability from both cultural eutrophication and physical human disturbance that resuspend sediment and therefore block light. Both (Costa, 1988) and (Short *et al.*, 1993) have matched eelgrass losses with the onset of known eelgrass disturbances such as development, nutrient loading, natural disasters, and wasting disease.

Costa, 1988 used seed density and bittium snails as indicators of historical eelgrass loss in the coastal areas of Buzzard’s Bay where eelgrass has been declining steadily since the height of its recovery from the wasting disease in 1970 (Figure 2). Costa matched peaks of eelgrass seeds with a known history of eelgrass abundance.

Eelgrass seeds are resistant to decomposition and can be ingested and passed through animals without damage. Eelgrass plants deposit seeds in close proximity to the eelgrass bed as well (Costa, 1988) (Figure 3). Yet, varying environmental conditions within a system including light levels, depth, temperature, nutrient concentration, and sediment redox state can greatly affect seed production (Granger *et al.*, 2002) and germination once seeds are deposited in the sediments. Thus, eelgrass seed abundance in the sediments may be confounded by several environmental factors.

Eelgrass blade detritus has a heavy carbon stable isotope signal of -10‰ compared to other marine primary producers including phytoplankton (~-20‰), macroalgae (-16‰), and terrestrial derived organic matter (~-28‰). *Spartina alterniflora*, a marsh grass that grows on the fringes of many estuaries has a  $\delta^{13}\text{C}$  of (-

12‰) close to that of eelgrass. McClelland and Valiela, found that the tidal amplitude in Waquoit Bay was too low to wash spartina detritus from the fringes of the bay to the sediments (McClelland and Valiela, 1998). We assume for this study that *Spartina alterniflora* contributes small amounts of particulate organic matter to the harbor's sediments. The wide range of sedimentary plant sources with different  $\delta^{13}\text{C}$  signals contributing to the total organic matter content in the sediments makes it impossible to determine the historical plant composition in sediments solely based on the  $\delta^{13}\text{C}$  of the organic matter (Boschker et al., 1999). Furthermore, as bacteria decompose organic matter in the sediments, its isotopic signal may change (Benner et al., 1987). Thus tracing eelgrass presence in sediments using the  $\delta^{13}\text{C}$  of the sedimentary organic matter is ineffective.

Eelgrass is a vascular plant containing lignin, a structural organic compound that is more resistant to decay than other organic compounds, providing a long-term pool of particulate organic matter in the sediments (Vichkovitten and Holmer, 2004). Because of its recalcitrance, lignin in sediments also provides a quantitative representation of historical vascular plant input (Haung, Y et al., 1999). The concentration of lignin in the sediments could thus be a good indicator of eelgrass presence over time in conjunction with trends in lignin  $\delta^{13}\text{C}$  signature to verify its vascular plant source.

The goal of this study is to answer two questions: 1) Can we use lignin,  $\delta^{13}\text{C}$  of lignin, and eelgrass macrofossils in the sediment to determine fine scale (temporal and spatial) changes in eelgrass cover over time? 2) Do sedimentary indicators of eutrophication and boat use explain why eelgrass disappeared first from the southern harbor?

I analyzed three sites within the inner harbor, one site with current eelgrass cover (site one) and two bare sites with known histories of cover in 1995 (site two) and 1980 (site three) respectively (Figure 4). I used trends in concentrations of trace metals with depth from each site as proxies for boat traffic and boat induced disturbance at each site. I used trends in total sulfur in the sediments with depth and  $\delta^{15}\text{N}$  of the sediments with depth to establish the onset of eutrophication in the system.

### **Site Description:**

West Falmouth Harbor is a shallow-water embayment located on the southeastern side of Buzzards Bay, Massachusetts. Converging land masses separate the inner harbor from the outer harbor. The outer harbor has a low water residence time (<0.5 days) and sandy sediments while the inner harbor has a high water residence time (4.5 days) and muddy sediments. Present day eelgrass meadows cover the outer harbor while the inner harbor has lost most of its eelgrass from the southern part of the harbor. Plumes of high nutrient waste-water from the Falmouth Sewage Treatment Plant and residential sewer systems seep through the groundwater and enter West Falmouth Harbor at the northern part of the inner harbor, ironically the same area where eelgrass is still present in the inner harbor (site one). Eelgrass covered West Falmouth Harbor until 1930 when the wasting disease killed off over 90% of its cover (Costa, 1988). Eelgrass communities subsequently reemerged in the harbor reaching a maximum 80% cover in 1980 (Costa et al., 1996). Since 1980, eelgrass cover has declined primarily in the southern region of the inner harbor.

### **Methods:**

SES divers took duplicates of 6.5-cm diameter sediment cores from three sites (site 1 -present cover , site 2- 1995 cover, and site 3- 1980 cover) in West Falmouth Harbor. I refer to each core according to its site and replicate e.g., 1A, 1B, 2A, 2B, 3A, 3B. Sediment Core samples ranged in depth from 16 to 40 cm. I sliced each core into 2 cm sections for the top 10 cm. and 4 cm. sections for the remaining sediment. Wet samples from each section were placed in plastic bags for seed, snail, and macro eelgrass-part analysis. I dried each section and determined bulk density (g dry sediment/ ml wet sediment) and water porosity (ml water/ ml sediment). I ground and homogenized each section for further analysis.

I analyzed sediment from each depth in all sites for total sulfur as a % weight of dry sediment using a LECO SC-32 sulfur analyzer and coal standards. I normalized % sulfur of selected sections from selected replicate cores to corresponding % organic carbon and graphed the average of the two cores. I assumed the same % organic carbon for each site as I only ran % C on one core from each site. I digested each section in 10% HCL to extract the readily available metal fractions (mostly bound in oxides, carbonates) and exchangeable fractions. Each sample was shaken over night and centrifuged. I ran the supernatant of each section for Copper (Cu), Lead (Pb), Zinc (Zn), and Chromium (Cr) on a Perkin-Elmer 2380 atomic absorption spectrometer. Trace metal concentrations are converted to  $\mu\text{g}$  metal/g sediment.

I extracted and determined lignin content as a % dry weight from 5-6 spaced out depths from each site for a total of 18 samples (including an eelgrass leaf sample) using 70% Sulfuric acid according to the last step in a sequential extraction of organic compounds (Cite source). I normalized values for % lignin to the organic carbon content

of each corresponding sediment section. While this extraction isolated mostly lignin, the samples also include other acid insoluble organic compounds including humic acids from vascular and non-vascular primary producers. For convenience, I will refer to acid insoluble samples as “lignin” for my results and discussion.

I submitted selected sediment and lignin samples from each site of for Carbon 13 and Nitrogen 15 stable isotope analysis. Molar carbon and nitrogen content for each lignin sample and corresponding sediment sample were also determined in conjunction with the isotope analysis. I wet sieved the preserved wet sediment to obtain particle sizes > 1mm and identified and counted eelgrass seeds, ruppia maritime seeds, *bittium reticulatum* snails, and eelgrass leaf, rhizome, root parts. I recorded eelgrass leaf parts as “many” “few” or “none” for each section.

## **Results:**

### **Lead Profile:**

Sites 1 (present eelgrass cover) and 3 (1980 cover) had similar lead profiles varying little between replicates, rising at about 20 cm and peaking at 10 cm (Figure 5). Lead concentrations from site two (1995 cover) remained relatively low (10 µg Pb/g sediment) below 5 cm depth and increased in concentration above background levels only in one replicate (Figure 6). The abnormal lead profile at site two suggests that the sediment was disturbed, probably from sediment dredging in the area. Because the sediment does not display an intact chronological profile from site two I will not report results nor make conclusions about this site.

### **Lignin, C:N, C Isotopes**

The concentration of lignin at site 1 (normalized to the organic matter fraction i.e., g lignin/ g organic matter) remained constant with depth, ranging from 20-25% of organic matter by weight (Figure 7).  $\Delta^{13}\text{C}$  values for lignin at site one were also constant with depth, deviating less than 0.5‰ from -19‰ (Figure 8).  $\Delta^{13}\text{C}$  of the sediment at site one also remained constant with depth, deviating less than 0.4‰ from an average of -16.7‰ (Figure 9). The C:N ratio of lignin with depth from site one varied little with depth (Figure 10).

Site three had considerable variation in lignin concentration with depth ranging from 17-35% lignin of the organic carbon fraction with the highest values near the surface and lower values below 10 cm (Figure 7). Lignin  $\delta^{13}\text{C}$  showed an opposite trend with depth, gradually decreasing from -18‰ at 40 cm depth to -19‰ near the surface.  $\Delta^{13}\text{C}$  of the sediments displayed a similar trend to that of lignin (Figure 9). The C:N ratio of lignin remained constant below 5 cm and increased in the top part of the sediment profile (Figure 11).

