Biogeochemistry and vegetation in a cranberry bog chronosequence

Genevieve Noyce
Mount Holyoke College, South Hadley, MA
Semester in Environmental Science, MBL, Woods Hole, MA

Chris Neill, advisor
Ecosystems Center, MBL, Woods Hole, MA

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Abstract

Abandoned cranberry bogs are becoming more abundant all over Cape Cod. I was interested in the vegetation trends over time in these abandoned agricultural systems and the biogeochemical controls on these trends. I looked at fourteen abandoned bogs and two active ones, all in southeastern Massachusetts, to create a 70+ year chronosequence. I compared the shrub and tree species composition, which included density, percent cover, and species diversity, with soil biogeochemical characteristics for all the sites. I also compared the abandoned bogs to oak forests. After abandonment, shrub and tree species increased significantly in diversity, density, and cover, but the vegetation in the oldest abandoned bogs was different from oak forests in species composition and richness. There were significant correlations between the vegetation trends and soil NO_3 and C, but not with soil pH and PO_4. There was no trend between water table depth and presence of trees or their growth rates. Invasive species were rarely present in these sites.

Keywords: abandoned cranberry bogs, succession, biogeochemical controls, exotic species, forests

Introduction

Agricultural cranberry bogs are found all over southeastern Massachusetts (the mainland, Cape Cod, Martha's Vineyard) as well in other parts of the United States. Of these bogs, some of them were made from existing kettle-hole bogs, formed by glacial deposits, while others are completely man-made on level patches of ground and artificially cared for with a system of reservoirs (Mason 1926). No matter what their origination, all the bogs have some attributes in common, because all sites are maintained to achieve a particular environment. Each has very low species diversity, because they are maintained with herbicides or hand-pulling to produce only cranberries (Sandler, et al. 2007). Every few years, sand is added to the agricultural bogs, creating soil with alternating layers of sand and organic matter (Mason 1926). Because *Vaccinium macrocarpon*, the cultivated species of cranberry, grows best in acidic soil, the pH of these ecosystems may be artificially lowered (Larson, et al. 1980).

Active cranberry bogs were once numerous, but over time many of them have been abandoned. Sometimes this is the result of the fields being damaged, other times it's related to fluctuations in the cranberry market. In the vicinity of Cape Cod, there are bogs that were abandoned upwards of 70 years ago. As is to be expected, when agricultural bogs are no longer being maintained, they tend to take on a slightly different form. Half of a given wetland class can change within 20 years (Larson et al. 1980). Depending on their origination, a pre-existing wetland or not, water can be present at varying depths below the soil surface. The soil composition of these bogs can shift, because sand is no longer being added, as well as the pH. Abandoned bogs can also have varying types of vegetation. They are often colonized by shrubs and trees, including invasive species (Mason 1926). Some bogs will even progress completely to shrub swamps (Larson et al. 1980). This is an interesting issue, since many people want to preserve the look of their cranberry bogs rather then have them become swamps. There is also concern about the colonization by invasive species, which can alter nutrient and water cycling in the soil (Sandler, et al. 2007). Land-use history strongly affects the presence of exotic species, particularly in open areas (Von Holle and Motzkin 2007).

In this project, I investigated the biogeochemical controls on vegetation in these abandoned bogs and how they change over time. Since it was impossible for me to follow a single bog from its cultivation stage to fifty years after abandonment, I instead used a chronosequence, looking at current bogs, old abandoned bogs, and some in between. I wanted to know what happens as abandoned bogs age, in particular the vegetation trends over time. I was interested in what causes an abandoned bog to be colonized with trees and shrubs, including invasive species, and what affects their growth rates. As a first attempt at answering this question, I investigated many soil properties to see which of them were correlated with vegetation trends.

Methods

Site description

I examined sixteen sites: two active cranberry bogs and fourteen abandoned ones. The active bogs were in East Wareham, MA and are currently owned and operated by A.D. Makepeace. The abandoned bogs were located on Cape Cod in the towns of Bourne, Falmouth, and Mashpee and had all been used as agricultural cranberry bogs for at least several years. The oldest site was abandoned prior to 1930 and the youngest were active until 2004. (Table 1)

Sample collection

Sampling was done on November 12-26. At each site I defined an 8 m radius plot with typical vegetation for that site. In each plot, I conducted a vegetation survey. As part of this, I identified every shrub and tree species and tallied the number of stems of each in the plot. I did not include herbaceous species. For sites with very dense shrub growth, I only counted stems in a half or a quarter of the plot. I then estimated percent cover in the entire plot for all identified species, using classes of rare, <1%, 1-5%, 6-15%, 16-25%, 26-50%, 51-75%, and 76-100%. I measured the DBH of all trees greater than 3.5 cm in diameter. I also took tree cores from the two largest trees at each site, where applicable.

I collected three 10 cm soil cores (5 cm diameter) from different points in the plots to create one composite soil sample for each site. Elsewhere in the site, I dug a soil pit which I used to find the hue and chroma of the soil and measure the depth to the water table when it was less than 30 cm below the surface. I also noted when standing surface water was present at the sites. I considered chroma of 2 or lower to be the low chroma mottles than signify the presence of water for most of the year (USDA 2003).

In addition, I took GPS coordinates at each site. I also estimated the year in which each site was abandoned, using a combination of personal communication and aerial photographs dating back to 1943. I considered this to be the age of each site.

Measurements

I measured soil-moisture content by determining the change in weight between fresh and oven-dried soil. Using the oven-dried weights and the volume of the soil corer, I estimated bulk density for each site. I analyzed subsamples of these composite soil samples for various nutrients and pH. I extracted 15 g of fresh soil from each site with 1M KCl for 24 hours and then filtered the extracts using GFFs. I then analyzed these samples for nitrate on a QuikChem 8000 Lachat Flow Injection Analyzer (Wood, et al.

