Since 1990, the Dawes Arboretum in Newark, Ohio, has undertaken a large scale ex situ conservation project with *Metasequoia glyptostroboides*, the dawn redwood. Ex situ conservation is defined as the conservation of genes or genotypes outside their environment of natural occurrence (China, in the case of dawn redwood). There are challenges and limits to ex situ conservation, but for some threatened or endangered plants and animals it is an essential component in efforts to keep the species from extinction. For a long-term conservation project to be successful and sustainable, a large sampling of genetic material is desirable to maintain the existing and potential variation within a particular species. Many attempts at rescue efforts are done on a limited basis, and they hold relatively small numbers of specimens due to insufficient space and budgetary limitations. Ideally, ex situ collections should have the capacity to grow the requisite number of individuals essential for preserving the base...
gene reserve with a goal of capturing as large of a part of the genetic diversity within the species as possible. Some species require relatively few individuals to capture that genetic range, while others require much larger population sizes. Studies of the genetic variation within dawn redwood have been and still are being conducted. Early results indicate that there is a fairly low genetic diversity, although there is some differentiation within the native populations throughout the overall range of the species.

Ex situ conservation does have its limits, and ideally it should complement in situ protection in the natural environment. Preserving a native, wild population is the best option, and this should be the primary focus of any conservation program. One of the particular problems with ex situ conservation lies in the inevitable environmental differences between the site of origin and the site of the ex situ collection. If plants in the ex situ site are allowed to sexually reproduce, environmental conditions in this new setting favor the selection and survival of the progeny best adapted to that site. Progeny that survive in the ex situ location may have different traits than progeny which would have survived in the original site. While this may have advantages from a horticultural standpoint (e.g., selection of plants with greater cold hardiness or better drought tolerance), it is a disadvantage for most conservation goals. Preserving the genetic diversity of a species ex situ may be best accomplished by maintaining clonal populations. However, seed banking of species with orthodox seeds (seeds that survive drying or freezing) can also be important in securing a species for the future, and there is the advantage that seeds can be stored in a much smaller space than living plants. A combination of both seed banking and living plants offers the most opportunities for conservation research.
Meet *Metasequoia glyptostroboides*

Dawn redwood (*shui-shan* in Chinese, meaning “water-fir”) is a deciduous conifer similar to bald cypress (*Taxodium distichum*). The soft, distichous needles of dawn redwood are arranged oppositely, easily distinguishing it from bald cypress with its alternate needle arrangement. When dawn redwood—once thought to be extinct—was discovered still growing in southeastern China in a mild and wet climate, it was not believed that it would survive in the United States north of Georgia. The provenance testing done since *Metasequoia* seeds arrived in the United States in 1948 shows that it can survive in USDA Hardiness Zones 5 to 8 (average annual minimum temperature -20 to 20°F [-28.8 to -6.7°C]) in areas with sufficient rainfall (or with supplemental watering). In its native Sichuan, China, the average rainfall is around 40 inches (100 centimeters) per year but dawn redwood has survived in parts of the United States with lesser amounts of rainfall.

The typical form is a large tree, up to 150 feet (45 meters) tall in the wild, pyramidal in youth, becoming more open-crowned with great age. The trunks on older specimens become strongly buttressed. It is fast growing when moisture is available and can add over 3 feet (1 meter) of growth per year. It is heliophilic (requiring full sun), which has limited its use as a commercial timber tree since it does not grow well in competition.

Many millions of dawn redwoods have now been planted throughout China, but the condition of the native population has remained stagnant. The 2009 *IUCN Red List of Threatened Species* gives dawn redwood a status of critically endangered, saying that the few remaining trees have been protected but that the habitat has not been, and there are poor prospects for natural regeneration. The valleys the tree prefers have been denuded of vegetation and mature trees are often limbed up—all the way to the top—for firewood. Seedling reproduction is unlikely in this altered environment. In the past, natural seeding was also hampered because the seeds were collected and sold by farmers for various uses such as timber plantations. This practice has become less common in recent years, since other Chinese conifers have provided lumber of greater quality. In addition, propagation from cuttings has proven to be advantageous for producing new plants. Recent surveys indicate that 5,396 native trees (of all ages) still remain in the native range in China. The majority of trees (5,363) grow in western Hubei, while 28 grow in eastern Chongqing. Only 5 trees remain in Hunan.
A Case of Depression and the “Single Tree” Theory

In 1983, Dr. John Kuser, a forestry professor at Rutgers University, surmised that cultivated *Metasequoia* in the United States were suffering from inbreeding depression. He said, “Apparently, variation in the amount of genetic load carried by different trees causes some to be incapable of producing fertile self-pollinated seeds but allows others to produce a few viable seeds and occasional trees to self quite well.” He noted that *Metasequoia* pollen is wingless and “tends to clump together.” The best seed germination was found to occur on trees that had been located advantageously for cross-pollination.

At the time, the popular belief was that the poor germination of seedlings was the result of trees in the United States having all originated from the single “type” tree in the village of Maudao, China. However, allozyme variation work done in 1995 showed that the 1947 seeds were not likely to have come from a single isolated tree. Furthermore, a copy of a previously unpublished paper by W. C. Cheng dated March 25, 1948 revealed, as stated above, that Hwa had found more than 1000 *Metasequoia* and about 100 “big ones.” Apparently seeds from many

Map of native dawn redwood distribution and seedlot collection sites.
trees had been collected and disseminated. Poor seed set seems to stem from the fact that most seed production outside of China is the result of selfing (due to isolation of specimens).

