# Plant community structure and soil properties along stream corridors of cranberry bogs since discontinuation of agriculture.

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## Abstract

Many cranberry bogs in Cape Cod have been cultivated since the early 1800s. Recently an interest in restoring these environments has arisen. My study looks at the patterns and rates of succession in vegetation and soils of the riparian area along the sides of rivers which run through cranberry bogs. The main site of my study was along the Coonmaessett River, in East Falmouth, MA. I found that important woody plants grow up after 1 decade, and a very different community composition appears after 8 decades. In soils, the cycling of nitrogen by mineralization seems to have a faster rate after at least 8 decades. The surface of the soils retains more water in active bogs and younger sites. Below the surface, the physical structure seems to change very slowly. This information about succession patterns and rates could be important for managing naturalizing sites or sites that are being restored, and could also make it possible to speed up succession of vegetation by planting certain important early successional woody species, especially along the river bank.

*Key words: riparian succession, soils and vegetation, cranberry bog, Coonamessett River.*

## Introduction

Cranberry bogs have had a very important impact on the environment of Cape Cod, Massachusetts, since the beginning of the cultivation of cranberries in 1810. In the 1920s, Cape Cod produced more than half of the cranberry crop for the entire United States. Cranberries (*Vaccinium macrocarpon*) are native to coastal plain ponds, and grow in areas of sandy acidic soil and fluxuating water levels.  In order to cultivate cranberries on a large scale, forested areas along rivers were cleared and flattened, and berms were built across the river at the bottom of each bog in order to dam the rivers occasionally. Many areas of the Cape have been cultivated for cranberries almost continuously since the 1800s, and although some practices have changed, such as the introduction of fertilizer and insecticide, the basic structure of farming remains the same. Cranberry bogs are flooded several times a year for harvest, and to protect the crop from insects and the cold. Sand is also spread over the bogs about three to five times a year to keep productivity high (Mason 1926).

The practice of cranberry cultivation is highly disruptive to this important riparian ecosystem in the river corridors in several ways. The vegetation is highly disturbed by the original clear-cutting and the artificial monoculture which is maintained there. Woody plants are excluded from this area, and therefore the river is very exposed, and can reach higher summer temperatures than normal. The soils of this area are also changed by the regular sanding and flooding of the bog.

Cranberry bogs are very interesting sites because they exemplify two historical and cultural ways in which humans have used the natural resources of Cape Cod, through the cranberry industry and the anadromous herring (*Alosa pseudoharengus* and *A. aestivalis*) and brook trout (*Salvelinus fontinalis*) fishery of the river. Both are natural resources which have been utilized for over 100 years, but in recent times, things have begun to change.

As the population and development of Cape Cod continues to grow, maintaining and restoring natural areas becomes more and more important. Essential environments, such as riparian ecosystems, provide many ecosystem services which will become increasingly important with higher populations (Kremen, 2005). Ecosystems provide important services to the natural world when they are intact, rather than in the highly disturbed state of cranberry cultivation (Wilson and Carpenter, 1999).

The health of the herring run in many Cape Cod rivers, especially the Coonamessett River, has been declining, and there has been a trend of cranberry bogs being discontinued or bought by conservation organizations. These areas are either naturalizing on their own, or in some cases, are undergoing active restoration to return them to a more natural state (Neil, 2006). There are hopes that restoring the riparian habitat surrounding the Coonamessett will improve the herring run, lower summer river temperatures, and therefore provide higher value ecosystem services (Pitcher, 2001). Since 2006, the Coonamessett River Trust has been working to return the natural flow of the river in order to improve habitat and hopefully, increase the run of herring in the spring (Neill, 2006).

My study describes the riparian ecological succession in cranberry bogs of Cape Cod, or how cranberry bog stream banks are changing since the discontinuation of agriculture. I used space-for-time substitution to look at ecological changes in two of the most disturbed aspects as a result of cranberry cultivation, vegetation and soils. My study focuses of plants and soils because these aspects are part of both the biological and physical aspects of the riparian environment. Recently, plants have been recognized as potential autogenic ecosystem engineers which are able to change the environment in which they grow, and modify the flow of resources. Woody early succession plants are especially thought to be important in the succession of riparian areas (Corenblit et al. 2009 and Lawton 1994). I look at the patterns and rates at which the structure and composition of vegetation and soils change, in order to assess whether these riparian areas will ever return to their natural pre-agricultural state, and how they will get there.

This information will be helpful in guiding conservation organizations, such as the Coonamessett River Trust, in how they decide to manage old cranberry bog areas in order for them to reach the natural state desired.

## Sites

In this study I looked at eight riparian sites, six of which were once involved in cranberry agriculture, and two which served as controls (Table 1). Each site is on the Lower Cape (Figure 1).

The first site is the along the Mashpee River (Mashpee, MA), which has never been used for agriculture, but has similar morphology to areas which were cranberried. The river is shallow and sandy, with a fairly flat but small floodplain. The second control site is the Forested Section of the Connamessett River, in East Falmouth, MA, which has also never been a cranberry bog. This section, however, was disturbed in the past as evidenced by the stone retaining wall along the river. This area is also down-stream from currently active cranberry bogs.

The next two sites are also along the Coonamesset River. Flax II Bog and Lower Bog were both discontinued in 2004, however, Lower Bog has been undergoing some light active restoration by the Coonamessett River Trust, while Flax II has seen very little active maintenance. The restoration has involved the removal of any invasive willow species (*Salix* atrocinera) on the bog platform. Those growing along the river bank were left for improved stabilization. These two bogs were grouped under the title “1 decade old bogs”. The next site is Red Brook, which was a cranberry bog, but agriculture was discontinued about 100 years ago. This site is in Wareham, Massachusetts. Zeke’s Way Forested Bog is back along the Coonnamesset River, and agriculture was discontinued here about 80 years ago. These two sites, for simplicity’s sake, are grouped under the title “8 decades old”. The last two bogs, Reservoir Bog and Middle Bog, are currently active bogs on the Coonamessett River. These continue to be harvested and maintained by farmers every year. Recently these bogs have switched from conventional farming to organic farming.

## Methods

*Vegetation* -- The vegetation data was comprised of three sub-sets: two 10x10 meter plots, six 2x2 meter plots, and three 30 meter point transects. Within each 10X10m plot, which had one side directly along the river bank, I measured the diameter at breast height (DBH) of all the trees larger than 3 cm, and identified them. Within the smaller plots, all plants were identified, and percent cover was estimated, using size categories of <1%, 1-5%, 6-25%, 26-50%, 51-75%, and 76-100%. The midpoints of these categories were used for their percent cover values. Where possible, the plot sets were divided evenly between two sides of the river bank. The 30 meter point transects were laid out directly along the bank, alternating bank side for each transect. At every meter, a box of 25 centimeters was estimated, with the meter mark in the middle of the side closest to the river, and up to 5 of the most abundant plant species within this box were identified and recorded. Later, this was simplified to label each point along the bank as dominated by one of five categories of structure: Woody Vegetation, Roots, Herbaceous Vegetation, Non-Living Structures, or Un-Vegetated bank.

*Soils* --I took two kinds of soil samples at each site. The first was a surface bulb core of about the top 10.5 centimeters of soil, which was used to look at nitrogen pools ($NH_4$ and $NO_3$) and mineralization rates at each site. Five replicates were taken from each site, from within 10 meters of the river bank spaced about 2 meters apart, and at least one meter away from any lateral channels. Once back in lab, the nitrogen was extracted using the methods of Foreman, in KCL extractions of soils for N Mineralization (2010). The solutions were filtered with Swinex filters (Fisher Scientific, Fair Lawn, NJ), and analyzed for ammonium using the modified technique of Strickland and Parsons (1972), and Solarzano (1969), as outlined by Foreman in Ammonium Protocol (2010). The nitrate was analyzed using the methods outlined by Wood, E.D et al (1967). After the first measurements were taken, the soils were incubated for 4 weeks at a temperature of 20°C, and then the pools were measured again.

The second samples collected were soil cores of at least 30cm deep from each site, using the AMS soil core sampler (American Falls, ID). I took two cores from the Forested Section, the second called "Forested Platform", which I took from up off of the floodplain. The cores were extruded and cut into 2 centimeter sections. Each section was homogenized, weighed, oven dried at 50°C, and weighed again.