### **Seed, Snail, and plant parts.**

The abundance and distribution of eelgrass seeds, bittium snails, and eelgrass leaf, stem, and rhizome parts differed between sites one and three. At site one, eelgrass seeds were only abundant in the middle of the core and were absent from the sediment closest to the surface (Figure 12). Seeds were present and in high abundance at all depths at site three. Eelgrass leaf fragments were absent from the first 4 cm at site three (Figure 13). Roots and rhizomes were also not present throughout the sediment profile. The

abundance of bittium snails did not correlate strongly with eelgrass seed abundance between sites (Figure 14).

### **Total Sulfur and $\delta^{15}\text{N}$**

Total sulfur normalized to organic carbon (g Sulfur/g Carbon) remained constant with depth at site one (Figure 15). Total sulfur from site three decreased slightly between 40 and 15 cm and increased steadily from 15 cm to near the surface (Figure 15). Trends in  $\delta^{15}\text{N}$  values from sites one and three show little correlation with their respective total sulfur trends.  $\Delta^{15}\text{N}$  values from site one increased sharply both near the surface and at 35 cm. Site three remained constant in  $\delta^{15}\text{N}$  with depth, fluctuating between 4 and 4.5‰ (Figure 16).

### **Trace metals**

Trace metal profiles show minor differences between sites one and three. Concentrations of trace metals are similar with depth across sites and replicates (Figure 17). Cu, Pb, and Zn concentrations range from 0 to 80  $\mu\text{g/g}$  sediment at both sites. Pb, Zn, and Cr peak at around 8 cm at site three while Cu concentrations at site three continue to increase to the surface and begin to increase at a lower depth than the other trace metals (Figure 17).

## **Disussion:**

### **Eelgrass indicators**

Trends in trace metal concentration from site two indicate that the sedimentary profile was disturbed as trace metals remained at background levels until 5 cm in both replicates (except Zn in 2B) and don't show peaks in either replicate. Site two is located in an area close to where a canal was dredged for boat access. A disturbed sedimentary profile will skew all other trends in the profile and thus we are unable to make any inferences from site two.

The substantially lower C:N ratio of lignin in the sediments compared to an estimated lignin C:N of eelgrass suggests that the acid insoluble fraction contains other organic compounds in addition to lignin including refractory compounds from non-vascular primary producers. While the impurity of the lignin samples may skew the accuracy of the measured  $\delta^{13}\text{C}$  lignin signal, most of the error associated with non-vascular plant input is minimal. We thus assume that non-vascular primary producers will not affect trends in vascular plant content. We also assume that eelgrass detritus and terrestrial detritus are the primary inputs of lignin into the sediments of West Falmouth Harbor and thus the  $\delta^{13}\text{C}$  value of the sediments should reflect a combination of the  $\delta^{13}\text{C}$  values of these inputs. Based on  $\delta^{13}\text{C}$  values of eelgrass lignin (-13‰) and that of terrestrial plant material (-28‰),  $\delta^{13}\text{C}$  values of sedimentary lignin should fall into the range of -20 ‰. Lignin from all sites fell into the range of -22‰ to -18‰ and each site showed different mean  $\delta^{13}\text{C}$  values suggesting that different sites contain different combinations of vascular plant detritus. If we assume consistent loading of allochthonous material at each site, trends in  $\delta^{13}\text{C}$  indicate fluctuations in eelgrass cover. For example, if lignin concentrations drop at the same depth that  $\delta^{13}\text{C}$  stable isotope signal of lignin becomes lighter (i.e., less enriched in  $\text{C}^{13}/\text{C}^{12}$ ) we can infer that eelgrass

density was declining. Lignin trends from site one supports this conclusion, showing similar trends in lignin concentration and  $\delta^{13}\text{C}$  lignin values. In site three however, we see trends that support the conclusion that terrestrial input has changed during eelgrass decline. Trends from site three show lignin concentrations increasing sharply near the surface while  $\delta^{13}\text{C}$  values decrease. Trends in molar C:N ratio of lignin also reflect the constant eelgrass cover in core one and to a lesser extent the changes in eelgrass cover in core three, assuming that eelgrass lignin has a lower C:N ratio than that of terrestrial derived lignin.

### **Site One**

Based on the  $\delta^{13}\text{C}$  values of lignin from site one, eelgrass makes up about 60% of the acid insoluble plant material input into site one's sediments. The similar trends and minor variance of % lignin,  $\delta^{13}\text{C}$  lignin, and C:N of sediment vs. lignin throughout the sediment profile suggest that eelgrass cover has remained constant over time up to the present. The presence of eelgrass leaf fragments throughout the sediment profile of core one further supports this conclusion. The absence of eelgrass seeds from the top of the profile suggests that seeds are not a good indicator of eelgrass cover. Greater wastewater inputs near site one could stress eelgrass seed production, however, the relationship between eelgrass seed production and environmental conditions is poorly understood.

Lignin trends showing constant eelgrass cover with depth at site one do not show a sharp decline during the approximate depth when wasting disease wiped out most of the eelgrass cover from the East Coast of the US. We can only speculate that the slime mold did not affect this part of the harbor.

### **Site three**

At site three the recent increase in lignin concentration is not consistent with the known history of eelgrass cover from this site. Eelgrass has not inhabited this site since the 1980's and thus a recent increase in lignin suggests that the lignin came from another vascular plant source. The lighter  $\delta^{13}\text{C}$  lignin values at the top of the profile suggests that the recent increase in lignin is from terrestrial sources. While the C:N of the lignin remained constant from 40 - 8 cm depth, it's slight increase near the surface is consistent with an increase in terrestrial material. No eelgrass leaf parts were present within the first 4 cm of sediment supporting the known history that eelgrass declined in recent years. Yet, eelgrass seeds were present in high abundance in the first 4 cm of replicate 3B and eelgrass leaf parts fluctuated with depth in both replicates suggesting low correlation and high variability between eelgrass parts and a known history of eelgrass. The high variability of bittium snails between replicates and depths suggests that snails are not consistent indicators of eelgrass presence. Top down controls on bittium snails may be the most important constraint on snail abundance. The tidal movement of water between the inner and outer harbor could also transport eelgrass seeds, leaf parts, and associated bittium snails from present eelgrass beds to bare sediments, and may explain the variability in the amount of seeds, and associated snails at both sites.

### **Eutrophication**

Trends in  $\delta^{15}\text{N}$  show signs of recent waste-water input at site one, reflecting the known waste-water inputs at this site. The consistent and relatively low total sulfur

values at site one compared to site three suggest that recent and historical nutrient pollution has not caused changes in the redox potential of the sediment. Eelgrass may play a major role in maintaining low and consistent redox potential of the sediment as it brings oxygen down to the rooting zone to maintain respiration in its roots. We are unable to conclude whether the recent increase in total sulfur at site three is a cause or an effect of eelgrass decline in recent years. Recent studies have shown a negative response of eelgrass to increasing sulfur concentrations (Holmer and Laurson, 2002). Site three does not show a significant trend in increasing  $\delta^{15}\text{N}$  because it is located the furthest from where the waste-water plume seeps into the harbor (Figure 18). We are more confident in the  $\delta^{15}\text{N}$  trends to predict the onset of eutrophication than total sedimentary sulfur because sediment redox potential can vary from site to site based on plant cover and sediment chemistry.

While data show a slightly higher waste-water signal at site one, further study will need to corroborate these results with more robust evidence. We cannot conclude with confidence that eutrophication varies spatially in West Falmouth Harbor based on sedimentary  $\delta^{15}\text{N}$  and total sulfur. Thus, we cannot attribute the decline of eelgrass from the southern harbor to spatial differences in nutrient pollution.

### **Trace Metals**

Similar lead profiles to other trace metal profiles suggest that the primary source of Pb deposition in the sediments is boat gasoline. At no site did Pb concentrations increase in the top 5 cm of sediment suggesting that recent lead in gasoline use has declined. Because Pb is so tightly associated with boat use it is difficult to assume peaks

in Pb correspond to the ban of Pb in gasoline in 1972. We were thus unable to date the sedimentary profile using Pb peaks.

The steady increase in Cu concentrations at 20cm at sites one and three suggests that both sites have similar sedimentation rates and boat use histories. The earlier initial increase in Cu compared to Zn and Pb at site three indicates that boaters started using copper in bottom paint after they started using leaded gasoline and zinc in sacrificial anodes. The more shallow peak in Cu compared to Zn and Pb at site one indicates that boaters have continued using Cu in bottom paint through recent years. Based on similar trace metal profiles and similar concentrations of trace metals between sites one and three suggests that boating impacts did not vary spatially within the harbor and thus we cannot attribute the recent decline at site three to differential boating impacts.

## **Conclusions**

Sedimentary lignin is a promising bio-indicator of eelgrass cover, yet only when the  $\delta^{13}\text{C}$  of the lignin can verify that the lignin comes from eelgrass. Different sites contain different magnitudes and combinations of vascular plant sources and different decomposition rates. We can thus only compare trends in lignin across sites to predict spatial differences in eelgrass cover change. Cross contamination of eelgrass leaf fragments and seeds and high inputs of *spartina alterniflora* may lower the effectiveness of lignin as an indicator of eelgrass cover, especially in small systems where eelgrass cover varies spatially, such as West Falmouth Harbor.

