Sediment Records of Fire and Vegetation History from Solution Holes in The National Key Deer Refuge, Monroe County, Florida

Report on Research Funded by the U.S. Fish and Wildlife Service
Submitted to the National Key Deer Refuge
Anne Morkill, Director

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Background and Scope of Report

A grant of $14,100 from the U.S. Fish and Wildlife Service (US FISH & WILDLIFE SERV-401817G045-HORN) funded an investigation of sedimentary charcoal and pollen in solution holes in pine rocklands of the National Key Deer Refuge, Monroe County, Florida, as a means of obtaining evidence of past fire and vegetation that can inform conservation and management. Two sites on Big Pine Key were selected for study based on reconnaissance conducted in February 2007, prior to the grant period. The reconnaissance field party consisted of Professors Sally Horn and Ken Orvis, and graduate student Joshua Albritton, from the Department of Geography at the University of Tennessee; Paige Schmidt of the US Fish and Wildlife Service; and Chris Bergh of The Nature Conservancy. Anne Morkill, Refuge Director, provided housing and logistical support for the reconnaissance visit, and Chris Bergh covered transportation costs. In August 2007, Sally, Ken, and Joshua returned to Big Pine Key with the USFWS funding to recover sediment cores from the two sites. This reports describes the field work, the nature and ages of the sediments cored, and the charcoal and pollen evidence of past fire and vegetation preserved in the sediments. Additional results and interpretation will be included in Joshua Albritton's M.S. thesis, scheduled for completion in Spring 2009.

Core Sites

The two sites cored for this project are located within one half kilometer of each other in the north-central portion of Big Pine Key. Key Deer Pond (unofficial name) is located on refuge lands between Pine Avenue and Key Deer Boulevard, and Blue Hole Wetland (unofficial name) is located on the northeastern side of the Blue Hole quarry, near the intersection of Key Deer Boulevard and Big Pine Street (Figure 1).

Key Deer Pond (24° 42′ 29.50″ N, 81° 22′ 36.12″ W) is a small pond located ca. 100 m from the intersection of Geraldine Street and Pine Avenue. At the time of coring, the water

depth in the pond was slightly over 0.5 m (varying between 0.54 and 0.64 m). The water had a pH of 7.9 (moderately alkaline). Although this water could be considered "fresh," chemical analyses revealed notable concentrations of Ca, Na, and Cl, among other ions (Table 1).

We cored the pond from a platform created by positioning an extension ladder across it (Figure 2), using a locking-piston sediment corer (Colinvaux *et al.* 1999) that recovers 1-m long sections. We collected a total of 9 core sections from two areas of the pond, including material from overlapping and parallel holes. We reached a depth of about 3.5 m at Site 1 and 3.0 m at Site 2, and focused on our later laboratory analyses on the deeper profile obtained at Site 1. Here we collected three successive core sections in Hole 1A (from 0.11–1.11 m, 1.11–2.11 m, and 2.11–2.64 m below the mud-water interface), and two successive core sections from Hole 1C (1.61–2.61 m and 2.61–3.61 cm below the mud-water interface.) The deepest core section bottomed out on rock. All core sections consist of dark (primarily Munsell 10 YR 2/1) sediment with abundant wood and other plant fragments, becoming increasingly peaty with depth.

Blue Hole Wetland (24° 42′ 22.56″ N, 81° 22′ 49.62″ W) is located along an access trail closed to the public on the northeastern end of the Blue Hole quarry. Dense vegetation made coring somewhat difficult (Figure 3). At our first coring site, the water depth was less than 0.20 m but the upper meter of "sediment" proved to be a dense, water-filled root mat. We positioned wooden planks across site, and began coring 1 m below the root mat. We obtained three successive core sections to a depth of 3.8 m, at which point we encountered rock. From a second coring site with deeper water and fine sediment we recovered material from 0.15–1.15 m below the mud-water interface.

The water analysis revealed high concentrations of Na, Cl, and other ions in the Blue Hole Wetland (Table 1). These values lead to a designation of "brackish." The pH was slightly alkaline (7.8).

Laboratory Analyses

Sediment cores in their original aluminum coring tubes were returned to the University of Tennessee, where core tubes were opened longitudinally using a specialized router, and cores were sliced longitudinally. Freshly cut core surfaces were photographed and described prior to sampling for radiocarbon, water content, loss-on-ignition, macroscopic charcoal, and pollen and microscopic charcoal analyses. All analyses other than radiocarbon dating took place in the Laboratory of Paleoenvironmental Research at the University of Tennessee, directed by Sally Horn and Ken Orvis. The laboratory and data analyses reported here were carried out primarily by Sally and graduate student Joshua Albritton, who is completing his MS thesis on analyses of the Key Deer Pond sediment core. Graduate students Alisa Hass, Maria Caffrey, and Chris Underwood, and undergraduate students Joshua Brown and Charles Batey, also participated in laboratory work.

Results and Discussion

Radiocarbon Dating and Core Chronology

AMS radiocarbon dating of basal wood establishes that the profiles from both sites span over 1500 years (Tables 2 and 3). The Key Deer Pond record extends to 1660 calibrated years before present (cal yr BP) and the Blue Hole Wetland record extends to 1813 cal yr BP. Radiocarbon dates were calibrated using the CALIB 5.0.1 computer program (Stuiver and Reimer, 1993) and the dataset of Reimer et al. (2004). The single-year calibrated values cited above represent the weighted means of the probability distributions of the calendar calibrations; complete age ranges are in the tables. "Average" sedimentation accumulation rates, extrapolated from the basal dates, are 0.20 cm/year at both sites.

Multiple radiocarbon determinations on the Key Deer Pond profile (Table 2) revealed a normal stratigraphic sequence, discounting two dates slightly out of order (Figure 4). The discrepancy is less when the entire calibrated age ranges are plotted, rather than just the weighted means of the probability distributions (Figure 5). These apparent reversals may result from the in-built age of charred wood, or from bioturbation, though the fact that most of the dates are in order argues against extensive bioturbation.

Sediment Composition

Sediment samples were dried overnight and ignited for one hour each at 550° and 1000° C to determine water content and to estimate organic and carbonate content based on loss-on-ignition (Dean, 1974). Results (Figures 6 and 7) confirm the highly organic (peaty) nature of the sediments. The plant debris includes large wood fragments and some leaves. However, the leaves are not arranged in layers suggesting deposition in the wake of defoliation in hurricanes.

Macroscopic Charcoal Analysis

Macroscopic charcoal was examined at high resolution in the upper meter of the Key Deer Pond profile, and at intervals throughout the length of the Blue Hole Wetland profile. The uppermost core section from Hole 1A (0.11–1.11 m depth) was sampled at contiguous 1-cm intervals using a brass sampler with a rectangular cutting edge that extracts samples with a volume of 4 cm^3. The four Blue Hole Wetland core sections were sampled at coarse resolution, using a spoon with a volume of 5 cm^3. Samples were soaked overnight in cosmetic grade 3% hydrogen peroxide (Schlachter and Horn, in press) and wet-sieved through screens with mesh sizes of 250 µm and 500 µm. Retained particles were transferred to Petri dishes and counted under a dissecting scope.

The Key Deer Pond macroscopic charcoal record (Figure 8) reveals repeated, local fires during the past ca. 450–500 years (age extrapolated from upper panel in Figure 4; note that 400 cal yr BP means 400 years before AD 1950, or 458 years before AD 2008). That every sample analyzed contained abundant macroscopic charcoal argues for the long importance of fire in pine rockland habitats. Based on the estimate that each 1-cm interval in the upper meter corresponds to about 5 years, the charcoal data are consistent the idea that pine rocklands typically burn twice

a decade (Snyder, 1986) or every 3–7 years (Hofstetter, 1973). Fires at much longer intervals would be expected to result in some sediment intervals with less charcoal.

The variations in charcoal concentrations with depth are intriguing. They suggest possibly greater fire activity from about 200 to 300 cal yr BP (AD 1650–1750) , a time period that corresponds in part to the interval known as the "Little Ice Age." The Little Ice Age has been recognized in some paleoecological records from southern Florida and the wider circum-Caribbean region as a time of drier climate.