I then took samples of dry soil from each depth section, and extracted the lead using the nitric acid filtration method. First I took 0.2 to 1.0 grams of the dry sediment, placed it in a centrifuge tube, and added 10 mL of 1.6 Molar $HNO_3$ . These tubes were shaken for 8-16 hours, 4 mL of

$HNO_3$ was added, and then they were shaken for 3 hours. The sediment was then filtered through a GF/F 47mm circle and 55mm filter paper (Fisher Scientific, Fair Lawn, NJ). The filtered solution was placed in scintillation vials, and later analyzed using an Atomic Absorption Spectophotometer. I took a second set of dry soil samples from the top 10cm, and analyzed these for their carbon, nitrogen, and hydrogen (CHN) content, following methods of Foreman in Preparing, Packing & Organizing CHN Samples (2010).

**Results**

*Vegetation* -- Much of the vegetation data from my study showed very clear composition and structure trends of changes over time.

From the 10X10 meter plots, sites showed a trend of increasing DBH with increasing age (Figure 2). The sites which have not been farmed in many years have higher DBH values than the recently discontinued bogs, and Mashpee River had an average DBH of 25.88 cm, the largest average of all the sites. The youngest bog which had trees which were big enough to measure DBH was Zeke's Way, which had been discontinued for roughly 80 years. Flax II bog had 28 small saplings which were not even tall enough to measure, and Lower Bog had 7 saplings.

Although the average number of species per 2X2 meter plot remains somewhat constant in all the sites, once the sites are old enough to have saplings or tree species, the number of species in each overall plot is much higher (Figure 3). Reservoir Bog has an average species count of 3.5 species, and Red Brook has the highest average species count of 8.3 species. The number of tree species found also grows from the 1 decade old site pair to the 8 decade old pair, and then falls again. The site with the greatest overall species count is Red Brook, and the site with the lowest species count is Reservoir Bog.

When looking at the herbaceous plant composition as measured by the 2X2 meter plots, there is also a clear pattern of change over time (Figure 4, Table 2). The overall percent cover of the dominant species and species groups falls from the active to the natural sites. Lower Bog has the highest number of dominant species and species groups present in one site. As the percent cover of cranberries (*Vaccinium macrocarpon*) falls from the active bogs to the 1 decade old bogs, also many other species begin to appear, such as Northern Dewberry (*Rubus flagellaris*), various monocots, and Poison Ivy (*Toxicodendron radicans*). Shrubs begin to appear. In the 8 decade old sites shrubs are the most dominant plant type, with ferns coming in second. In the older sites, shrubs remain the most dominant plant by percent cover in the 2X2 plots, even in the never cranberried sites (Forested Section and Mashpee River).

The plant composition of the river banks has very clear trends between the sites (Figure 5). The active cranberry bogs have 100% and 96.7% herbaceous plant cover along the rivers in Reservoir Bog and Middle Bog, respectively. The percent of the bank which is covered with woody vegetation begins to grow in the 1 decade and 8 decade bogs. By 8 decades, it covers more than 50% of the bank in Red Brook. As woody vegetation grows and herbaceous vegetation shrinks, the percent cover of roots, non-living structures and un-vegetated areas also grows.

*Soils* -- The ammonium pools at all sites were fairly similar, having an average of 1.31 µmols of $NH_4$ (Figure 6). Excepting the mineralization rates at Red Book (7.14 µmol/day $NH_4$), there is a positive correlation between site ages and mineralization rates I observed (Figure 7). Mineralization rates were highest in the Red Brook, followed by the pristine river site, Mashpee River (5.84 µmol/day $NH_4$).

The pools of nitrate were also all relatively similar, excepting Middle Bog and the Forested Section (0.05 µmols and 0.08µmols of $NO_3$, respectively, Figure 8). Nitrification rates were also similar, excluding Lower Bog and Flax II bog, which have 3.88 µmols and 1.28µmols of $NO_3$, respectively, compared to the average of the other 6 sites, which comes out to be 0.10 µmols (Figure 9). After incubation of the soils, these two sites had two replications with concentrations of nitrate one or two orders of magnitude greater than the other replications, which caused high overall nitrification rate averages for the whole site.

Most of the soil profiles showed higher percentages of carbon towards the top, which experienced a sharp decline from 3-7 cm (Figure 10, 11). The active cranberry bogs both change from about 35% carbon at 1 cm to about 0.8% carbon at 9 cm, a difference of about 34. The other two sites which show the greatest change from the surface to 9cm are Zeke’s Way and the Forested Section. There is a weak correlation (ignoring Zeke’s Way and the Forested Section) of less change in percent carbon in older sites. The two profiles for the 8 decade old bogs are very different from each other, Zeke’s Way having a very large difference between top and bottom, similar to the active bogs, and Red Brook having a much smaller difference, similar to the 1 decade old bogs (Figure 10). In the never cranberried set, the two cores from the Forested Section are similar to the active bogs, with a sharp drop in percent carbon at 5cm, while the Mashpee River core looks nothing like any of the other cores, beginning with the highest value of any site, 44.35% carbon, and increasing below the surface, ending at its lowers percent carbon of 39.01%.

The percent water profiles for the 8 sites show that active bogs have a much higher percentages of water in the surface layer (Figure 12). Middle bog has 81.5% water, and Reservoir Bog has 83.2% water. From the surface down to 27 cm, the active bog percent water declined to about 20% water. Most of the bogs had between 15 to 25% water at 27 cm deep. Although only the active bogs had such high percent water values for the surface, there does not seem to be a direct linear trend of declining percent water with increasing age. In red Brook, where the deepest core was taken, percent water increased with depth, but to about 80% at 25cm. At this depth, chips of cedar wood were found in the core soils.

Percent water strongly correlates with the percent carbon in the soils. For example in the Forested Section, which has an $R^2$ of 0.9723 (Figure 13). $R^2$ values in the other sites ranged from 0.8148 to 0.9763, with an outlier of 0.6737 at Reservoir Bog.

The active bogs have a spike in lead concentrations at the surface, as does Red Brook and the two cores from the Forested Bog (Figure 14). The Mashpee River sediment core includes a spike in lead concentrations (728.93 µg/g soil) a whole magnitude larger than any values seen at any other sites, seen at 11cm deep.

## Discussion

Vegetation -- The vegetation of these 8 study sites shows clear patterns of succession. All sites of all ages show similar average species count for herbaceous and shrubby vegetation, indicating that the diversity of this group of plants remains fairly constant (Figure 3). The diversity is high even on the active bogs because an array of species exists, although the bog is dominated by cranberry plants (*Vaccinium macrocarpon*) (Figure 4). By the time these areas have not been cultivated for 1 decade, overall species diversity increases with the growth of small sapling trees, which by 8 decades have a fairly large DBH, perhaps an indicator of age (Figure 2). More saplings seen in Flax II Bog than Lower Bog is most likely the result of Lower Bog being actively restored, with the current goal to keep the space open. None of the sites showed an average tree DBH similar to that seen at Mashpee River, which may indicate that succession must take place for significantly longer than 8 decades for this DBH to be reached, or it may indicate a different species composition of trees, with different growth patterns and speeds.

Shrubs begin to grow after 1 decade, and by 8 decades they dominate in terms of percent cover (Table 2, Figure 4). Herbaceous plants like ferns, Northern Dewberry (*Rhubus flagellaris*), Poison Ivy (*Toxicodendron radicans*), and monocots are much more common after 1 decade, however, as woody plants begin to take over and shade out the understory, they then become less dominant (Figure).

Along the river bank, herbaceous plants gradually decline, as woody plants begin to dominate (Figure 5). These plants are very important, as they provide stream habitat, bank structure, and also shade the river. The switch from herbaceous to woody plants on the bank occurs at about 8 decades, when the woody species begins to shade out the understory, and so herbaceous plants become less dominant, and more areas are un-vegetated. The increase in woody plants along the bank also increases the occurrence of roots from these plants (which help to structure the bank even more). Nonliving structures, such as fallen logs also increase in percent cover, only when woody species area growing nearby, and they die or a branch falls off, and this takes a while to decompose, structuring the bank and changing water flow.

Two sites did not exactly follow the pattern of greater woody species and less herbaceous species with increasing site age. Both Zeke's Way and the Forested Section continued to have more or an equal percent cover by herbaceous species than woody species, even in or after the 1 decade mark (Figure 4). This could be because both areas are very close to development and roads; perhaps even enough so to call them disturbed areas. Zeke's Way is very close to a dirt road, and trash is dumped regularly nearby. The Forested Section is sandwiched between houses and lawns, and trash is also seen here. The high amount of nonliving structures along the river in the Forested Section is due to the fact that there is a rock retaining wall along the river's edge.

