Journal of Paleolimnology **16:** 59–66, 1996.

Human impact on the forests of Bermuda: the decline of endemic cedar and palmetto since 1609, recorded in the Holocene pollen record of Devonshire Marsh *

Bruce F. Rueger[1] & Theodore N. von Wallmenich[2]
[1]*Department of Geology, Colby College, Waterville, ME 04901 and Institute of Arctic and Alpine Research, University of Colorado, Boulder, CO 80309, USA (email: bfrueger@colby.edu)*
[2]*GeoEngineers, Inc., 8410 154th Ave., NE, Redmond, WA 98052, USA*

Received: 12 October 1994; accepted 3 August 1995

Key words: Bermuda, Devonshire Marsh, peat marshes, palynology, anthropogenic influence

Abstract

The wreck of the *Sea Venture* on Bermuda reefs in 1609 initiated continuous habitation by humans on these islands. Colonization brought significant changes to the native and endemic flora of Bermuda. Original floral diversity was low, due to the effects of isolation and lack of previous anthropogenic influences. Two dominant endemic components of the flora, Bermuda cedar (*Juniperus bermudiana*) and Bermuda palmetto (*Sabal bermudana*), were extensively utilized by the colonists. Cedar was used for housing, furniture, shipbuilding and export, while the palmetto was used for roof thatch, basketry, food and drink. Exploitation of these species occurred to such extent that the General Laws of Bermuda included resolutions protecting them as early as 1622. Later, in the period between 1946 and 1951, two accidentally introduced scale insects eliminated 95% of the existing cedar population.

While the flora and geography of upland habitats on Bermuda have been drastically modified by humans, the peat marsh basins have remained relatively unaffected. From the peats of one of these, Devonshire Marsh, a 9-m core was extracted for pollen analysis and to evaluate the potential for further study. The pollen record below 1.6 m indicated very little change in the native and endemic flora of Bermuda, but above that depth statistically significant changes in the relative abundances of pollen of Bermuda cedar and Bermuda palmetto are noted. Relative abundances of both species decreases significantly above this depth. This decrease is interpreted to represent the arrival of colonists and their impact on the cedar and palmetto populations. A second decrease in relative abundance of Bermuda cedar is recorded above 0.7 m. This reflects the scale infestation and decimation of the remaining cedar population. Coincident with decreases in cedar and palmetto are increases in relative abundance of Poaceae and Asteraceae, indicative of cleared land and the spread of weedy taxa. A radiocarbon date of 520 ± 70 yr BP at a depth of 1.7 m and major changes in relative abundance of palynomorphs in proximity to the marsh surface allows their interpretation as a record of human impact on the endemic flora of Bermuda.

Introduction

Bermuda consists of a small group of islands, situated approximately 1000 km east of North Carolina in the western Atlantic Ocean (Fig. 1). The underlying bedrock of Bermuda is dominated by eolian calcarenites. Deposition of these units culminated during high stands of sea level correlative to interglacial episodes during the Pleistocene, as determined by the use of amino acid racemization dating techniques (Hearty & Vacher, 1994). As sea level rose from minimal levels (approximately 121 m below modern sea level (Fairbanks, 1989)), sands accumulated on the beaches. This sediment was subsequently reactivated and deposited as broad-scale dunes by wind action. At low stands

* This is the 19th in a series of papers published in this special AMQUA issue. These papers were presented at the 1994 meeting of the American Quaternary Association held 19–22 June, 1994, at the University of Minnesota, Minneapolis, Minnesota, USA. Dr Linda C. K. Shane served as guest editor for these papers.