The sedimentary records from the northern and southern parts of the inner harbor show minor spatial differences in eutrophication indicators and no spatial differences in

boat use indicators. Yet, when we compare the spatial distribution of other environmental factors including depth and flushing rates to eelgrass cover distribution we see that eelgrass beds are currently present in low depth areas and areas of high flushing (Figure 19). When assessing reasons for the observed spatial differences in eelgrass cover change we must take into account other environmental conditions that control the extent to which anthropogenic stressors promote eelgrass loss.

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### **Charts and Figures:**

Figure 1: Correlation between eelgrass cover and nitrogen loading in Buzzards Bay embayments. From BBP technical report.

Figure 2: Change in eelgrass cover in Buzzard's Bay, MA (1900-1990). From Costa, 2003. State of Buzzards Bay presentation.

Figure 3: Density of living seeds in surface sediments with distance from a surviving refuge bed in Waquoit Bay in Falmouth (from Costa, 1988b).

Figure 4: Core sampling sites (Ma DEM, 2005). Not shown: eelgrass present at site three in 1980 (Costa, 1988).

Figure 5: Lead and copper profiles from sites one and three.

Figure 6: Lead and copper profiles from site two replicates A and B.

Figure 7: Comparison of lignin concentration with depth between sites one and three.

Figure 8: Comparison of lignin  $\delta^{13}\text{C}$  with depth between sites one and three.

Figure 9: Comparison of sedimentary  $\delta^{13}\text{C}$  with depth between sites one and three.

Figure 10: C:N ratio of lignin with depth (site one).

Figure 11: C:N ratio of lignin with depth (site three).

Figure 12: Comparison of seed densities profiles with depth between sites one and three. Note depth is on the "X" axis.

Figure 13: Comparison of leaf fragments with depth between sites one and three. "Y" axis marked indicates leaf fragment abundance: 0= none 1=few 2=many.

Figure 14: Relationship between eelgrass seed abundance and bittium snail abundance.

Figure 15: Comparison of Total sulfur (normalized to % organic carbon) with depth between sites one and three.

Figure 16: Comparison of  $\delta^{15}\text{N}$  with depth between sites one and three.

Figure 17: Comparison of trace metal profiles between sites one and three.

Figure 18: bathymetric map of West Falmouth Harbor. Blue represents the most shallow areas. Eelgrass still covers the shallowest and most flushed areas of the harbor including the northern part of the inner harbor and the outer harbor.

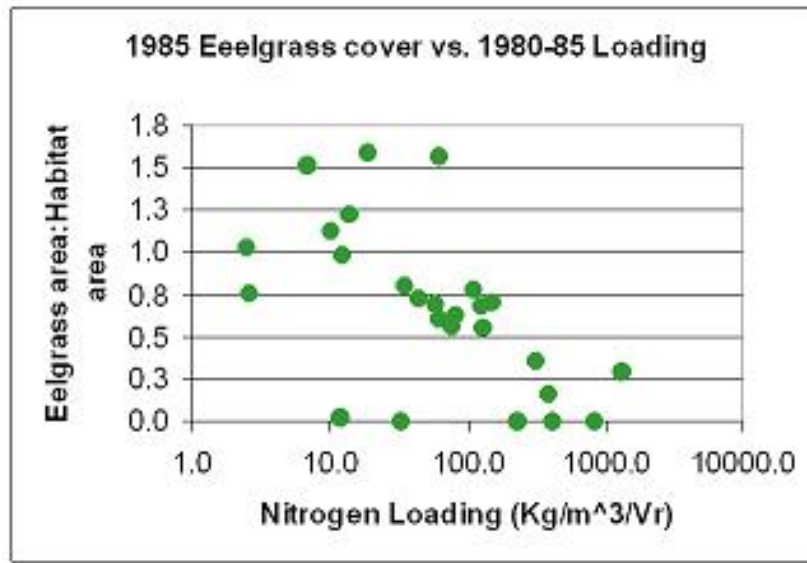


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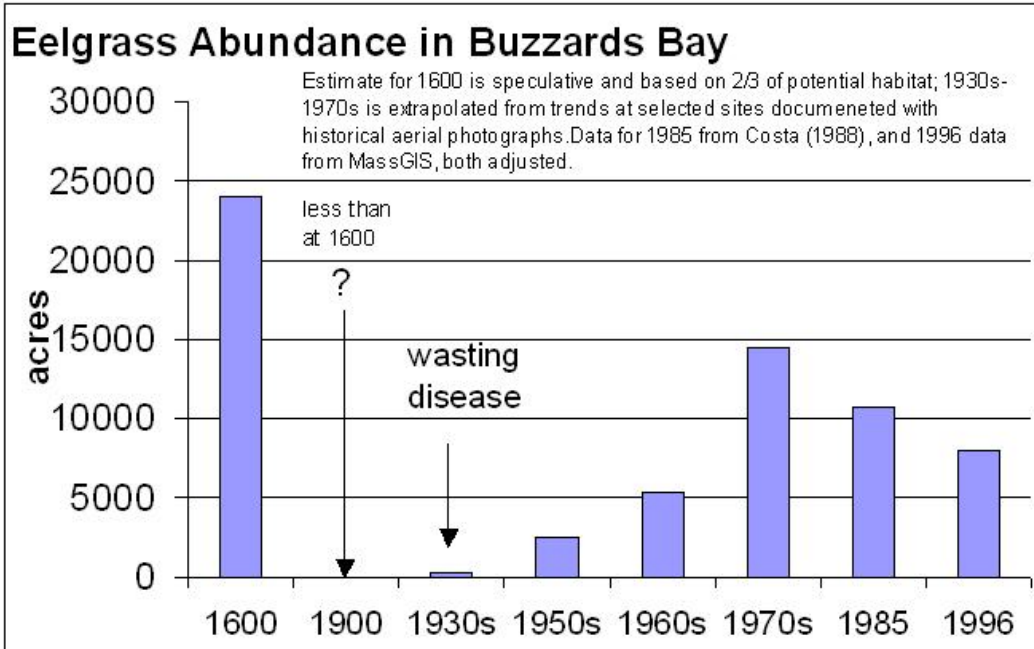


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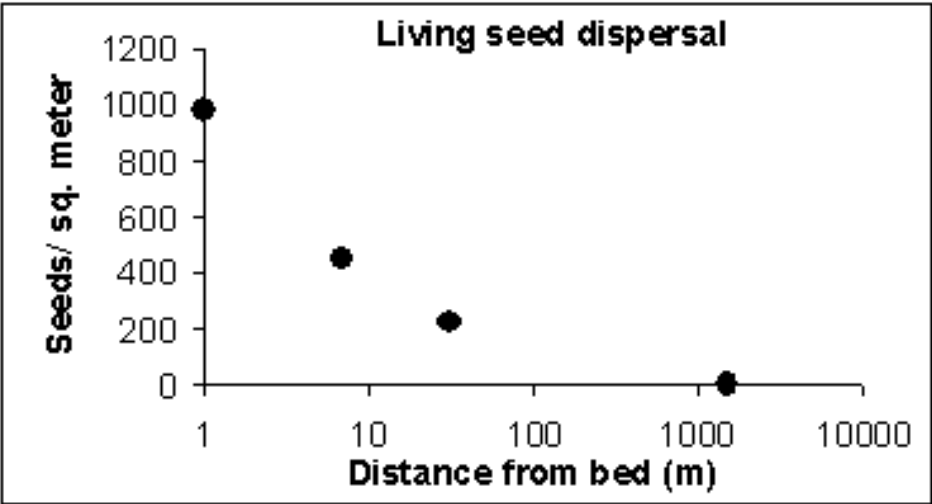


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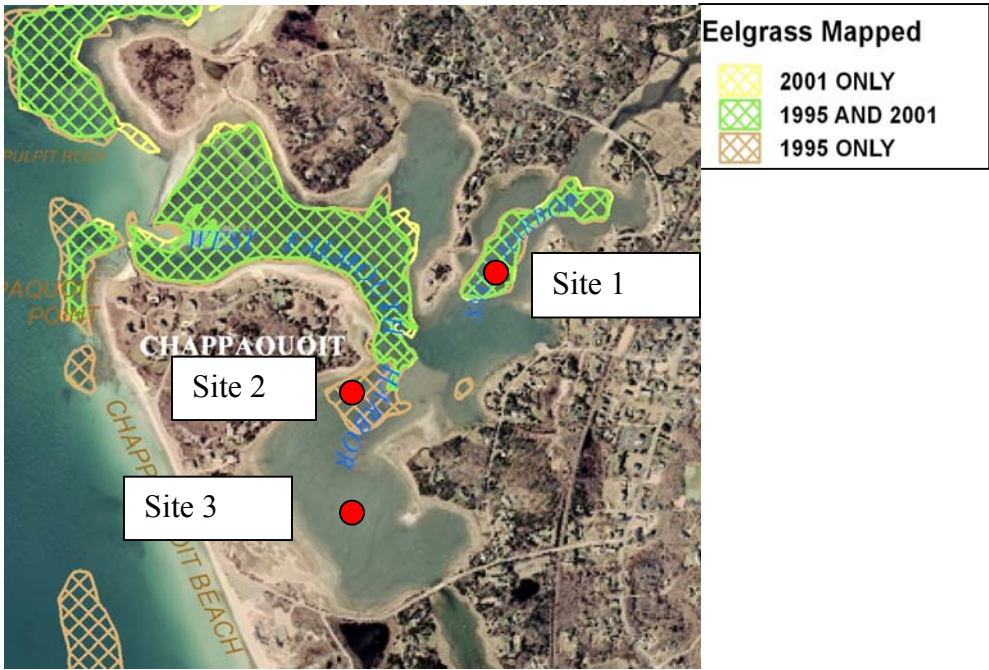