Overall, the vegetation is clearly transitioning. Shrubs and saplings appear after 1 decade, and by 8 decades, the composition of the species in the site has clearly changed. These early successional woody species are very important for helping the site grow and change (Corenblit et al. 2009). The transition between the 8 decade old sites and the never cranberried sites has less resolution, however, and it is unclear weather the naturalizing bogs will ever reach the same exact vegetation composition and structure of large DBHs, and understory and stream bank of almost exclusively shrubs.

Soils – The succession of soils in these sites is harder to see, perhaps because the soils change on a longer timescale than the 4 time points my study used. All the sites showed similar size ammonium pools, however, because there was slightly higher mineralization rates in older sites, this means that the uptake by plants is also greater with age (or larger pools would build up, Figure 6, 7). This makes sense because these sites have higher diversity and therefore greater use of resources (Tilman, Wedin and Knops, 1996). The negative mineralization rates seen in the active and 1 decade old bogs may indicate immobilization by microbes is taking place, or, because at Lower Bog the error bar overlaps the x-axis, it could also indicate a very small mineralization rate and poor resolution based on the method used to measure it. The two largest mineralization rates are seen in the two least-disturbed sites, which may indicate that not only age, but closeness to development, may have an effect on the nutrient cycling in naturalizing bogs. If the two remaining sites for 8 decades and never cranberried were not in developed areas, they might have shown higher mineralization (and therefore uptake) rates.

The nitrate pool size in each site was very close to each other, and showed no significant differences between the sites based on age (Figure 8). The nitrification rates were all also very close, not including the large outliers of Lower Bog and Flax II Bog (Figure 9). These sites were thrown off by two samples from Flax II, and three samples from Lower Bog which had extremely large nitrate values after incubation. If these outliers are excluded, nitrification rates for all sites are very similar. Once again, however, Red Brook and the Mashpee River sites are very similar, and have the lowest nitrification rates, at 0.01 µmoles/g soil/day. This may be an indication of lower nitrification rates with increased naturalization and decreased disturbance, but the trend is very small.

In the soil profiles, it was very clear that the active bogs had the lowest percent carbon below the surface, meaning that they had the greatest percent sand (Figure 10). These sites also had two of the largest differences between percent carbon at the surface and at 9 cm (Figure 11). Once again, Zeke's Way and the Forested Section had percent carbon differences and profiles more similar to the active bogs than to Mashpee River, or even Flax II Bog and Lower Bog. The large difference seen here between Mashpee River and all the other sites may indicate that once an area is used for the cultivation of cranberries, the soil may never return to its original state, or it may take an order of magnitude longer than my study encompassed. The smaller differences in the percent carbon between the surface and 9 cm seen in Flax II Bog, Lower Bog, and Red Brook may indicate that these sites are naturalizing better or faster than Zeke's Way, or these differences may be based on different original soil composition.

It can be seen that once a bog is no longer cultivated, the amount of carbon accumulated on the top decreases, but the carbon deeper in the soil increases, however, with only two age replicates, and only 4 age classes, nothing more is able to be seen at this resolution.

It is very clear that the surface of cranberry bogs contains more water than any of the other sites (Figure 12). In most sites, the water capacity is highest at the surface, and declines with depth. The 44.5 cm core taken from Red Brook shows a large increase in percent water (to around 80%) starting at 25 cm, and going until 39cm. The Mashpee River site continues to have high percent water (about 80%) down to a depth of around 15 cm. There is also a very high correlation between low percent carbon in the soil and high percent water (Figure 13). This means that the high percent water at 25 cm in the Red Brook core could be an indication of the old sandy cranberry bog platform from about 8 decades ago. However, the soil at Mashpee River had very high percent carbon values *as well as* high percent water values, and therefore correlation between low percent carbon and high percent water does not necessarily imply causation – high percent water doesn't necessarily mean the soil is very sandy. Keeping this in mind, and seeing that Mashpee River had high carbon and high water values, the section of the red Brook core with high percent water may be an indication of the original soil before the area was cultivated. The fact that cedar wood chips were found in this area indicates that the core goes down to a depth from when the land was cleared. This supports both ideas –the large percent water could be an indication of the original soil (Like Mashpee), or the cranberry bog the was cultivated there after clearing (Like the active bogs).

The lead profiles taken from each site show very little patterns (Figure 14). The Mashpee River site has a very large spike in lead, which may have been caused by lead shot from hunting in the area. The higher percent lead seen at the surface of the cores may be more of an indication of the percent carbon than the concentration of lead, as it is very difficult to get a consistent lead profile from sandy soil – and all of the sites except for Mashpee River have very sandy soils(Van Benschoten, 1994).

## Conclusion

The vegetation of these sites is clearly undergoing succession. Active bogs, once discontinued, transition to an environment shared more equally between several important species within the 1st decade of naturalization. In this time, the species diversity goes up dramatically as trees begin to grow. By 8 decades, although the species diversity remains similar, the site displays fewer species that are very dominant. The shrub becomes a very dominant plant at this time. The DBH of trees is large enough to be measured. Herbaceous vegetation along the river bank begins to decline with increasing percent cover by woody species, and more areas are un-vegetated, or covered with roots or nonliving structures, such as fallen logs.

The main transition period for the vegetation of cranberry bog riparian environments seems to be at around 8 decades, although the early successional woody species that move in quickly are very important, especially in preparing the area to change and grow.

Patterns in the succession of soils are much harder to see. There may be a trend of increasing mineralization and pant uptake in older site, beginning around 8 decades. Smaller differences between the percent carbon at the surface and at 9 cm seems to indicate a change since cultivation, however, these changes of increased carbon and decreased sand content occur very slowly, and there is hardly any difference between the active bogs and the 8 decade old bogs. Even the Forested Section, which was never cranberried, shows a similar profile to the active bogs. The percent water at the surface also may indicate the age of a site, however, rates of change are hard to tell with only four time-points and two age replicates.

It is important to keep these two rates and patterns in mind when organizations restore cranberry bogs. Vegetation changes and grows much more quickly than soil accretion can take place and the structure can change. Some aspects of cranberry cultivation may never be reversible, and the soil may never have the same content as the Mashpee River, but as plants grow, they also change their own environment, leading to further succession both in the riparian terrestrial area, and also in the river itself.

In the future it would be very interesting to do a similar study, but with many more time-points and age replicates. The sites of Zeke's Way and the Forested Section throughout my study constantly showed data more similar to the active bogs than to any of the other sites, especially Mashpee. Red Brook and Mashpee River sites both acted more similar to each other than to their own age pairs of Zeke's Way and the Forested Section. These two sets of two sites which acted similar to each other may have been caused by the closeness of Zeke's Way and the Forested Section to development, and the relative isolation of Red Brook and Mashpee River. I only had two age replicates, so when this happened, strong trends were hard to see. It would be very helpful in future studies to choose more similar age pairs or have more age replicates.

The succession of plants in naturalizing cranberry bogs takes place at a rate that is recognizable at about 1 decade increments, while it seems that changes in soil properties take at least 8 decades, but most likely much longer. In my study, the jump from 8 decades of naturalization to never cultivated was very large, and it would be interesting to have more ages in between, to see more resolution in the rates and patterns of vegetation, but especially soil succession.