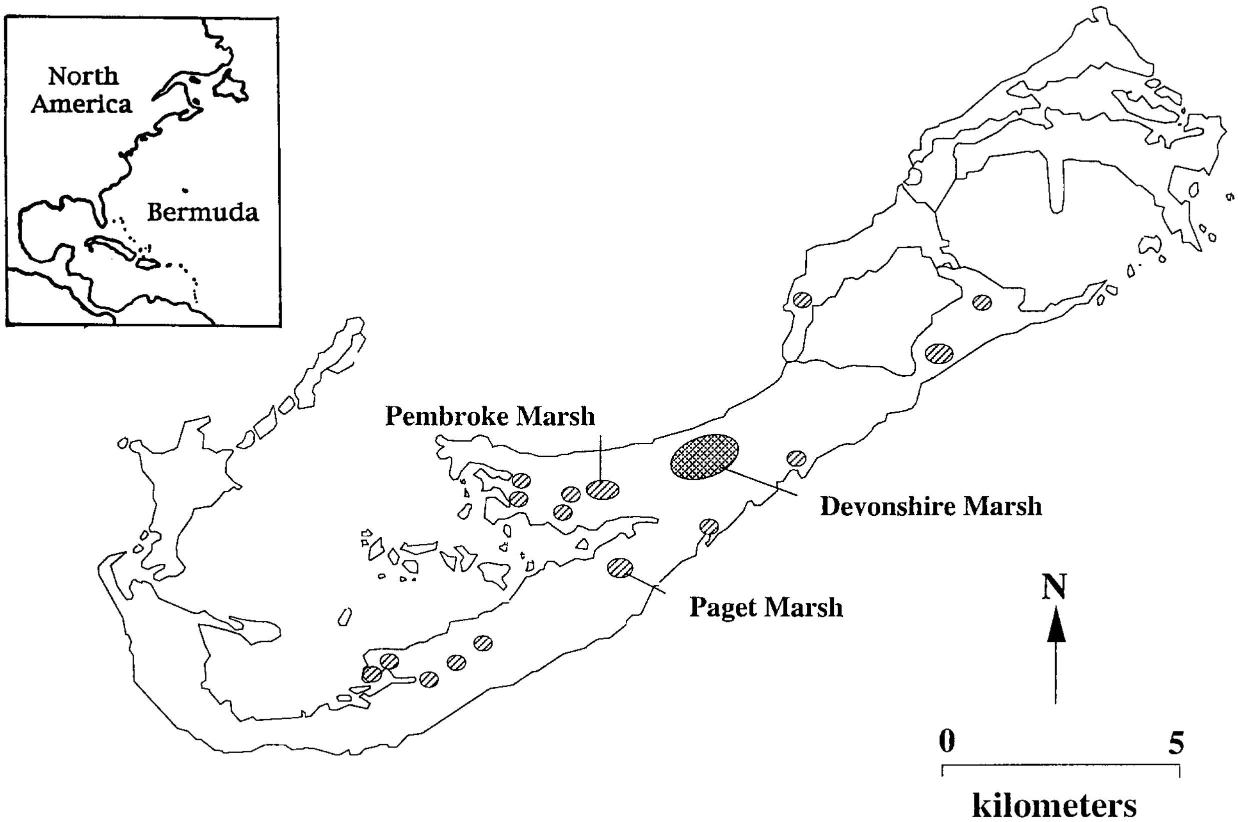


Fig. 1. Map of Bermuda illustrating extant peat marshes, wetlands and lakes (designated with the diagonal-line pattern). Devonshire Marsh, the focus of this study, is the largest on the islands (designated with the cross-hatched pattern). These areas presently represent refugia for some native and endemic plants of Bermuda.

of sea level Bermuda became a large forested plateau (Knox, 1940), calcarenites became indurated and soils developed. This alternation of dunes and paleosols was repeated during several major glacial-interglacial cycles occurring in the Pleistocene (Rowe, 1990).

Due to enclosure by an extensive reef system which prevented easy access to safe anchorages, continuous human occupation did not occur until the wreck of the *Sea Venture* on the northeastern reef tract in 1609. The *Sea Venture* was part of a British fleet en route to replenish supplies and bring colonists to Virginia when it was driven off course in a tempest and wrecked. Other than occasional instances of short stays on the island (Wilkinson, 1958; Zuill, 1946), 1609 represents the beginning of widespread human occupation of Bermuda. Upon arrival, these marooned individuals made extensive use of the main components of the endemic forest vegetation, the Bermuda cedar and the Bermuda palmetto. Since settlement, historical documents provide a record of the effects of colonization on Bermuda and impact upon the native and endemic flora of Bermuda (Lefroy, 1876; Verrill, 1902; Britton, 1918; Collett, 1987).

Because colonization by the British in 1609 is coincident with continuous occupation by humans, Bermuda becomes a significant locale for the evaluation of anthropogenic impact on the native and endemic flora. The Bermuda cedar (*Juniperus bermudiana*) was used extensively for housing, principally framing and furniture and for construction of ships and small water craft. The Bermuda palmetto (*Sabal bermudana*) was used for roof thatching on early houses, basketry, woven hats for export, food, and the production of an alcoholic beverage called bibby.