The genetic variation of dawn redwood in China was believed to be much greater than that in the United States, and in 1990 a cooperative research project on *Metasequoia* began between Dr. W. J. Libby at the University of California, Berkeley, Professor Minghe Li at Huazhong Agricultural University in Hubei, China, and Dr. Kuser. A number of organizations contributed to fund the project, and it was at this point that the Dawes Arboretum became involved in provenance testing of *Metasequoia*. Professor Li collected *Metasequoia* seeds from several locations in its native range in October 1990. In April 1991, 53 packets of seeds were received at Rutgers University from Professor Li, 52 from trees that still had seed cones, and one packet of mixed seeds. These seed lots were germinated, and only four of the collections produced no seedlings. The remaining 48 “families” were grown on, and complete collections were planned for both Rutgers and Dawes. The remaining seedlings were distributed to nearly 20 cooperating institutions and individuals in the United States and United Kingdom. (The Arnold Arboretum received 125 of these seedlings.)

In 1993 the Dawes Arboretum received two shipments of the dawn redwood seedlings from Rutgers. A total of 344 trees were planted in the Dawes plantation. Because of the large size (8 acres [3.2 hectares]) of the Dawes site we were able to plant the trees 25 feet (7.6 meters) apart so no subsequent thinning was necessary.

**Current Status of the Dawes Collection**

The Dawes plantation of seedlings from Professor Li and Rutgers currently consists of 320 trees, which makes it one of the largest living ex situ conservation collections of documented wild-origin dawn redwood trees outside of China. Through 2009, 24 trees have been lost...
from this plantation, and one seed lot family has been lost completely from both the Dawes and Rutgers plantations. In 2009, Dawes began contacting other institutions to see what living accessions they had from the original 52 seed lots; 29 new accessions (in the form of vegetative cuttings) representing trees from seed lots where Dawes had few representatives were obtained from these institutions. Since each of these trees was originally grown from seeds, every tree is genetically unique and therefore valuable for its individuality. These cuttings are currently doing well in propagation and will help to provide more genetic stock to add to the diversity of the plantation.

The search for additional collections of this Li/Rutgers project is ongoing. Any other modern or historical collection of wild material would be invaluable to add to the Dawes collection. One of the seed lots that had no germination was the only lot from Hunan, collected from three individual dawn redwoods there, so we are especially interested in acquiring germplasm from the few trees in Hunan.

In addition to the plantation trees, Dawes has a few other accessions of wild-collected Metasequoia: three accessions from the original 1947 seedlings, received in 1950 from Ralph Chaney who presumably got his seeds from Merrill; a grove of 44 trees propagated by cuttings in 1960 from the previous accession; and three individuals also propagated from the original accession.

**Into the Future**

In Metasequoia, female cones (mac sporangiate strobili) are typically produced when trees reach a height of 30 to 50 feet (9 to 15 meters). Male cones (microsporangiate strobili) are not produced until trees are 60 to 83 feet (18 to 25 meters) in height. At this point, neither female nor male cones have been observed on the Dawes Arboretum plantation trees.

As the grove continues to grow and seed production begins, the resultant progeny will represent the greatest level of genetic variation within dawn redwood outside of China. The origins of these plantation trees are from across the estimated 800 square kilometer (312 sq. mi.) native range in central China where full cross-pollination is very unlikely. Studies have shown that trees in the native populations show a lack of spatial genetic flow, indicating

Wide spacing allows ample room for trees in the dawn redwood plantation.
In 2009, both the genetic and taxonomic (cultivar) collections of dawn redwoods at the Dawes Arboretum were granted full status as a North American Plant Collections Consortium (NAPCC) collection. This symbolizes the commitment of the staff and organization to fulfilling the duty of preserving this important collection. As a repository for North America, requests for propagation material are honored for research purposes.

Of horticultural interest, there are well over two dozen cultivars of *Metasequoia* that add to the range of variation within the species. ‘Miss Grace’ and ‘Bonsai’ are dwarf selections, ‘Jack Frost’ has a hint of variegation, and ‘Ogon’ (syn. ‘Gold Rush’) is a Japanese cultivar with bright yellow foliage that originated from irradiated seeds. Several cultivar selections could be made from the Dawes plantation trees, as there are some interesting habits and foliage types. Tree heights of the plantation trees are from scarcely 3 feet (1 meter) tall to over 33 feet (10 meters), and habits range from squat and round to tall and narrow with many forms in between. Foliage varies from large and coarse to small and fine, with colors in shades of green and bronze. A witches’-broom—which may yield dwarf forms—has even been found on one specimen.
genetic isolation due to habitat fragmentation [Leng et al. 2007]. As stated earlier, natural pollen dissemination is limited.

Since these wide-ranging Chinese collections are located together in a single plantation at Dawes, broad genetic combinations could occur. The resultant mixed, open-pollinated seeds could prove useful for horticultural purposes as well as for selecting for resistance to any future insect or disease pressures. These seeds would have limited use for some conservation projects (since they are from mixed meta-populations), but there is potential for controlled crossing within the separate seed lot collections, which would give greater conservation value. The seeds produced here will be made available to seed banks, researchers, and growers.

This collection holds many opportunities for future studies and research to be conducted without traveling to China. The sister population at Rutgers University is currently the subject of an amplified fragment length polymorphism (AFLP) analysis to assess the breadth of the genetic diversity of the collection. Since most of the genotypes at Rutgers are duplicates of dawn redwoods in the collection at Dawes, the data from the AFLP study will pertain to this collection as well. We hope that this successful ex situ collection at the Dawes Arboretum will aid in the conservation and further understanding of this ancient and impressive species.

Bibliography


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Greg Payton is the Plant Records Specialist at the Dawes Arboretum in Newark, Ohio.