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Table 1 The ages of every site, their locations, and their position on the rivers.

| **Approximate time since cultivation** | **Site Location** | **River GPS Coordinates** | **River Position** |
|---|---|---|---|
| Currently active | Reservoir Bog, Coonamessett River | N41 35.475<br>W70 34.311 | Below reservoir |
| Currently active | Middle Bog, Coonamessett River | N41 35.303<br>W70 34.381 | Below active bogs |
| **1 Decade** | **Flax II Bog, Coonamessett River** | **N41 35.218**<br>**W70 34.209** | **Below reservoir** |
| **1 Decade** | **Lower Bog, Coonamessett River** | **N41 34.950**<br>**W70 34.360** | **Below active bogs** |
| 8 Decades | Zeke's Way Forested Bog, Coonamessett River | N41 34.895<br>W70 34.409 | Below active bogs |
| 8 Decades | Red Brook, Wareham, MA | N41 46.045<br>W70 38.139 | Below active bogs |
| **Natural Disturbed** | **Forested Section, Coonamessett River** | **N41 36.016**<br>**W70 34.331** | **Below active bogs** |
| **Natural** | **Mashpee River, Mashpee, MA** | **N41 46.045**<br>**W70 38.139** | **Pristine river** |

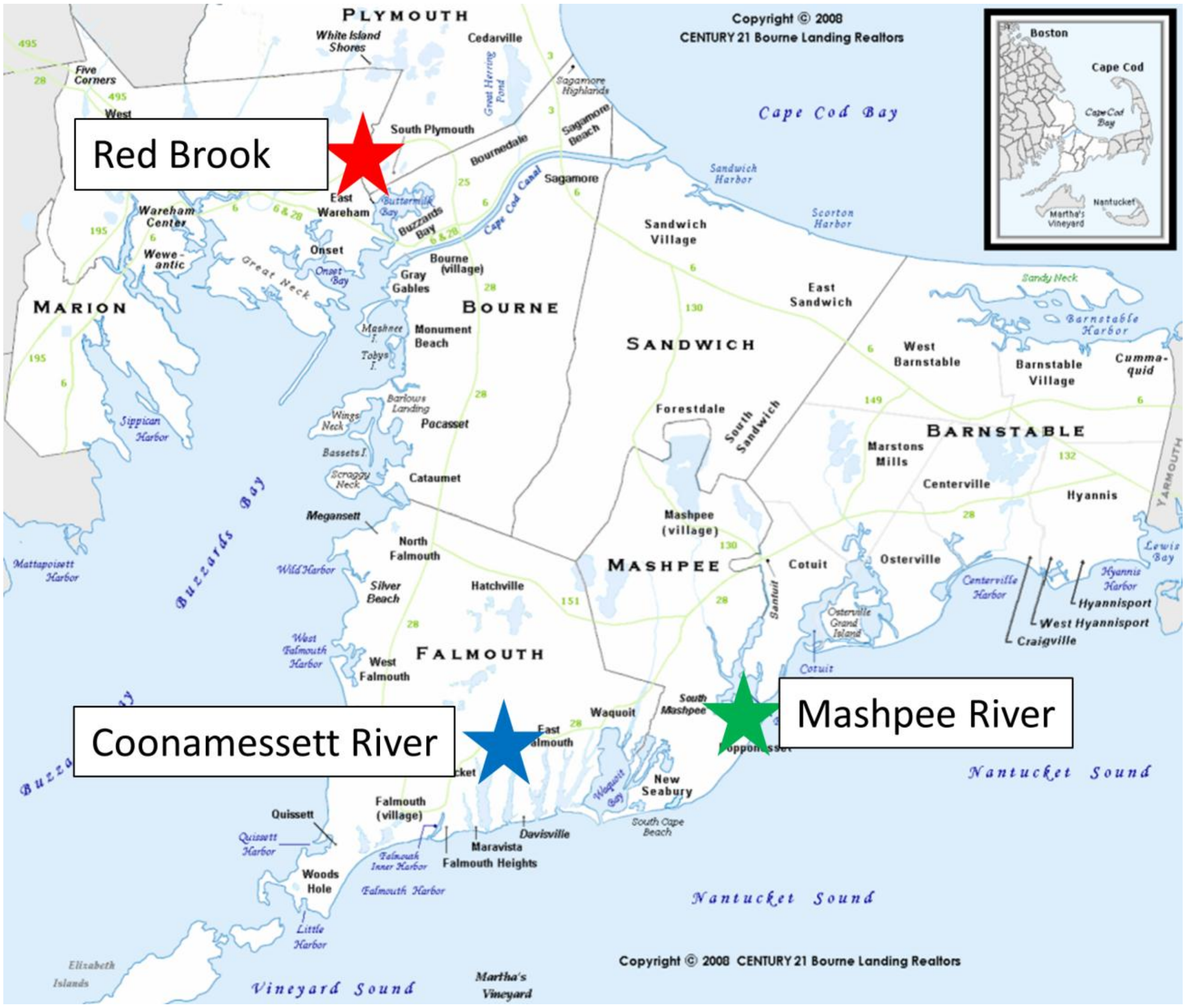

Figure 1 A map of site locations on the Lower Cape.

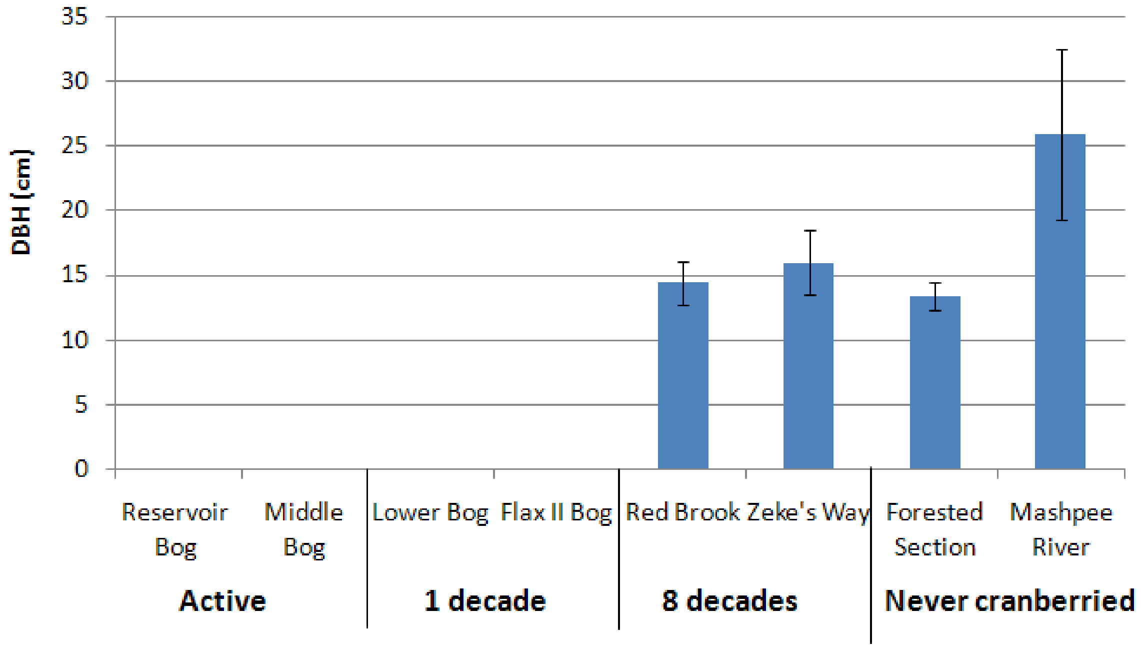

Figure 2 The average diameter at breast height (DBH) of the trees larger than 3 cm from each site. Error bars are included. The 1 decade old set had trees, but none big enough to measure.

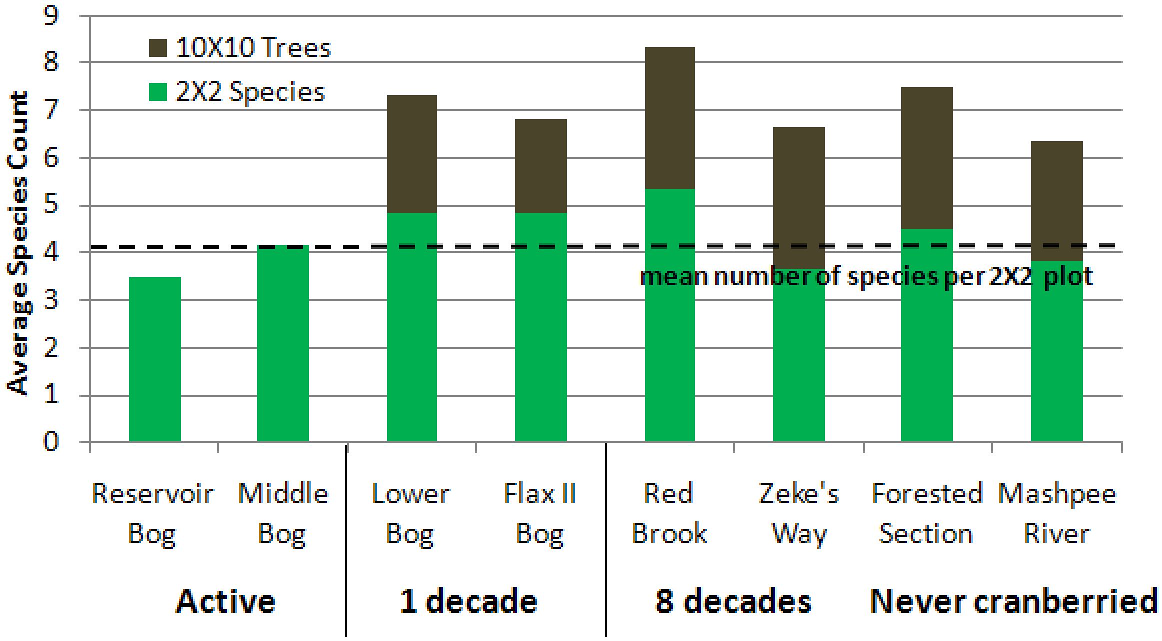

Figure 3 The average number of species found per plot in each site, as a measurement of diversity.