1967) and for ammonium on a Cary 50 spectrophotometer (Strickland and Parsons 1972). I made soil-DI water slurries with 10 g of wet soil and 50 mL of DI to measure pH using an Accumet20 pH and conductivity meter. I combined 5 g of dried soil with 200 mg of charcoal and 20 mL of 0.05 M HCl and 0.0125 M H_2SO_4 and shook the samples for five minutes (ed. Bigham 1996). I filtered these extracts and analyzed them for phosphate on a Shimadzu UV-1601 spectrophotometer (Murphy and Riley 1962). In addition, I ground a small amount of dried soil from each site with a mortal and pestle and analyzed these samples for total C and N content on a Perkin Elmer Series II CHNS/O Analyzer 2400.

I used the DBH measurements to establish basal areas for all forested sites. I sanded the tree cores and counted their rings to determine growth rates. Using these two sets of data, I determined the ages of trees in each site.

Data analysis

Using Statistical Analysis Software, v9, I used stepwise linear regressions to examine the relationships between the main dependant vegetation variables (shrub density, tree density, basal area, and species diversity) using my measured independent variables. From these, I modeled values for the dependent variables. I also created a correlation table using both independent and dependent variables. For significance, I used a 95% confidence interval ($p<0.05$).

Results

Of all the sites, six were less than ten years old, including the two active sites (Fig. 1). Five were between 10 and 60 years old and five were abandoned more than 60 years ago (Fig. 1). Age of the site is only significantly correlated with extractable N ($p=0.04$), total N ($p=0.02$) and total C ($p=0.03$) concentrations and not any other soil properties.

In the abandoned bogs in general, shrubs and trees account for about equal amounts of ground cover, though shrub cover varies more widely (Fig. 2). For sites than have only been abandoned for a few years, the main species was still *Vaccinium macrocarpon* (Fig. 3). More trees were present than shrubs, with about equal cover by *Acer rubrum* and *Salix sp.*, but species richness was relatively low (Fig. 3). The trees were also only young seedlings (Fig. 4). In the older abandoned sites, *Vaccinium macrocarpon* was still present, but had been out competed by *Clethra alnifolia* and *Acer rubrum* (Fig. 5). Plant ground cover increased by about ten-fold (Fig. 5). The numbers of shrub and tree species were considerably more numerous and shrubs had the highest overall percent cover (Fig. 5). In these older sites, *Acer rubrum* was decidedly the dominant tree (Fig. 5) and was no longer only present as seedlings (Fig. 4). With one exception, all sites over ten years old were colonized by trees, regardless of water availability (Table 2). The one tree-less site also had the highest water table (Table 2). However, a deep water table seems to adversely affect the growth rate of trees in these sites, though there is no real trend (Fig. 6).

Invasive species were not present in any of the sites that had been abandoned for fewer than ten years. In the older sites, they only accounted for 0.5% of the percent cover (Table 3). The presence of exotics was not significantly affected by the water Table depth or presence of low chroma mottles.

There are significant positive correlations between age and shrub and tree density, basal area, and species diversity. Older sites have more species ($p=0.008$) and higher shrub ($p=0.04$) and tree densities ($p<0.0001$) (Table 4). Similar trends are also apparent with increased NO_3 concentrations (Table 4). For shrub density and species diversity, NO_3 is more strongly correlated than age (Table 4). There is not a significant correlation between age and soil NO_3 concentration, though the NO_3 concentration in the older bogs is much higher than in all the rest (Fig. 7). The total C in the soil also increases over time (Fig. 8). 83% of the observed species diversity can be attributed to the NO_3 concentration and mass of C in the soil ($p<0.0001$, $p=0.003$). These variables are also responsible for 84% of the shrub density trends ($p<0.0001$, $p=0.05$). Tree density variability and basal area are 70% ($p<0.0001$) and 58 % ($p=0.0006$) caused by age, respectively. These independent variables predict relatively accurately the observed trends in the dependent variables (Figs. 9,10,11,12).

Discussion

Though the sites vary in vegetation, they do show consistent trends in vegetation after abandonment. Over time, trees and shrubs begin to colonize abandoned bogs, leading to the concern that these unique wetlands are just going to become another forest or swamp. Though the young bogs are often characterized by *Acer rubrum* and *Salix sp.* seedlings, the older bogs generally contain more shrubs than trees. When there are full-grown trees, they're mostly *Acer rubrum*. These characteristics set these sites apart from other forests in the area. Wooded areas on Cape Cod are typically oak forests of not much more than 100 years old (Schwarzman 2002). Even though the abandoned bogs I looked at are probably slightly younger, the sites are close enough in age to illustrate the differences in succession end points. The main forest tree species are *Pinus rigida* and *Quercus sp.* (Fig. 13). *Acer rubrum* is barely present in the oak forests, while accounting for almost half of the trees in the bogs older than 70 years (Fig. 13). The forests also have about half again as many trees as the old bogs (Fig. 13). This is because the bogs tend to grow up into much more shrubby systems than the typical forest, with nearly double the shrub cover (Fig. 14). Additionally, shrub and tree species diversity is slightly higher in the old bogs than in the oak forests, despite the particular soil properties of these systems (Fig. 15). I cannot attest to the herbaceous species diversity. Essentially, even after these bogs have undergone decades of succession, they are not just becoming forests, but instead retain some degree of uniqueness.

Time is not the only possible control on these vegetation trends; soil nutrients might also play a part. In the active bogs, the only form of N in the soil is NH_4. Cranberries preferentially take up NH_4 over NO_3, so active bogs are generally fertilized with NH_4 (DeMoranville). However, over time the amount of C in the soil increases, as a result of the increased vegetation. More vegetation produces more litter, which means there is more organic material in the soil. There is also no longer a supply of mineral sand mixing with the organic soil. As organic matter increases, the release of NH_4 increases (DeMoranville). Any residual ammonium that is not taken up by the plants is nitrified, possibly resulting in the high NO_3 observed in the oldest sites (Aber and Melillo 2001). Nitrification is also controlled by pH. Soils with a ph of 5.0 or high tend to have high levels of nitrification (Aber and Melillo 2001) and the abandoned bogs ranged in ph from 4.2-6.0. Nitrification also increases in dry soils, so by collecting my samples at the end of summer I may have observed an artificial increase in NO_3.

