***Juglans* Vulnerability Statement**

**March 2024**

***Juglans* Crop Germplasm Committee**

**Production Trends and Value of *Juglans***

The United States produces approximately 720,000 metric tons of Persian (English) walnuts annually with a farm-gate value of $1.1 billion, almost entirely from California. Approximately 2/3 of the US crop is exported, accounting for 27% of the world supply and 68% of international commercial trade. Chile with 7% of world production accounts for 16% of international trade. China is the other major player with 42% of world production and a rapidly increasing 13% of trade.

Nut production of the native eastern black walnut is principally from natural stands in the eastern US and averages 17 metric tons annually. Annual timber harvest exceeds 12 million cubic feet. The total standing volume is estimated to exceed 3.4 billion cubic feet with a value in excess of $500 billion. Annual exports of walnut wood products are estimated at $325 million.

**Crop Vulnerability**

The major problems facing the walnut industry are nematodes, Botryosphaeria, walnut blight, husk fly, *Phytophthora* spp., crown gall, cherry leafroll virus, water availability, salts (sodium, boron, chloride), and insufficient chilling during some winters. Over 80% of the walnut industry in California is based on four cultivars, Chandler, Tulare, Howard, and Hartley. Dependence on only a few clonally propagated cultivars results in a high degree of genetic vulnerability and there is a relatively narrow germplasm base in reserve to combat these problems.

The few remaining stands of native butternut are severely threatened by both butternut canker and hybridization with introduced heart nut. Thousand cankers disease, a fungus vectored by the walnut twig beetle, is a potential threat to black walnut forests of the eastern US, and current germplasm collections. Most other *Juglans* species are forest trees valued for their wood and nuts, often with limited natural ranges in regions experiencing population pressure, and threatened by logging, grazing, and other human activities.

**Germplasm Activity**

Germplasm is maintained by the National Clonal Germplasm Repository (NCGR) at Davis CA, the NCGR at Corvallis OR, the University of Missouri (MU), and Purdue University. Breeding programs are primarily in the public sector. The University of California-Davis breeding program emphasizes Persian walnut yield, harvest date, and disease resistance, and use of diverse species for rootstock improvement. Black walnut programs are directed at timber (Purdue) and nut (MU) production. Butternut accessions are kept at NCGR-Corvallis, Missouri and Purdue. Collecting activities have emphasized broadening the narrow germplasm base found in existing cultivars and identifying sources of disease resistance. Latin American walnut species have been sparsely collected and poorly characterized. The rapid decline of butternut warrants accelerated efforts to identify and collect disease resistant genotypes.

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I. Introduction

The genus *Juglans* includes about 21 species of trees and large shrubs whose natural distributions range, in the Old World, from southeastern Europe to eastern Asia and Japan, and, in the New World, from the eastern half of the US, California, and the southwestern states south through Mexico and Central America to South America and the West Indies. The most economically important species is *J. regia*, the English or Persian walnut, cultivated for its edible nuts; second in economic importance is *J. nigra*, the eastern black walnut, grown primarily for its timber. Several other species and hybrids, notably *J. hindsii* (northern California black walnut) and Paradox (hybrids of *J. hindsii* and *J. regia*, sometimes with contributions from other species), have considerable commercial importance as rootstocks for cultivars of *J. regia*.

In 2022, annual world Persian walnut production approximated 2,247,000 metric tons (all figures in-shell basis). The United States produces approximately 720,000 metric tons annually, approximately two thirds of which is sold as shelled kernels, and 2/3 of the US crop is exported. In 2022, the US supplied 27% of worldwide commercial walnut production at a farm-gate value of $1.1 billion. China (1,110,000 MT) and Chile (157,000 MT) are the other major producers (International Nut and Dried Fruit Council).

Most (99%) of Persian walnuts produced in the US are grown in California, which in 2023 had 380,000 bearing acres of the crop. Although there is an interest in growing walnuts in other parts of the US, acceptable cultivars adapted to the different growing environments are not available.