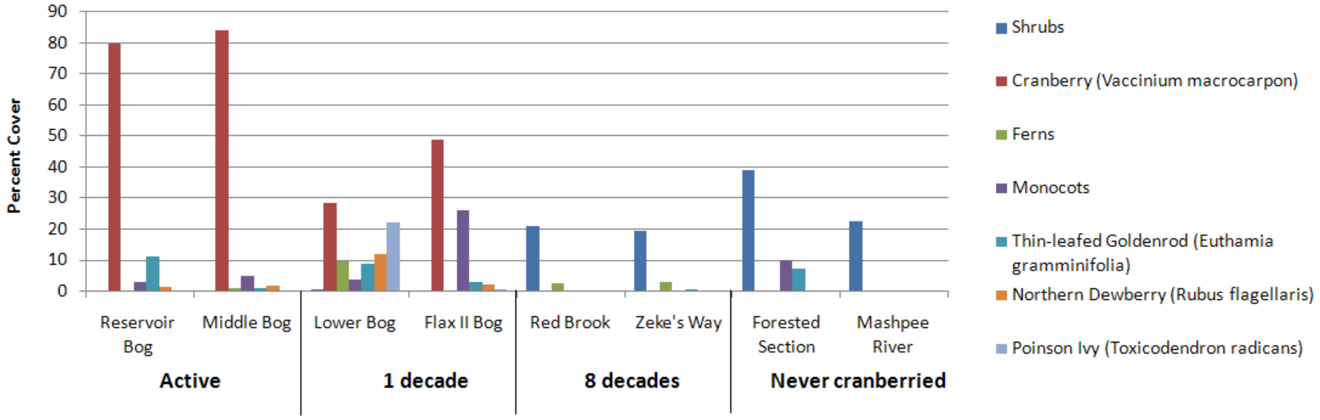

Figure 4 The average percent cover of dominant plants and plant groups found in 2X2 m plots at each site. A list of species found in each large group is found in Table 2.

Table 2 The species included in each dominant plant group found in Figure 4.

| Common name | Scientific name |
|---|---|
| Shrub | |
| Highbush Blueberry | *Vaccinium corymbosum* |
| Sweet Pepper Bush | *Clethra alnifolia* |
| Inkberry | *Ilex glabra* |
| Swamp Azalea | *Rhododendron kaempferi* |
| Witch Hazel | *Hamamelis virginiana* |
| Eastern Teaberry | *Gaultheria procumbens* |
| Maleberry | *Lyonia ligustrina* |
| Arrowwood | *Viburnum dentatum* |
| Ferns | |
| Brackenfern | *Pteridum aquilinum* |
| Sensitive Fern | *Onoclea sensibis* |
| Marsh Fern | *Thelypteris palustris* |
| Monocots | |
| Soft Rush | *Juncus effusus* |
| Sallow Sedge | *Carex lurida* |
| Wool-grass | *Scirpus cyperinus* |
| Common Grasses | |

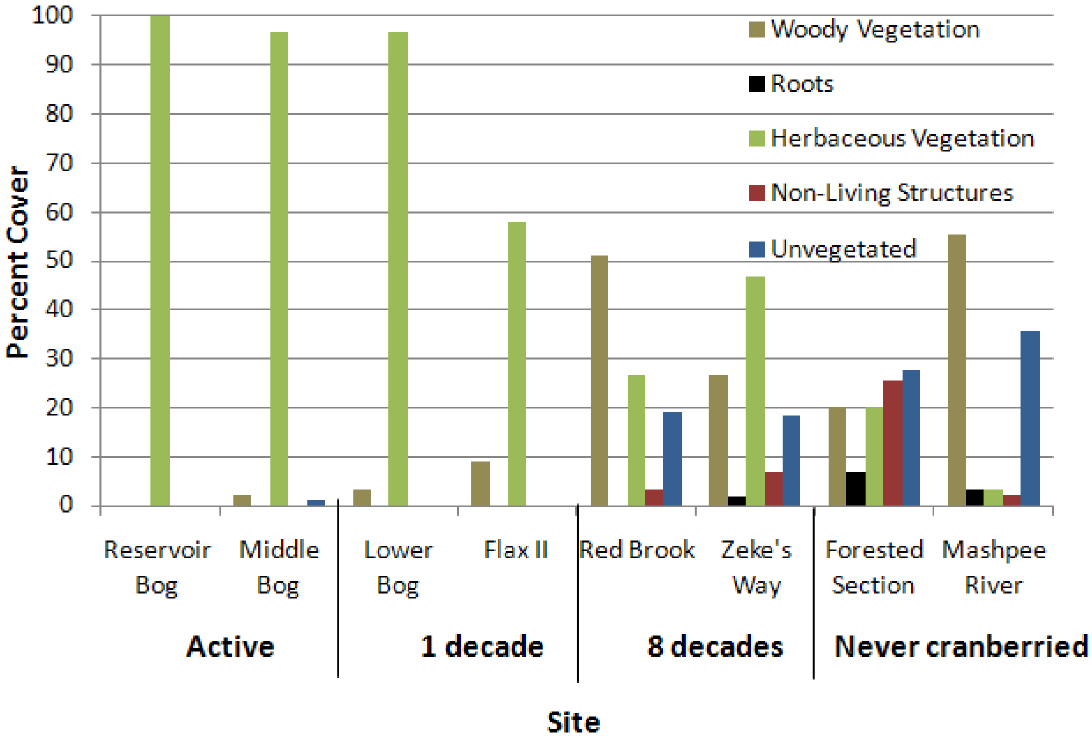

Figure 5 Average percent cover of plant composition along river banks of each site. Non-living Structures includes fallen logs and branches.

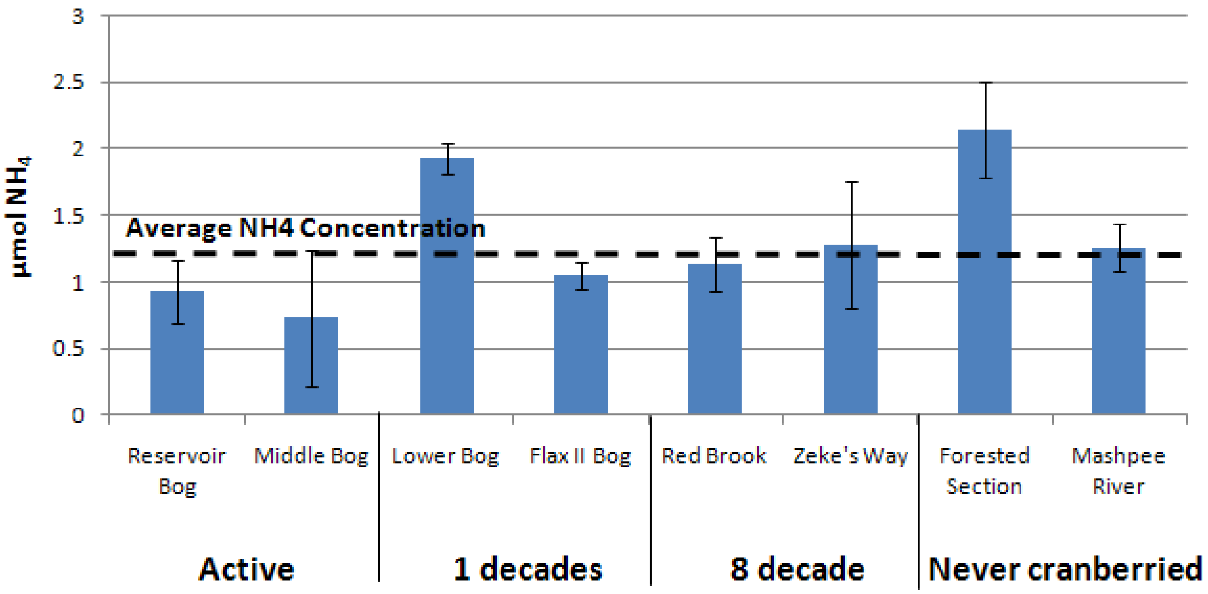

Figure 6 Average ammonium pool concentrations at each site, with error bars included. The average $NH_4$ concentration is 1.31umols/g soil.