Additional evidence for local fires is provided by the radiocarbon dates on charcoal fragments in the Key Deer Pond profile (from both within and below the section analyzed for macroscopic charcoal), and by the coarse-resolution charcoal record from Blue Hole Wetland (Figure 9). In contrast to the Key Deer Pond site, and most other temperate and tropical sites at which my students and I have studied macroscopic charcoal in sediments, at Blue Hole Wetland particles >500 µm in size are not markedly less common than particles 250–500 µm in size (in fact, in some samples there are more fragments in the larger size class than in the smaller.) This finding may relate to the morphology of the basin and local drainage patterns, neither of which could be easily assessed in the field owing to the very dense vegetation that now grows within and surrounding the site. The vegetation presently surrounding the Blue Hole Wetland supports greater hardwood diversity and appears to have burned less recently than that surrounding Key Deer Pond. Projecting this back into the past, we initially hypothesized that the Blue Hole Wetland might contain less evidence of past fire. In fact, the sediments of Blue Hole Wetland actually contain slightly *higher* macroscopic charcoal concentrations than do the sediments of Key Deer Pond (Figure 10). While the average concentration of particles in the 250–500 µm size is nearly the same at the two sites (46.5 particles/cm^3 in the Blue Hole Wetland profile and 47.7 particles/cm^3 in the Key Deer Pond profile), the concentration of particles >500 µm is 31.9 particles/cm^3 in the Blue Hole Wetland profile and only 11.8 in the particles/cm^3 in the Key Deer Pond profile.

Microscopic Charcoal Analysis

Microscopic charcoal analysis of pollen slides prepared from the Key Deer Pond profile provides further evidence of fire history (Figure 11). We quantified microscopic charcoal concentrations using point counting, which provides an estimate of the total cross-sectional area of charcoal on slides. The charcoal fragments on our pollen slides are small enough to have passed through a 125 µm mesh screen during pollen processing. Many of the fragments are small enough to have been carried long distance by wind, and could potentially be signaling fires that occurred at some distance from the core sites. However, the fact that small particles might be carried long distances by wind does not necessarily mean that they were; the microscopic charcoal, as well as pollen, in the Key Deer Pond sediments may primarily derive from the local area.

We have used the same point-counting techniques to quantify microscopic charcoal in the sediments of ponds and wetlands within the pine rocklands of Abaco Island, the Bahamas (Stork, 2006; West, 2007; Horn, unpublished data). Microscopic charcoal concentrations are slightly higher in the Key Deer Pond sediments than in sediments from four sites on Abaco. However, these sites are larger basins, with core sites positioned at greater distance from shore than at Key

Deer Pond. Also, the rockland on Abaco is much more jagged than on Big Pine Key. This jagged limestone may trap more charcoal particles before they can be washed or blown into ponds or wetlands.

Pollen Analysis

Samples were processed for pollen analysis using standard palynological procedures (HF, HCl, KOH, acetolysis; Berglund, 1986) and the addition of *Lycopodium* control spores to enable calculation of pollen concentration and influx (Stockmarr, 1971). We found the Key Deer Pond site to contain well-preserved pollen in countable concentrations. The pollen diagrams (Figures 12–14) reveal long-term dominance by pine with some variation in the importance of associated woody and herbaceous taxa. We have not identified strong correlations between the charcoal variations and pollen assemblages. However, the long-term dominance of pine is in keeping with the charcoal evidence of high fire activity, and with knowledge of the modern ecological dynamics of pine rockland ecosystems.

The Blue Hole Wetland sediments, in contrast, do not preserve high concentrations of pollen. The reasons for this are unclear, but both sites are alkaline and pollen is best preserved in acidic environments. We prepared pollen slides from 11 levels, but none of the preparations yielded residues with pollen in countable quantities. Quick scans of the slides suggested that fern spores may be more important in these samples than in the samples from Key Deer Pond. However, this finding may also reflect preservation, as fern spores tend to be more resistant to decay than other palynomorphs.

At the onset of this study, we wondered if we might find pollen evidence of threatened native species or introduced exotics in our analysis. We have found pollen of *Polygala* and *Chamaesyce* in the Key Deer pond sediments, but it does not appear possible to distinguish threatened species from native species in these same genera. We have not yet found any pollen grains that could only derive from introduced plants.

Conclusions

Our examination of sediment cores from two solution holes on Big Pine Key confirms a long history of pine dominance and fire on Big Pine Key. Though not a surprising finding, our results appear to constitute the first stratigraphic evidence of long-term fire and vegetation history available from pine rockland environments in the Keys and possibly in all of Florida. The pollen and charcoal records from Key Deer Pond may also provide evidence of Late Holocene climate change, a topic that Joshua Albritton is exploring in his ongoing MS thesis research. The results of our paleoecological study on Big Pine Key complement our own ongoing work on Abaco Island, The Bahamas, and other studies in the Bahamas and wider circum-Caribbean region.

Information about past ecosystem conditions and disturbance regimes derived from the study of charcoal, pollen grains, and other proxy indicators in sediment cores from lakes and wetlands can provide information useful in designing management strategies directed toward the restoration of "natural" communities (Heyerdahl and Card, 2000). For example, such studies can reveal long-term interactions between vegetation and fire that can assist in the development of

fire management plans. The historical perspective on ecosystems provided by paleoecological records can also help managers communicate and justify to the public the need for particular management activities, for example, the possible need for prescribed fire in areas that have experienced historic fire suppression owing to concerns over the protection of human developments. We hope that the information on past vegetation and fire provided by our study can contribute to the management of pine rockland ecosystems and to public education efforts both inside and outside of the National Key Deer Refuge.

The results of this study suggest opportunities for expansion. We originally proposed to carry out high-resolution macroscopic charcoal analysis on the upper meter from one site. We chose to work on the Key Deer Pond sediments, and were able to stretch the grant funds to also include some coarse-resolution analysis of the Blue Hole Wetland sediments. It would be interesting to expand upon work at both sites – moving downcore with a high-resolution approach with the Key Deer Pond sediments, and increasing the sampling density on the Blue Hole Wetland core.

Investigating additional sites could also be worthwhile. Some coastal ponds may preserve evidence of vegetation and fire in adjacent uplands. Additional solution ponds may exist for sampling in upland communities. During our reconnaissance visit, Chris Bergh showed us many very small solution holes, that might trap very local records of fire. Some of these sites were less than 0.5 m in diameter, but we could probe them to a depth of more than 3 meters. There may also be some hardwood hammock sites that could be cored and studied to obtain comparison records of fire and vegetation history.

Finally, it would be worthwhile to integrate studies of sediment charcoal with studies of tree-ring evidence of fire history. We have had relatively good success developing chronologies from fire-scarred pines on Abaco Island (Miller, 2007), and it would be interesting to explore what could be done with tree ring analyses in rocklands of the keys.

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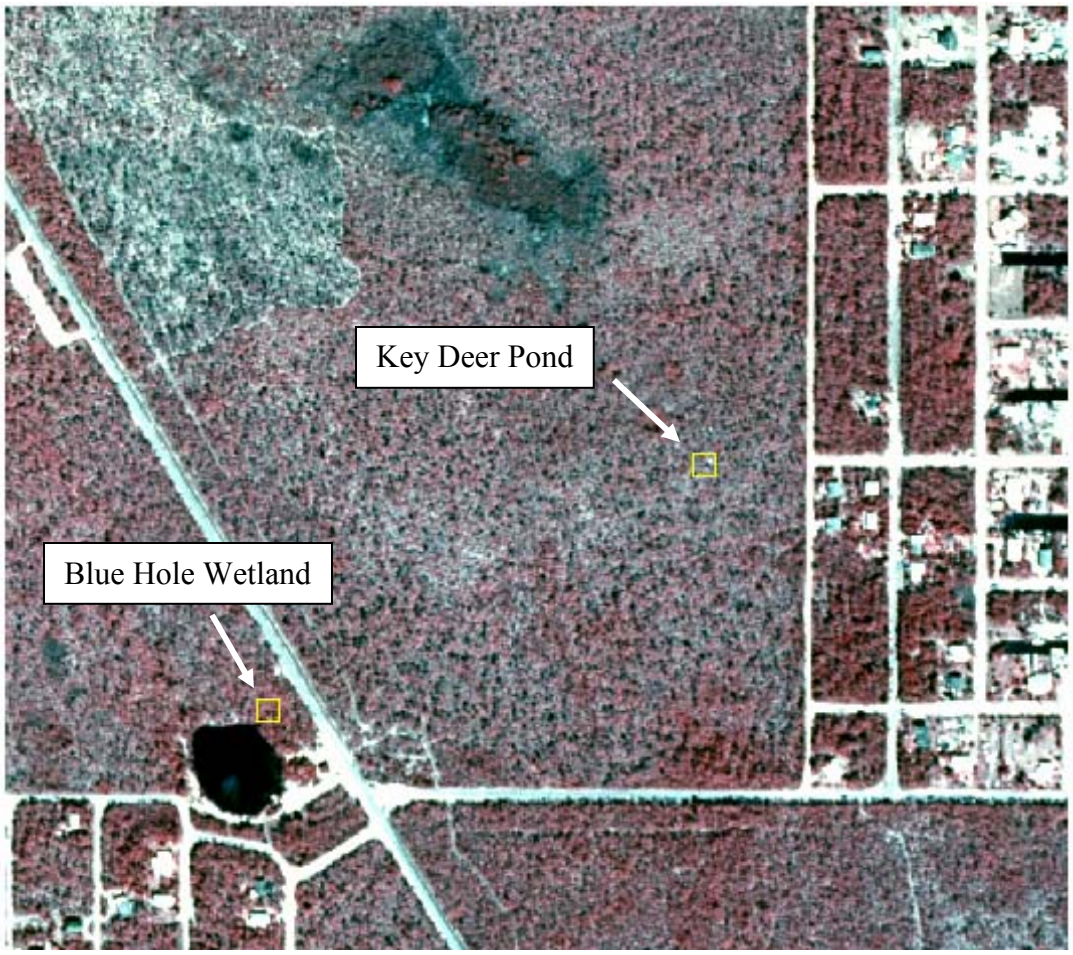