*J. nigra* (Eastern Black walnut) yields in excess of 11,000 tons of in-shell nuts annually but demand for black walnut kernels continues to exceed supply. Most of these nuts are collected from wild trees in Missouri, Illinois, Indiana and Iowa. Eastern black walnut is also one of the most highly valued hardwood species. The USDA Forest Service Forest Inventory Analysis (FIA) indicates that more than 15.4 million acres of timberland in 30 states contain black walnut. The vast majority of this resource is in natural stands, with a small percentage grown in plantations. US production of walnut wood exceeds 12 million cubic feet annually. Due to high commercial value and the long time required to produce saw-timber grade trees, the demand for this species has exceeded supply for several decades.

The primary commercial importance of the Northern California black walnut (*J. hindsii*) is as a rootstock for commercial Persian walnut (*J. regia*) orchards or as parent of the widely used hybrid rootstock ‘Paradox’ (*J. hindsii x J. regia*). This species is also a producer of high-quality burl wood. Likewise, the primary commercial importance of Texas black walnut (*Juglans microcarpa*) is as a parent of hybrid ‘Paradox’ rootstock (*J. microcarpa x J. regia*). Additional black walnut species native to Latin America typically have limited ranges, may be endangered, and have local nut and timber use. Few are available in the US but are of interest for rootstock breeding.

Butternut (*J. cinerea*) was once an important component of the Eastern Hardwood Forest but has been decimated by butternut canker, a fungal disease. Few examples of the pure species remain due to disease losses and hybridization with the introduced Japanese walnut, *J. ailantifolia*. This native species is already listed as endangered in Canada.

II. Present Germplasm Activities

The National Plant Germplasm System *Juglans* collection, with the exception of butternut (*J. cinerea*) is assigned to the National Clonal Germplasm Repository in Davis, California (NCGR-Davis). Butternut accessions are maintained at the National Clonal Germplasm Repository in Corvallis, Oregon (NCGR-Corvallis). Collections of *Juglans* spp. maintained elsewhere in the US include a University of Missouri collection of 57 *J. nigra* cultivars selected for nut production that have been recently characterized using microsatellites and seven phenological descriptors (Coggeshall and Woeste 2009). In addition, the largest collection of black walnut genotypes suitable for wood production is located at Purdue University, West Lafayette, IN. There is also a collection of *Juglans* species maintained by the US Forest Service at Southern Illinois University, Carbondale IL.

A. Collection and maintenance, NCGR, Davis

Trees are maintained in approximately 12 acres of permanent orchard blocks at the Wolfskill Experimental Orchard in Winters, CA. The collection at Davis now contains 478 active (410 available) accessions (2056 total trees) of *Juglans* representing 17 species. Related material includes 10 accessions from two *Pterocarya* species and 7 accessions from two *Carya* species. Each accession either represents a single clonal genotype with multiple copies, or a genetically diverse but related seedling family (typically from a wild or market collection). Some taxa, such as *J. neotropica*, are not hardy in the field and instead are maintained in containers under frost protection at the nursery in Davis. Availability is based on the presence of healthy budwood for distribution. Accessions with unavailable inventory may be in decline or in repropagation, and may still be available for pollen or seed collection.

Table 1. Accession availability from the USDA-ARS collections in Davis.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Taxon** | **Clonal accessions** | **Seedling family accessions** | **Total accessions** | **Available**  **accessions** |
| Juglans regia b | 111 | 238 | 349 | 310 |
| Juglans hindsii | 2 | 16 | 18 | 18 |
| Juglans californica | 0 | 14 | 14 | 10 |
| Juglans nigra b | 9 | 1 | 10 | 5 |
| Juglans major | 0 | 18 | 18 | 18 |
| Juglans microcarpa | 1 | 7 | 8 | 7 |
| Juglans mollis | 0 | 1 | 1 | 1 |
| Juglans cinerea a | 0 | 2 | 2 | 1 |
| Juglans olanchana | 0 | 1 | 1 | 0 |
| Juglans australis | 0 | 3 | 3 | 0 |
| Juglans neotropica | 0 | 3 | 3 | 0 |
| Juglans ailantifolia b,c | 2 | 13 | 15 | 13 |
| Juglans mandshurica b,c | 2 | 17 | 19 | 14 |
| Juglans x hopeiensis | 1 | 0 | 1 | 1 |
| Juglans sigillata | 2 | 1 | 3 | 3 |
| Juglans hybr. | 9 | 3 | 12 | 9 |
| Juglans spp. b | 0 | 1 | 1 | 0 |
| Carya illinoinensis d | 6 | 0 | 6 | 0 |
| Carya ovata b,d | 1 | 0 | 1 | 0 |
| Pterocarya fraxinifolia b | 0 | 4 | 4 | 3 |
| Pterocarya stenoptera b,c | 0 | 6 | 6 | 5 |