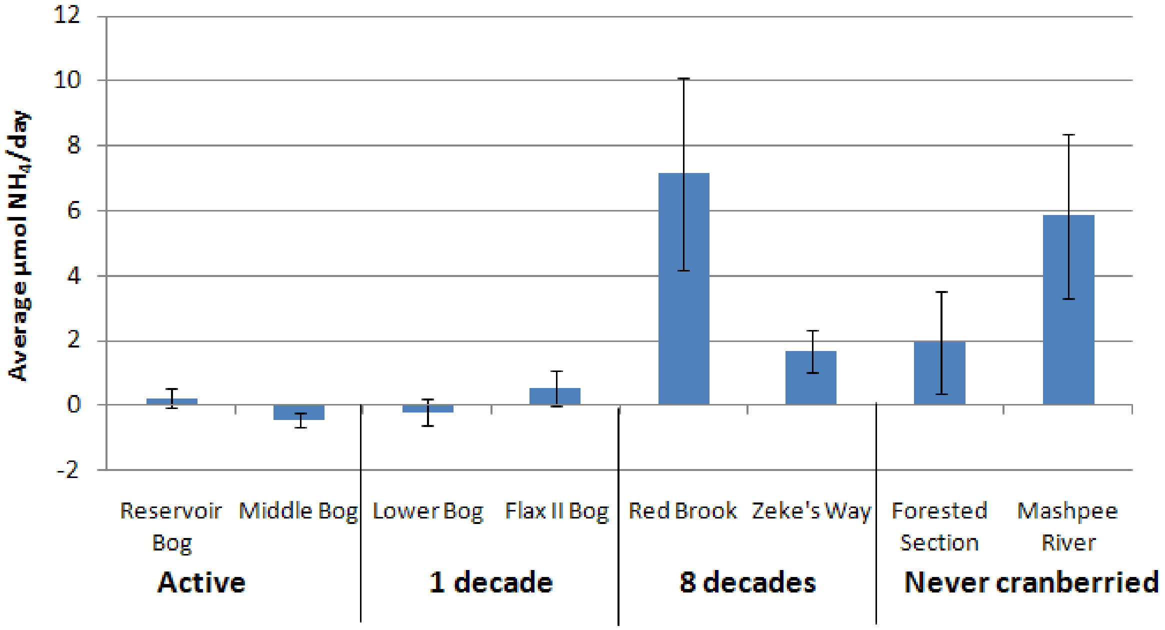

Figure 7  The average mineralization rate of each site, with error bars included.

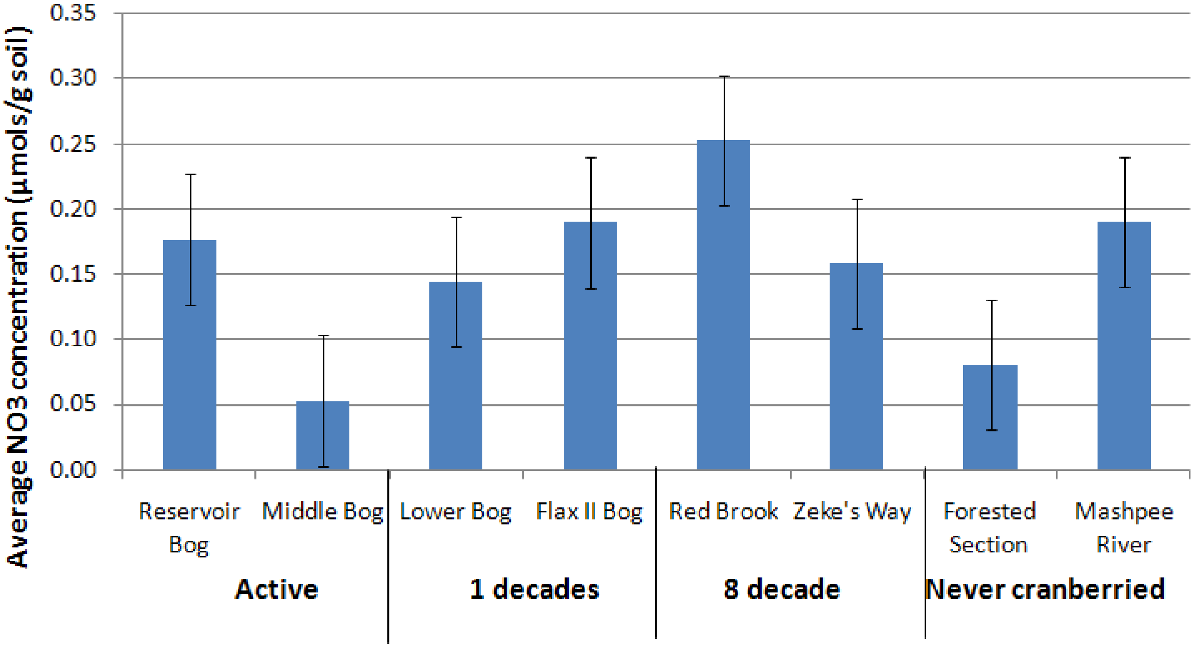

Figure 8 The average concentration of nitrate in each site, with error bars included.

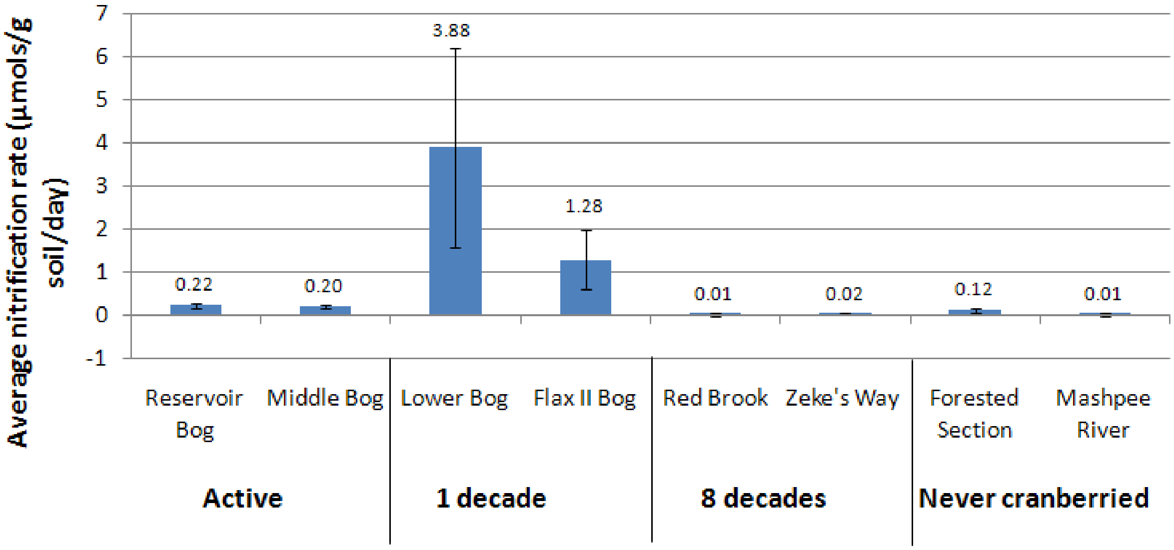

Figure 9 The average nitrification rate of each site, with error bars included. The Lower Bog rate includes three very large outliers, and the Flax II Bog rate includes two.

