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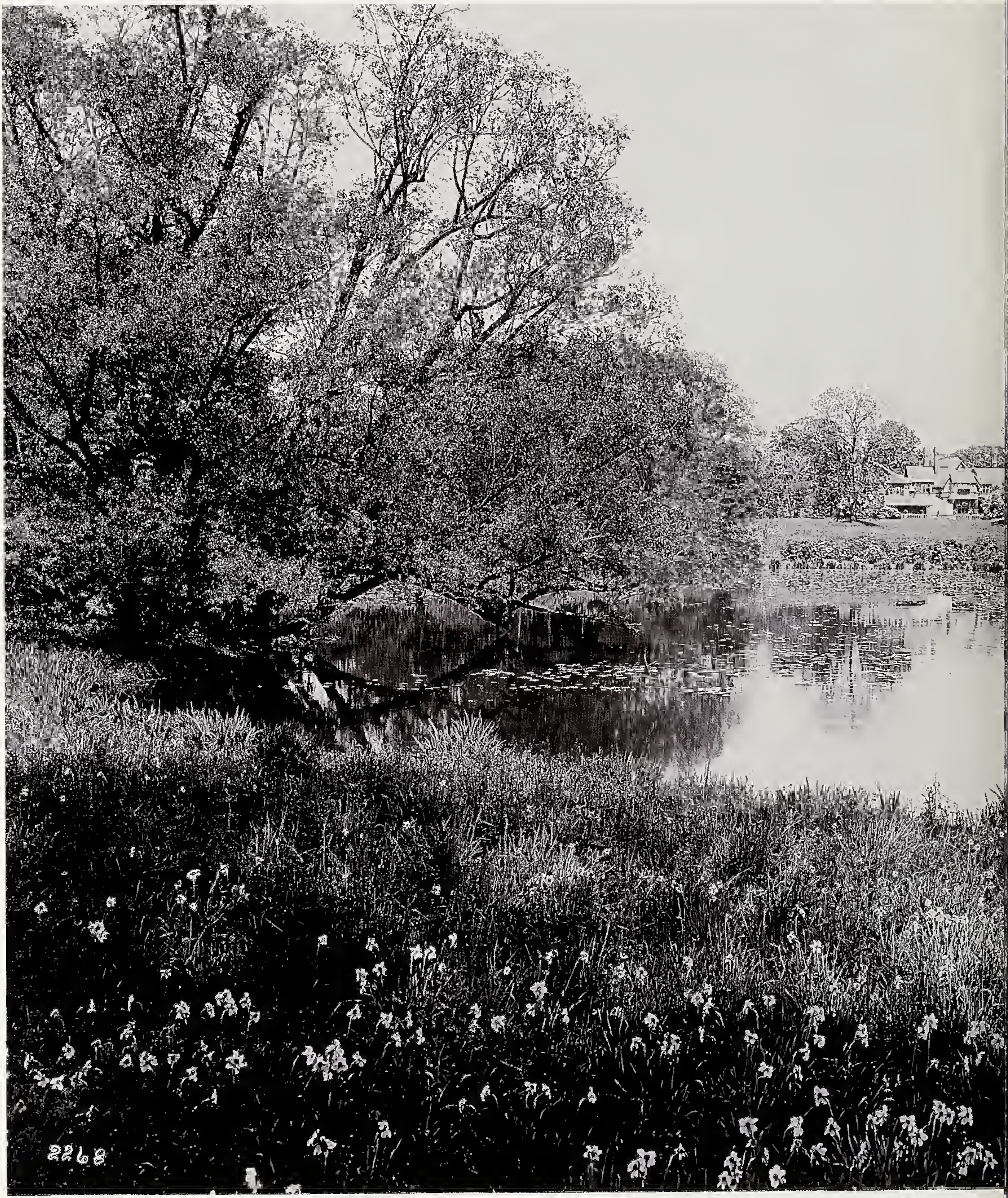
Front cover: A view of Charles S. Sargent's Brookline estate, Holm Lea, photographed in summer 1933 by T. E. Marr. From the Archives of the Arnold Arboretum.

Inside covers: *Trillium erectum* L. and *Phytolacca americana* L. (pokeweed) painted in watercolor by Ida Hrubesky Pemberton. From *The Healing Plants of Ida Hrubesky Pemberton*, published by the Hunt Institute for Botanical Documentation, Carnegie Mellon University.

Back cover: *Stewartia* 'Scarlet Sentinel', a new spontaneous hybrid from the Arnold Arboretum, photographed by Peter Del Tredici.


2268

The Arnold Arboretum and the Early Years of Landscape Design Education in America

Phyllis Andersen

It was now gay with carriages in lilac time, and the attendance of students was frequently noted. Every spring and fall, John G. Jack could be seen leading a coterie of teachers and the horticulturally inclined from plant to plant. At times in between, Benjamin M. Watson's horticultural students from the Bussey Institution, or scholars of landscape gardening from Harvard's Lawrence Scientific School or the Massachusetts Institute for Technology, were observed, notebook in hand, pacing up and down the shrub collection rows or scrutinizing a label on the trunk of a healthy specimen tree. —A scene described by Ida Hay in her 1995 history of the Arnold Arboretum, *Science in the Pleasure Ground*

On July 1, 2002, the thirty-four-year-old Radcliffe Seminars Program in Landscape Design and Landscape Design History became the Arnold Arboretum's first formal program in landscape design. However, in the years between the Arboretum's founding in 1872 and the death in 1927 of its first director, Charles Sprague Sargent, the Arboretum was at the center of efforts to transform the practice of landscape gardening into the profession of landscape architecture.

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Holm Lea, the estate of Charles Sargent, in 1900, looking across the pond and Sargent's edge plantings to the main house.

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Holm Lea, the estate of Charles Sargent, in 1900, looking across the pond and Sargent's edge plantings to the main house.

ity, and his research interests that defined the institution. Sargent brought to his position an unshakable commitment to the picturesque landscape sensibility as espoused by William Gilpin, Uvedale Price, and Andrew Jackson Downing. Like his colleague Frederick Law Olmsted, Sargent was contemptuous of excessive horticultural display, controlled formal patterning, and showy floriferousness. His commitment had been formed by European travel, by his reading of Downing and others, and by his admiration for the country estates of his cousins Henry Winthrop Sargent and H. H. Hunnewell. During his early years at the Arboretum, Sargent transformed Holm Lea, his own 150-acre estate in Brookline, Massachusetts, into one of the most admired country places in America. He experimented freely at Holm Lea, creating a landscape of open pastoral views framed by groves of native trees, drifts of wildflowers, a bucolic pond with cattle grazing at its edges. In the words of landscape historian Cynthia Zaitzevsky, Sargent was "the last in the great tradition of gentlemen landscape gardeners, at least in this region." Holm Lea, with all its apparently effortless scenery and its references to the pastoral, was no less manmade than the formal displays in Boston's Public Garden.

By the 1880s, a growing market in both public park and estate design was pointing to a need for training more American landscape designers. The success of Central Park and Prospect Park in New York had been publicized by many articles and illustrations in popular magazines, and planners in other cities had begun to recognize the need for parks to provide outdoor activities and a healthy environment for their own growing urban populations. At the same time, designers like Frederick Law Olmsted, Samuel Parsons, and Horace Cleveland, writing in literary magazines and journals of public affairs, were articulating a role for landscape designers in the public sphere. As a group they felt a need to assert their special knowledge of land planning, planting schemes, and their advocacy for both scenery and recreation. They felt they had to differentiate themselves from the architects, civil engineers, and horticulturists against whom they were competing for public contracts.

In 1932 Henry Vincent Hubbard, a landscape architect and longtime faculty member in Harvard's Department of Landscape Architecture (and, in 1901, the program's first graduate), reflected on the early years of his profession:

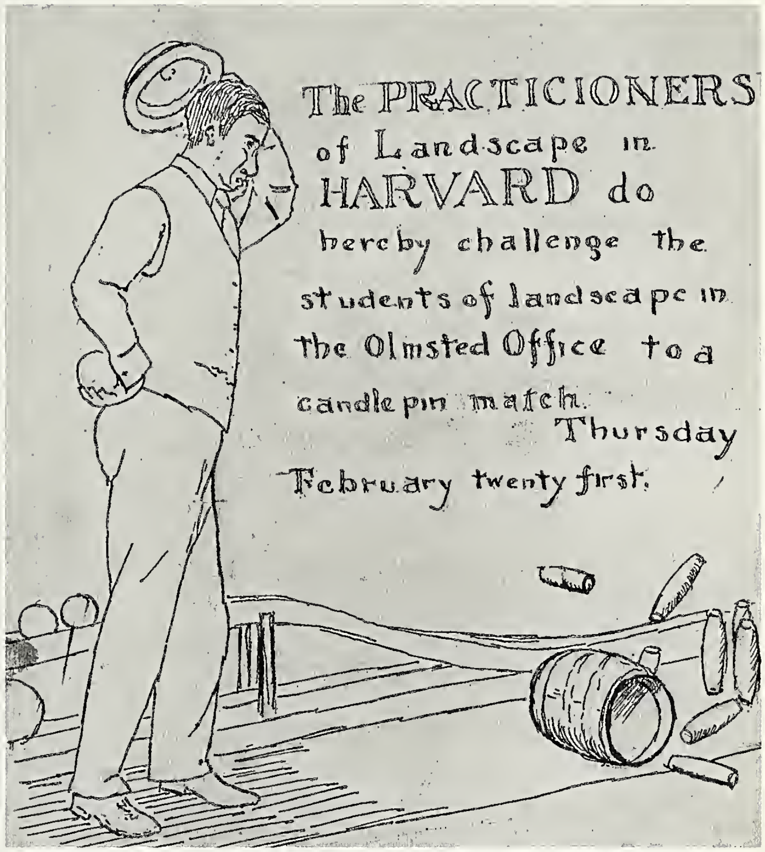
> In 1880 . . . landscape architecture was beginning to take its rightful place as one of the arts in America, recalling its traditional status of honor in Italy, France, England and Germany, and its still more ancient role in China and Japan. Olmsted and Vaux, drawing inspiration from the legacies of Michaelangelo, LeNôtre, Repton, and Prince Puckler, had departed from the horticultural taste lingering in the works of Andrew Jackson Downing, and had given in the Central Park, New York, and Prospect Park, Brooklyn, a great public object-lesson in the differentiation of the landscape art from horticulture on the one hand and from architecture on the other, as well as from the basic and contributory science of engineering.[1]

The Apprenticeship Period of Landscape Design Education

By 1883 Frederick Law Olmsted had moved his home and office from New York City to Brookline, Massachusetts, in order to deal more efficiently with his firm's many projects in the Boston area. The Olmsted office quickly became the training ground for a generation of landscape architects that included Charles Eliot, Warren Manning, and the Olmsted sons, Frederick Jr. and John Charles. In 1895, near the end of his professional career and with weakening health, Olmsted concentrated on making his office a disciplined training ground. "We are gradually preparing a grand professional post-graduate school here," he wrote to his son Frederick Jr. In the absence of academic programs in landscape architecture, a period of apprenticeship, combined with travel and supervised reading, was the only way to enter the profession. Working without pay or for a nominal stipend, apprentices trained with senior designers while providing a substantial service to the firm by taking on the time-consuming tasks of surveying, drafting, and various kinds of fieldwork. Sargent encouraged young men who wanted a career in landscape architecture to join the Olmsted firm for the educational experience. Two of his nephews, Henry Sargent Codman (1864–1893) and his younger brother Philip (1867–1896), joined Olmsted and Company after a rigorous tour of Europe during which their itinerary was closely supervised by their uncle.

Sargent also guided the early training in landscape design of Beatrix Jones (Farrand) (1872–1959). In the early 1890s—a time when few opportunities for formal education were available to women—Ms. Jones became a private student of Sargent, using the Arnold Arboretum as a laboratory for studying horticulture and design.

> It seems almost funny to look back on the haphazard way in which we forerunners of the army of women landscape architects got our education. My own work was started at the suggestion of Professor Charles Sprague Sargent of the Arnold Arboretum who, knowing my great interest in plants, suggested that I begin studying them with the idea of later practicing landscape architecture or, as we called it then, landscape gardening. The whole scheme seemed to me so wild that it took some time to appreciate Professor Sargent's earnestness. Thanks, however, to his kindness and the hospitality of his family, I spent several months working at the Arboretum under his enthusiastic direction and with the benefit of his criticism.
>
> —Letter from Beatrix Farrand to Clarence Fowler, a trustee of the Cambridge School of Architecture and Landscape Architecture, n.d.[2]



NATIONAL PARK SERVICE, FREDERICK LAW OLMSTED NATIONAL HISTORIC SITE

A 1903/04 cartoon from the scrapbooks of the office of Olmsted Brothers. The Olmsted office continued to be a training ground for students even after the founding of the program in landscape architecture at Harvard.

Male practitioners, too, were growing weary of "haphazard" training and looking for ways to elevate their profession to an academic discipline. Jacob Weidenmann, an early partner of Olmsted, then with his own office in Chicago, believed that Sargent should fill the void:

> If a learned and scientific man like Sargent wishes, he would succeed in establishing a Public Institute for Landscape gardening and by chance Landscape Architecture would soon have to give way to real qualified talents.
>
> —Letter from Jacob Weidenmann to John Charles Olmsted, December 14, 1887[3]

Garden and Forest: A Journal of Horticulture, Landscape Art and Forestry 1888–1897

Sargent did not set up an academic curriculum at the Arboretum, but he did found *Garden and Forest* in 1888. While it was not technically an official publication of the Arnold Arboretum, it was perceived as such by the general public and by the Harvard administration. Subtitled "A Journal of Horticulture, Landscape Art and Forestry," it offered the then (and now) unique perspective that the three fields were inextricably linked. Sargent listed himself as "conductor," but the editor was William Stiles, an experienced New York journalist with a strong interest in public park design.

The magazine became the voice of the emerging profession. Articles by leading landscape architects (Frederick Law Olmsted, Charles Eliot, H. W. S. Cleveland, George Kessler, Frank Waugh) began to define the field for an American audience as well as offer new strategies for land stewardship and preservation. *Garden and Forest* also published carefully crafted essays on landscape gardening by the art critic Marianna Van Rensselaer, later gathered in her book *Art Out of Doors* (1893). It made recommendations for readings on landscape gardening, described educational opportunities, and discussed the need for qualified practitioners. As landscape architect and historian Ethan Carr has written, "In an era before a professional organization or academic instruction existed in the field of landscape architecture, *Garden and Forest* took on aspects of both."[4]

The Arnold Arboretum and Landscape Architecture Studies at Harvard

By the early 1890s, many people were urging that Harvard develop a landscape architecture program, a notion supported by President Charles W. Eliot and by the geologist Nathaniel Shaler, the very popular dean of Harvard's Lawrence Scientific School. Since at that time it was the only department of the University that offered advanced instruction in the physical and natural sciences, the Lawrence Scientific School was the logical home for such a program, and in 1900 Harvard launched the first degree-granting program in landscape architecture in the United States in that school. Frederick Law Olmsted Jr. was named its first director; his appointment honored the legacy of Frederick Law Olmsted Sr. and set a precedent for practitioner/academic faculty appointments that is still followed by landscape architecture programs across the country. The University aligned the landscape architecture program with the newly established program in architecture, indicating an expectation of a close collaborative relationship between the fields, a collaboration that drew on science, engineering, and fine art.

The Arnold Arboretum and its allied institution in Jamaica Plain—the Bussey Institution—played integral roles in the new program.

> Particular attention will be given to the study of plants both as individuals and as elements of landscaping. In the first year will be given lectures and laboratory work in Botany, supplemented by study of plants and garden-work at the Botanic Garden. The second year includes a course in Horticulture at the Bussey Institution, consisting of lectures, with study and practice in the greenhouses and in the field and garden. In the third and fourth years will be given successive courses on Plants in Relation to Landscape Planting, conducted mainly at the Bussey Institution and the Arnold Arboretum.
>
> —Announcement of the Programme of Courses in Landscape Architecture, Lawrence Scientific School, March 1900.[5]

A one-year graduate program was instituted in 1906 with previous courses in both horticulture, botany, and geography recommended for admittance. Again, the Arnold Arboretum was to be a venue for plant courses.

From the beginning, the Arboretum's collection was of significant pedagogical value to students. The full spectrum of American species would eventually form the backbone of the collection, but the Arboretum focused first on assembling plants native to New England. Since students in the early years of the Harvard program were drawn primarily from the New England region, where they often began their practice, their plant study at the Arboretum was immediately useful to them after graduation.

The Bussey Institution was also well positioned to serve as a resource for the new landscape program. The Bussey was Harvard's experiment in scientific agriculture and husbandry from 1871 to 1908 when it was converted to a graduate school in applied biology. Describing its mission as "not educating farmers' sons in a knowledge of their fathers' trade . . . but . . . recognizing the high and difficult character of husbandry," it had been the only Harvard program offering training in horticulture to landscape architects before the design program was established. It was unique at Harvard for allowing women to attend classes from time to time; Benjamin Watson, who taught horticultural classes at the Bussey, was particularly supportive of women students:

> Mr. Watson would also like to receive women in his course on Trees and Shrubs, or in the course on general Horticulture. He says that he has one good woman student in Landscape Gardening, and that another woman has applied for the course in gen-

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John George Jack instructing students at the Arnold Arboretum.

eral Horticulture. Watson is in favor of giving women the same opportunities that he gives men.