Cedar was consumed to such a degree and rate that legislation was introduced in 1622 limiting its use (Tucker, 1970). In addition to overuse by humans, the cedar population was also devastated during the decade

Table 1. Radiocarbon dates obtained from the Devonshire Marsh core and sea level altitudes for Barbados (Fairbanks, 1989) and Bermuda (Neumann, 1971). * indicates sea level altitude cannot be accurately determined due to the spurious basal ^{14}C date

Depth (m)	^{14}C Date (y BP)	Sea level (Fairbanks, 1989)	Sea level (Neumann, 1971)
0.3	present	present	present
1.7	520±70 (AA-14999)	− 3 m	− 1 m
5.9–6.0	3520±100 (I-16939)	− 6 m	− 5 m
8.9–9.0	3320±80 (AA-15000)	*	*

following 1946 by the introduction of two scale insects, the juniper scale (*Carulaspis visci*) and the oyster-shell scale (*Lepidosaphes newsteadi*) on shipments of ornamental junipers from the United States (Challinor & Wingate, 1971). In the absence of biological controls, the scale insects quickly destroyed 95% of the remaining cedar population, leaving only the hardiest to survive (Phillips, 1984). As Bermudians capture most of their drinking water by collecting what falls on their rooftops, use of pesticides was precluded and the introduction of more than 25 species of coccinellids (ladybird beetles) was too late to stop the decimation of the cedar population by scale insects (Challinor & Wingate, 1971). Naturally resistant individuals were subsequently nurtured and their progeny are being successfully replanted in hospitable environments around Bermuda.

While Bermuda is principally known for pristine beaches and clear waters, it is, in the peat marshes that the record of these vegetational changes are preserved. Devonshire, Pembroke, and Paget Marshes constitute the three largest marshes on Bermuda, with approximately fourteen smaller peatlands also occurring on the islands (Fig. 1). Many of these have been destroyed as landfill sites, but others have been protected as nature reserves and preserved in a near pristine state. These undisturbed extensive peat marshes offer an opportunity to evaluate the anthropogenic impact on the flora of an island ecosystem.

From Devonshire Marsh, beginning in 0.3 m of water, a continuous core 9.0 m in length was recovered in April, 1991. The core was subsampled for palynomorph content and abundance. These samples yielded data that corroborate the historical record and indicate that the native and endemic flora, particularly the Bermuda cedar and the Bermuda palmetto, has indeed been impacted by anthropogenic influences.

Site description

Of the marshes of Bermuda, Devonshire Marsh was selected as the focus of this investigation for three reasons. First, it is the largest marsh on Bermuda, being 19.6 ha area (Fig. 1). Second, Devonshire Marsh is centrally located and therefore, it was thought to contain the most representative pollen assemblages of the surrounding vegetation. Third, of the three large marshes, it has been the least disturbed by humans and yet provided most ready access for coring purposes.

All the present marshes on Bermuda have developed in interdune lowland areas. The three largest marshes, Devonshire, Paget and Pembroke, are fresh water marshes and reflect an intersection of the major fresh water lenses of Bermuda with the land surface (Vacher, 1974). Late Holocene development of Devonshire Marsh is tied directly to the Pleistocene geology of Bermuda and the consequent rise in sea level beginning 14 000 y BP. As sea level continued to rise during the Holocene, the fresh water lenses on Bermuda have risen with it. Where the fresh water lenses intersect these interdune lowlands, marsh development occurs. Development of marsh vegetation has kept pace with the rise in sea level (Neumann, 1971). As sea level has been rising since the last glacial maximum, the present marshes are Holocene in age as far as is presently known. Basal peats in Devonshire Marsh have yielded an age of 7200 ± 120 y BP (A. C. Neumann, unpublished data).

The modern vegetation surrounding the coring site in Devonshire Marsh was sampled by 11 relevé analyses (Rueger, 1994). The flora near the coring site is dominated by ferns, principally southern bracken fern (*Pteris caudata*) and cinnamon fern (*Osmunda cinnamomea*), and saw grass (*Cladium jamaicensis*). Occasional tree species in the area include endemic Bermuda cedar, endemic Bermuda palmetto, intro-