|  |
| --- |
| a Main collection held at NCGR-Corvallis |
| b Additional accessions at the US National Arboretum, Washington DC |
| c Additional accessions at the North Central Plant Introduction Station, Ames IA |
| d Main collection held at National Collection of Genetic Resources for Pecan and Hickory, Somerville TX |

There are trees in the collection at Davis that are severely stressed and threatened by a variety of problems including crown gall disease (*Agrobacterium tumefaciens*) and poor irrigation management due to rodent damage. *Juglans californica* trees in the A and B blocks have failed to thrive in the collection for many years, and over time, many have died, often from thousand cankers disease. Interestingly, most *J. californica* trees in the C block, and those that were repropagated and are in the S block, are growing well, likely because they are grafted rather than on their own roots. Repropagation has been hampered by lack of available land upon which to relocate the National *Juglans* collection.

The clonal collection at Davis is at risk of disease or catastrophic weather events. Backup at the National Laboratory for Genetic Resource Preservation in Fort Collins, CO is limited for *Juglans* due to a lack of successful protocols for budwood cryopreservation. Cryopreservation of pollen is underway, but a true security backup of the collection is lacking.

B. Exploration and acquisition

Eighteen exploration missions have been completed since 1983 (Table 2). These trips have resulted in acquisition of valuable wild *Juglans* species that have filled some of the critical genetic gaps in the NCGR collection. Material from the Republic of Georgia is still grown on very close spacing in the nursery S (seedling) block at Wolfskill. The Seybold collection from the southwest US is currently maintained similarly at UC Davis, and has not yet been added to the publicly available NCGR-Davis collection. Research partners at the San Diego Botanical Garden and others have been engaged in collection and conservation efforts for *J. californica*. Due to restrictions on international germplasm collection and lack of land to accommodate a larger collection, no new collection trips are planned. Lack of field space at NCGR-Davis also limits the ability to incorporate material that has already been collected by research partners. This leaves important gaps in wild *Juglans* genetics in the public collection.

Table 2. *Juglans* collection explorations.

1983 - Westwood, Japan, *J. ailantifolia*

1984 - Parfitt, New Mexico, Arizona, *J. major, J. microcarpa*

1987 - Parfitt, Mexico, *J. olanchana J. mollis J. pyriformis*

1989 - Dixon, Ecuador *J. neotropica*

1988 - Thompson, Pakistan, *J. regia*

1990 - McGranahan, Leslie, Barnett, China *J. re*gia

1990 - \*Millikan, USA, *J. cinerea*

1990 - Thompson, Sperling, Ramming, Uzbekistan, USSR, *J. regia*

1994 - McGranahan, Leslie, Kyrgyzstan, *J. regia*

1995 - McGranahan, Leslie, China *J. regia*

1999 - McGranahan, Argentina, *J. regia J. australis*

2000 - Simon, Potter, Ukraine, *J. regia*

2006 - Postman, Stover, Republic of Georgia, *J. regia*

2006 – Prins, Balser Collection- Washington, *J. regia*, *J. nigra*, *J. ailantifolia*

2007 – Aradhya, Parfitt, Azerbaijan, *J. regia*

2010 - Aradhya, Republic of Georgia, *J. regia, J. cathayensis*

2010 - Grauke, Texas, *J. microcarpa*

2011 - Preece, Postman, Albania, *J. regia*

2014 - Aradhya, Republic of Georgia, *J. regia*

2018 - Seybold, Leslie, New Mexico and Arizona, *J. microcarpa* and *J. major*

\*Located at Corvallis NCGR

C. Evaluation.

1. Description of NCGR accessions

Characterization of the collection has been a high priority of the Juglans Crop Germplasm Committee. Juglans accessions in the NCGR collection have been described using the standard descriptors published in the International Plant Genetic Resources Institute (IPGRI) guideline Descriptors for Walnut (*Juglans* spp.), (McGranahan et al., 1994).