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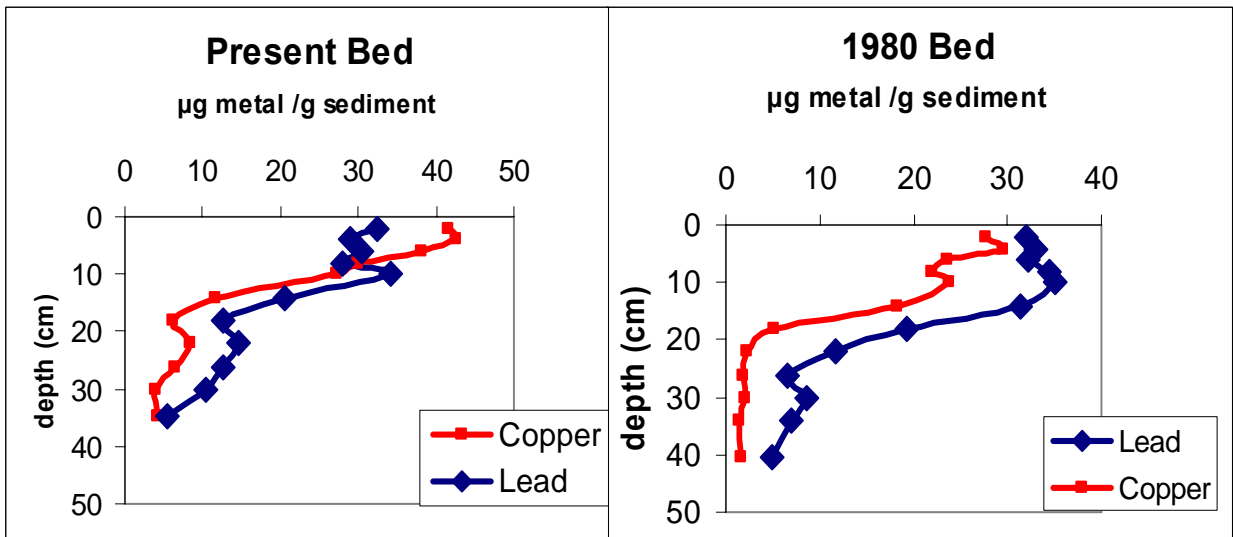


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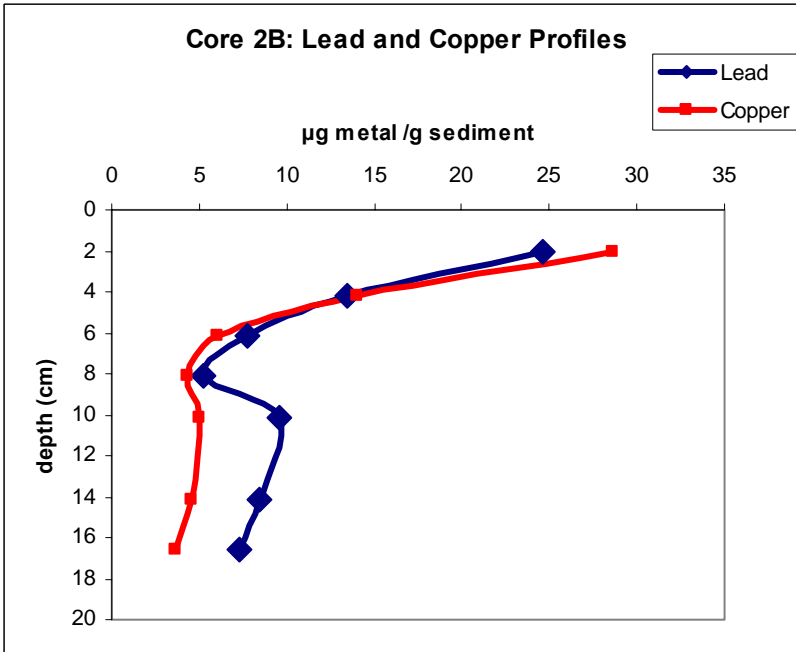
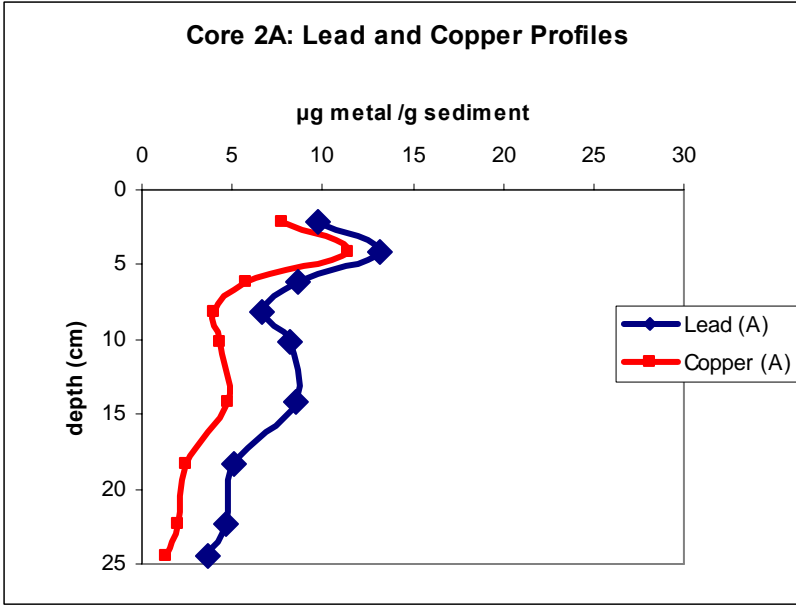


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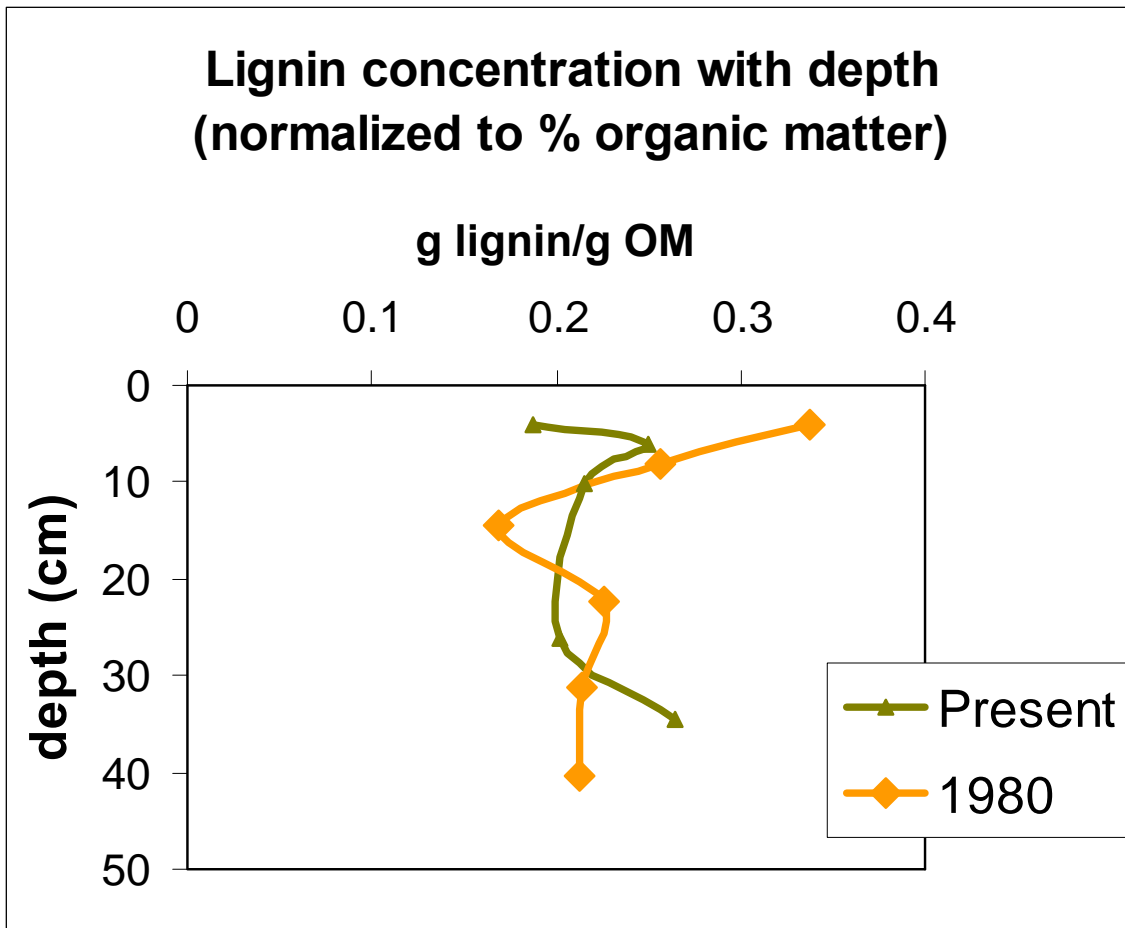