Because the NO_3 and C increases are correlated with the vegetation trends, it is possible that they have a significant effect. On the other hand, because all the trends are correlated with age, I cannot say which cause the others. For species diversity and shrub density, I did use NO_3 and C to model the trends with pretty accurate results. However, for tree diversity and basal area, age alone is enough to model. In order to know more conclusively what the controls actually are, I would need to conduct an experiment in which I artificially lowered and raised the NO_3 and C concentrations in the soil. On the other hand, since there are no significant correlations between vegetation and pH and PO_4, future experiments probably do not need to take them into account.

The amount of water present at a given site does not have the result on tree growth that I expected. Though the one old site with a significant amount of standing water does not have trees, all the others do, even though their soils range from being very wet to dry. In systems with varying water table depths, shrub and tree biomass increases with lower water tables (Bubier et al. 2006). Consequently, I expected tree growth to be limited in bogs with very water-saturated soils. The exception to this is possibly because *Acer rubrum*, which is most prevalent in these abandoned bogs, is often able to germinate under flooded conditions, which would give it a chance of getting started even when the water table is high (Moizuk and Livingston 1966). However, a more likely explanation is merely just that my methods of assessing water availability did not accurately capture what is actually occurring in these bogs. At the end of the summer, the water table in bogs is generally considerably lower than the seasonal average (Treat et al. 2007), making a one time measurement essentially useless as a prediction. This means that two sites could have drastically different water tables in the spring, but by November be more than 30 cm below the surface, which was my cutoff for measurement. In order to get an accurate portrayal of the interaction between water and tree growth, I would need to have measured the water table multiple times throughout the growing season to find a seasonal average. While I did also look for low chroma mottles, they were not significantly correlated with any vegetation trends, probably because chroma is a fairly subjective analysis. Because the low chroma and water table depths are not significantly correlated with each other, this supports my hypothesis that I do not have a good picture of water dynamics.

I expected to find invasive species in the drier abandoned sites, but this was not the case. Despite surveying 14 abandoned bogs, only one of them contained any exotics (*Lonicera morrowii* and *Rosa multiflora*). In general, the concern of invasive species colonizing abandoned cranberry bogs is unfounded. Old agricultural grasslands been shown to have significantly more invasive species than their native counterparts due to the prior disturbances (Neill et al. 2007). In the case of cranberry bogs, past agricultural history does not seem to affect the abundance of exotics. This is in keeping with Sandley et al. (2007) who did not find many invasive species on the interiors of cranberry bogs, regardless of their past history. This is possibly because cranberry bogs are harsh environment, acidic and sandy, to begin with.

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Figures and Tables

Table 1. GPS coordinates and sampling dates for all 16 sites.

Site	Coordinates		Date Sampled
1	41°34'53.9" N	70°34'24.3" W	18-Nov-07
2	41°35'40.5" N	70°34'20.3" W	18-Nov-07
3	41°36'47.6" N	70°34'21.6" W	18-Nov-07
4	41°34'24.3" N	70°34'24.3" W	14-Nov-07
5	41°35'14.9" N	70°34'12.2" W	14-Nov-07
6	41°35'23.9" N	70°34'23.3" W	18-Nov-07
7	41°47'22.6" N	70°40'07.6" W	26-Nov-07
8	41°35'33.3" N	70°30'26.1" W	14-Nov-07
10	41°35'04.7" N	70°30'53.9" W	14-Nov-07
11	41°39'2.00" N	70°26'48.6" W	12-Nov-07
12	41°29'05.4" N	70°26'46.0" W	12-Nov-07
13	41°45'38.3" N	70°36'06.0" W	12-Nov-07
14	41°45'54.9" N	70°38'00.9" W	12-Nov-07
15	41°47'31.7" N	70°40'19.4" W	26-Nov-07
16	41°45'58.5" N	70°38'06.8" W	12-Nov-07
17	41°38'58.1" N	70°27'29.1" W	12-Nov-07

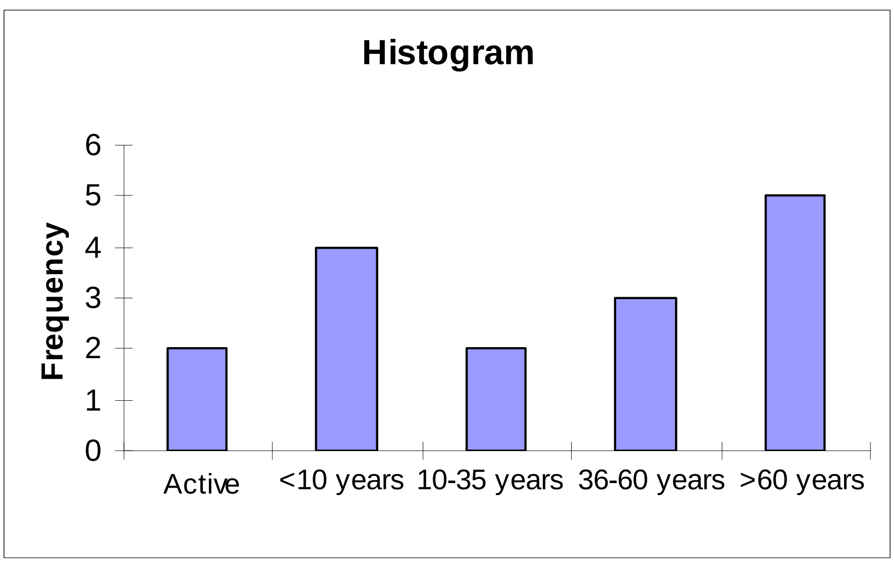

Figure 1. Histogram showing number of sites in age class.