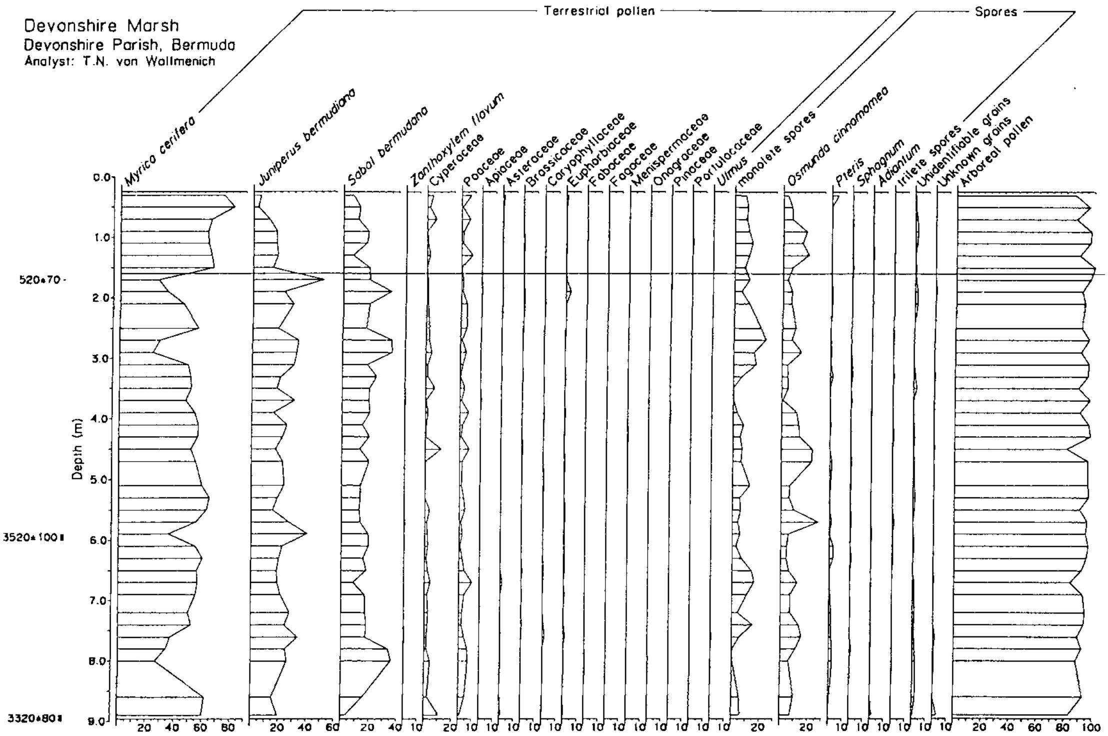


Fig. 2. Pollen diagram produced from the Devonshire Marsh core; two pollen zones on the far right are delineated by cluster analysis using CONISS dendrograms (Grimm, 1987). The basic pollen sum (Σ) is based on approximately 300 pollen grains and spores (ranging from 294–308) (from Rueger & von Wallmenich, 1993).

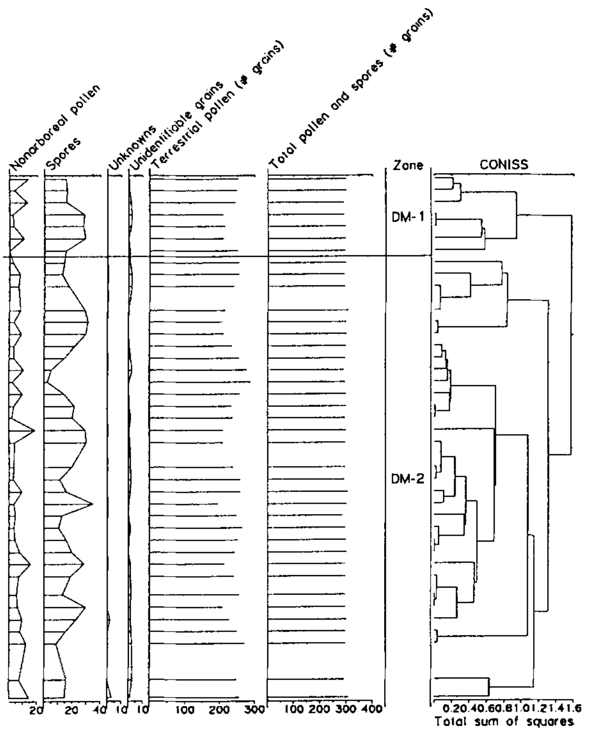
duced Brazil pepper (*Schinus terebinthifolius*), and introduced Indian laurel (*Ficus retusa*). Shrub species in the vicinity of the coring site include native wax myrtle (*Myrica cerifera*), endemic St. Andrews cross (*Ascyrum hypericoides*), and introduced red sagebush (*Lantana camara*). The minimum sampling area for the *Osmunda cinnamomea-Cladium jamaicensis* plant community near the coring site is 100 m^2 (Rueger, 1994).