For five consecutive years (1988-92), data on phenology, flowering, and yield characteristics were obtained from 524 trees of Juglans spp. at the NCGR, Davis and entered into GRIN. Most of the *J. cathayensis, J. mandshurica, J. californica, J. ailantifolia, J. microcarpa,* and *J. hindsii* accessions were evaluated during that period.

During 1995-2000, evaluations concentrated on *J. regia* accessions. Data collected included both field characteristics (phenology, bearing habit, yield, incidence of insect and disease) and seventeen descriptors of nut traits (kernel weight, percent kernel, kernel color, shell seal and strength, etc.). Nut traits were evaluated only for trees with ten or more nuts. Only field data was collected on *J. nigra* and *J. mollis* accessions. This evaluation data has been entered into GRIN as it was collected.

More recently, all accessions in the collection have been evaluated for disease resistance traits, particularly those of interest for rootstock breeding, including nematode and crown gall resistance. J*. microcarpa*, J*. major* and *J. mandshurica* are among species that have shown promise and are being used in breeding efforts.

Material in the collection has also been evaluated for variation in chilling requirements and susceptibility to pistillate flower abscission.

2. Molecular markers and genomics

Genome assemblies of 9 *Juglans* species are now (as of 2/28/24) available on NCBI, including *regia* (cultivars Chandler, Donggou, and R1), *sigillata, cathayensis, mandshurica, nigra, hindsii, californica, macrocarpa, and cinerea*. The genomic diversity of black walnut species from Central and South America (eg: *mollis, australis, neotropica, boliviana*) remains relatively uncharacterized. The NCBI Short Read Archive includes 90 distinct BioProjects for Juglans (as of 2/28/24), including 55 RNA-seq, 15 whole genome sequencing (WGS), and 4 miRNAseq projects. Of BioProjects where a source country is listed, 80% are from China and 16% are from the USA. Just over half (n=46) of the BioProjects are focused on *J. regia*. Transcriptome (RNA-seq) data include multiple BioProjects focused on kernel (embryo), pellicle (endopleura), shell (endocarp), and hull/peel (exocarp). One WGS BioProject is notable for its size: Li *et al.* (2021)

resequenced 815 trees of *J. regia* from China, Pakistan and Iran, and identified candidate genes for pellicle color (ANR) and oil composition (FAD2).

The NCGR has collaborated with the UC Davis Plant Sciences Department on genome sequencing, transcriptome analysis, and trait mapping (Chakraborty et al., 2015; Luo et al., 2015; Martinez-Garcia et al., 2016, Stevens et al., 2018, Marrano et al., 2019, Marrano et al., 2020, Sideli et al., 2020), and with the Genetics and Crop Pathology Unit, USDA-ARS, UC Davis on walnut rootstock breeding and susceptibility to pathogens (Dvorak et al., 2007; Kluepfel et al., 2016; Westphal et al., 2017).

A new chromosome-scale reference genome for butternut (*J. cinerea;* Guzman-Torres et al., 2024), a genome assembly for *J. ailantifolia*, and a massARRAY developed by the Canadian Forest Service for use in identifying species-specific markers, all promise to help identify loci that confer resistance to butternut canker disease and witch’s broom, both of which threaten *J. cinerea* across its native range.

Research on the biology, morphology, and genetics of Eastern Black walnut, *J. nigra*, has been well-documented (Aradhya et al., 2007; Schneider et al., 2019). The search for superior eastern black walnut varieties led to the initiation of genetic tool development for selective breeding, alongside explorations into the species' evolutionary history, genetic diversity, and population structure, starting in the 1980s (Coggeshall, M.V., 2011), with notable advancements occurring in the recent decade (Schneider et al., 2019) leading to introduction of genetic markers such as microsatellites and paternity analysis (Woeste et al., 2002; Ebrahimi et al., 2018), studies of genomic sequences (Stevens et al., 2018; Ebrahimi et al., 2019), and development of specialized transcriptomic resources (Chakraborty et al., 2015). Recently, chromosome-level genomic assemblies of black walnuts were published by Zhou et al., 2023.