Figure 1. Location of Key Deer Pond and Blue Hole Wetland coring sites on Big Pine Key in the Lower Florida Keys. This false-color visible infrared image is from the United States Geological Survey; core site locations from GPS data by K. Orvis. Main East-West road near bottom of the image is Big Pine Street. North-South road on the right (forming eastern border of forest patch) is Pine Avenue. Key Deer Boulevard trends Northwest-Southeast. Typical pine rockland vegetation in managed fire rotation in this infrared image is mottled pink and gray, except for stands recently burned or otherwise disturbed (darker gray patches at top of image, including wetland). Long-unburned tree stands near housing show deeper shades of red.

Table 1. Chemical analyses of water samples from Key Deer Pond and Blue Hole Wetland. The samples were collected in August 2007 and analyzed at the University of Wisconsin Soil and Plant Analysis Laboratory using ICP-OES and ICP-MS.

	Key Deer Pond	**Blue Hole Wetland**
pH	7.9	7.8
Alkalinity (mg $CaCO_3$/L)	83	83
P (ppm)	<0.05	0.06
K (ppm)	1.95	44.16
Ca (ppm)	41.48	117.64
Mg (ppm)	8.3	126.29
S (ppm)	4.40	95.86
Zn (ppm)	<0.001	<0.001
B (ppm)	0.06	0.41
Mn (ppm)	0.001	0.003
Fe (ppm)	0.004	<0.001
Cu (ppm)	<0.005	<0.005
Al (ppm)	<0.005	<0.005
Na (ppm)	73.55	932.03
Si (ppm)	0.32	0.19
F (ppm)	0.04	<0.01
Cl (ppm)	138.52	2589.24
NO_2 (ppm)	<0.01	<0.01
Br (ppm)	1.21	12.26
NO_3 (ppm)	0.56	<0.01
PO_4 (ppm)	<0.01	<0.01
SO_4 (ppm)	11.23	270.47

Figure 2. Coring Key Deer Pond in August 2007.

Figure 3. Coring Blue Hole Wetland. Dense vegetation surrounded the core site. Note iguana observing the activity in bottom image.

Table X. Radiocarbon determinations and calibrated ages of macrofossils from Key Deer Pond sediment core.

Lab number[a]	Site, Core and depth (cm)	Depth below sed/water interface	Sample ID[b]	$\delta^{13}C$ (‰)	Uncalibrated ^{14}C Date (^{14}C yr BP)	Calibrated age range[b] ± 2 σ	Area under probability curve	Weighted mean calibration age[c]
β-251140	Key Deer Pond 1–2 m/30–31	41 cm	Charcoal	–26.5	340 ± 40	408–308 cal yr BP	1.000	396 cal yr BP
β-251141	Key Deer Pond 1–2 m/48–49	59 cm	Charcoal	–25.7	230 ± 40	30– –2cal yr BP	0.116	219 cal yr BP
						222–139 cal yr BP	0.411	
						324–259 cal yr BP	0.396	
						366–362 cal yr BP	0.002	
						428–376 cal yr BP	0.076	
β-247699	Key Deer Pond 1–2 m/68–69	79 cm	Charcoal	–25.5	490 ± 40	557–485 cal yr BP	0.950	526 cal yr BP
						626–605 cal yr BP	0.050	
β-247700	Key Deer Pond 1–2 m/93–94	104 cm	Charcoal	–26.2	320 ± 40	481–302 cal yr BP	1.000	387 cal yr BP
β-251142	Key Deer Pond 2–3 m/81	192 cm	Pine needle and dicot leaf fragment	–27.6	670 ± 40	609–555 cal yr BP	0.459	619 cal yr BP
						682–622 cal yr BP	0.541	
β-251141	Key Deer Pond 3–4 m/13–15	224 cm	Partially charred pine cone bract	–25.9	790 ± 40	776–669 cal yr BP	1.000	714 cal yr BP
β-251141	Key Deer Pond 3.5-4.5 m/30–31	291 cm	Pine twig	–24.2	1120 ± 40	1095–936 cal yr BP	0.921	1028 cal yr BP
						1140–1103 cal yr BP	0.068	
						1168–1161 cal yr BP	0.011	
β-235603	Key Deer Pond 3.5-4.5m/88	349 cm	Wood	–27.4	1750 ± 40	1741–1553 cal yr BP	0.950	1660 cal yr BP
						1783–1755 cal yr BP	0.035	
						1810–1796 cal yr BP	0.016	

[a]Analyses were performed by Beta Analytic, Inc.

[b]Calibrations were calculated using CALIB 5.0.1 (Stuiver and Reimer 1993) and the dataset of Reimer et al. (2004).

[c]Weighted mean of the 2 σ calibrated radiocarbon probability density function.

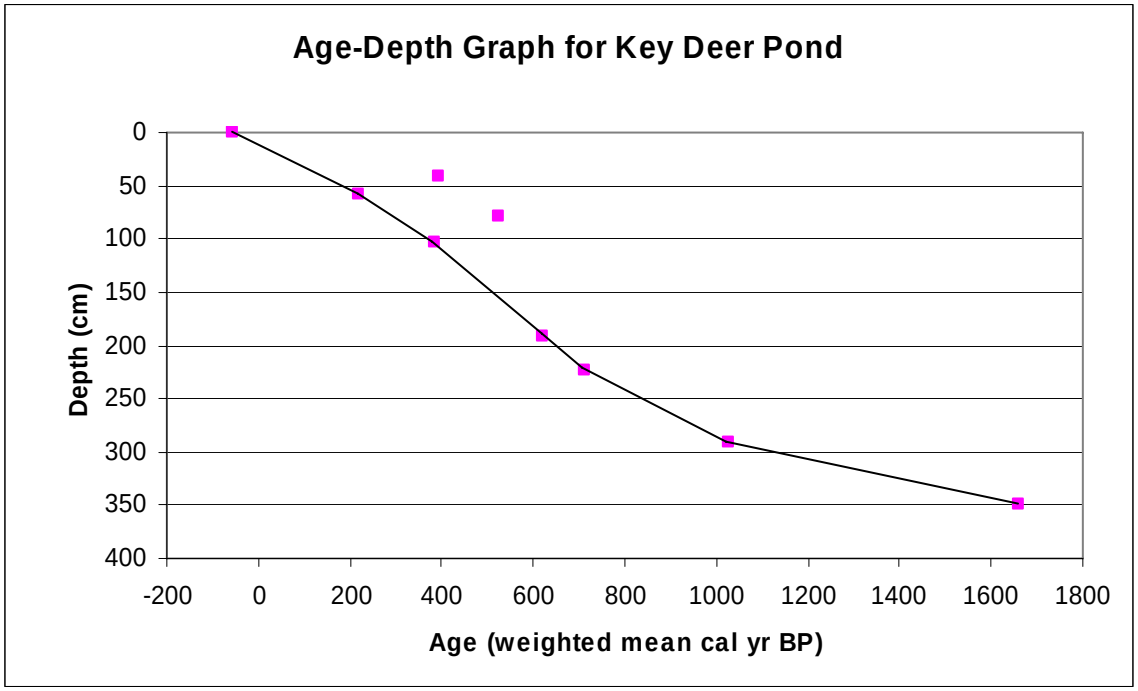
Table 3. Radiocarbon determinations and calibrated ages of macrofossils from Blue Hole Wetland sediment core.