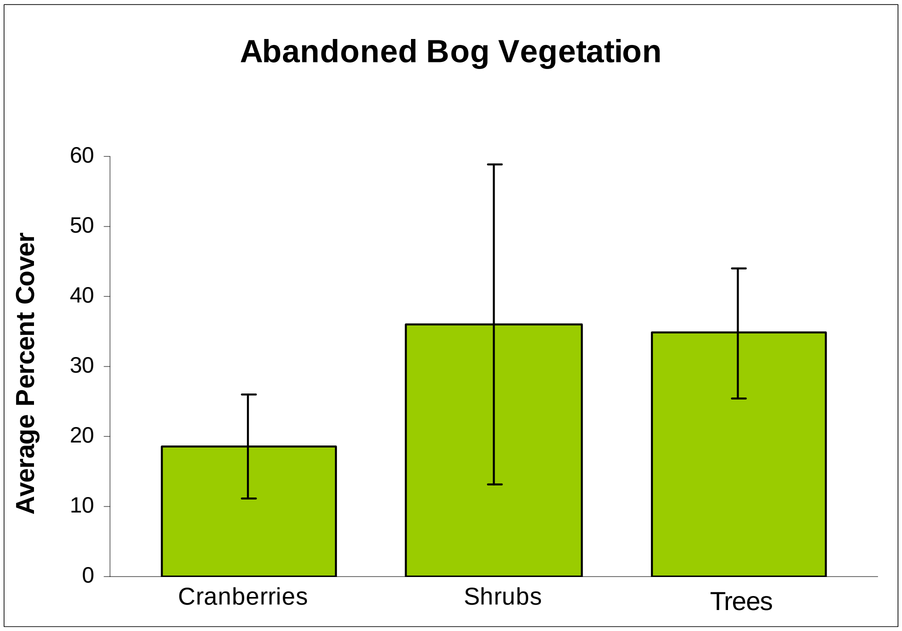

Figure 2. Average percent cover of cranberries, shrubs, and trees for the 14 surveyed abandoned bogs, including standard error.

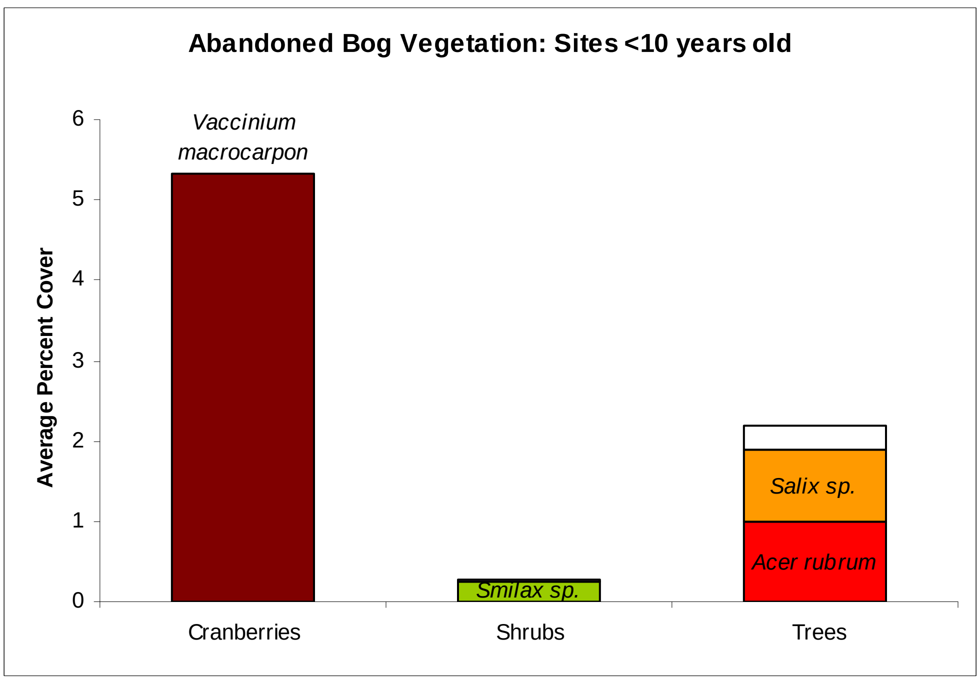

Figure 3. Average percent cover of cranberries, shrubs, and trees (sub-divided into the main species) for the four surveyed bogs that were abandoned less than ten years ago. All trees are seedlings.

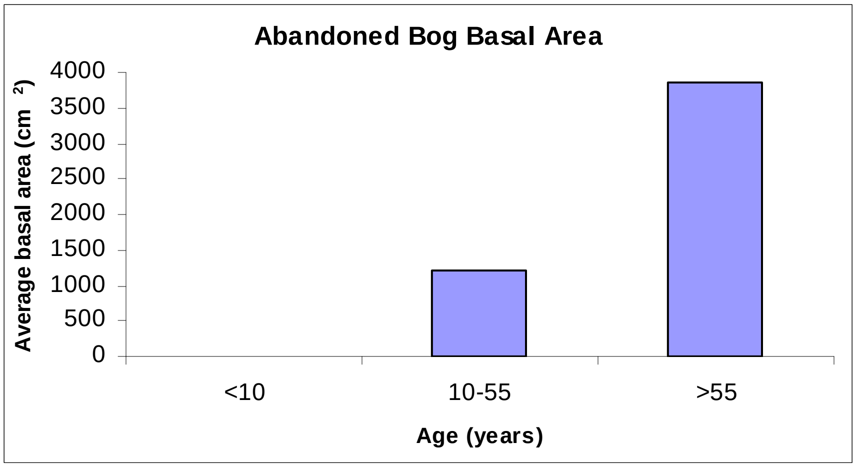

Figure 4. Average basal area of trees in fourteen abandoned sites, with respect to age.