D. Enhancement

1. Breeding programs – Persian walnut

a. US: Walnut Improvement Program, UC Davis

The Walnut Improvement Program at the University of California - Davis is a comprehensive program incorporating classical breeding, genomics, and genetic engineering to develop new Persian walnut cultivars. It is a cooperative effort between UC Davis, USDA, and the California Walnut Board. The program is led by Dr. Pat Brown, Department of Plant Sciences, UC Davis, in collaboration with Chuck Leslie, Specialist in the same department. The program also includes the independent and cooperative work with several collaborators. Scion breeding emphasizes precocity, early harvest date, late leafing, high yields, kernel color, shelf-life, and disease resistance. These include blackline disease (cherry leafroll virus) and walnut bacterial blight (*Xanthomonas*). Rootstock breeding emphasizes development of genetic resistance to Phytophthora root and crown rots, parasitic nematodes, and crown gall disease.

b. France: INRAE

Walnut improvement at the French National Institute for Agronomic Research (INRA), led by Eric Germain, from 1977 to 1995, emphasized late leafing, blight resistance, and lateral fruitfulness, using California cultivars as a source of lateral bearing, and released several cultivars. From 1996 to 2007 E. Germain and F. Delort continued the program using a large and diverse collection of material from the Mediterranean region, Iran, Japan, and Central Asia to avoid inbreeding issues. This work was discontinued in 2007 and much of the germplasm has been lost, but more recently INRA successor INRAE (National Research Institute for Agriculture, Food and Environment) and CTIFL (Interprofessional Technical Center for Fruit and Vegetables) cooperatively initiated a new breeding and genetics research program under Fabrice L’Heureux. Program goals include characterization of remaining material collected by Eric Germain, development of genomic information and tools for marker assisted selection, and release of cultivars with resistance to major walnut pathogens.

c. China: Ministry of Forestry

Walnut improvement in China emphasizes development of varieties with adaptation to China’s growing conditions. They are also focusing on high yields per tree and a tree with short lateral branches for denser plantings and greater yields per hectare. Nearly all provinces that grow walnuts have selection programs; actual breeding is occurring at Zhengzhou Fruit Research Institute, Chinese Academy of Agricultural Sciences. Recently, several cultivars from Xinjiang Province, notably Wen182, with very high kernel percentage but shells too thin for mechanical harvest, have been marketed internationally with some success.

d. **Iran:** Horticulture Science Research Institute (HSRI) and the University of Tehran (UT).

The Persian walnut breeding programs in Iran aim to develop climate-compatible cultivars and rootstocks. Key scion breeding objectives include: high yield, quality, lateral bearing, late-leafing, light kernel color, thin shells, low chilling requirement, and early harvest; Rootstock objectives include drought and salinity tolerance, and dwarfing. Breeding strategies include traditional methods (germplasm evaluation, targeted cross-breeding) and molecular techniques (molecular markers, haploid plant production, gene transfer, metabolomics, genome sequencing, GWAS, GBS, transcriptomics). The HSRI's program has introduced six commercial cultivars: ‘Jamal’, ‘Damavand’, ‘Persia’, ‘Caspian’, ‘Chaldoran’, and ‘Alvand’. UT's program has identified 58 promising genotypes, with three undergoing stability and compatibility evaluation. A targeted breeding program for drought-tolerant rootstocks is underway.

e. Other Breeding programs

Many other countries have activities related to enhancement. Most notable are Turkey, Spain, India, Hungary, Romania, Ukraine and New Zealand. Descriptions of activities can be found in the Proceedings of the International Walnut Symposium published as Acta Horticulturae Numbers 159, 284, 311, 442, 544, 705, 861, 1050, and 1318.

e. Goals of Persian walnut breeding programs

i. Lateral bud fruitfulness

The most significant component of yield that can be manipulated through breeding is lateral bud fruitfulness, a bearing habit in which the lateral buds produce flowers. Lateral fruitfulness is also associated with precocity. Old cultivars and the preponderance of germplasm from Europe are terminal bearing. Incorporation of this trait into new cultivars is a high priority in all breeding programs. Another approach is to increase the number of nuts per cluster.