Lab number[a]	Site, Core and depth (cm)	Depth below sed/water interface	Sample ID[b]	$\delta^{13}C$ (‰)	Uncalibrated ^{14}C Date (^{14}C yr BP)	Calibrated age range[b] ± 2 σ	Area under probability curve	Weighted mean calibration age[c]
	Blue Hole Wetland 2–3 m/61–63	261–263 cm	Charcoal					
β-235602	Blue Hole Wetland 3–4 m/81	381 cm	Wood	–28.7	1880 ± 40	1897–1714 cal yr BP 1916–1915 cal yr BP	0.999 0.001	1813 cal yr BP

[a]Analyses were performed by Beta Analytic, Inc (β-235602) and the University of Georgia Center for Applied Isotope Studies (results pending). The basal wood sample consisted of a single piece of wood. The charcoal submitted to the University of Georgia for dating consisted of two pieces sieved from the same 2 cm interval.

[b]Calibration was calculated using CALIB 5.0.1 (Stuiver and Reimer 1993) and the dataset of Reimer et al. (2004).

[c]Weighted mean of the 2 σ calibrated radiocarbon probability density function.



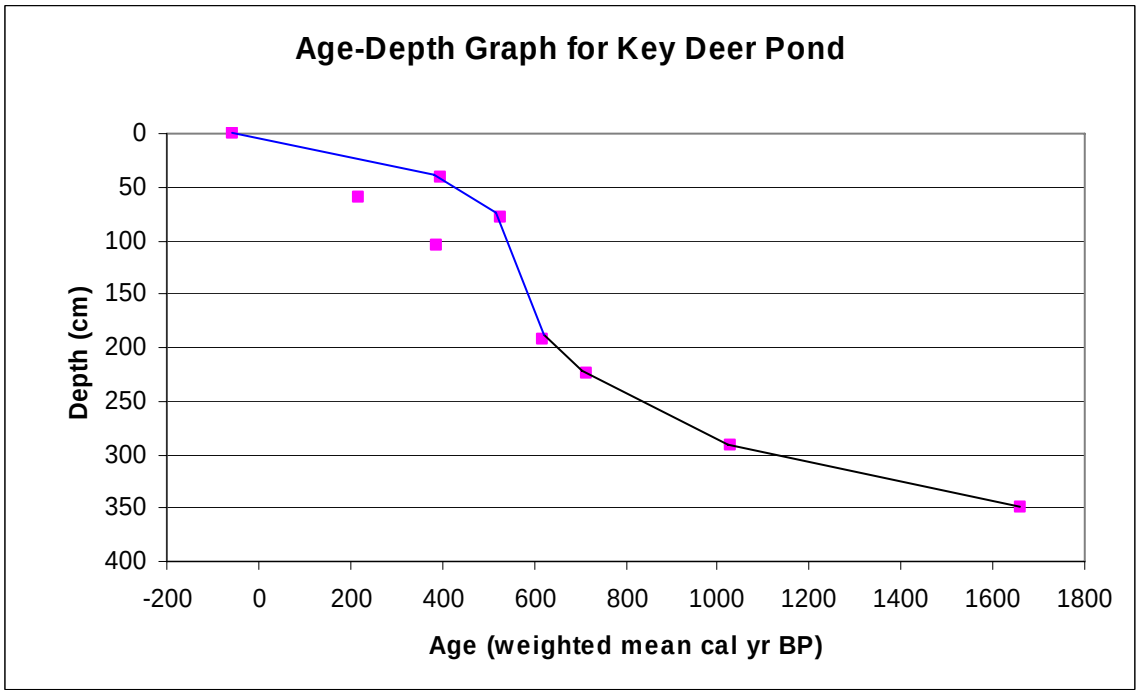


Figure 4. Two possible interpretations of an age-depth graph for Key Deer Pond, based on the single age estimates provided by the weighted means of the probability distributions of the calibrated dates. The upper interpretation, which we favor, excludes two dates that appear anomalously old. In the lower panel, two dates are considered anomalously young. Such an interpretation implies a very high sedimentation rate during the deposition of the second meter of the profile.

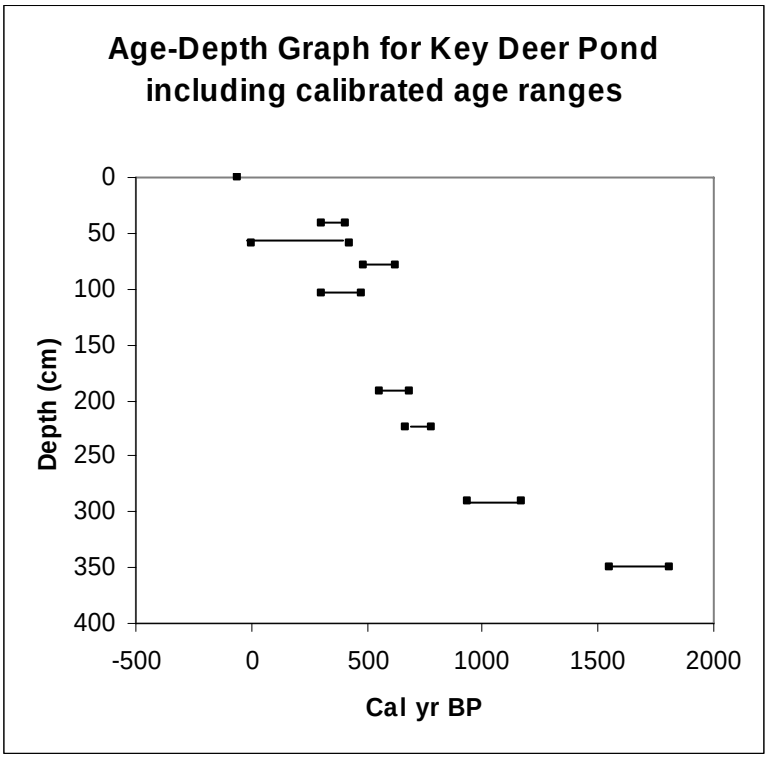


Figure 5. Alternate age-depth graph for the Key Deer Pond sediments, showing effect of considering entire calibrated age range. Two dates still appear somewhat too old, but the discrepancy is not as marked.