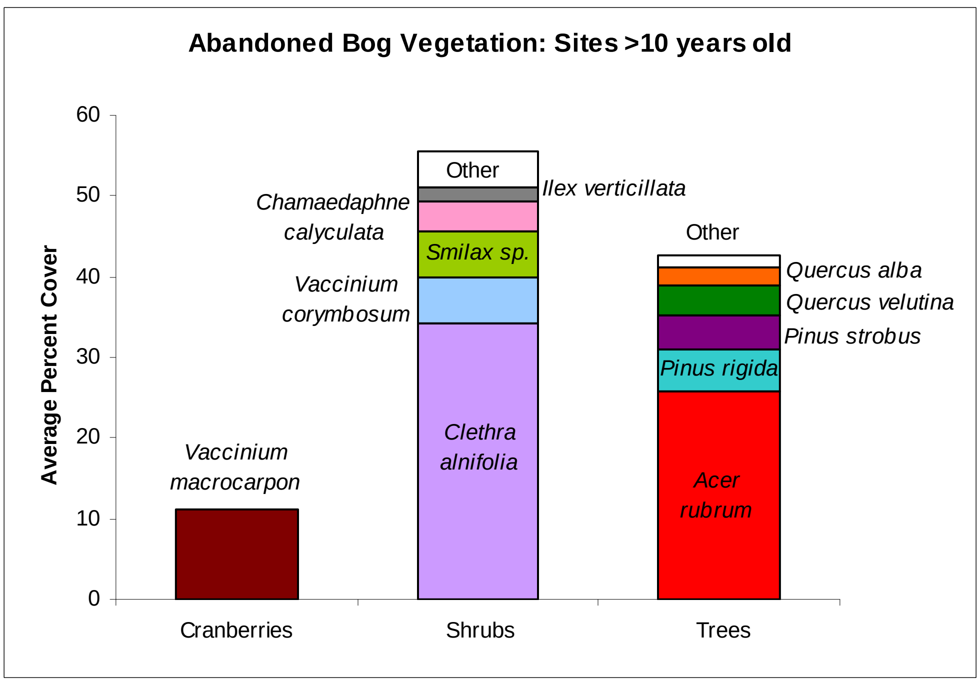

Figure 5. Average percent cover of cranberries, shrubs, and trees (sub-divided into the main species) for the ten surveyed bogs that were abandoned more than ten years ago.

Table 2. Number of sites more than ten years old with and without trees in each water table class.

	Standing Water	**0-10cm**	**11-20cm**	**21-30cm**	**>30cm**
Trees	1	1	1	2	4
No Trees	1	0	0	0	0

Table 3. Percent cover of native and exotic species in abandoned bogs, sorted by the length of time since abandonment.

	<10 years	**>10 years**
Native	100%	99.5%
Exotic	0%	0.5%

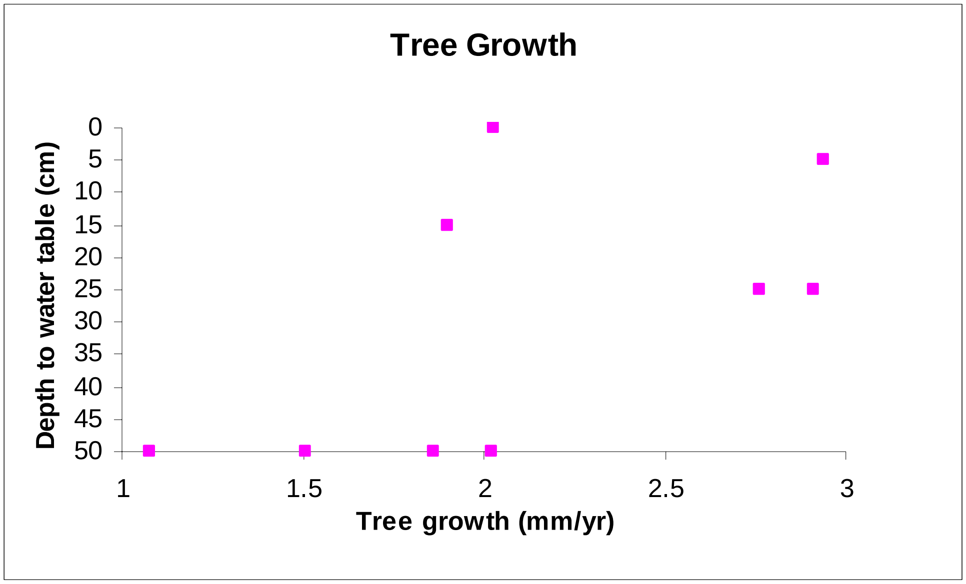

Figure 6. Rate of radial tree growth in abandoned sites older than ten years in relation to water table depth.

Table 4. Pearson correlation coefficients and p-values for linear correlations between dependent variables (shrub density, tree density, basal area, and diversity) and independent variables (age and NO_3 concentration).

	Age	**NO_3**
Shrub Density	0.514 0.042	0.883 <0.0001
Tree Density	0.834 <0.0001	0.616 0.011
Basal Area	0.762 0.0006	
Diversity	0.640 0.0076	0.805 0.002

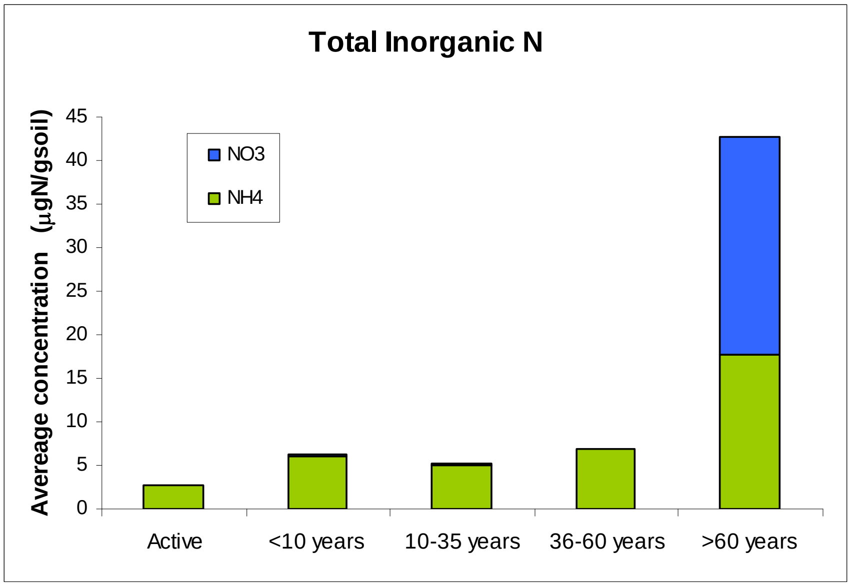

Figure 7. Average concentrations of extractable inorganic N (both NH_4 and NO_3) in the soil of abandoned cranberry bogs in each age category.