—Letter from Harvard President Charles W. Eliot to Professor Frank Storer, October 18, 1898[6]

The MIT Program in Landscape Architecture

The Arnold Arboretum had a direct link to the program in landscape architecture at the Massachusetts Institute of Technology (MIT), which began in 1900 and ended in 1908: it was developed by Guy Lowell, who was married to Charles Sargent's daughter Henrietta. The MIT program, one of two options offered to architecture students, was open to both undergraduates and graduates until around 1904 and to graduates only from then until 1908, when the program was discontinued. The importance of the Arboretum's role in the program was clearly outlined in the program description:

> A very thorough course in Horticulture at the Arnold Arboretum which is under the direction of Mr. Charles S. Sargent [will be part of the program]. Horticultural and botanical studies in the laboratory and the field will extend through three years, and ample opportunities will be offered not only to learn the habits of trees, shrubs and plants but also to study landscape gardening effects in the park of the Arboretum . . . We are fortunate in being able to establish a connection to the Arboretum, which Mr. Sargent's publications have made known throughout the world as a great horticultural station.[7]

The Arboretum's courses for MIT were taught not by Sargent, who demurred at both formal teaching and lecturing, but by John George Jack (1861–1949), a Quebec native who had joined the Arboretum in 1886 to handle plant records. Because he showed a talent for working with the public, Sargent soon entrusted him with full responsibility for both public and academic education. Jack's lectures and field walks were always well attended and he was eventually given the title of Lecturer.

Unlike Harvard in the early years of its program, MIT admitted several women. The landscape architect Martha Brookes Hutcheson said of her MIT education:

> I saw at once that the curriculum did not give nearly enough time to what must be known of the "plant world," the riches in material and easy study obtainable in the nearby Arnold Arboretum were too great to be but half known so, during three summers, I made exhaustive notes there for my card catalog.
>
> —"Three Women in Landscape Architecture"[8]

Marian C. Coffin also valued her experience at the Arnold Arboretum as an MIT student:

> At that time the course given at "Tech" was termed "Landscape Architecture" and was an option in the architectural course and under the guidance of Guy Lowell . . . The last year we diverged into purely landscape problems, while during the entire four years, we had engineering problems and attendant mathematics of our own, as well as at least two days a week for study in the Arnold Arboretum and for various trips about Boston to see fine examples of landscape design . . . To the splendid training in design we were given, to the three years of such hard work as I fancy few of the schools now insist upon, as well as to the patience and enthusiasm of Prof. Jack who guided our steps through an intensive training in plant material, I feel more than grateful.[9]

ARNOLD ARBORETUM OF HARVARD UNIVERSITY

ARCHIVES OF THE ARNOLD ARBORETUM OF HARVARD UNIVERSITY

Ida Hay chose this contemporary view of the Arnold Arboretum for the cover of her book, Science in the Pleasure Ground. *It bears a striking similarity to a view of the Ramble in Central Park printed in* Garden and Forest *(1888).*

Reminiscing about his Arboretum teaching responsibilities later in life, John Jack speculated that MIT dropped the landscape architecture option in 1908 because MIT was working closely with Harvard to avoid duplication of small, specialty programs. Since Harvard's program was well financed and thriving, it seemed prudent for MIT to end their involvement in the field.

With Harvard's program closed to women until the early 1940s, some regretted the closing of MIT's program, which removed the only option for women in the region. Two independent schools of landscape design in the Boston area filled the gap. The Cambridge School of Architecture and Landscape Architecture was founded in 1916 and based in Harvard Square. Under its director, Henry Atherton Frost, a member of Harvard's Department of Landscape Architecture, the School offered women a shadow version of the Harvard curriculum. The Lowthorpe School of Landscape Architecture was founded by Judith Motley Low, a descendant of Benjamin Bussey, and based at her country home in Groton, Massachusetts. The program emphasized residential design and offered intensive study of plant form, planting design, and horticultural skills. Students at both schools used the Arboretum extensively to study woody plants both as individual species and in a design context.

Charles Sargent's death in 1927 coincided with a shift in the landscape architecture curriculum at Harvard to embrace town planning and the rebuilding of cities. Plant studies continued to be part of the curriculum but their value diminished as the scale of projects increased and the sites studied were no longer regional. Students came from many parts of the country with a growing contingent of international students, many leaving the region upon graduation. The Arboretum continued to be a resource for the program with field walks and courses taught by both Arboretum staff and Harvard faculty but, ironically, despite enhanced public transportation and improved roadways, the six-mile distance between Cambridge and Jamaica Plain seemed, at times, an insurmountable barrier.

More significantly, the taxonomic arrangement of the Arboretum, which places plant families together disregarding native growing conditions and plant associations, made the collection less relevant to those studying plants from an ecosystem perspective. Unlike museum collections of paintings, sculpture, or artifacts the Arboretum's living collections cannot be realigned or portions stored until their unique value is rediscovered by new generations of scholars and students. The Arboretum's collections of native trees and shrubs in many stages of maturity, its display of rare species from all over the temperate world, and its high curatorial standards for individual specimens remain a unique international resource for plant study. Many have called the Arboretum's landscape one of the best-preserved examples of the work of Frederick Law Olmsted. It is now the responsibility of faculty and staff to interpret all of these resources for a new generation of students.

Endnotes

Two recent publications explore the history of landscape architecture at Harvard in great detail:

Anthony Alofsin. *The Struggle for Modernism: Architecture, Landscape Architecture, and City Planning at Harvard* (New York: W.W. Norton), 2002.

Melanie Simo. *The Coalescing of Different Forces and Ideas: A History of Landscape Architecture at Harvard, 1900-1999* (Cambridge: Harvard University Graduate School of Design), 2000.

[1] Henry Vincent Hubbard. "Landscape Architecture." In *Fifty Years of Boston: A Memorial Volume Issued in Commemoration of the Tercentenary of 1930* (Boston, 1978), p. 347.

[2] Clarence T. Fowler. "Three Women in Landscape Architecture." *Alumnae Bulletin of the Cambridge School of Domestic and Landscape Architecture* (April 1932) 4(2): 7.

[3] Jacob Weidenmann to John Charles Olmsted. 14 December 1887. Manuscript Collection, Library of Congress.

[4] Ethan Carr. "*Garden and Forest* and 'Landscape Art'" (2000). *Arnoldia* 60(3): 5.

[5] Lawrence Scientific School. Announcement of a Four Years' Programme of Courses in Landscape Architecture (March 1900), 4.

[6] Charles W. Eliot to Frank Storer. 18 October 1898. Archives of the Arnold Arboretum of Harvard University.

[7] Massachusetts Institute of Technology. *Class of 1894 Decennial Catalogue* (June 1904), 35.

[8] Fowler. "Three Women in Landscape Architecture," 9.

[9] Ibid., 11.

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Landscape Architect/Landscape Architecture: A Short History of the Terms

The terms used to describe the process and profession of designing the landscape can be confusing. In the late nineteenth century the Anglo-American term *landscape gardening* evolved into the professional and academic discipline of *landscape architecture* and took on precise professional and legal boundaries. *Landscape design* is a designation that continues to transcend disciplinary and professional boundaries and captures the essence of the process.

Contrary to popular opinion, Frederick Law Olmsted did not invent the term *landscape architecture* nor was he particularly partial to it when it was used by the architect Calvert Vaux, his partner in the design of Central Park.

> I am all the time bothered with the miserable nomenclature of L.A. Landscape is not a good word, Architecture is not; the combination is not—Gardening is worse . . . The art is not gardening nor is it architecture. What I am doing here in California, especially is neither. It is sylvan art, fine art in distinction from Horticulture, Agriculture, or sylvan useful art . . . If you are bound to establish this new art, you don't want an old name for it. And for clearness, for convenience, for distinctness, you do need half a dozen technical words at least. —Frederick Law Olmsted to Calvert Vaux, 1 August 1865

Olmsted did adopt its use near the end of his professional career as he found no better term to describe his work.

> With reference to your undertaking there is less room for choice than may be supposed among the landscape gardeners or landscape architects of the country (I have come to prefer the latter term, tho' I much objected to it when it was first given to me. I prefer it because it helps to establish the important idea of the distinction of my profession from that of gardening, as that of architecture from building—the distinction of an art of design. —Frederick Law Olmsted to the Board of Parks Commissioners, Rochester, New York, 1888

The use of the term *landscape architecture* can be traced back at least to early nineteenth-century literature.

1828

Gilbert Laing Meason. *The Landscape Architecture of the Great Paintings of Italy* (London). One of the first uses of the term by the Scottish writer, a friend of Sir Walter Scott. However, Meason was referring to the appropriateness of *buildings* in the landscape not the landscape itself: the Roman villa, towers and turrets, picturesque country houses.

1840

John Claudius Loudon, editor. *The Landscape Gardening and Landscape Architecture of the Late Humphry Repton* (London). This was Loudon's title for his compilation of the writings of Repton; again, Loudon was referring to buildings in the landscape. *Landscape architecture* was Loudon's term, not Repton's.

1841

Andrew Jackson Downing. *A Treatise on the Theory and Practice of Landscape Gardening* (London). In Section IX, "Landscape or Rural Architecture," Downing writes that "architectural beauty must be considered cojointly with the beauty of the landscape or situation . . . the harmonious union of buildings and scenery." But like Loudon, Downing was referring to building style and landscape compatibility.

1858

Frederick Law Olmsted and Calvert Vaux use the term in Central Park documents.

1863

The title *landscape architect* is used for the first time by the Board of Central Park Commissioners in New York City.