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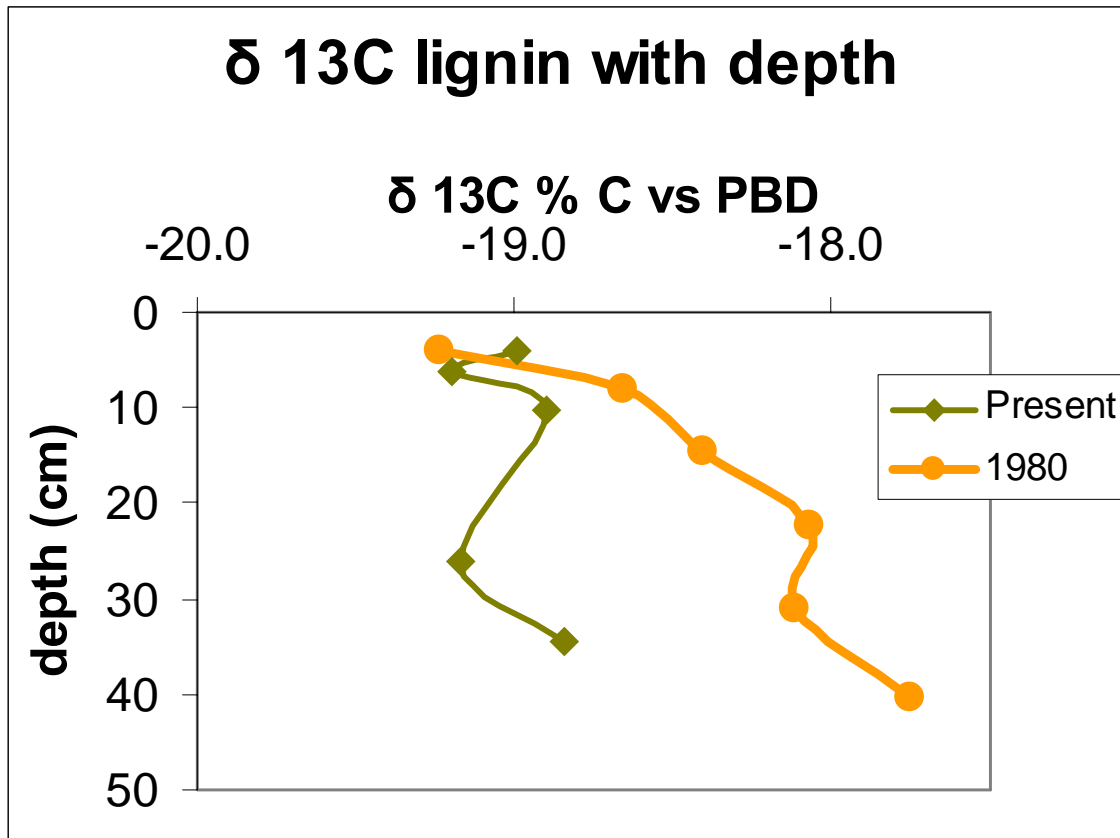


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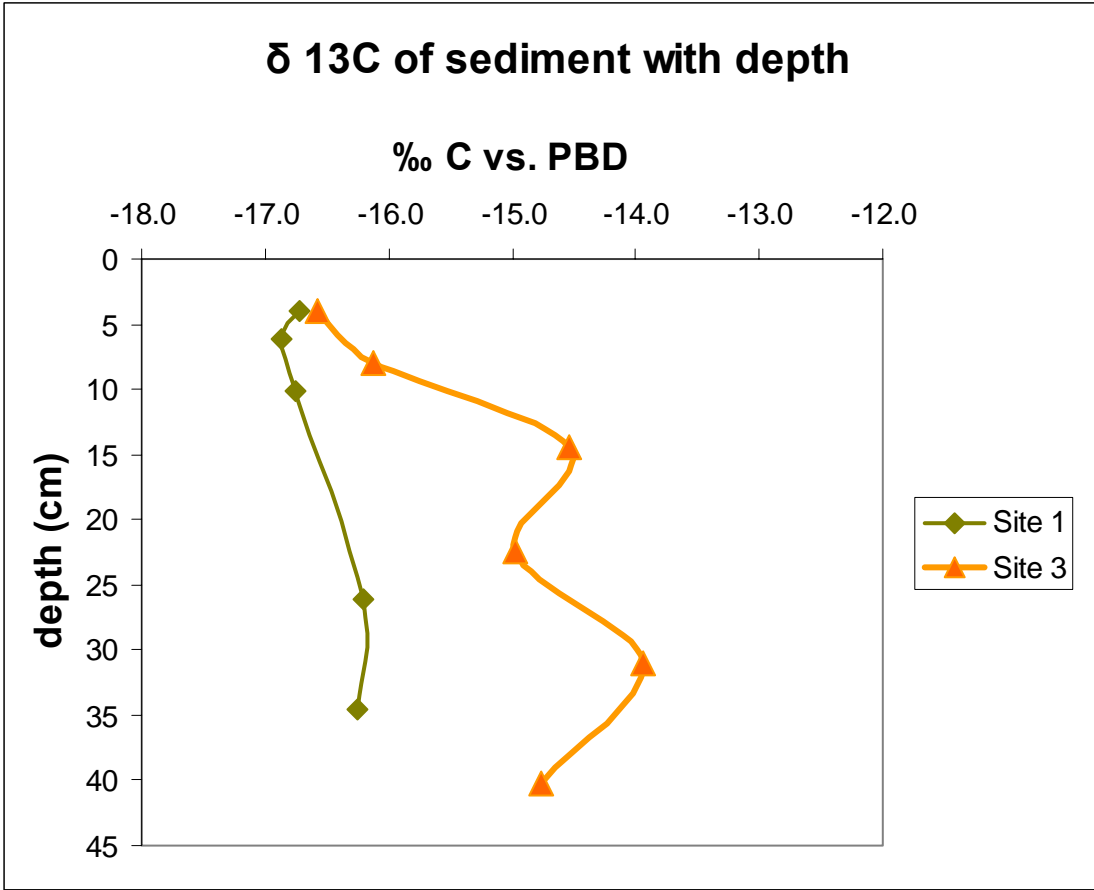


Figure 9.

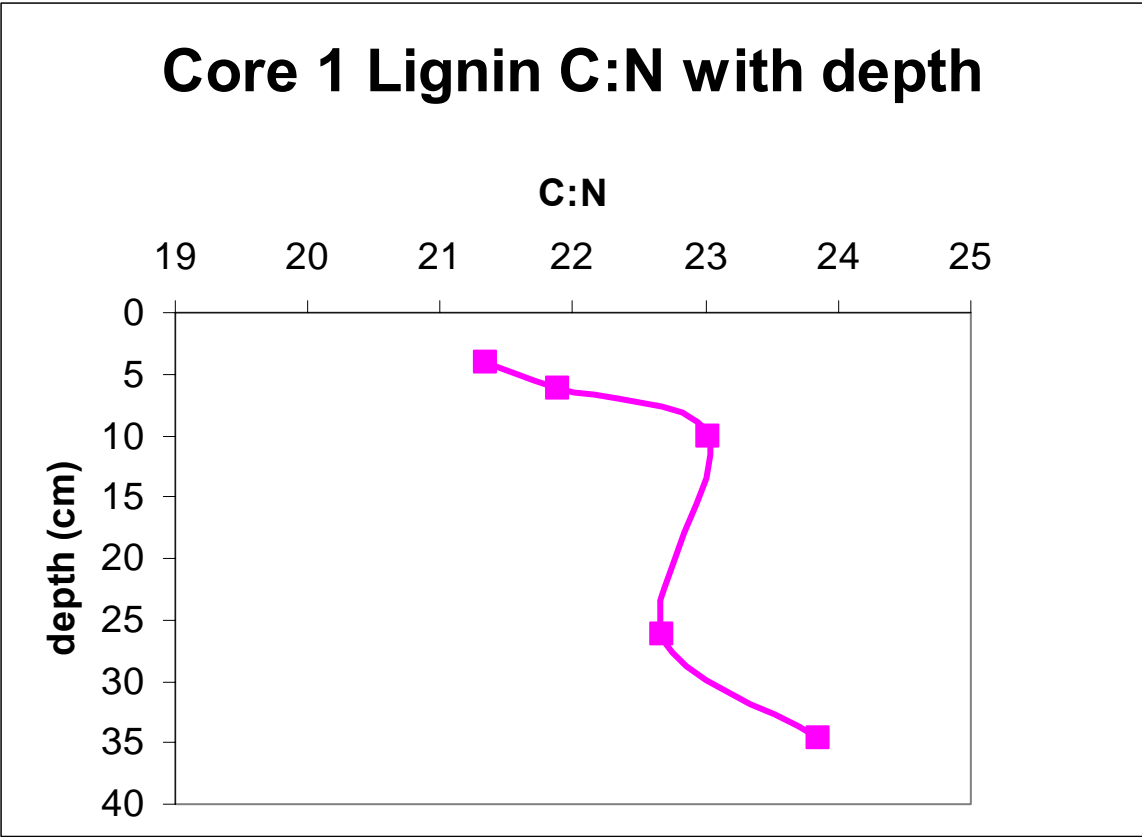


Figure 10.