ii. Shell and kernel quality

Improved walnut cultivars require a well-sealed shell to prevent breakage during mechanical harvest and for exclusion of codling moth and navel orange worm. Nuts should contain more than 50% kernel by weight. Light kernel color is an essential marketing trait. Walnuts are marketed for their healthy oil composition but oil instability leading to rancidity limits product development and is a major marketing concern.

iii. Phenology

Phenology is a major concern in many breeding programs. Late leafing is especially important in France and other areas with late spring frosts. Late leafing cultivars also tend to escape blight in areas with spring rains and dry summers. A recent emphasis in the UC Davis program has been on breeding for an earlier harvest than is typical of late leafing cultivars.

iv. Diseases

Disease resistance is a goal in several breeding programs. In the US and France resistance to blight is of primary importance. Several potential sources of blight resistance have been identified in introduced germplasm. Germplasm introduced for potential blight resistance from high moisture areas in the Republic of Georgia is currently being evaluated. Resistance to blackline disease caused by the cherry leafroll virus is a goal in the UC Davis program. Botryosphaeria is an increasingly serious disease in California and resistance in germplasm needs to be determined.

v. Insect pests

The major insect pests affecting the fruit include walnut husk fly, codling moth, and navel orangeworm. The walnut twig beetle vectors the fungus responsible for thousand cankers disease. In some instances, flathead borers can damage trunks. Insect-resistant germplasm has not been identified but factors involved in husk fly attraction and/or establishment in the hull and factors influencing twig beetle infestation are being investigated.

vi. Soil-borne pests in rootstocks

One of the most serious soil borne problems is nematodes, particularly *Pratylenchus vulnus*. Once walnut orchards become infested with *P. vulnus* there is no known practical remedy. A fallow period of 10 years without any host of nematodes might be adequate. Potentially useful resistance to *P. vulnus* has been observed in *J. cathayensis, J. major,* and *J. microcarpa*. The search for additional sources of resistance is continuing and success is critical in view of the current lack of available post-plant nematicides, the previous phase out of methyl bromide, and the current regulatory and economical pressure on 1,3-D (Telone) applications.

Another important soil-borne pathogen in the United States is *Phytophthora*. Many species of *Phytophthora* can affect walnut, but *P. cinnamomi* and *P. pini* (a member of the *P. citricola* complex) are the most aggressive. Seasonal floods that occur in low-lying fields and heavier soils that are slow to drain can accentuate infection by *Phytophthora*. Selection of rootstocks that are resistant or tolerant to *Phytophthora* species is a high priority of the walnut breeding program at Davis. Commercial rootstock RX1 was selected for its strong resistance to this pathogen; it is a hybrid developed from *J. microcarpa* accession DJUG 29.11 in the USDA collection. *J. microcarpa* continues to be promising source of resistance in current rootstock breeding.

Crown gall (*Agrobacterium tumefaciens*) is primarily a rootstock problem, caused by this gall-forming soil borne bacterium. Efforts are underway, using primarily NCGR *J. microcarpa* accessions as seed sources, to identify Paradox (hybrid) rootstocks with resistance. Several promising candidates have been identified and are currently in trials. Genetic engineering using RNAi suppression of the gall forming genes has resulted in complete resistance to gall formation but rootstock selections remain in the deregulation process and have not been released to the industry.

2. Breeding programs – Black walnut

Breeding and selection programs for *J. nig*ra are centered at the University of Missouri, Columbia and at the US Forest Service Hardwood Tree Improvement and Regeneration Center (HTIRC), housed within the department of Forestry and Natural Resources, Purdue University, West Lafayette, IN. The program at the University of Missouri is focused on selection for nut production and the use of black walnut in agroforestry plantings. The program at the HTIRC was focused on stem straightness, diameter growth and other traits important to the hardwood and veneer industries but work related to wood quality, tissue culture, rooting, and nursery practices is no longer supported. HTIRC research now is aimed at basic genetics, genetic diversity, and genetic structure of wild populations. Existing orchards at this location are maintained by Purdue University.