1873

Horace William Shaler Cleveland. *Landscape Architecture as Applied to the Wants of the West* (Chicago):

> Landscape Gardening, or more properly Landscape Architecture, is the art of arranging land so as to adapt to it most conveniently, economically and gracefully, to any of the varied wants of civilization . . . The term "landscape architecture" is objectionable, as being only figuratively expressive of the art it is used to designate. I make use of it, under protest, as the readiest means of making myself understood, in the absence of a more appropriate term. If the art is ever developed to the extent I believe to be within its legitimate limits, it will achieve for itself a name worthy of its position.

1899

The American Society of Landscape Architects is formed at a meeting in New York. It was organized to include only professional landscape architects as full members and to exclude nurserymen, contractors, builders, and others engaged in commercial work. The group did allow those calling themselves *landscape gardeners,* such as Beatrix Farrand, to join.

1910

Landscape Architecture magazine is founded by three graduates of Harvard's landscape architecture program, Robert Wheelright, Charles Downing Lay, and Henry Vincent Hubbard.

1916

Liberty Hyde Bailey attempts to clarify the continuing confusion in terminology in his *Standard Cyclopedia of Horticulture,* Vol. IV.

> The art that designs and makes landscapes is known mostly by the name landscape architecture, although there is now a tendency to call it by other names. Landscape gardening is the older term; but this is considered not to be broad enough or bold enough to suggest the large elements of design that form an underlying part of the art.

2003

American Society of Landscape Architects website (www.asla.org) offers this definition of *landscape architecture:*

> Landscape architecture is the art and science of analysis, planning, design, management, preservation and rehabilitation of the land. The scope of the profession includes site planning, garden design, environmental restoration, town or urban planning, park and recreation planning, regional planning, and historic preservation.

P. A.

The Special Role of Historical Plant Records in Monitoring the Impact of Climate Change

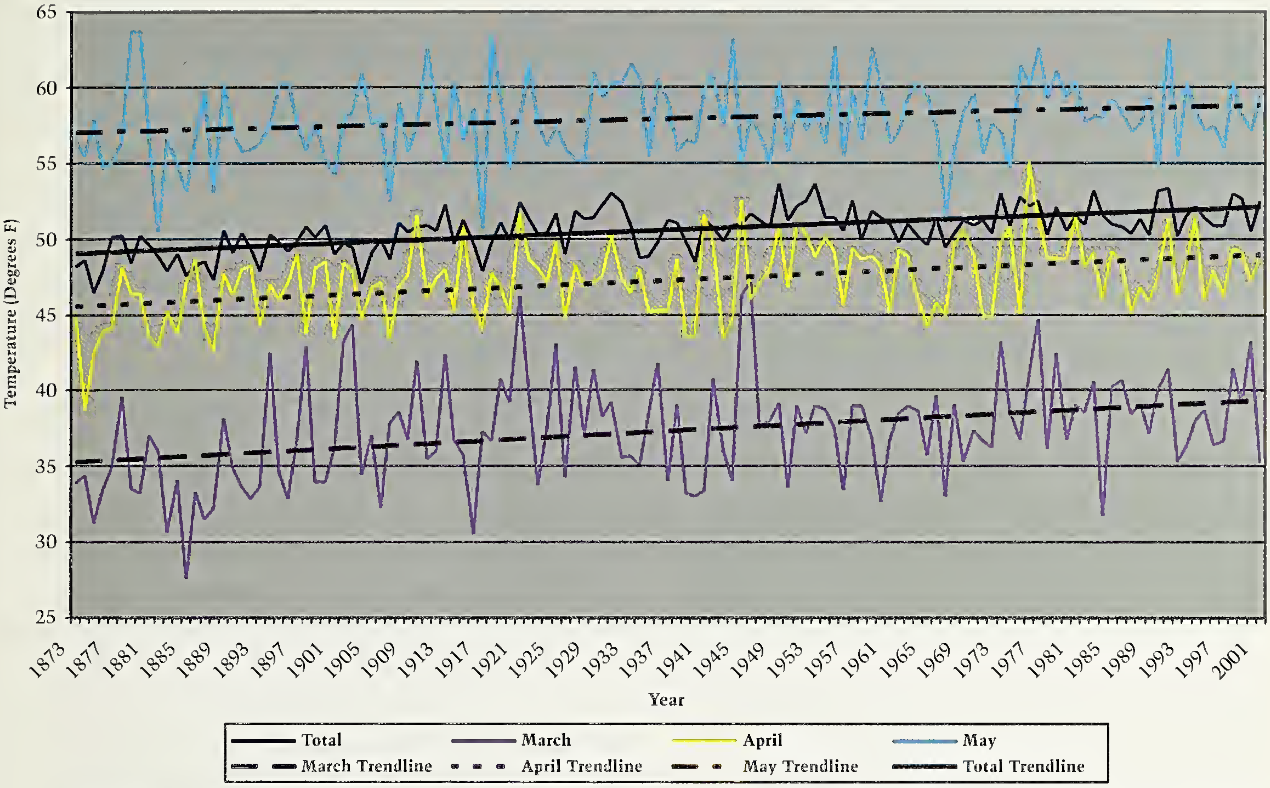
Richard Primack

The best available scientific evidence suggests that the world's climate will change significantly over the present century because of increases in the greenhouse gases that result from burning fossil fuels and destroying tropical forests. Worldwide temperatures have already risen by sixth-tenths of one degree centigrade over the last four decades, according to the Intergovernmental Panel on Climate Change of the World Meteorological Organization and the United Nations Environmental Program. Estimates of the increase to be expected over the next hundred years range from three to ten degrees Fahrenheit. This change is comparable to the one that occurred after the last ice age.

The warmer temperatures will have a radical effect on many plant species. Some will no longer be able to grow at their present locations and will either migrate or go extinct. Others will be able to maintain their present ranges but will change their behavior—leafing out earlier, flowering and fruiting earlier, and holding their leaves later in autumn. Indeed, earlier flowering times will be one of the first indications that the climate is changing. This may at first strike some people as a pleasant change, but warmer summer temperatures, especially in dry years, are likely to reduce populations of many sensitive native plant species while favoring more heat-tolerant species. There are already signs that certain drought- and temperature-sensitive species could experience higher than normal mortality rates, as Peter Del Tredici described in a recent article in the *New York Times*. To put it another way, horticulturists' longstanding concern about plants' winter hardiness is being displaced by concerns about drought- and heat-tolerance. Taking a larger view, the expected increases in temperatures will have huge implications not just for horticulture but for agriculture, forestry, and wildlife conservation as well.

Behavior changes of this sort are the raw material of the science of phenology, the study of how biological phenomena are affected by climate and seasonality. Clearly, observations of phenological events in plants will play an important role in our efforts to evaluate the effects of rising temperatures. Climate change will affect the full range of organisms—plants, fungi, animals, and even microorganisms—but the sudden onset and cessation of flowering in plants make them particularly well suited to research on its effects. More important, we have extensive records of plant flowering times going back decades and even centuries, many of them gathered by government weather bureaus for agricultural purposes and others maintained by private individuals. By comparing current flowering times with historical records of this sort, a network of observers at European botanical gardens has found that European plants are now flowering six days earlier than they were in the 1960s and that the overall growing season has increased by one or two weeks.

The most comprehensive attempt to correlate weather and flowering times in North America was made by the Weather Regional Phenological Network (WRPN) between 1957 and 1994. The network spanned the United States, eventually including two thousand observers who monitored the behavior of three designated cultivars: the common lilac, *Syringa vulgaris* f. *purpurei*, and two honeysuckles, *Lonicera tartarica* cv. 'Arnold Red' and *L. korolkowii* var. *zebelli*. The observers were given specific instructions on how to record the dates of leafing out, of first flowering, of peak flowering, and of flower withering.



Average monthly temperatures with linear trendlines. The data was taken from online records of the United States National Weather Service. While the temperatures are variable from year to year, temperatures are getting warmer during this period.

The WPRN project was closed down in 1994 for lack of permanent institutional backing, but the massive data sets it generated are still being analyzed. Thus far, the major finding is that plants across the United States are now flowering about one week earlier than in the 1950s when the WPRN observations began. The data also showed a high degree of correlation among the various phenological events—in years with earlier first flowering, leafing out also occurred earlier—indicating that the events are developmentally linked. This finding can largely be explained by the responsiveness of the observed species to spring temperatures: they flower earlier when there are warm springs, and warm springs have become more common. Unfortunately, all the plants observed by the WPRN were exotic cultivars, which may respond to climatic variation differently from our native species. To understand the impact of climate change on native species, we need long-term observations of species living in their native habitats.

Not all recording of phenological events has been done by large organizations. In the United Kingdom, for example, there is a long tradition of families carrying out observations on their farms and estates. From 1736 to 1947 the Marsham family of Norfolk County observed and recorded the times of leafing out and flowering for a variety of plant species as well as of bird migrations. Their reeords show clearly that plants respond to annual fluctuations in climate; presumably they will continue to do so as the climate gradually warms.