Coring was undertaken near the center of Devonshire Marsh using a Hiller coring device. Samples were collected in the field at 10 cm intervals and analyzed generally at 20 cm to 40 cm intervals.

Material and methods

Processing was performed using standard palynological extraction techniques (Faegri & Iversen, 1975). Treatment includes 5% KOH solution to eliminate humines, followed by washing the remaining residue through a 250-μm screen. The residue was then treated with 10% HCl and 48% HF to remove carbonates and silicates, respectively. The remaining organic residue was treated with an acetolysis solution composed of 9 parts acetic anhydride and 1 part concentrated sulfuric acid. Residues were mounted on glass slides using silicon oil as a mounting medium. Between 294 and 308 terrestrial palynomorphs were counted for each of the 39 levels studied. Terrestrial pollen sums were based on the sum of nonarboreal pollen (NAP) and arboreal pollen (AP). Spores were excluded from this sum but included within the sum of total pollen and spores (number of palynomorphs).

Cluster analysis of pollen spectra from the Devonshire Marsh core was performed using CONISS dendrograms (Grimm, 1987) produced within the TILIA pollen diagramming computer program (Grimm, 1993). 95% confidence limits for Bermuda cedar, Bermuda palmetto and Wax Myrtle were calculated using nomograms developed by Maher (1972).



Results

The upper 1 m of the core was peat (Munsell color grayish brown, 5YR 3/2), dominated by undecomposed fern rhizomes and grass roots. Below that depth the core was relatively homogeneous, partially decomposed woody peat (Munsell color blackish red, 5R 2/4) to the base of the core at 9 m. This material consists of woody peat dominated by plant material with many roots preserved. This lithologic transition reflects the changeover at 1 m depth from a persistent swamp-forest peat to an herbaceous marsh peat.

Three samples at depths of 1.7 m, 5.9–6.0 m and 8.9–9.0 m were submitted for radiocarbon analysis (Table 1). The basal date at 8.9–9.0 m, at one standard deviation, is younger than the date obtained for a depth three meters above it. At two standard deviations, the dates at 5.9–6.0 m and 8.9–9.0 m are essentially the same. The basal date is thus considered suspect; the last drive of the core was incomplete and probably contaminated.

Pollen analysis of the core showed continuing presence of six major taxa (Fig. 2). These taxa include wax myrtle, Bermuda cedar, Bermuda palmetto, grasses (Poaceae), sedges (Cyperaceae) and monolete and trilete fern spores. The only major changes recorded are for Bermuda cedar and Bermuda palmetto, both showing significant decreases in the relative abundance at 1.6 m. Using cluster analysis provided by CONISS (Grimm, 1987), two zones are presented in the core. Therefore, these are defined on the basis of changes in abundance of the three most abundant taxa; wax myrtle, Bermuda cedar, and Bermuda palmetto. The upper zone (Zone DM-1), extending from the marsh surface to a depth of 1.6 m, is characterized by the highest relative abundance of wax myrtle in the diagram (Fig. 2). The lower zone (Zone DM-2), occurs from 1.6 m to the bottom of the core at 9.0 m (Fig. 2). This zone is characterized by higher relative abundances of Bermuda cedar and Bermuda palmetto.

Since peat accumulation in Devonshire Marsh is thought to be tied to rising sea level since the last glacial maximum, ^{14}C dates obtained from the core (Table 1) were used to develop a curve of peat accumulation through time (Fig. 3). By comparing the dates obtained from the Devonshire Marsh core with altitudes of sea level at corresponding times provided by Fairbanks (1989) from Barbados and Neumann (1971) from Bermuda (Table 1), this conclusion is substantiated.