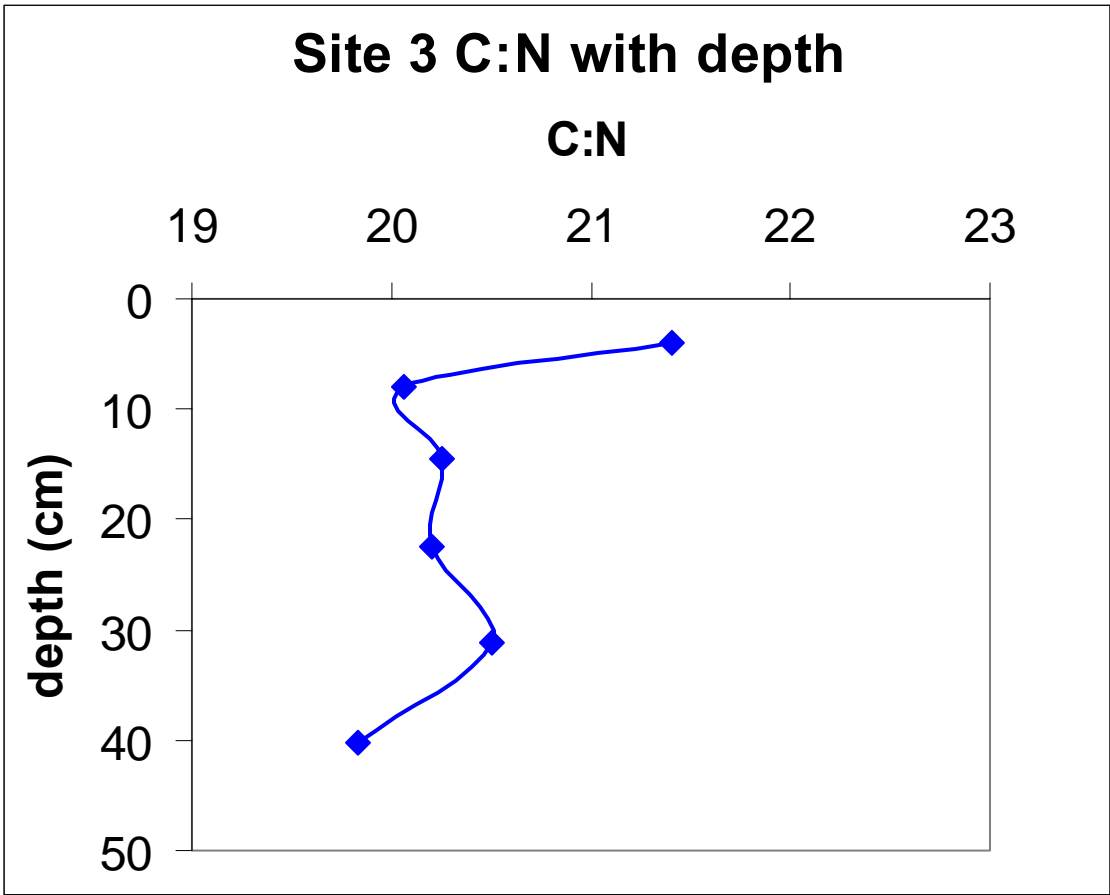


Figure 11.

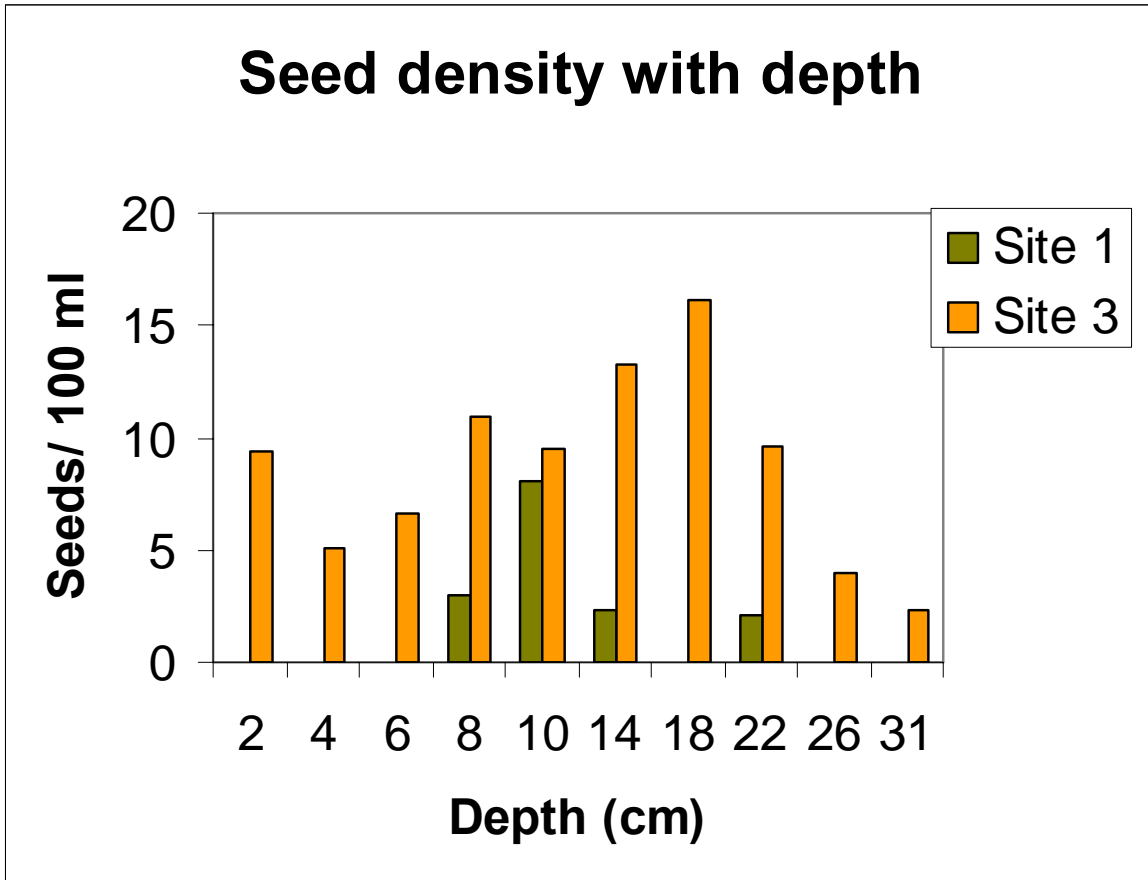


Figure 12.