III. Status of crop vulnerability

A. Domestic vulnerability

1. Persian Walnut

*J. regia* is an introduced species in the US. Except for NCGR collections, the gene pool in the US is largely limited to US cultivars and their relatives, which represent very little of the total species’ variation. Most domestic commercial walnut varieties are derived from the same gene pool of a few progenitors. Two cultivars, Chandler and Tulare, make up over 77% of the current production.

Over 10% of potential walnut production is lost to pests and diseases annually. For many of the major diseases, chemical forms of control are either unavailable or ineffective. Codling moth, walnut blight, Phytophthora root and crown rots, nematodes, and blackline disease (caused by cherry leafroll virus (CLRV) continue as major sources of loss in the walnut growing regions of California.

Thousand cankers disease (TCD), caused by an insect-vectored fungus (*Geosmithia* spp.) is a recognized threat to *J. nigra* in the intermountain western US and has been identified in California orchards during the past two decades, but has not developed into a significant threat to Persian walnut orchards, native *J. hindsii* commonly found in riparian habitats, or to *J. hindsii* or Paradox hybrid rootstocks*. J. californica*, native to southern California, appears to be more susceptible.

Other possible threats include butternut canker and witch’s broom, which have not been found in California, lack of adequate winter chilling due to a warming climate, and Lethal Paradox Canker, a phenomenon impacting Paradox rootstocks and resembling Phytophthora but with no identified pathogen.

2. Eastern Black Walnut

Of the black walnut species native to the US (*J. nigra, J. hindsii, J. californica J. microcarpa* and *J. major*), only *J. nigra* has been commercialized to any great extent for nut or wood production.

Most of the commercial harvest of eastern black walnuts is collected from wild trees in Missouri, Illinois, Indiana and Iowa. Demand for black walnut kernels exceeds supply, which is limited by insect pests and erratic bearing. Black walnut kernels have dark color and shrivel, which are the most limiting factors for marketable yield (Warmund, 2009).

Eastern black walnut is one of the most highly valued hardwood species. It is found throughout the eastern half of the United States, concentrated in stands on suitable sites. The USDA Forest Service Forest Inventory Analysis (FIA) indicates that more than 15.4 million acres of timberland in 30 States contain black walnut. The vast majority of this resource is in natural stands. In the North Central Region, an estimated 7 million cubic feet of black walnut growing stock and 5.3 million cubic feet of black walnut non-growing stock are harvested annually. Due to its high commercial value and the long time required to produce saw-timber grade trees, demand for this species has exceeded supply for several decades.

Midwestern landowners prize eastern black walnut as a multipurpose species: it provides valuable timber, is regionally adapted, and attractive to wildlife.

3. Other Black Walnuts

Two Juglans species are native to California. These are *J. hindsii*, the Northern California black walnut and *J. californica*, the Southern California black walnut.

At the time of European settlement, *J. hindsii* was found in only a few isolated sites in Northern California but has since been widely planted as an orchard rootstock and street tree and is common in riparian areas. Few, if any, original stands remain, but there is good genetic diversity within the current *J. hindsii* wild populations. The nuts are sometimes collected for marketing and trees with burls or desirable grain are extremely valuable. Individual trees capable of hybridizing with *J. regia* are prized as sources of hybrid ‘Paradox’ seed used commercially as a rootstock. Additionally, *J. hindsii* is used directly as a seedling rootstock for commercial *J. regia* orchards.

*Juglans californica* is a shrubby tree native to the coastal ranges of Southern California. Its small original range has been further reduced by agriculture and urban encroachment. *J. californica* appears to be particularly susceptible to thousand cankers disease, which may put additional pressure on remaining native stands.

*J. major* and *J. microcarpa*, both native to the southwestern US and northern Mexico, are also harvested for timber, but without a large impact on the germplasm. Timber theft, always a problem in *J. nigra*, is also an increasingly important issue for *J. major*, since this species commonly forms valuable burls at maturity.

There are no concerted efforts to plant *J. major* or *J. microcarpa* in the United States, but China has been buying seeds of *J. microcarpa* for use as a rootstock in alkaline soils. Both species have been of interest for rootstock breeding and development in California.