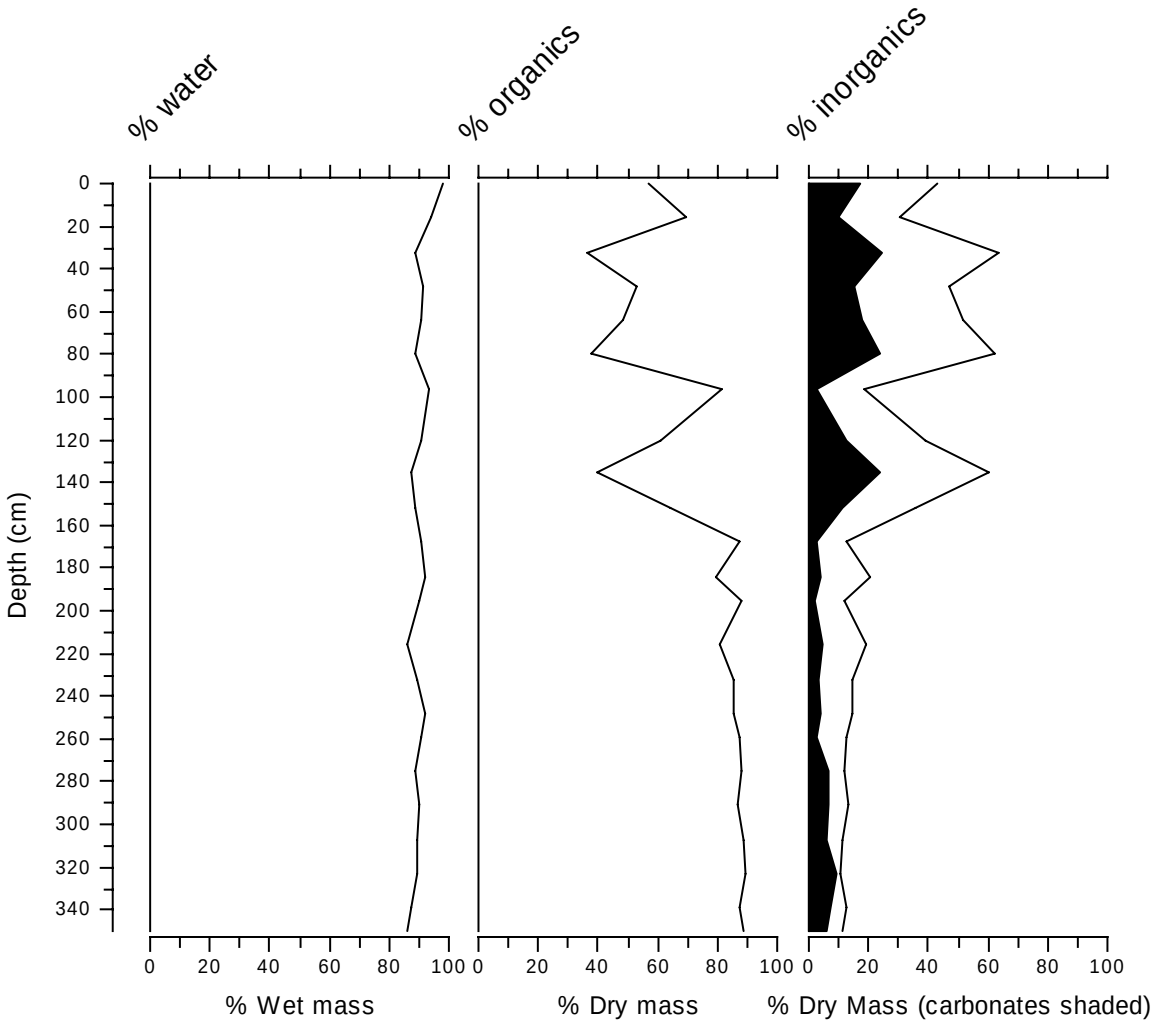


Figure 6. Water, organic, and inorganic content of samples from the Key Deer Pond sediment profile. The upper data point is from a surface grab sample collected in February 2007; all other samples are from core sections recovered in August 2007.

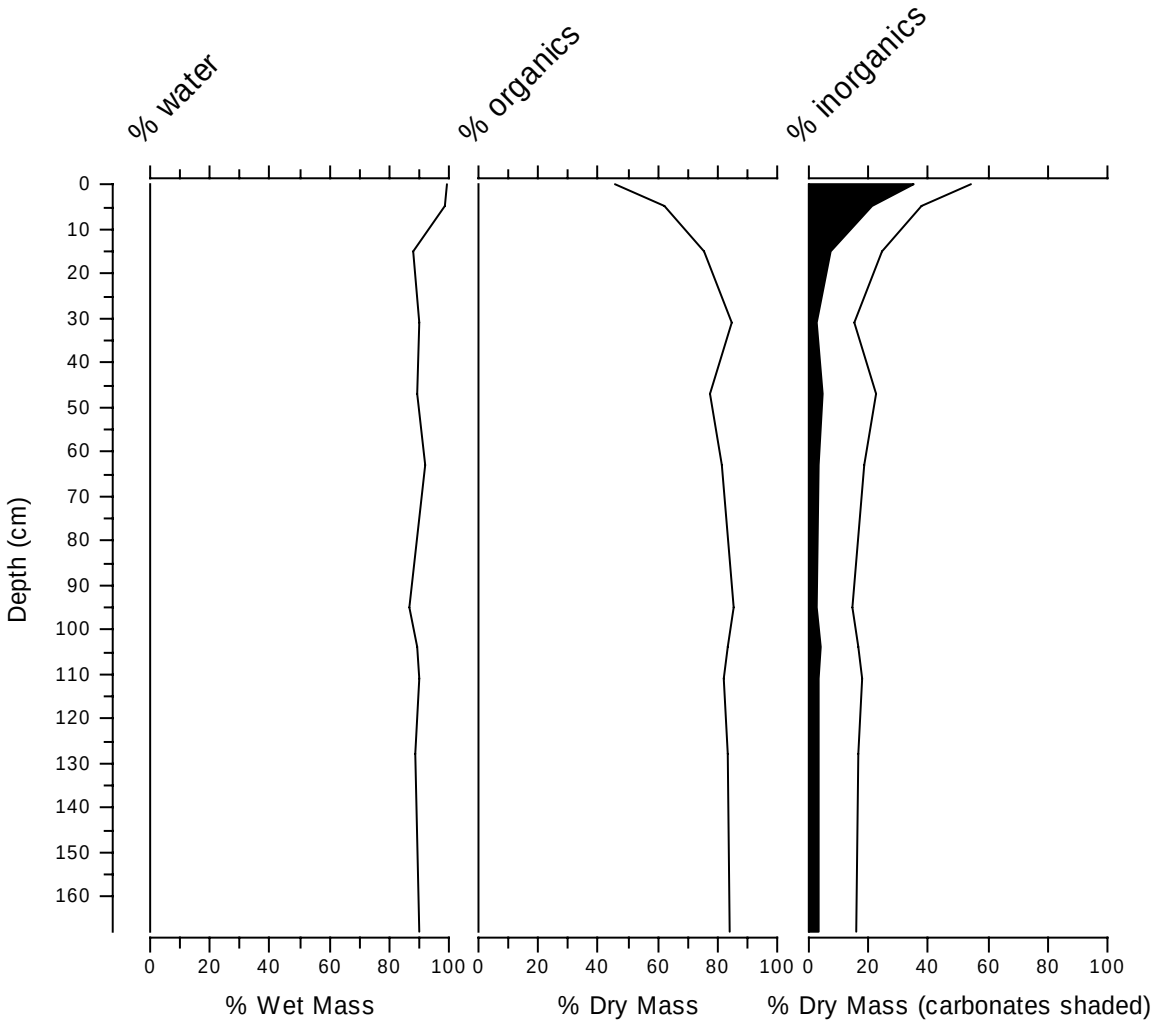


Figure 7. Water, organic, and inorganic content of samples from the Blue Hole Wetland sediment profile. The upper data point is from a surface grab sample collected in February 2007; all other samples are from core sections recovered in August 2007.

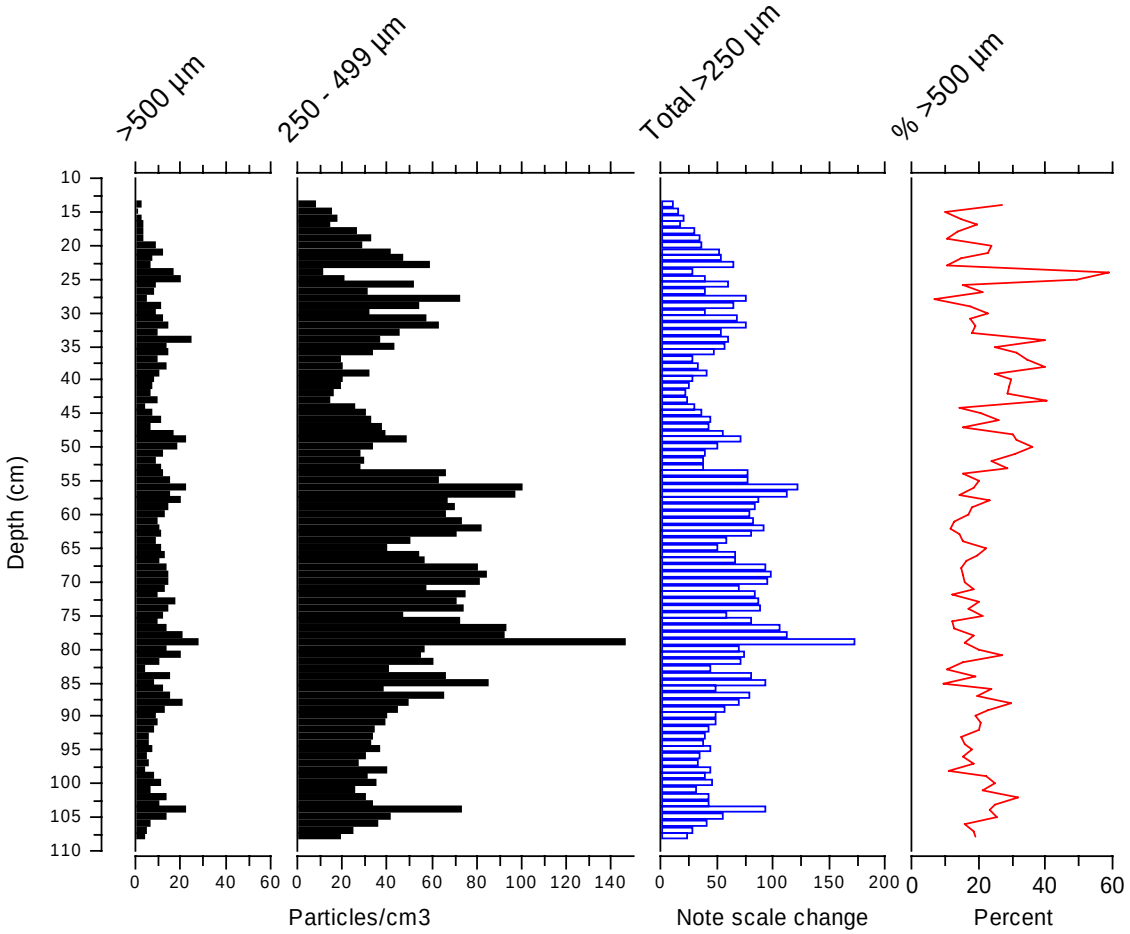


Figure 8. High-resolution macroscopic charcoal record for the upper meter of the Key Deer Pond sediment profile.