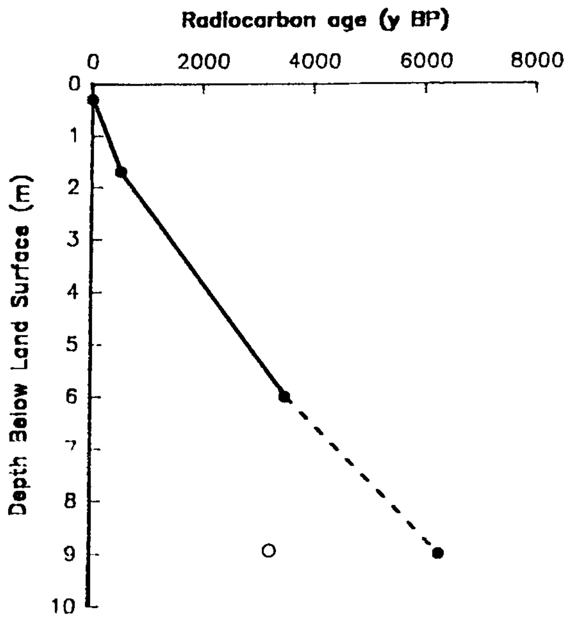


Fig. 3. Plot of radiocarbon ages *vs* depth below land surface in the Devonshire Marsh core. Open circle represents suspect basal date as provided in Table 1; dashed line projects sediment accumulation curve to probable age at this depth.

Discussion

Historical documentation indicates only infrequent, discontinuous human habitation on Bermuda prior to the wreck of the *Sea Venture* in 1609 (Zuill, 1946; Wilkinson, 1958). The effects of colonization and immigration on the flora since that time has been dramatic. Consequently, the native and endemic flora has been restricted within refugia such as Devonshire, Paget and Pembroke Marshes, limestone sinks and small isolated pockets in coastal areas.

To test the hypothesis that anthropogenic factors indeed had an influence on the native and endemic flora of Bermuda, values for the relative abundances of wax myrtle, Bermuda cedar and Bermuda palmetto were analyzed by comparison to 95% confidence limits derived from nomograms developed by Maher (1972). Figure 4 illustrates that statistically significant changes in relative abundance are evident in the upper 1.6 m of the Devonshire Marsh core for these taxa when compared to the remainder of the core.

The distribution curve for Bermuda cedar in Fig. 4 shows two changes, one beginning at a depth of 1.6 m and a second at a depth of 0.7 m. The lower of these