In the United States, one of the most complete sets of observations was recorded by the famous naturalist Aldo Leopold from 1936 to 1947 and continued from 1976 to 1998 by his daughter, Nina Leopold Bradley, at their farm in southern Wisconsin. Of the fifty-five phenological events they followed, thirty-six were the

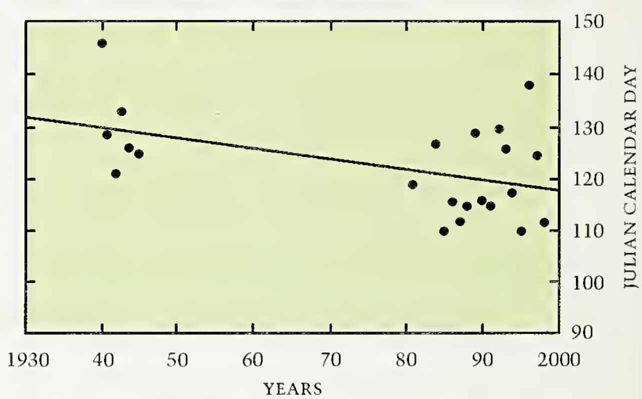
Sites of European botanic gardens participating in the Network of International Phenological Gardens. Solid black circles mark gardens still in the network; rings mark gardens that have dropped out of the network. Drawn from "Trends in phenological phases in Europe between 1951 and 1996," A. Menzel, International Journal of Biometeorology *(2000) 44: 76–81.*

first flowering of plants. A significant trend toward earlier flowering was shown in ten of the thirty-six plant species, including forest phlox *(Phlox divaricatus)* and columbine *(Aquilegia canadensis)*. An analysis of all their plant-related data showed that on average, the phenological events observed advanced by 0.12 days a year, the equivalent of about six days over a fifty-year period.

Historical records of this sort are of great value in tracking the effects of climate change. Another important resource is found in the herbaria of botanical gardens like the Arnold Arboretum, where extensive records of flowering times are preserved on the mounted sheets of flattened specimens. Many of the Arnold's approximately 80,000 herbarium specimens were collected on the grounds from flowering individuals that are tagged and individually numbered. By comparing the current flowering time of a plant with its past flowering time (indicated by the collection date on its herbarium specimen), we can determine the impact of climate change on its behavior. And because of the "heat-island effect" common to large cities—which has helped to raise average temperatures in Boston by about five degrees Fahrenheit over the last 120 years while that of eastern North America overall has risen by only two degrees*—the behavior of plants growing on the Arboretum's grounds may give an early warning of what will happen to plants growing in less urbanized locations in later decades.

In 2002 a group of Boston University students and I began to test this methodology at the Arnold Arboretum by making weekly observations of 67 plants for which the herbarium has flowering specimens. The sample size is not large, but the results were clear: plants did not flower any earlier in the warm year of 2002 than

Forest Phlox Blooms



Among thirty-six plants observed by the Leopolds, Aldo and his daughter Nina, over a sixty-one year period, Phlox divaricata *(forest phlox) was one of ten that showed a significant trend toward earlier flowering. Plants are clearly flowering earlier in the 1976 to 1998 period in comparison with the 1936 to 1947 period; the overall change is about 10 days. Each dot represents the first flowering date observed in one year. From N. Leopold et al., "Phenological changes reflect climate change in Wisconsin,"* Proceedings of the National Academy of Science *(1999) 96: 9703.*

* As shown by the National Weather Service. See also Roetzer et al. 2000, which points out that as cities become more urbanized, paved surfaces and buildings tend to absorb and retain heat from the sun, making the city warmer than the surrounding countryside.

Boston University students Dan Primack and Carolyn Imbres recording flowering times—in this case, Rhododendron vaseyi *(pinkshell azalea)—on Meadow Road at the Arnold Arboretum, May 2003.*

they had in the similarly warm period of 1990 to 2001. However, they flowered an average of four days earlier than they had in the 1980s, and fifteen days earlier on average than they had in the years before 1980. For example, a flower was collected from a *Rosa pendulina* plant on June 19, 1916; the same plant was in peak flower on May 25 in 2003, 25 days earlier. A *Viburnum furcatum* plant flowered 23 days earlier in 2002 than it had in 1937; and a *V. scabrellum* plant flowered 24 days earlier than in 1973. During the growing season of 2003 we expanded the study to include a much larger sample of plants, especially older ones for which we have herbarium specimens for more than one year.

These comparisons from the Arnold Arboretum, together with others being made throughout the world, will quantify and highlight the impact of climate change on biological communities. But much more historical data on phenological events, whether collected by professionals or dedicated naturalists, is needed to expand our knowledge about plants' responses to warmer temperatures. Especially, we need to increase the number of localities for which there are good long-term records on phenomena such as flowering and leafing times, bird and fish migrations, insect appearance, and amphibian calling and movement. Any readers of this article who have recorded their observations over past decades are urged to get in touch with me. Perhaps by analyzing our data together we can make a valuable contribution to this important research.

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Stewartia 'Scarlet Sentinel'

Peter Del Tredici

The cultivation of plants from different parts of the world in specialized gardens is a tradition that dates back at least to the time of the ancient Egyptians. Migrating from place to place, people carried along their plants, animals, and technologies and exchanged them with the people they met. More than anything else, the evolution of modern human culture is characterized by the free flow of information, products, and living organisms.

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The flower of Stewartia ovata *f.* grandiflora.

Christopher Columbus' "discovery" of the new world in 1492 provided endless opportunities for plant exploration and stimulated the development of botanical gardens throughout Europe for the cultivation of these new, exotic plants. With each advance in transportation and information technology, the process of transferring plants from one part of the world to another became less time-consuming and consequently more successful. In our own time, airplanes have reduced travel time to far-flung destinations from weeks or months to hours or days.

The biological implications of the transportation revolution have been profound. Species that evolved over millions of years—isolated from one another by mountains, rivers, deserts, or oceans—could now be cultivated together in a "common garden." In these gardens, the barriers that separated plants in nature were suddenly gone, leaving the plants to interbreed freely. Like it or not, botanical gardens have always been centers of uncontrolled experiments in genetic recombination.

Many of our important food plants originated as spontaneous hybrids in botanical gardens—strawberries and rhubarb are modern examples—as did many ornamental plants. Like its European counterparts, the Arnold Arboretum has produced its share of spontaneous garden hybrids, including the famous 'Arnold Promise' witch hazel, a cross between the Japanese and Chinese witch hazels. This article introduces the latest Arnold Arboretum hybrid, in the genus *Stewartia,* in the tea family (Theaceae).

Members of the *Stewartia* genus are among the choice ornamental plants that are avidly

The "camouflage" bark of Stewartia pseudocamellia.

sought by connoisseurs. The most widely grown species, *S. pseudocamellia*—commonly called the Japanese or Korean stewartia—is the quintessence of the horticultural Holy Grail, with multiseason interest and stately elegance rolled into one plant. A medium-sized tree that grows to twenty to forty feet, it produces an abundance of gorgeous flowers in early summer, rich color in the red-burgundy-purple range in autumn, and most famously, spectacular exfoliating bark in shades of ivory, buff, and tan that enlivens the winter and early spring landscape. Children who see the tree at the Arboretum typically call it the "camouflage" tree, while mature horticulturists develop a faraway look in their eyes as they stroke the trunk.

The Korean stewartia is the best-known member of the genus, but others are worthy of note: Chinese stewartia *(Stewartia sinensis)* has smaller flowers and exfoliating bark with the look and feel of alabaster; the bark of the tall stewartia, the Japanese species *S. monodelpha*, is smooth and cinnamon-colored. Two species are native to North America. One is *S. malacodendron* from the mid-Atlantic coastal plain, which has four-inch flowers with showy, bright purple anther filaments; unfortunately it is not reliably hardy in Boston's climate. The other is the mountain stewartia *(S. ovata)*, which is a hardier, more upland species that produces flowers about three inches across with white or yellowish anther filaments. There are two varieties of mountain stewartia—var. *ovata* with yellow anther filaments and the more striking var. *grandiflora* with dark purple anther filaments. Neither of the American species possesses the exfoliating bark that is characteristic of the three Asiatic species described above.

The Arboretum's new hybrid stewartia has been given the cultivar name 'Scarlet Sentinel' and was formally described in a recent issue of *HortScience*—37 (2): 412–414. Initially the plant's heritage was unknown, but subsequent research has demonstrated that its parents are *Stewartia pseudocamellia* and *S. ovata* var. *grandiflora*. The original plant was collected in late spring of 1982 as one of a group of spontaneous seedlings growing beneath two mature specimens of *S. pseudocamellia* on Chinese Path.

The flower of Stewartia pseudocamellia.

(These plants, AA 11440-A & B, are among the handsomest trees in the Arboretum; they were collected in Korea by E. H. Wilson in 1918.) Fellow propagator Rob Nicholson and I were collecting the stewartia seedlings for distribution at the Arboretum's annual fall plant sale. The seedlings, presumed to be *S. pseudocamellia,* were given the Arboretum accession number 538-82 and were potted up and placed under shadecloth in an alleyway between two greenhouses. Over the course of the summer the seedlings flourished, growing several inches taller. As I was loading the flats of seedlings onto the truck for delivery to the Case Estates, I remembered that I "needed" a Korean stewartia for the front yard of the house I had recently purchased in Harvard, Massachusetts. Without thinking much about it, I scanned the flat of seedlings and quickly selected the one plant that stood out above the rest. Later that week I planted the seedling about ten feet from my front door, intending to admire its exfoliating bark in my dotage.