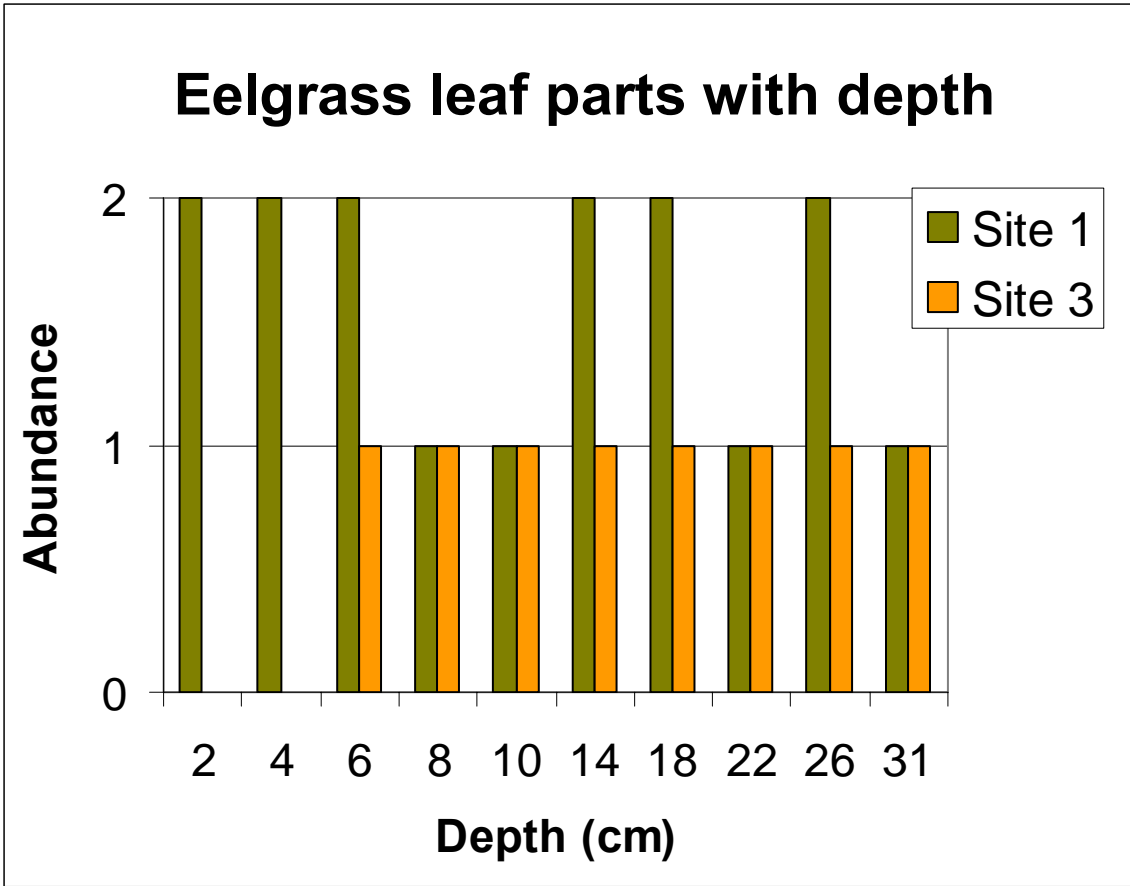


Figure 13.



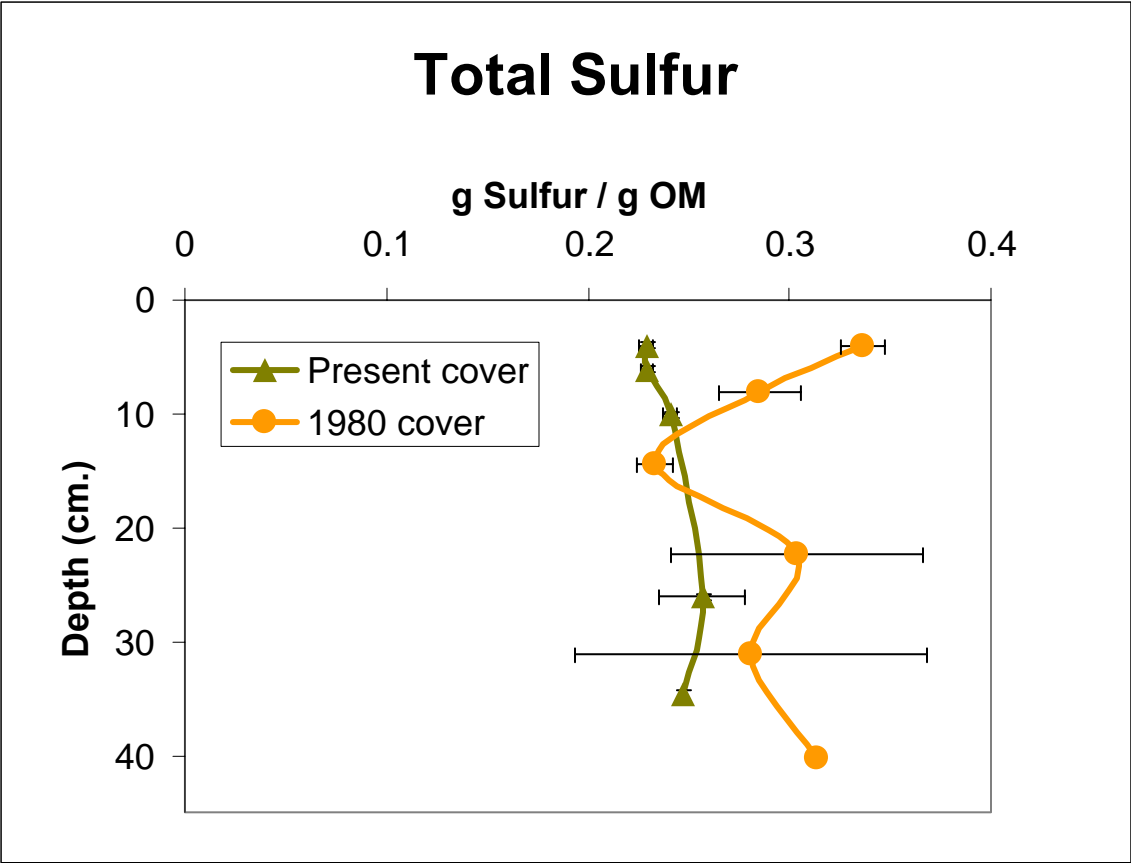


Figure 15.

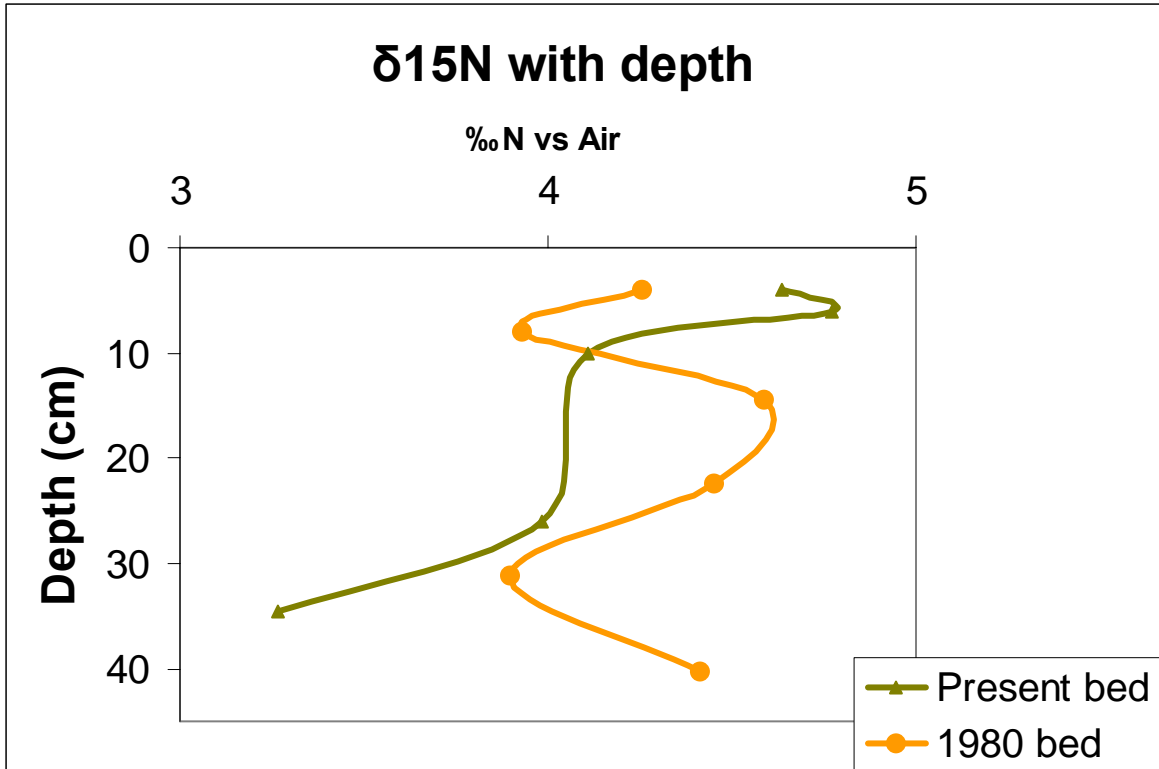


Figure 16.