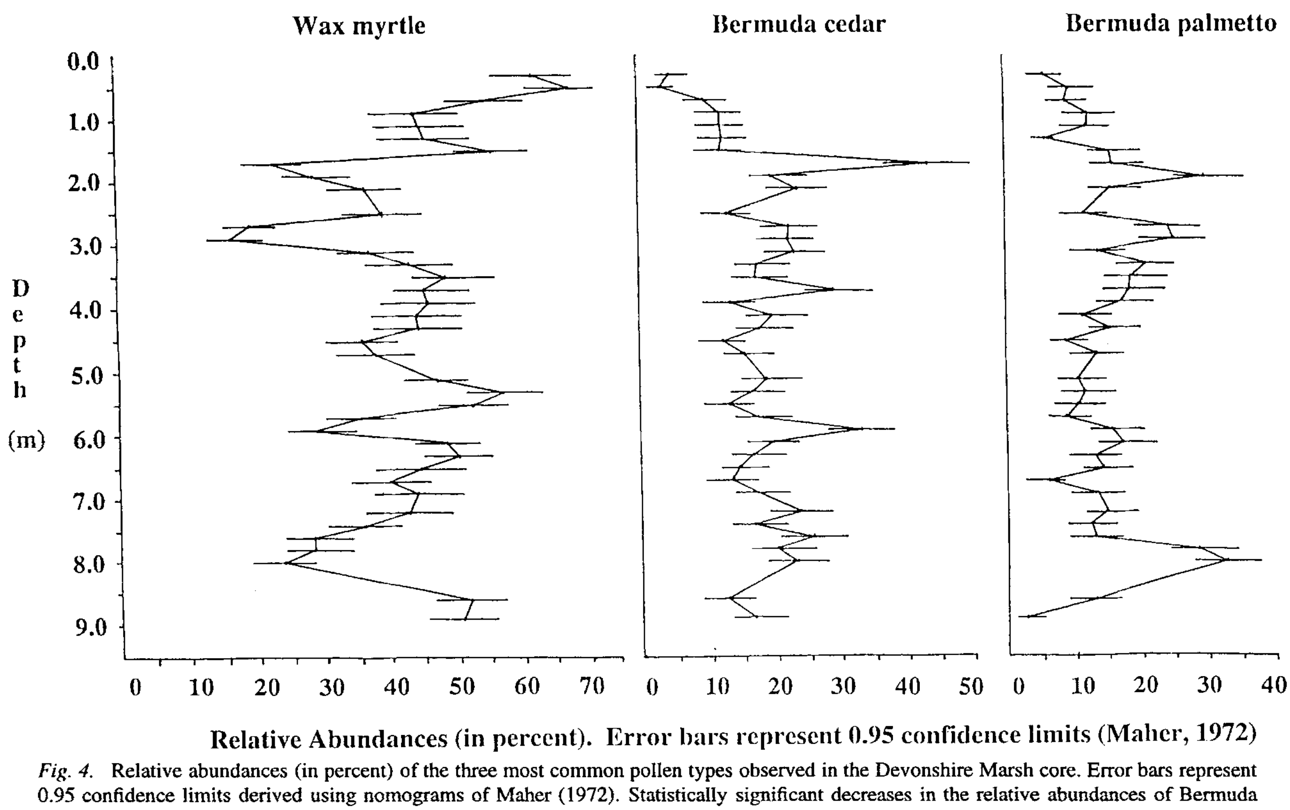


Fig. 4. Relative abundances (in percent) of the three most common pollen types observed in the Devonshire Marsh core. Error bars represent 0.95 confidence limits derived using nomograms of Maher (1972). Statistically significant decreases in the relative abundances of Bermuda cedar and Bermuda palmetto are noted in the upper 1.6 m of the section.

two decreases in relative abundance of Bermuda cedar is probably indicative of the anthropogenic effects of colonization beginning in 1609, while the upper represents the scale insect infestation beginning in 1946. A similar decrease at a depth of 1.6 m is noted in the relative abundance of Bermuda palmetto and is also attributed to colonization. The increase in relative abundance of wax myrtle at this point is attributed to the decreases in relative abundance of both Bermuda cedar and Bermuda palmetto since the pollen sum must equal 100%. Wax myrtle, part of the understory in the marshes, readily expands into niches vacated by loss of the principle canopy species, cedar and palmetto (D. Wingate, personal communication).

The anthropogenic impact on the endemic cedar and palmetto is corroborated by further examination of the data using cluster analysis (Fig. 2). Cluster analysis grouped the pollen spectra in the upper 1.6 m of section into a pollen zone, DM-1, distinct from the remainder of the core, which constitutes a second zone, DM-2.

Yellow-wood (*Zanthoxylem flavum*) and southern hackberry (*Celtis laevigata*) were both abundant trees on the landscape of Bermuda in 1609 and were heavily utilized by colonists. Yellow-wood, which has been reduced to approximately 20 specimens on the islands, occurs in very small amounts in Fig. 2. Pollen of southern hackberry was not found in the core in any amount (Fig. 2). Watts & Hanson (1986), found the opposite occurrence at Mangrove Lake on the south shore of Bermuda. Southern hackberry was observed, but no trace of yellow-wood is recorded. This is due to the fact that both of these plants are vector pollinated or produce small amounts of pollen; if trees are not in close proximity, they may not be represented at all in the pollen record.

From these statistical analyses, it can be determined that two distinct pollen zones exist within the Devonshire Marsh core. The lower zone represents the relatively unchanging native and endemic flora prior to colonization in 1609. With the onset of human impact, the flora was modified by the extensive utilization of some species and the introduction of others, causing major changes in the distribution of Bermuda cedar and Bermuda palmetto in and around Devonshire Marsh. Also apparent in Fig. 2 is a subtle increase of Poaceae, Cyperaceae and Asteraceae, attributable to the loss of forest-type vegetation, such as Bermuda cedar and Bermuda palmetto, and the increase of land cleared for agricultural purposes around Devonshire Marsh.

Conclusions

Analysis of pollen profiles from Devonshire Marsh, Bermuda, by computing 0.95 confidence limits (Maher, 1972) indicate statistically significant changes in relative abundances of wax myrtle, Bermuda cedar and Bermuda palmetto in the upper 1.6 m of the core. Cluster analysis using CONISS (Grimm, 1987) groups pollen spectra above a depth of 1.6 m together within a distinct zone. Statistically significant variation in Bermuda cedar and Bermuda palmetto pollen profiles in the upper part of the core corroborate historical sources documenting widespread usage of these taxa for shipbuilding, housing and thatching by colonists. The cedar blight beginning in 1946, which eliminated 95% of Bermuda's cedar population, is also recorded in the changes in relative abundance of Bermuda cedar pollen in the Devonshire Marsh sediments.