The little seedling flourished in its new home and even survived a close brush with death when my car, which I had forgotten to put in park, rolled over it on its way down to the bottom of the hill the house is perched on. But the tree sprang back to life—quite literally—and grew rapidly. Despite its tenacity, I was disappointed because it failed to show the beautifully patterned bark that I had expected. In fact, after waiting expectantly for nearly ten years, I began to contemplate replacing it with a "proper" Korean stewartia with the exfoliating bark I so coveted. Such thoughts evaporated one early morning in July 1992 when I noticed a spent stewartia flower on the ground, the first one the tree had ever produced. I picked it up and to my utter amazement I saw that unlike the flower of *Stewartia pseudocamellia,* which has a ring of yellow anther filaments, this one had bright, cherry-red anther filaments, quite unlike any stewartia flower I had ever seen.

I collected the few flowers still on the tree and brought them to the Arboretum for more careful study. Based on their comparative morphology, I decided that the plant was probably a hybrid between *Stewartia pseudocamellia* and *S. ovata* var. *grandiflora,* a specimen of which was growing between the two Korean stewartias that E. H. Wilson had collected. This plant (AA 18244-C), which had been collected by a Mr. T. G. Harbison in 1925 from the wilds of Highlands, North Carolina, has striking purple anther filaments and tight, nonexfoliating bark. 'Scarlet Sentinel' is intermediate between the two in most of its morphology including its bark, which flakes off in thin, linear strips. Stephen Spongberg, then taxonomist at the Arboretum, agreed with my opinion about the new hybrid's parentage and showed me another plant at the Arboretum with similar characters, which he had determined to be a hybrid between *S. pseudocamellia* and *S. ovata* var. *ovata.* It had the same bark as my plant, but the flowers had yellow rather than red anther filaments. This independent corroboration made me even more certain about my tree's parentage, but absolute confirmation had to wait for several years, until Jianhua Li,

The flower of Stewartia *'Scarlet Sentinel'.*

The bark of Stewartia *'Scarlet Sentinel'.*

the Arboretum's present taxonomist, performed the detailed genetic analysis that confirmed my original hypothesis.

Description

'Scarlet Sentinel' has a narrow, upright growth habit. At twelve years of age, when it bore its first flowers, the plant was twenty feet tall by eight feet wide. At twenty-two years of age the tree is about thirty feet tall and fifteen feet wide, having become more wide-spreading following the loss of its leader in a heavy snowstorm in December 1996. Its leaves are alternate, simple, and ovate-to-broad-elliptic in shape. Both the upper and lower leaf surfaces are smooth or slightly pubescent and waxy to the touch. The petiole is less than one-half-inch (one cm) long, with slight wings that enclose the developing bud. The leaves are three to four-and-a-half inches (8 to 12 cm) long by one-and-one-half to just under three inches (4 to 7 cm) wide, with a pointed tip and a rounded base. The leaf margins are finely serrated.

'Scarlet Sentinel' produces large flowers that are between three and four inches (8 to 20 cm) wide when fully open. The most conspicuous feature of these flowers is their scarlet-colored anther filaments (Royal Horticultural Society color chart #58B in the red-purple group). The ovary in the center of the flower is about one quarter-of-an-inch (6 mm) long and covered with dense hairs; its five styles are fused for the lower third of their length, the upper two-thirds being free. The flowers typically have five petals, but many of them also have an extra one or two small, petal-like structures. The flowers appear to be sterile, producing little, if any, viable pollen and no mature fruits despite the presence nearby of a flowering specimen of *S. pseudocamellia* (which I finally went out and purchased). Table 1 summarizes the morphological intermediacy of 'Scarlet Sentinel' relative to *S. pseudocamellia* and *S. ovata* f. *grandiflora*.

The upright growth habit of Stewartia *'Scarlet Sentinel' prior to losing its leader in an ice storm.*

Propagation

The one source of frustration surrounding the development of 'Scarlet Sentinel' has been its propagation. Despite repeated efforts dating back to 1992, I have been unable to produce a single propagule that has lived longer than two years. This despite the fact that softwood cuttings collected between mid June and early August and placed under intermittent mist root in the range of sixty to one hundred percent. While most of the rooted cuttings initiated growth the following spring, many of them died during the following summer after producing two to four inches (5 to 10 cm) of new growth. Modification in the rooting medium, the type of container, the mode of overwintering, and the timing of transplanting increased the longevity of some of the cuttings, but all were dead by the end of their second summer (see table 2).

No doubt the rarity of stewartia cultivars in the nursery trade is the result of problems associated with vegetative propagation. At present, only one commercial nursery, Broken Arrow in Hamden, Connecticut, has been able to propagate and offer 'Scarlet Sentinel' for sale. A characteristic feature of the dead 'Scarlet Sentinel' cuttings at the Arboretum is that the tips die before the roots do. The first symptom of trouble is the browning of the leaves, starting with the tip and working back toward the petiole. The leaves then wither and fall, one by one, over a period of weeks or months, eventually leaving a lifeless, desiccated twig. The most curious aspect of this demoralizing sequence

Table 1. Morphology of 'Scarlet Sentinel' in comparison to its parents, *Stewartia ovata* f. *grandiflora* and *S. pseudocamellia*. Measurements represent the range of variation observed in ten flowers per taxon.

Morphological Feature	*Stewartia ovata* f. *grandiflora* (AA #18244-C)	*Stewartia pseudocamellia* (AA #11440-A)	'Scarlet Sentinel'
Number of floral bracts	1	2	2
Length of floral bracts (mm)(average)	10–13 (11.0)	2–4; 7–8 (2.8; 7.6)	4–10; 7–12 (6.0; 8.8)
Petiole type	winged	non-winged	semi-winged
Fully open flower diameter (cm)	7–9	7.5–9.5	8–10
Sepal length (mm)	15–22	10–14	12–14
Ovary length (mm)	5	6–9	6
Style length (mm)	12–13	8–12	9–12
Styles free or fused	100% free	100% fused	fused for the basal 30% of their length
Anther filament color (RHS chart)	83C (violet group)	16B (yellow-orange group)	58B (red-purple group)
Bloom times (USDA zone 6)	most of July	mid June to mid July	late June to late July
Fall color of leaves	yellow to red-purple	red to burgundy	orange to red
Bark type	nonexfoliating	exfoliating in large, irregular plates	exfoliating in thin, linear strips

Table 2. The history of efforts to propagate 'Scarlet Sentinel' at the Arnold Arboretum, 1992 to 2002.

Acc. #	Date	Treatment	# Cuttings Stuck	# Cuttings Rooted	Rooting Percentages
400-92	7 Aug 92	5,000 KIBA	24	24	100
400-92	7 Aug 92	10,000 KIBA	24	19	79
400-92	13 Aug 92	5,000 KIBA	24	11	46
400-92	13 Aug 92	10,000 KIBA	24	22	92
400-94	13 Jun 94	control	24	23	96
400-94	13 Jun 94	2,500 KIBA (3-6")	24	20	83
400-94	13 Jun 94	5,000 KIBA	48	40	83
400-94	13 Jun 94	10,000 KIBA	24	24	100
400-94	13 Jun 94	2,500 KIBA (2-3")	55	39	71
480-94	7 Jul 94	5,000 KIBA	49	29	59
399-95	26 Jun 95	10,000 KIBA	63	58	92
399-95	26 Jun 95	control	45	41	91
419-95	11 Jul 95	10,000 KIBA (direct stuck)	72	51	71
192-96	10 Jun 96	10,000 KIBA	42	40	95
177-2000	28 Jul 02	5,000 KIBA	38	28	74
390-2002	24 Jul 02	5,000 KIBA	39	31	79
Totals			619	500	81

A comparison of the flowers of Stewartia *'Scarlet Sentinel' (center) with its parents,* S. ovata *f.* grandiflora *(left) and* S. pseudocamellia *(right).*

becomes evident when the pot is tipped over and the plant is removed with its root system fully intact, healthy and turgid, with bright white, vigorously growing root tips. This is especially surprising because in my experience root system failure is the usual cause of death for rooted cuttings. We have screened many of the dying and dead plants for a variety of bacterial and fungal pathogens—including the dreaded Pierce's disease, which is caused by the bacteria *Xylella fastidiosa*—and have so far come up empty.

While this propagation failure has been personally frustrating, the success that Richard Jaynes of Broken Arrow Nursery has had with the plant indicates that the problems are not insurmountable. Currently two young plants of 'Scarlet Sentinel' from Broken Arrow are growing at the Arboretum and perhaps cuttings taken from them will improve our chances for propagation success in the future.

To end on a more positive note, the author encourages all readers of *Arnoldia* who might have purchased a stewartia seedling at the Arboretum's 1982 plant sale to check their plants to see if they might, perhaps, have a hybrid seedling like 'Scarlet Sentinel'. If you do, please let me know and I'll come by to check it out.

Peter Del Tredici is senior research scientist at the Arnold Arboretum.