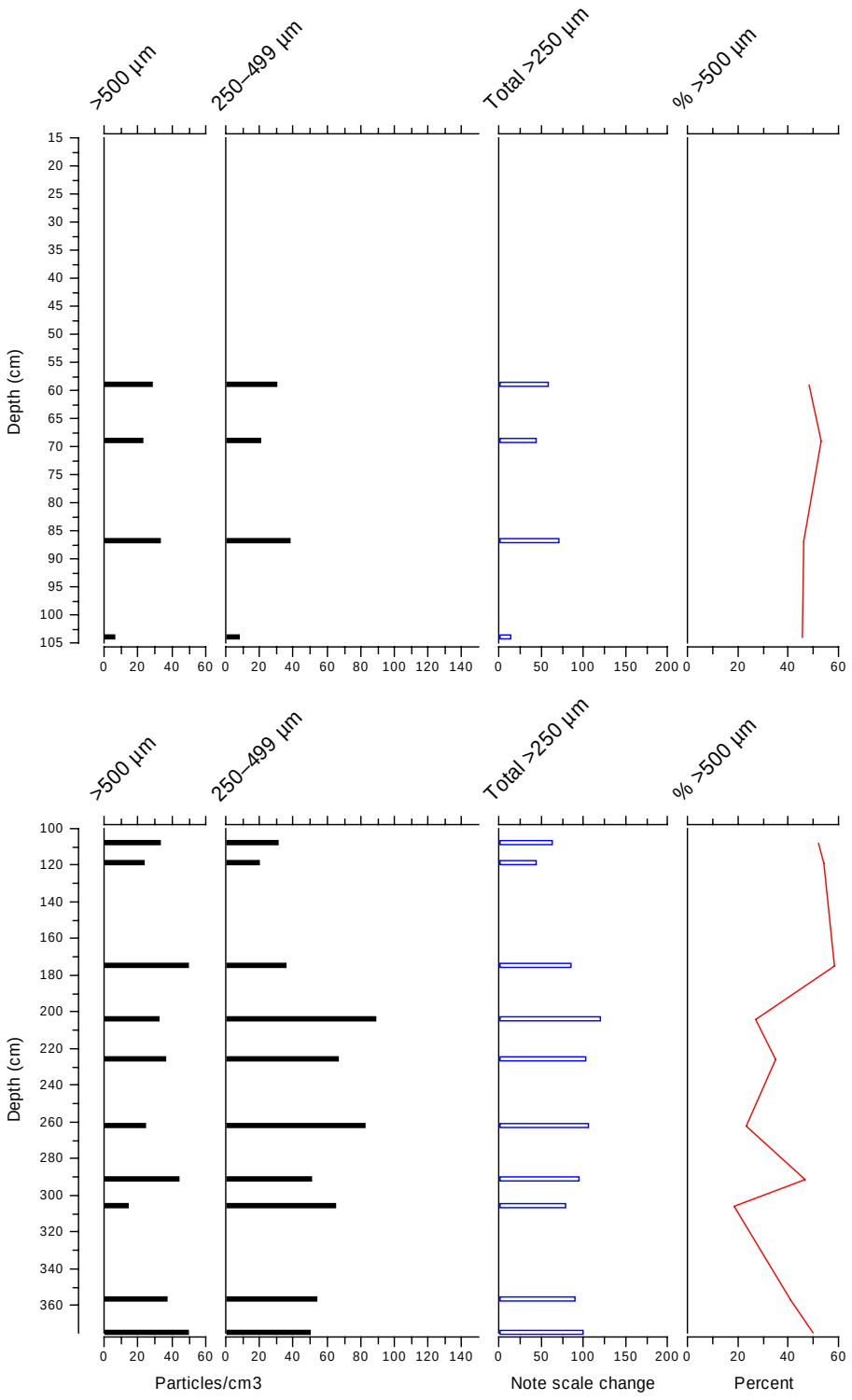


Figure 9. Macroscopic charcoal in Blue Hole Wetland. The lower graph shows charcoal results from Hole 1, where coring began 1 m below the surface root mat. The upper graph shows charcoal concentrations in Hole 2, where fine sediments were recovered starting at 15 cm below the sediment-water interface.

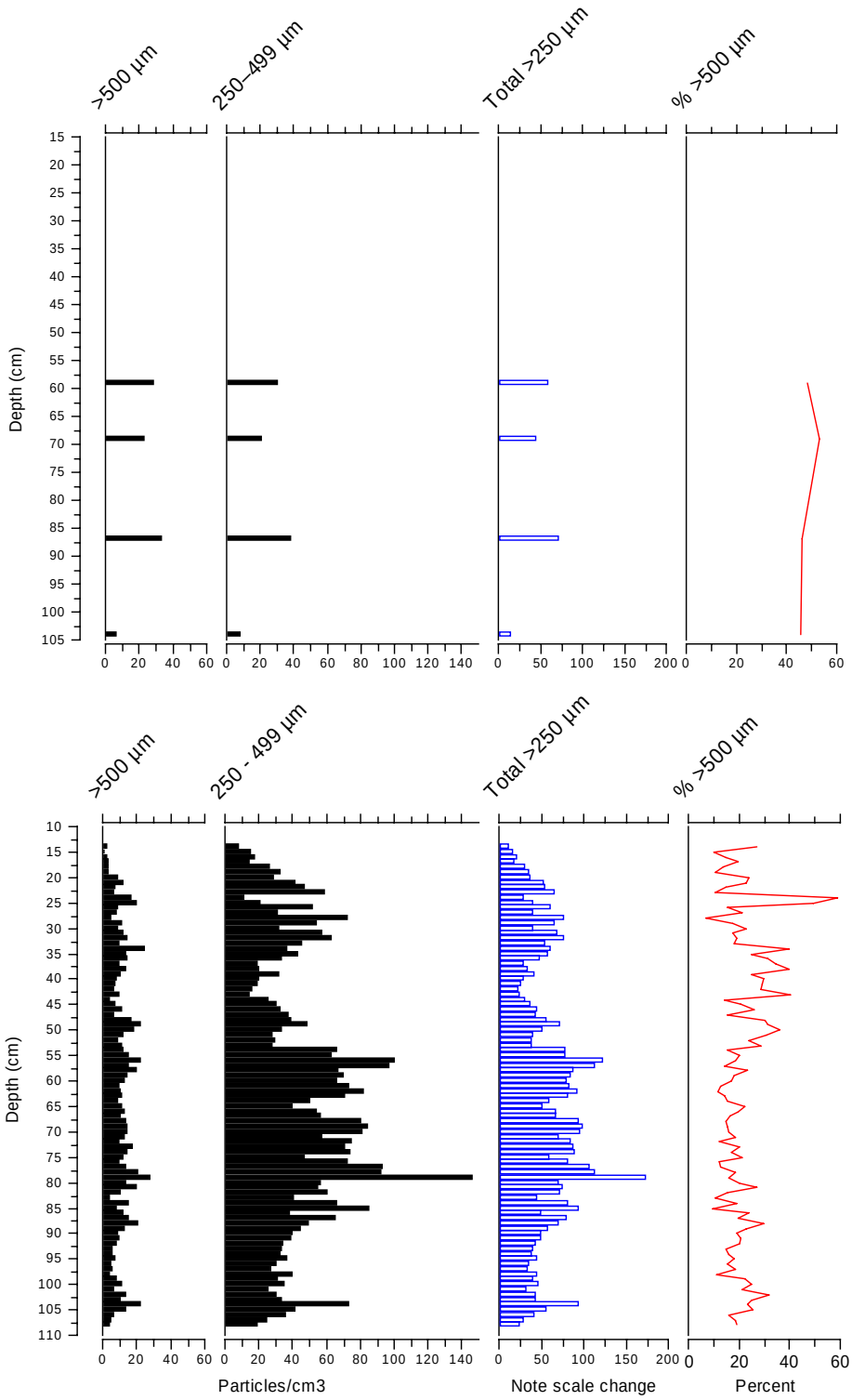


Figure 10. Macroscopic charcoal in upper sediments of Blue Hole Wetland (upper graph) compared to Key Deer Pond (lower graph).