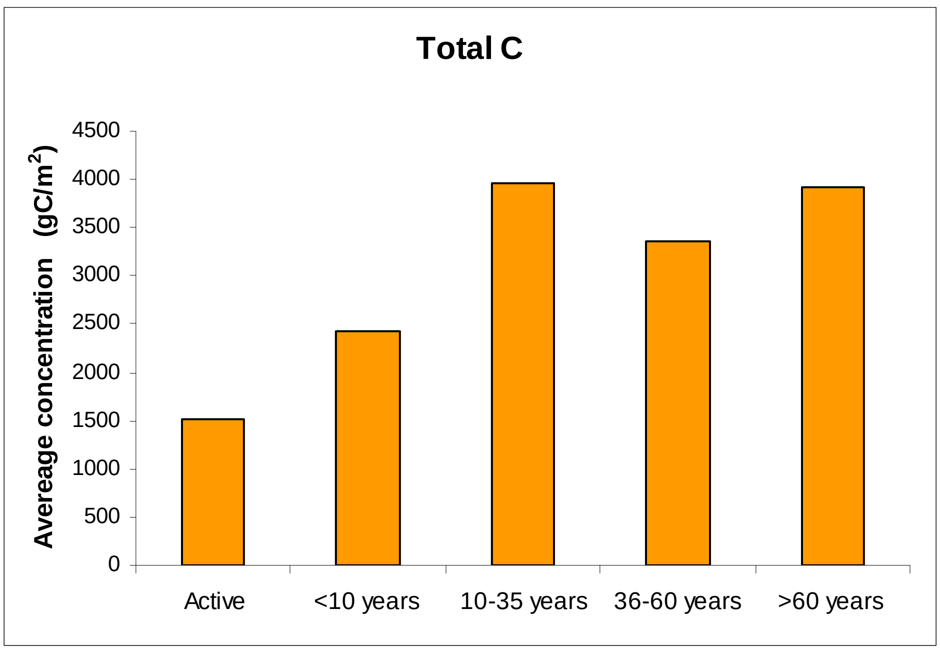

Figure 8. Average concentrations of C in the soil of abandoned cranberry bogs in each age category.

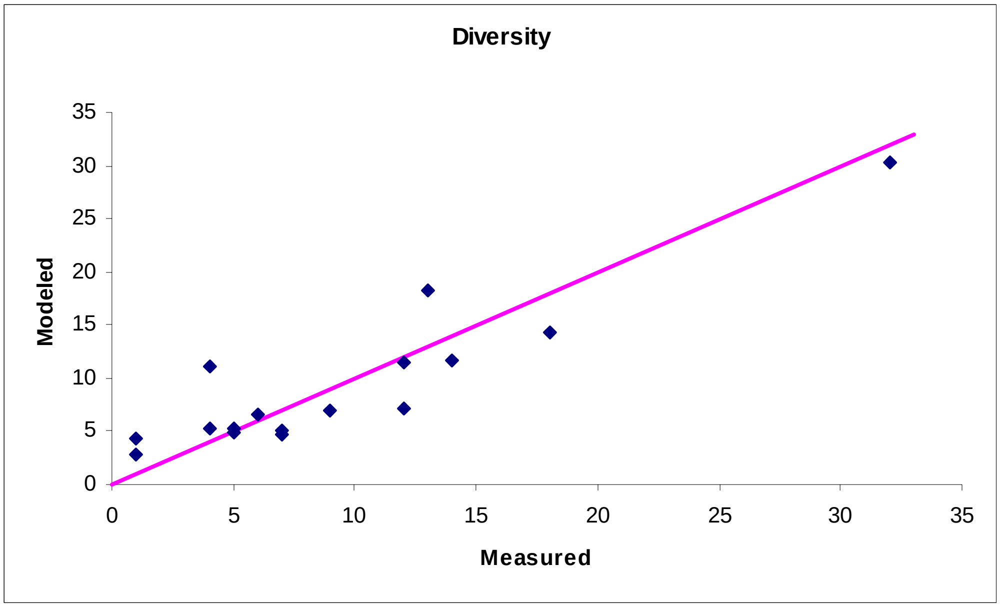

Figure 9. Measured versus modeled diversity. Modeled values calculated using NO_3 concentration and mass of C in soil.