The Hidden Mathematics of the Garden

Peter J. James

Claude Monet's exuberant garden at Giverny is, perhaps, as far removed from the severe mirrors and stainless steel of a modern Chelsea show garden as it is possible to be. Yet at the heart of both there lies a fundamental geometry. The word *geometry* means land measurement, and certainly the great landscape gardeners knew their geometry and how to apply it. Le Nôtre's complex parterres, "Capability" Brown's sweeping vistas, and Victorian "carpet bedding" all depended on the use of compass, ruler, and French curves. There were even manuals on garden geometry, such as Charles Hayward's *Geometrical Flower Beds for Every Body's Garden* (1853). For all the visual appeal of the end products of this geometry, they represent only the static orderliness of a stage set as the curtain rises. There is, however, a deeper, darker, more dynamic form of geometry that influences our understanding of plant growth.

Most of the physical and chemical processes on which gardeners depend occur at surfaces; soil particles, plant roots, and compost heaps are all examples of such surfaces and the compost heap in particular repays deeper study. These heaps consist of dead plant remains that are gradually decomposed by the action of microorganisms; the result of this decomposition is a complex cocktail of products, but the one of greatest practical importance to the gardener is humus. The microorganisms carry out these processes of decomposition by secreting exoenzymes that diffuse into the plant remains, but these exoenzymes can only gain access to the plant cell contents through their surfaces. It is a complex and multistage process, and it is subject to strict mathematical laws. In order to understand how these laws operate it is useful to regard the surface of the plant debris as the supply and its volume—or bulk—as the demand and to look at the mathematical relationship between them. As with any process, its effectiveness depends absolutely upon the ratio of supply to demand, which in this case is reflected in the surface-to-volume ratio.

Bulky material has a low surface-to-volume ratio; when that bulk is divided into smaller fragments, the volume remains the same while the surface area increases and the ratio of surface to volume, or supply to demand, therefore also increases. This simple mathematical logic suggests that the most effective composting process is to be achieved by minimizing the size of the plant fragments: unfortunately, things are not quite so straightforward.

To produce good-quality compost, oxygen is required for the breakdown of the simple sugars, proteins, celluloses, and lignins that constitute the bulk of plant material; oxygen must therefore have free access to the plant debris. Yet small fragments closely packed together will impede this aeration while water, obeying the mathematical rules of surface tension, will tenaciously remain in tiny pores or spaces between the fragments and further inhibit the free diffusion of oxygen. The solubility of oxygen, even in pure water, is very low, and decreases as temperature rises, so that oxygen present in the water between the fragments is quickly exhausted and, if the pores are too small to allow free drainage, the oxygen-bearing water is not replenished.

Oxygen and water availability are, therefore, intimately connected and are both dependent on the surface-to-volume ratio. So, finely chopped, compacted, airless, and waterlogged compost heaps quickly become anaerobic, a condition easily detectable by the smell of ammonia. To avoid this, another aspect of mathematics must be invoked, namely, optimality theory. This is the algebraic way of expressing a compromise situation. What it amounts to here is insuring that fragment size is large enough to result in pores that are not too small (not less than about fifty microns in diameter), but not so large as to create a disadvantageous surface-to-volume ratio.

All these mathematical threads—surface-to-volume ratios, fragment size, pore diameter, the laws of surface tension, and water availability plus Adolf Fick's laws of diffusion and optimality theory—become woven into an awesome mathematical Gordian knot. However, it is a knot that, mercifully, can be cut through in a practical sense not by a computer but by a humble manure fork and a piece of old carpet, the first to break up and aerate the heap, the second to protect the compost from becoming saturated with rainwater. Alternatively, you could rely on those wonderful but unsung mathematicians of the garden: the insects and the worms, who know exactly the size and number of pores to create in your compost heap.

While good compost requires aerobic conditions for its production, there are other circumstances in which the presence of oxygen is anathema. An example is in the northwest corner of the Adriatic, on the mudbanks of the Venetian lagoon, where for a thousand years "the stones of Venice" have rested securely on wooden (that is, lignin) props driven deep into the anaerobic mud. It is as well that these props are deeply buried, for were they more superficial and therefore exposed to the aeration produced by algal photosynthesis and (later) the churning propellers of passing shipping and (now) *vaporetti,* La Serenissima would long since have vanished beneath the waves. Exactly this piece of chemistry was involved when England's East Anglian fens were drained, exposing the anaerobic peat—a form of compost—to the oxygen of the atmosphere. Since the fens are all surface, an enormous surface-to-volume ratio was produced and, albeit very slowly, the rich peat was oxidized to carbon dioxide and water. The final outcome has been the gradual sinking of the land below sea level, and all the historical and economic consequences thereof. Long-term observation of any compost heap beautifully demonstrates this process in miniature. Just note the gradual contraction of the heap over the months.

PETER J. JAMES

All this, however, is only the beginning of the mathematics of the compost heap. The decomposition of plant remains is an example of a process known to ecologists as a "resource" or "substrate" succession. In this type of succession the available nutrients—the substrates—are progressively depleted. Decomposition is initially very rapid, but gradually slows down as the more readily available substrates such as proteins and simple sugars are consumed. Physical chemists call this a "first order reaction": they have their own mathematics to deal with it, and these too can be applied to the compost heap. After all the simple chemicals have been consumed, only the more recalcitrant biopolymers such as the celluloses and lignins remain. These latter are so difficult to break down that only a few microorganisms (fungi) have evolved the means by which to carry out the process and, happily, Venice remains standing and peat accumulates.

The mathematics used to describe the kinetics of these various breakdown processes are too complex to go into here, but there are two ratios of great practical significance. The first is the familiar surface-to-volume ratio, but in a different guise.

The breakdown of proteins and simple sugars is one of many chemical processes that generate heat and are known as exothermic reactions. The first stages of compost production involve bacteria and fungi, which promote these exothermic reactions and thus raise the temperature of the compost, sometimes quite dramatically. In the case of a pile of grass cuttings, for example, temperatures may reach 175 degrees Fahrenheit. The laws of thermodynamics mean that this heat flows toward regions of lower temperature, in the case of compost from the core of the heap outwards. This heat flow is again dependent on surface-to-volume ratio.

Because small objects have a higher surface-to-volume ratio than large ones, and compost heaps are no exception to this rule, it follows that—since heat generation is a function of volume and its dissipation a function of surface area—a small compost heap will lose heat more rapidly than a large one. Higher temperatures speed up chemical and biochemical reactions, so large, heat-retentive heaps will be more efficient compost-makers than small heaps, which lose heat too quickly to allow the core temperature to rise significantly. The usual recommendation is that compost heaps should have a minimum volume of one cubic meter, giving a surface-to-volume ratio of 6:1. The demand for oxygen must be borne in mind: the larger the heap, the longer it takes for oxygen to diffuse into the core, and at the same time it must be remembered that active microbial growth increases the oxygen demand still further. But the mathematics of these processes, like the oxygen demand, are spiraling out of comprehension and control and are perhaps best left to the heirs of the Swedish physical chemist Svante Arrhenius (1879–1927), who first developed the appropriate equations—which may certainly be ignored by the average gardener.

The second ratio is that of carbon to nitrogen, usually written C:N. Carbon and nitrogen are essential elements in all living organisms, and the compost heap reflects in small the global cycling of these elements.

Because of the low nitrogen content of the celluloses and lignins in plant cell walls, the average value for the C:N ratio of plant debris is about 30:1, a figure that varies considerably according to the woodiness of the plant material. Fresh leaves or grass cuttings may have a ratio as low as 10:1, whereas it might rise to 100:1 in woody twigs. Humus has a C:N of 10:1. If 30:1 is taken as being the rough average, the process of composting results in a reduction of the C:N ratio from 30:1 to 10:1. Where does the nitrogen come from to achieve this reduction?

Farmers and gardeners of old may not have known the biochemistry involved but they were very well aware that first-class compost could only be produced by adding animal waste to the mix. Animal manure has a C:N ratio of about 12:1 (for reasons of anatomy and physiology—which have been implicated in changing the course of history—horse dung has a higher absolute nitrogen content than that of cows). The nitrogen in dung (or from other sources) is immobilized in the bodies of the compost-producing microorganisms and these, as they die off and in their turn decompose, provide a slow nitrogen fertilizer when the compost is eventually spread on the soil.

It should be remembered that a mulch of undecomposed plant material, such as bark, will consume nitrogen during its decay, a loss that can be offset by a top-dressing of ammonium sulphate. Legume debris, with a C:N ratio of about 15:1, will do the opposite, releasing, or mineralizing, nitrogen in the course of its decay—but this soluble nitrogen can easily be lost by leaching, another reason why compost heaps should be protected from heavy rain, particularly if a high proportion of leguminous material has been incorporated.

These days, of course, it is quite difficult for the urban or even suburban gardener to obtain sufficient good-quality animal manure to provide the sole nitrogen source for a compost heap, and ammonium salts from the local garden center have to serve. However, whether the nitrogen comes from Buttercup and Black Beauty or from Monsanto, the mathematics of the C:N ratio remain valid.