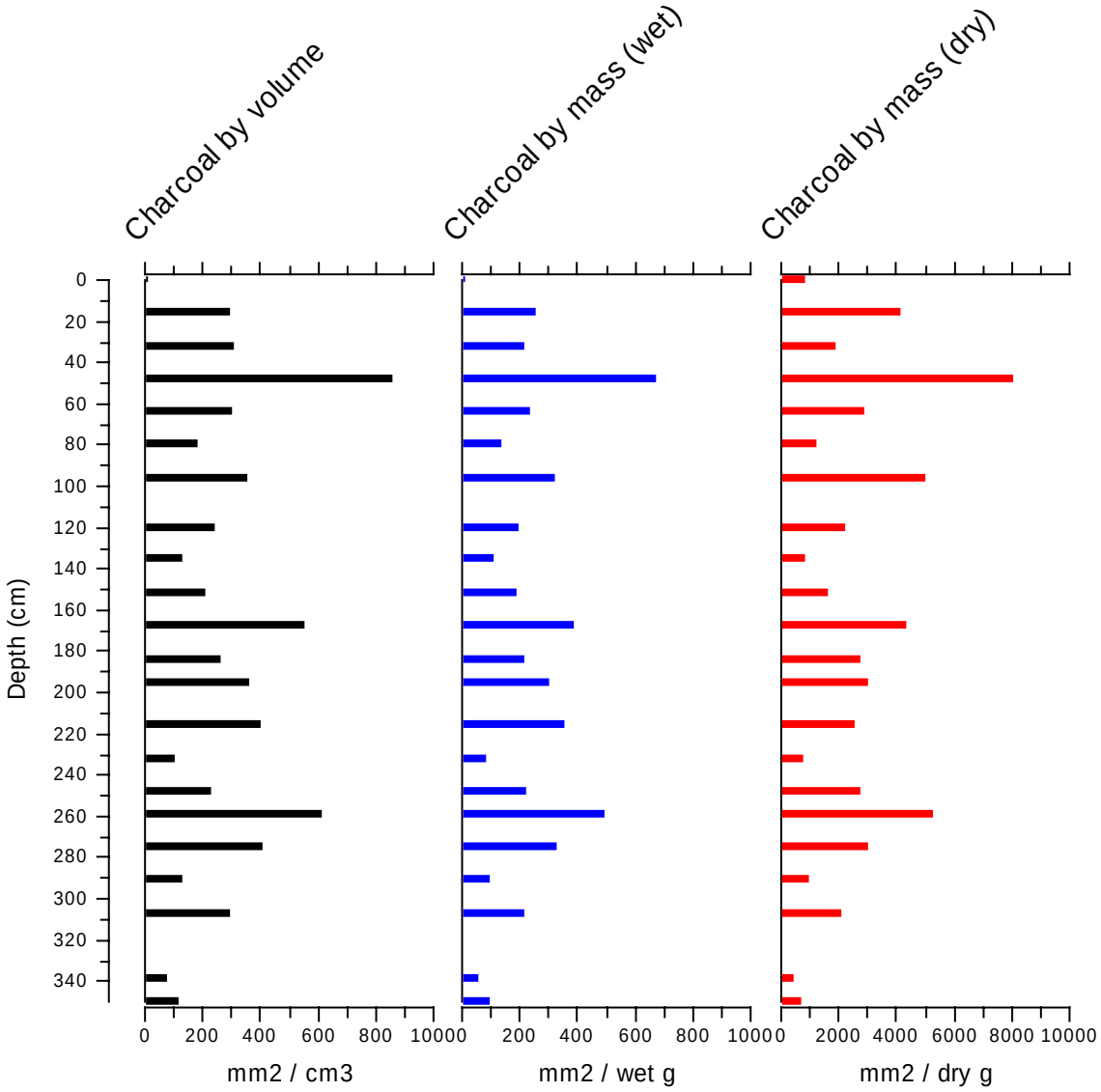


Figure 11. Microscopic charcoal record for the Key Deer Pond sediment profile. Data area based on point-counting of microscopic charcoal area and are expressed on the basis of wet sediment volume, wet sediment mass, and dry sediment mass.

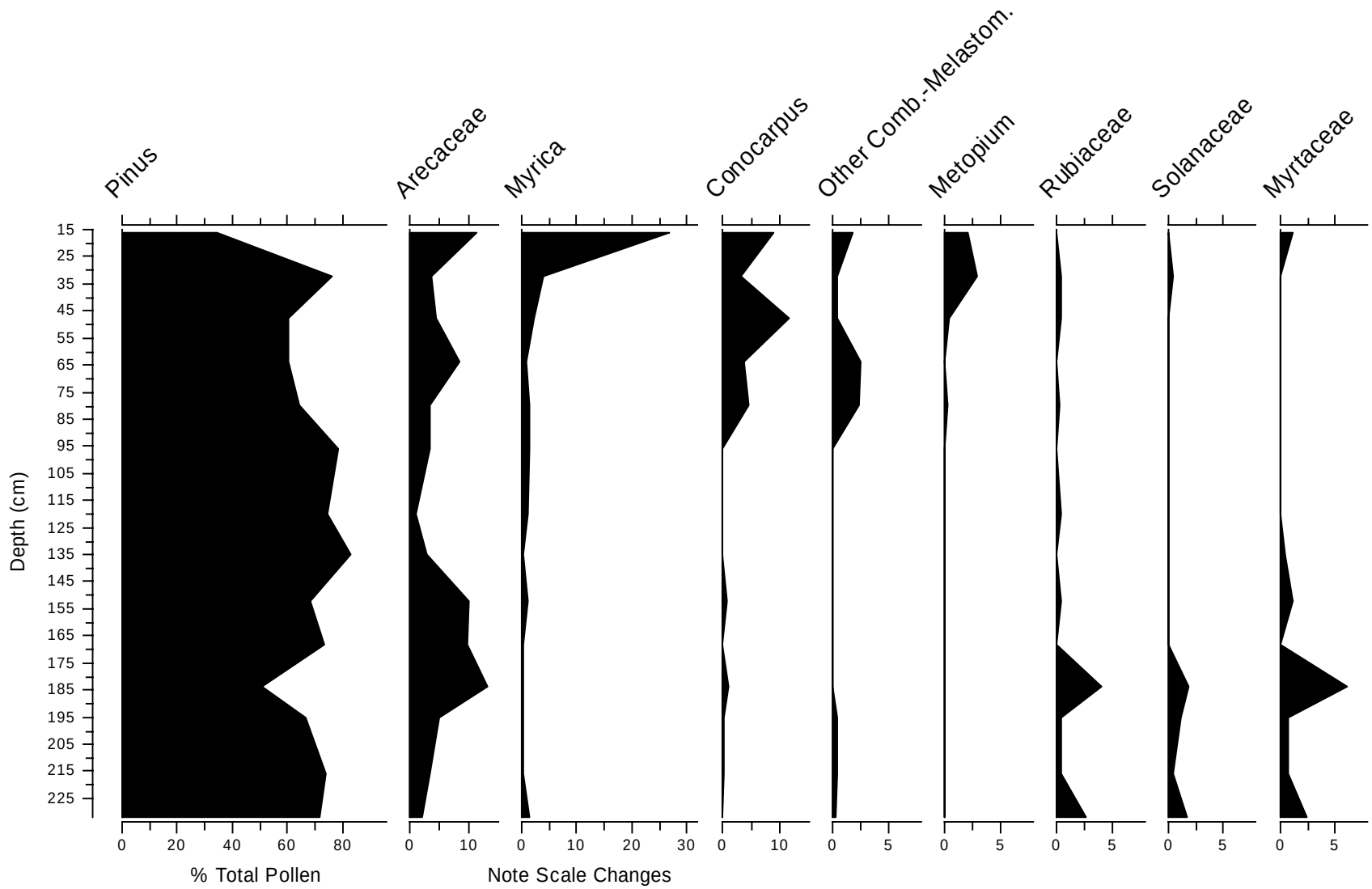


Figure 12. Percentage pollen diagram showing tree and shrub taxa in the Key Deer Pond sediment profile.