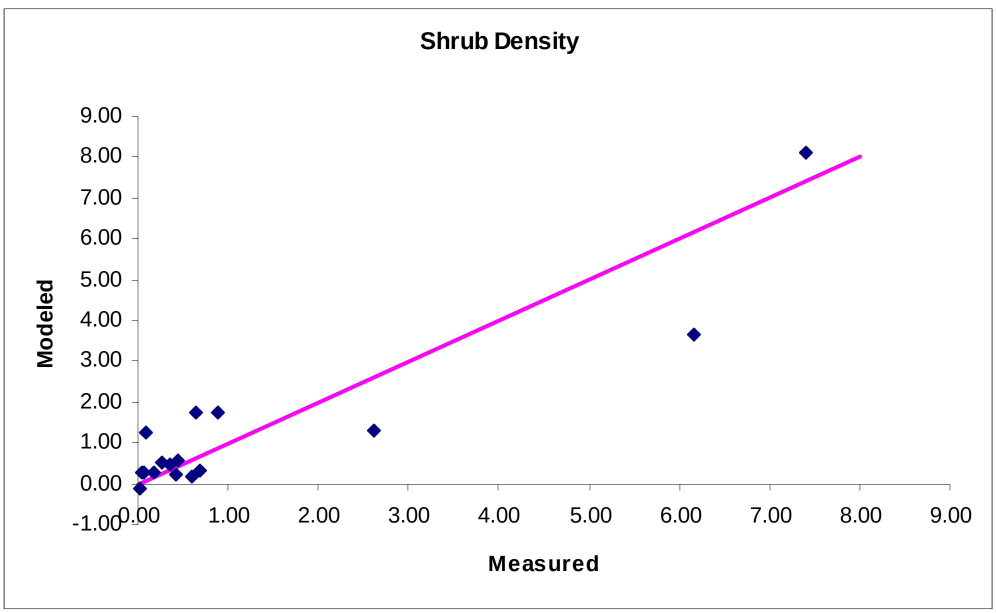

Figure 10. Measured versus modeled shrub density. Modeled values calculated using NO_3 concentration and mass of C in soil.

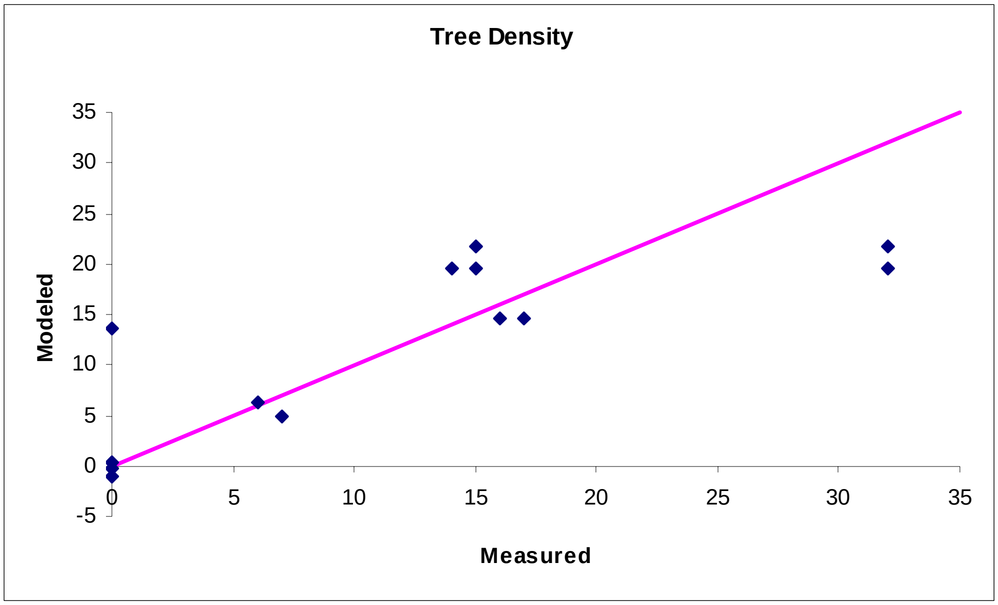

Figure 11. Measured versus modeled tree density. Modeled values calculated using age of site.

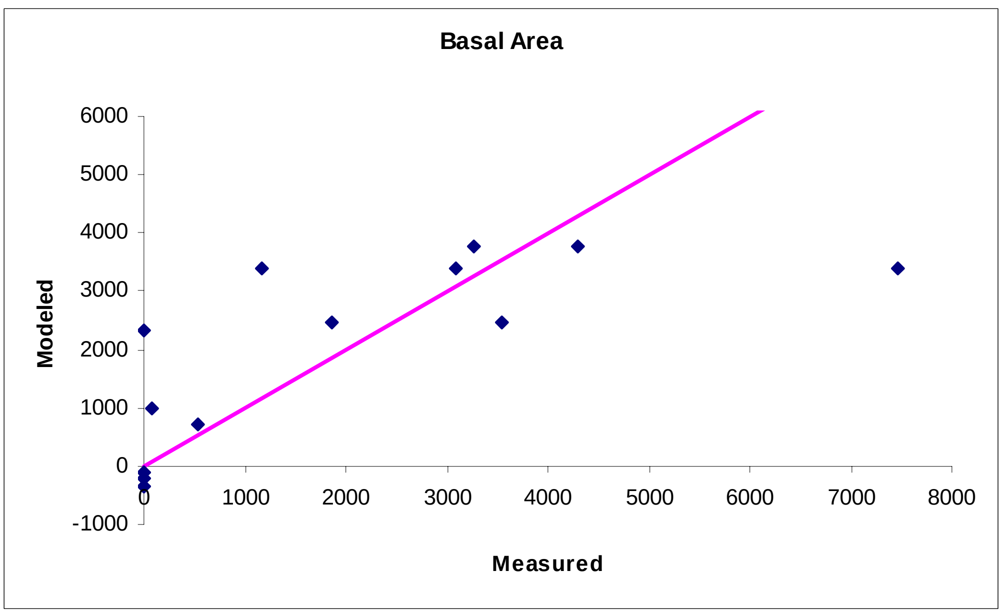

Figure 12. Measured versus modeled basal area. Modeled values calculated using age of site.