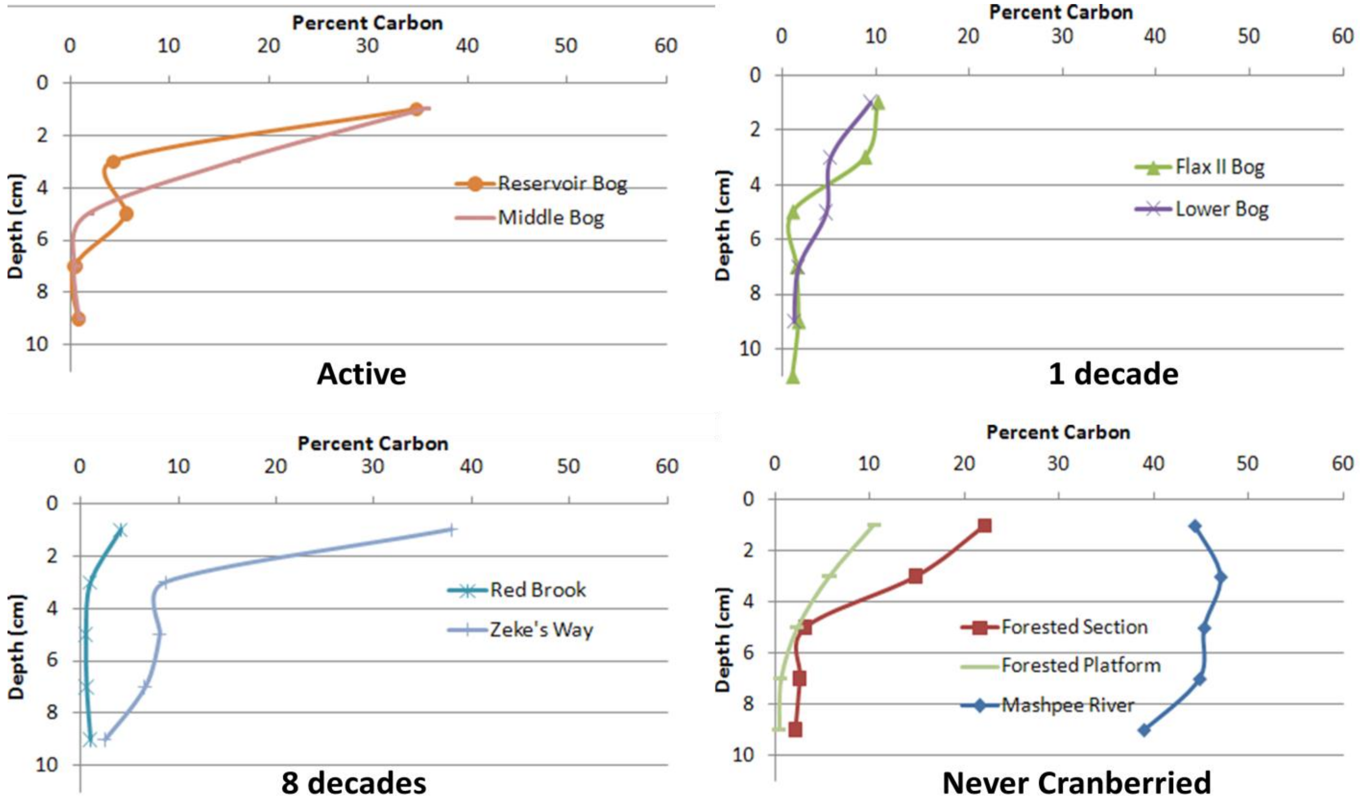

Figure 10 Percent carbon values for the top 10cm of each soil core, arranges in age pairs.

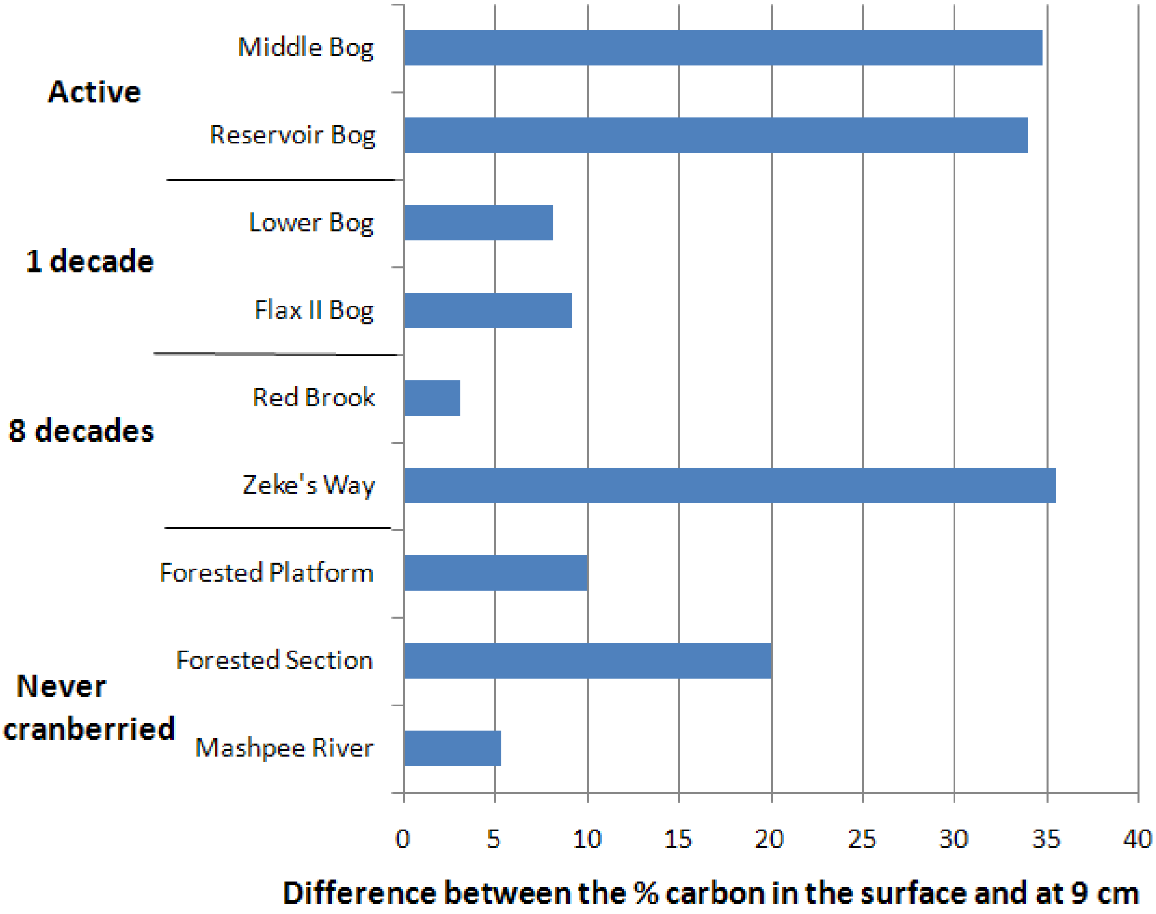

Figure 11 The difference between the percent carbon at 1cm and at 9cm in the soil core of each site.