Acknowledgments

Research included in this investigation was funded by grants from the Colby College Natural Sciences Division grant program, a grant from the Dean of the Graduate School's Small Grant Fund at the University of Colorado, Geological Society of America Graduate Research Grants Number 5237-93 and 5453-94, a Bermuda Zoological Society Research Grant, and by a Bermuda Biological Station for Research Grant-In-Aid. The conventional radiocarbon date used in this investigation was financed through the Colby College Student Special Projects Fund. The authors also thank Dr Joanna Ellison for the use of the Hiller corer and Dr Harold Pestana for bringing the project to the attention of the senior author. The senior author also expresses gratitude to Ms Lisa Greene, Collections Officer, Bermuda Aquarium, Museum and Zoo and Dr David Wingate, Conservation Officer, Bermuda Department of Agriculture, Fisheries and Parks, for without their immeasurable help this investigation would not have been possible. Dr Robert E. Nelson, David Wingate, Dr Vera Markgraf, and an anonymous reviewer provided critical review and greatly improved the content of this article. The author is eternally grateful for the expertise provided by Mr Tristram Hussey in the production of the pollen diagram. Dr Paul K. Doss produced the diagram illustrated in Fig. 3.

This is contribution #1414 of the Bermuda Biological Station for Research.

References

Britton, N. L., 1918 (reprinted 1965). The Flora of Bermuda. Hafner Publishing Company, N.Y., 585 pp.

Challinor, D. & D. Wingate, 1971. The struggle for survival of the Bermuda cedar. Biol. Conserv. 3: 220–222.

Collett, J., 1987. Bermuda, Her Plants and Gardens, 1609–1850. Macmillan-Bermuda National Trust, London, 104 pp.

Faegri, K. & J. Iversen, 1975. Textbook of Pollen Analysis. Scandinavian University Books, Munksgaard, 295 pp.

Fairbanks, R. G., 1989. A 17 000-year glacio-eustatic sea level record: Influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. Nature 342: 637–642.

Grimm, E. C., 1987. CONISS: A FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. Comp. Geosci. 13: 13–35.

Grimm, E. C., 1993. TILIA diagramming program. Illinois State Museum. Springfield.

Hearty, P. J. & H. L. Vacher, 1994. Quaternary stratigraphy of Bermuda: A high resolution pre-Sangamonian rock record. Quat. Sci. Rev. 13: 685–697.

Knox, A. S., 1940. The peat deposits of Bermuda and evidences of post-glacial changes in sea-level. J. Geol. 48: 767–780.

Lefroy, J. H., 1876. Memorials of the Bermudas or Somers Islands 1515–1685, I. Bermuda Historical Society and Bermuda National Trust, Hamilton, Bermuda, reprinted 1981.

Maher, L. J., Jr., 1972. Nomograms for computing 0.95 confidence limits of pollen data. Revue Paleobot. Palynol. 13: 85–93.

Neumann, A. C., 1971. Quaternary sea-level data from Bermuda. Quaternaria 14: 41–43.

Phillips, B., 1984. Bermuda cedar: Survival or extinction. Bermuda's Heritage: 150–151.

Rowe, M. P., 1990. An explanation of The Geology of Bermuda. Bermuda Ministry of Works and Engineering, Hamilton, 28 pp.

Rueger, B. F., 1994. Minimal sampling area of the *Osmunda cinnamomea-Cladium jamaicensis* entity within Devonshire Marsh (Bermuda) and its relationship to Late Holocene pollen history, Geol. Soc. Amer. Abs. with Programs, 26: A-57.

Rueger, B. F. & T. N. von Wallmenich, 1993. Palynological evidence of anthropogenic influence on the flora of Bermuda from Devonshire Marsh. Geol. Soc. Amer. Abs. with Programs, 25: 391.

Tucker, T., 1970. Orders and constitutions to preserve the cedars and other trees. Bermuda Hist. Quart. 27: 23–25.

Vacher, H. L., 1974. Groundwater hydrology of Bermuda. Bermuda Public Works Department, Hamilton, 85 pp.

Verrill, A. E., 1902. The Bermuda Islands: their scenery, climate, productions, physiography, natural history and geology, with sketches of their early history and changes due to man. Trans. Conn. Acad. Arts Sci. 11: 413–956.

Watts, W. A. & B. C. S. Hansen, 1986. Holocene climate and vegetation of Bermuda. Pollen Spores 28: 355–364.

Wilkinson, H. C., 1958. The Adventurers of Bermuda, second edition. Oxford University Press, London, 421 pp.

Zuill, W., 1946. Bermuda Journey, A Leisurely Guidebook. The Bermuda Book Stores, Hamilton, 426 pp.