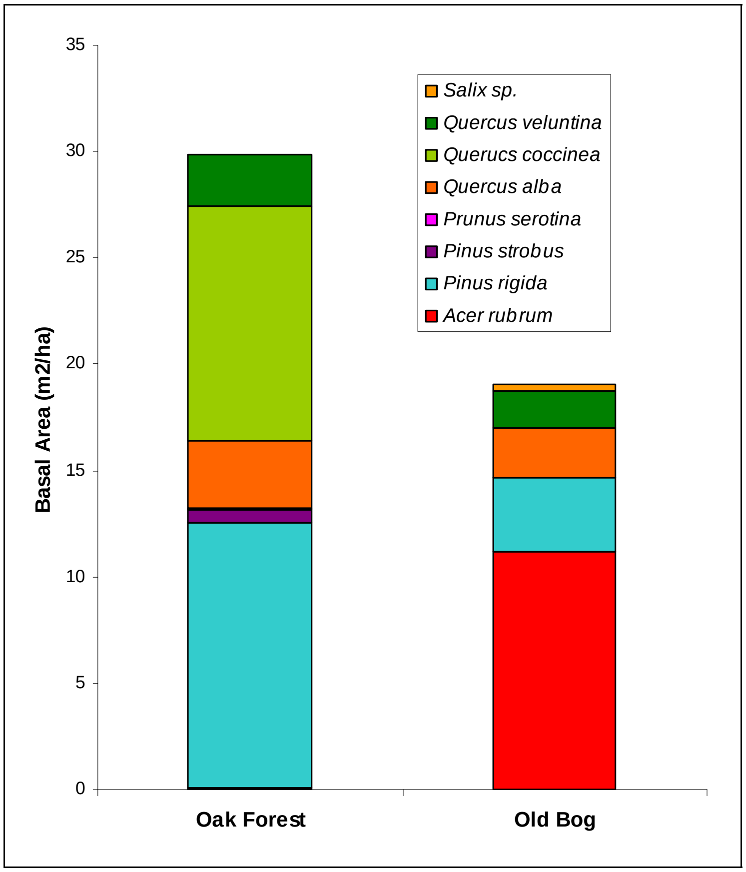

Figure 13. Comparison of basal area of tree species in old abandoned cranberry bogs (70+ years) and typical Cape Cod oak forests (Franks 2007).

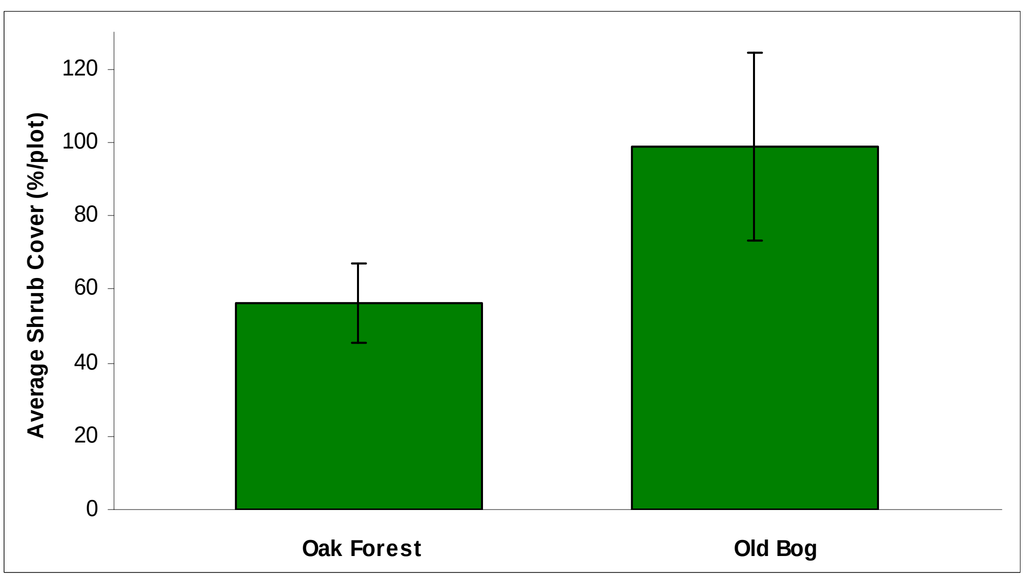

Figure 14. Comparison of shrub cover in old abandoned cranberry bogs (70+ years) and typical Cape Cod oak forests (Franks 2007).

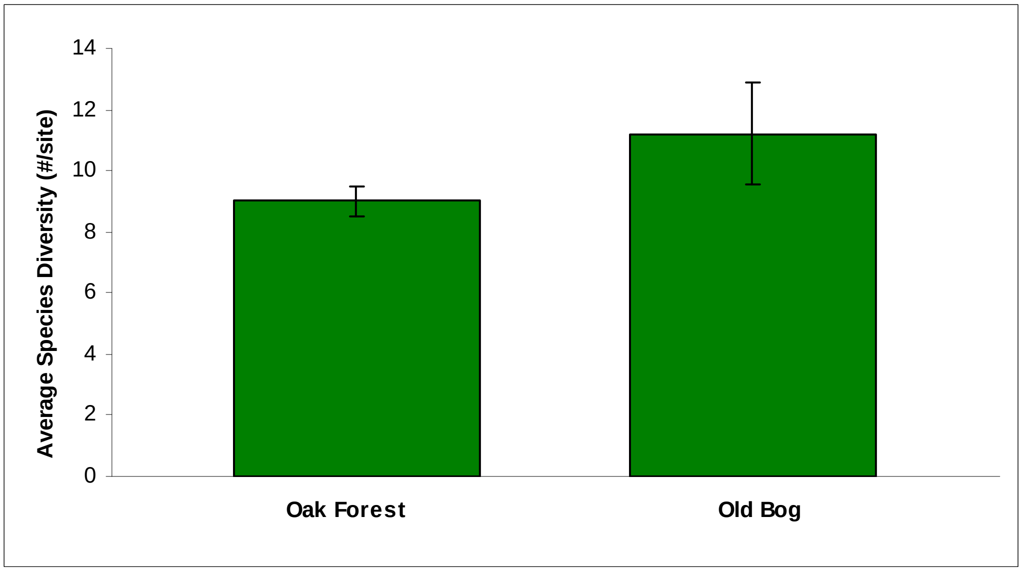

Figure 15. Comparison of species diversity in old abandoned cranberry bogs (70+ years) and typical Cape Cod oak forests (Franks 2007).