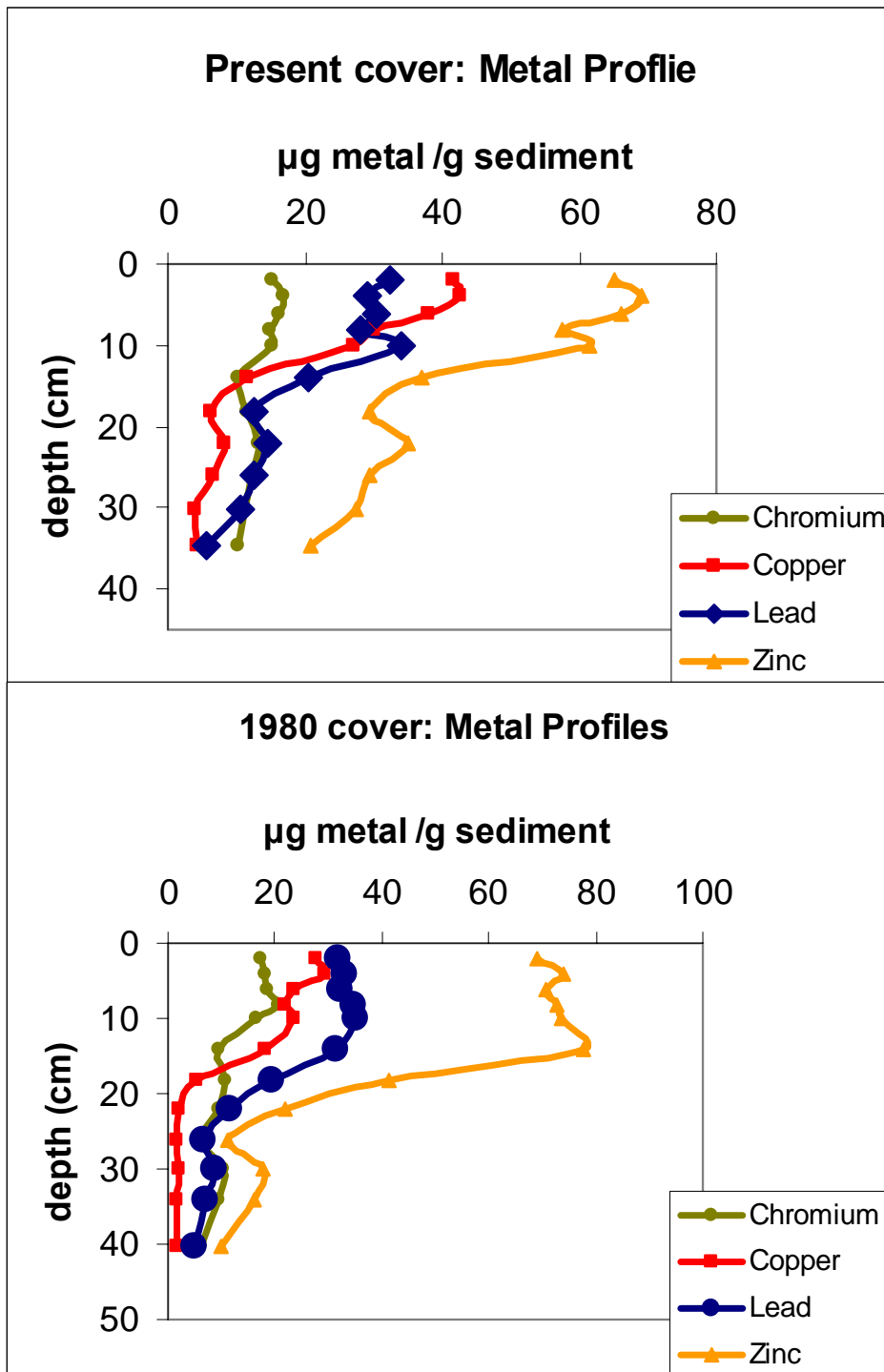


Figure 17.

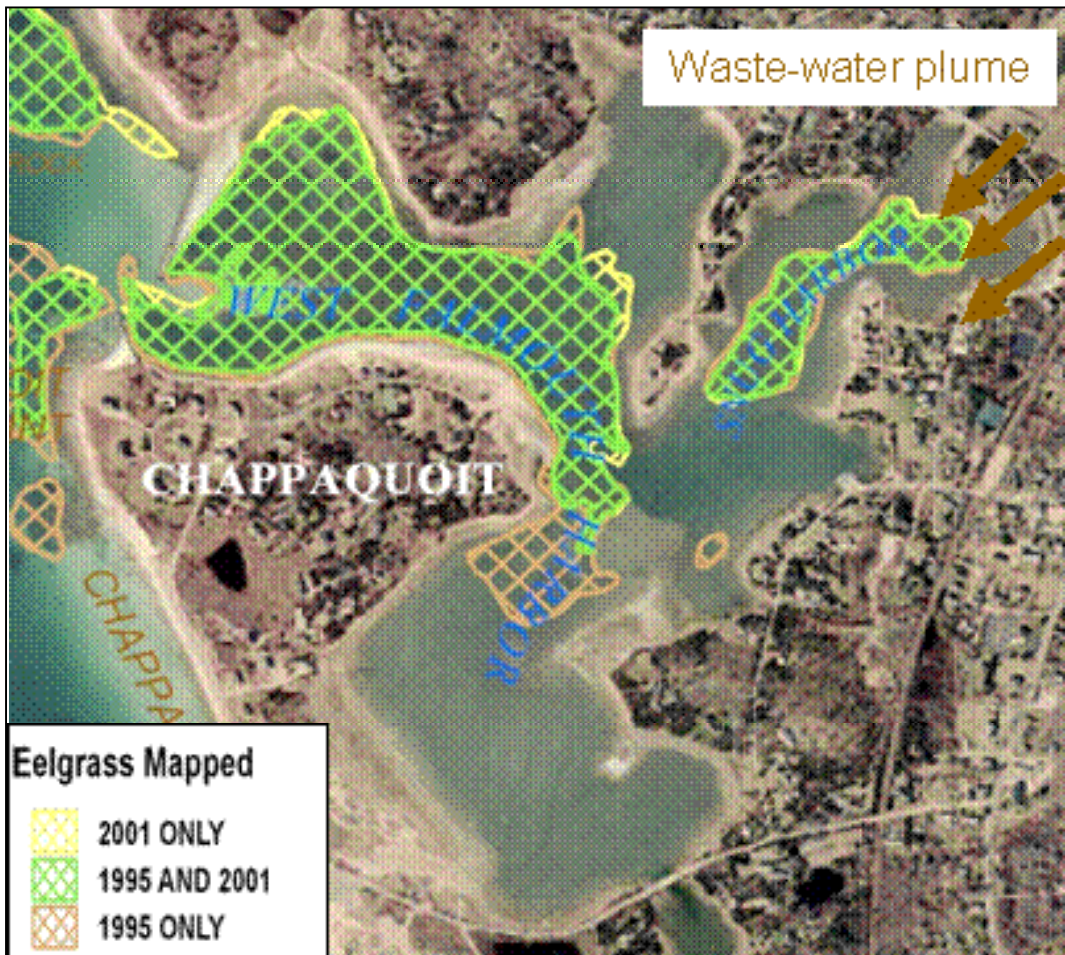


Figure 18.

# WFH: Bathymetry

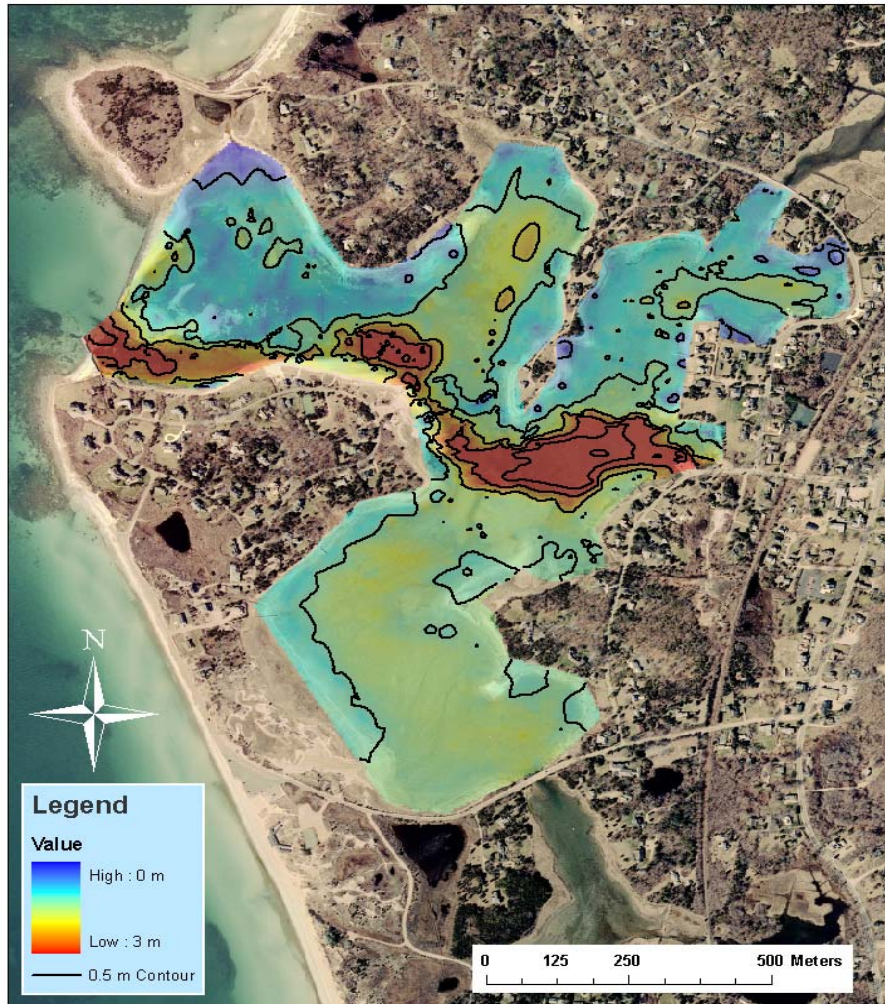


Figure 19.