The exploitation of the combined effects of surface-to-volume and carbon-to-nitrogen ratios carries us back into gardening history and folklore and has its apotheosis in that wonderful feature of gardens on great estates, the hotbed. The head gardeners of these estates may not have been familiar with the mathematics in question, but they were certainly able to manipulate the practicalities in order to raise exotic blooms and out-of-season fruits to supply the table of the big house.

Hotbeds were basically compost heaps that were artificially maintained at an early, hot stage of the ecological succession. Since their primary function was to generate and retain heat, aeration of the heap was more for the purpose of sensitive temperature regulation than for oxygen supply, although this was still important because anaerobic reactions produce little heat. Here again, the mathematics of optimality theory were intuitively applied: it was discovered that provided they were properly ventilated, the hotbeds could be made as large as necessary, with a low surface-to-volume ratio.

The hotbed's composition was a carefully calculated mixture of horse and cow (and possibly some sheep) manure and nonwoody plant remains. By this means heat production was maximized to provide a high and constant temperature for the growth of plant housed in a frame on the surface of the bed. Constant maintenance—watering, aerating, and topping-up of compostable materials—was required to keep these hotbeds functioning. The garden boys who were responsible for these jobs knew nothing of the underlying mathematics and all-important ratios but these operated all the same.

Equally ignorant of these is the Australian scrub hen, which builds itself a hotbed from plant detritus, leaves it to heat up, and then lays its eggs deep inside the mound, where the heat generated, and retained, is sufficient to hatch the eggs. The male bird acts as garden boy, attending to the needs of the heap. Nature was, as ever, long before us in exploiting these mathematics, which are in any case her own.

The latest application of mathematics to gardening originates from the work of Benoit Mandelbrot, the discoverer of fractal geometry. This geometry, unlike that of Euclid, is able to deal with the irregular shapes that are so characteristic of nature, such as those of soil particles or plant fragments. Fractal geometry enables us to calculate a parameter of such objects, known as the fractal dimension. The fractal dimension of soil particles has a close correlation with soil fertility: the higher this fractal dimension, the higher the fertility (an optimum value for good garden soil is 2.6). As an index of irregularity, fractal dimension reflects both the particles' surface-to-volume ratio and their ability to pack together and all that that implies about water-holding, aeration, and microbial population growth. The fractal dimension is thus an extremely useful index for the gardener—but its calculation is very technology intensive. In the end, although we may perhaps gain a deeper understanding of compost by examining Nature's mathematical laws, for practical purposes the manure fork and the old carpet will serve us for some time yet.

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Climate Change Symposium: A Summary

At what may be the first meeting of its kind anywhere, a multidisciplinary group of scientists recently met in Providence, Rhode Island, to examine the implications of climate change and increased atmospheric CO^2 on industries involved with fruit and vegetable crops and ornamental horticulture. The symposium—*Impacts of Climate Change on Horticulture,* held in conjunction with the centennial conference of the American Society for Horticultural Science—brought together climatologists, plant ecologists, policy specialists, and horticulturists to review the impact that global warming and changing rainfall patterns have already had on plant conservation, crop yields, water supplies, disease proliferation, and invasive species management; to make predictions about changes to be expected in the future; and to identify research and education priorities.

Of special note, Richard Bisgrove of the Centre for Horticulture and Landscape at the University of Reading, UK, discussed the new challenges faced by people trying to conserve rare plant species and important plant collections. His findings indicate that many species can no longer grow in their current locations and will have to be moved to cooler climates if they are to survive. He also pointed out, however, that the warming trend will provide new opportunities to grow plants in areas that were formerly too cold.

Cameron Wake of the University of New Hampshire put Bisgrove's findings into clear perspective: if current warming trends continue, in 100 years the climate of eastern Massachusetts will resemble the present climate of eastern Virginia, a pattern of change that is likely to be repeated around the world. The resultant northward expansion of plant species—as Bisgrove and several other speakers noted—will be accompanied by parallel migrations of pests and plant pathogens. Some speakers suggested that since plant species will not all migrate at the same rate, pests and pathogens are likely to encounter and infect new host species. Another concern is that pests and pathogens imported with plants will be able to thrive in areas that were previously too cold for them to thrive.

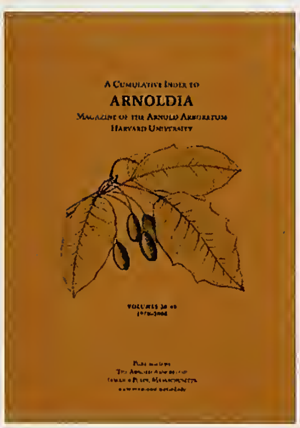
Speakers and audience members emphasized the need for scientists to work toward broader public awareness of the problem in several ways: by participating in public discussions of climate change; by organizing and making use of volunteer phenological networks and data collection programs in schools; and by making the results of their research more accessible to the general public. Participants expressed hope that a better-educated public will help define rational goals for addressing the biological effects of climate change and will cooperate in achieving those goals.

Abraham Miller-Rushing

The author is a graduate student at Boston University who is studying the effects of climate change on plants.

For more information related to the symposium, contact the organizer, David Wolfe of Cornell University (dww5@cornell.edu).

Announcing a Cumulative Index to *Arnoldia,* 1970–2000



A 148-page cumulative index to *Arnoldia*—volumes 30–60—is now in print. It references the plants, people, and places written about in *Arnoldia* from 1970 through 2000, and is preceded by a chronological list of the articles published in these thirty-one volumes.

This is the second cumulative index to *Arnoldia.* Its predecessor, which covered volumes 1–29, was published in 1969 and marked the retirement of Arboretum horticulturist and *Arnoldia* editor and principal contributor Donald Wyman, who had edited the magazine since 1936. *Arnoldia* was created in 1941 via a name change of the *Bulletin of Popular Information,* which had been published since 1911.

Copies of the new index can be obtained for $10: E-mail arnoldia @arnarb.harvard.com or write to *Arnoldia* Index, Arnold Arboretum, 125 Arborway, Jamaica Plain, MA 02130. A limited number of the 1941–1969 index ($5) are also available.

The Botanical Art of Ida Hrubesky Pemberton

COURTESY OF HUNT INSTITUTE FOR BOTANICAL DOCUMENTATION

The remarkable images that appear here and on the inside covers of this issue of *Arnoldia* are from the current exhibition at Pittsburgh's Hunt Institute for Botanieal Documentation,* *The Healing Plants of Ida Hrubesky Pemberton* and are included in the exhibition catalog by James J. White and Lugene B. Bruno (64 pages, paperback, $12; http://huntbot.andrew.cmu.ed). We learn in a biographical essay by Carolyn Crawford—herself a botanist and botanical artist—that Mrs. Pemberton (1890–1951) attended the Art Institute of Chicago for a time before her marriage in 1918. It wasn't until 1935, when her only child, a four-year-old, was struck and killed by a car, that she began to paint. By 1942 she had completed her 65 "drug plants."

Crawford tells us that information about Pemberton is scarce, but that one bit of history is repeated over and over in all available sources: She was an avid gardener, and "she grew all of the plants she painted from seed and bulbs she acquired from around the world." The intimate knowledge of her subjects that she gained from gardening as well as from her extensive colleetion of botanical and horticultural books is manifest in the paintings themselves, in what Crawford calls "the singularity of her thorough approach to botanical illustration."

Victoria Matthews, botanist, editor, and longstanding collector of botanical illustrations, contributed "An Appreciation" to the catalog in which she points out Pemberton's "outstanding ability to show great detail and produce representative paintings in whieh identification is in no doubt." She directs attention to the remarkable detail of minute dissections of flowers and fruits, praising "a technique that could express both strength and subtlety," and a sense of life as well:

> She painted in relatively broad strokes, refined by overpainting in more detail, yet without the tiny, often labored brushstrokes used by some artists—brushstrokes that sometimes kill the vitality of an illustration. Her paintings demonstrate her metieulous observation of the form and structure of plants and her accurate use not only of color but also of light and shade, both in the main plant portraits and in the dissections.

The artist's compositional skills can be seen in paintings such as the *Trillium erectum* (front inside cover) where a pale monochrome of the underside of a leaf integrates and frames the parts. Her compositional mastery is perhaps best demonstrated in her book jacket, above, where she joins elements from her paintings of autumn crocus *(Colchicum autumnale)* and pokeweed *(Phytolacca americana)* with the roots of the mayapple *(Podophyllum peltatum)* to link front and back covers.

Pemberton worked hard but unsuccessfully to have her drug plants published and never painted other groups of plants, as she had planned. After her death, her paintings were sold to the University of Colorado Museum of Natural History in Boulder, and from the 1950s to the 1970s were exhibited by the Smithsonian Institution at several locations across the eountry. Before the current exhibition in Pittsburgh, which will run through 29 February 2004, the illustrations had not been seen in 21 years. The catalog includes 45 of them, beautifully printed in color.

K. M.

* The Hunt Institute, a researeh division of Carnegie Mellon University, holds books, plant images, manuscripts, and portraits. Their data files encompass botanical art and illustration, history of science, horticulture, botanic gardens and gardening, scientific education and exploration—all of increasing value to plant scientists and researchers.

la H. Pemberton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