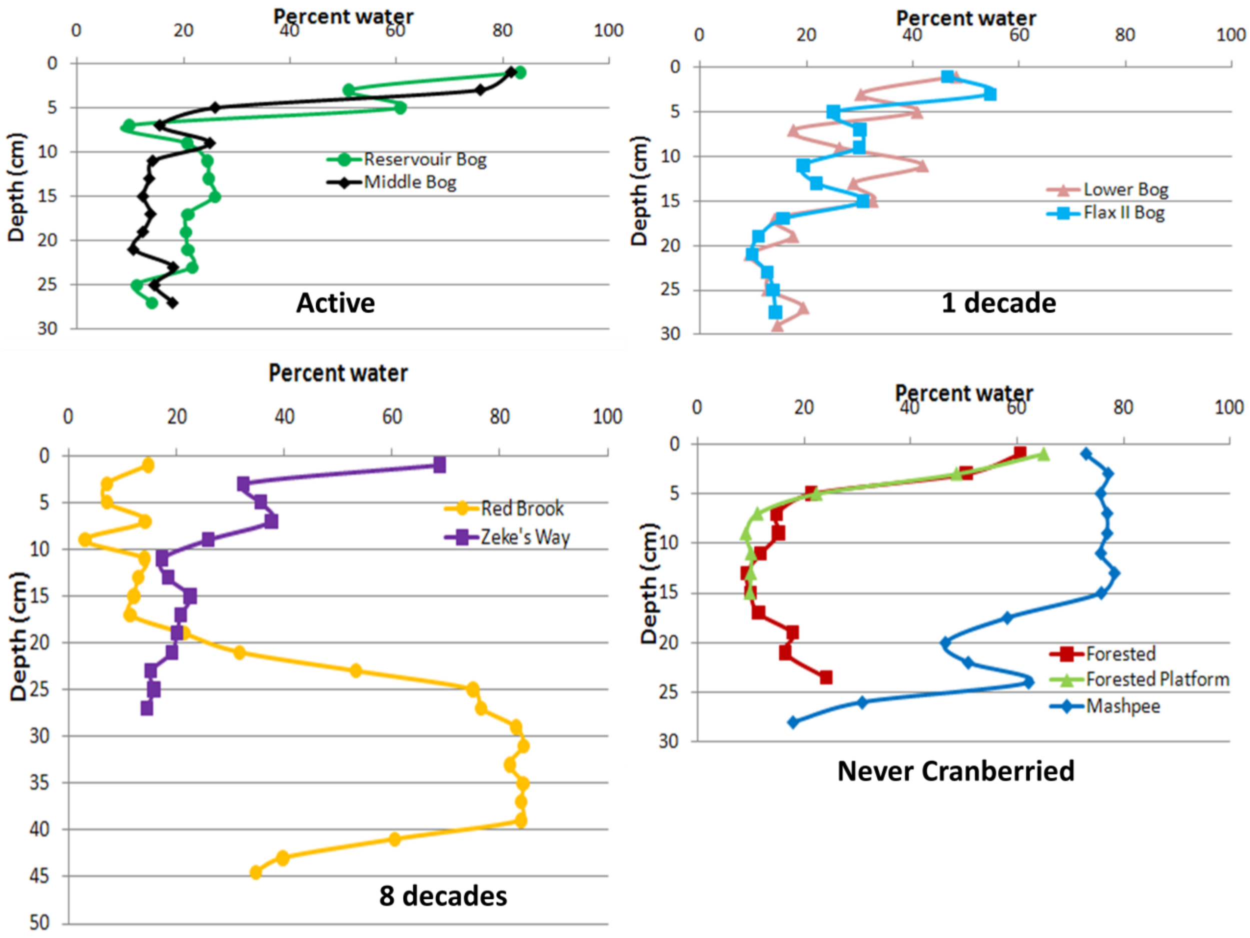

Figure 12  The percent water in soil cores for each site.

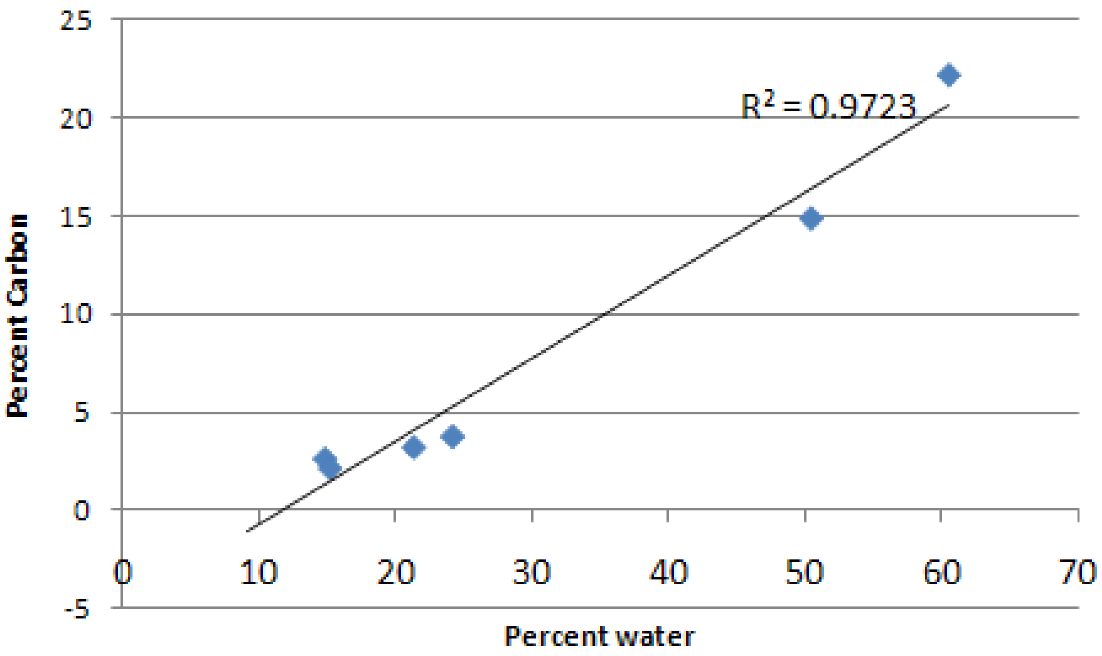

Figure 13 The correlation between percent water and percent carbon in the top 10cm of the soil core from the Forested Section. Other sites showed $R^2$ values for this correlation between 0.8148 and 0.9763, with an outlier of Reservoir Bog having a value of 0.6737.

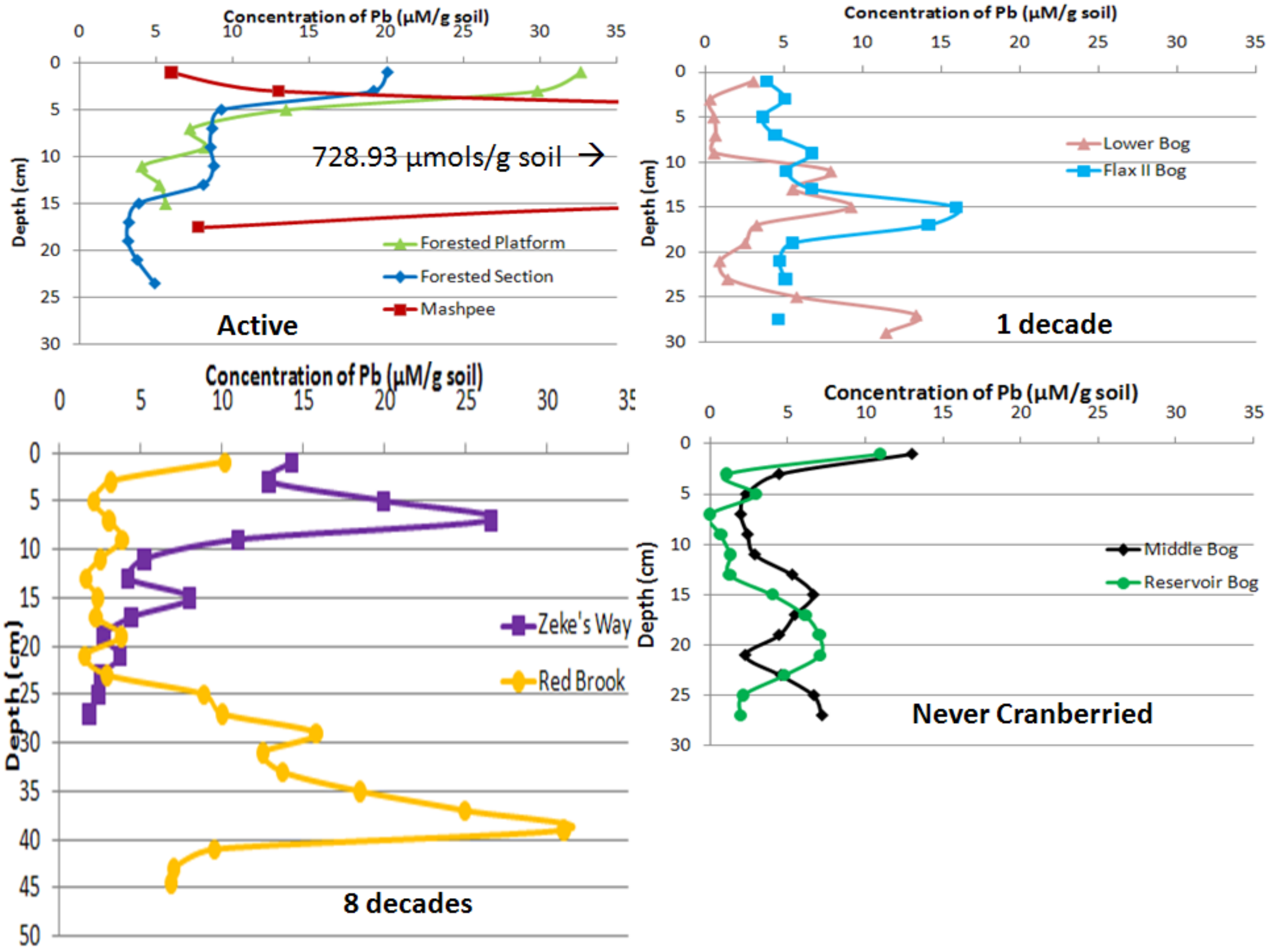

Figure 14 Lead concentrations in the soil cores from each site.