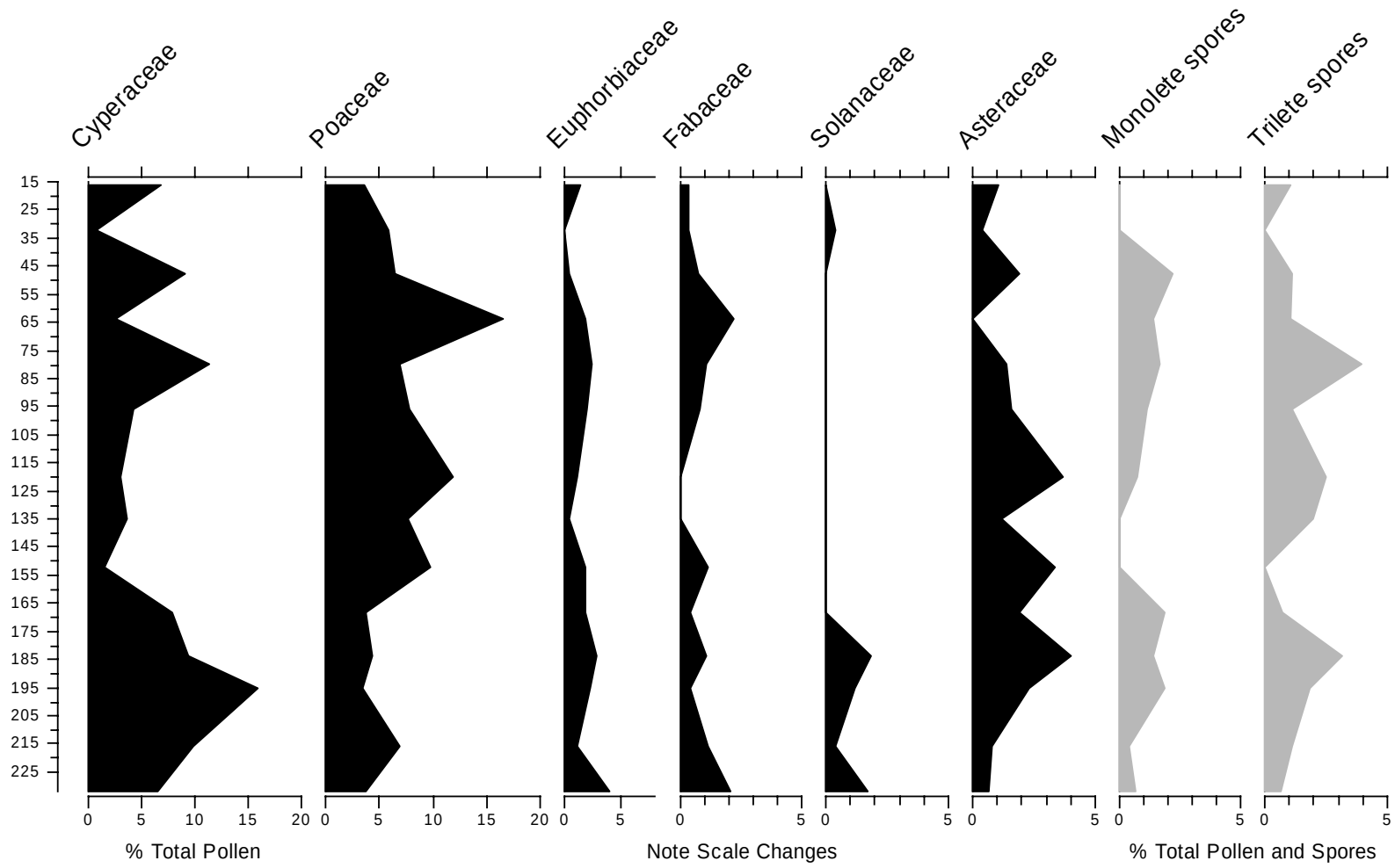


Figure 13. Percentage pollen diagram showing herbaceous taxa and ferns in the Key Deer Pond sediment profile.

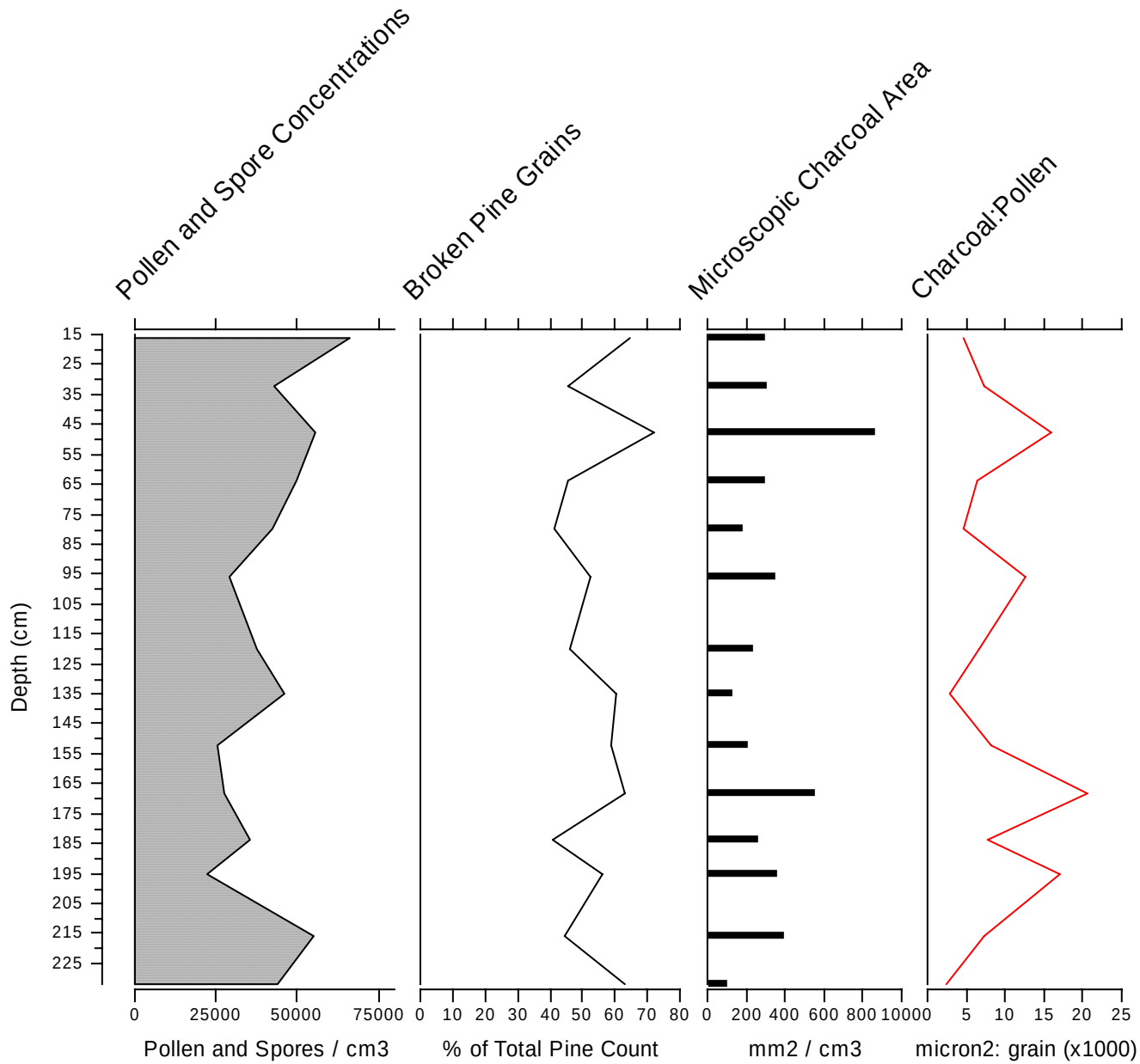


Figure 14. Diagram showing pollen and spore concentrations, broken pine pollen grains as a percentage of total pine grains, and charcoal:pollen ratios in Key Deer Pond sediments. Charcoal concentrations repeated from earlier figure to allow comparison.