The impact of selective harvest, habitat fragmentation, urbanization, and other environmental changes on populations of North American black walnut species is not clear. Areas of local or unique genetic diversity have not been identified for any of these species.

4. Butternut

Butternut (*Juglans cinerea*), also called white walnut, grows on rich loamy soils along stream banks in mixed hardwood forests and on well-drained, rocky soils of limestone origin. Its native range is similar to eastern black walnut, extending farther north but not as far south. Its native range is from eastern Canada west to Minnesota and as far south as Arkansas, Alabama, Georgia, and Mississippi. Butternut has been planted widely outside of its native range.

Butternut is seriously threatened or endangered throughout its range due to butternut canker, caused by what is believed to be an introduced pathogen Ophiognomonia *clavigignenti-juglandacearum* (formerly known as Sirococcus clavigignenti-juglandacearum). The sticky spores of the pathogen are spread locally by rain splash and long distance on seed and most likely by insects and birds. Multiple branch and stem cankers often girdle and kill infected trees of all ages. Stump sprouts, if they develop at all, are quickly infected and killed.

The disease, first observed in Wisconsin in 1967, has since killed up to most of the butternut in the Eastern US and Canada, and is threatening its survival as a viable species throughout North America. The fungus is not known to be present in the western United States.

Although butternut is the only species that is killed by the pathogen, eastern black walnut (*J. nigra*) and heartnut (*J. ailantifolia* var. *cordiformis*) have been found infected in plantings where the fungus causes a twig blight but not stem cankers on these species. Other hardwood species such as pecan, hickories and *J. regia* have been shown to be susceptible in inoculation experiments. However, it is not known if the fungus is naturally present on these other species or if it could threaten walnut plantations in the west if it was accidentally introduced.

Nut growers in the Eastern United States have long planted cold-tolerant heartnuts, smooth-shelled selections of Japanese walnuts (*J. ailantifolia*). These hybridize readily with butternut. Hybrids are more resistant to the canker so that most surviving “butternuts” are now likely hybrids between butternut and heartnut, with few pure butternut trees remaining.

Efforts are underway to identify, screen and propagate putatively tolerant and resistant genotypes. *J. cinerea* is harvested for timber on an occasional basis as suitable trees are identified. This practice tends to remove the larger and potentially more tolerant genotypes, placing the species at even greater risk from the disease.

As more butternut hybrids are produced and introduced to nurseries, walnut bunch disease has dramatically increased as a threat. Japanese walnut appears unusually susceptible, so it passes this trait on to butternut hybrids. A method for rapid detection of bunch disease has been developed recently. This disease is the reason butternut cannot be added to repositories in the western US, so it is a significant factor in butternut germplasm management and risk.

Butternut is listed as a sensitive species or a species of special concern in many states and the harvest of healthy butternut on Federal lands and on land managed by several states is restricted. Butternut is now listed as endangered in Canada and conservation and restoration efforts are underway. Even in the absence of the disease, butternut is dying from old age. Decline in regeneration is attributed to insufficient site disturbance needed to create optimum seedbeds (light, bare soil) and to seed predation.

B. Foreign vulnerability

1. Central and South America

The status of most of the species of *Juglans* occurring in Mexico, Central and South America, and the Caribbean is uncertain. Based on observations by Dan Parfitt during his exploration in Mexico in 1987, however, it is probable that at least *J. pyriformis*, *J. olanchana*, and J. mollis are endangered species. Other species occurring in these regions include *J. hirsuta* (Mexico), *J. steyermarkii* (Guatemala), *J. jamaicensis* (West Indies), *J. soratensis* (Bolivia), *J. boliviana* (Bolivia), *J. venezuelensis* (Venezuela), and *J. australis* (Argentina). *Juglans neotropica*, native to northern South America, is more widely distributed. All of these are potentially important timber species and *J. australis*, which is used in Argentina as a rootstock, may have value as a source of Phytophthora resistance. Many of these species are endangered due to their value for timber combined with their limited geographic distributions. The potential of these species as sources of genes for disease resistance and/or valuable secondary compounds is mostly unknown. Most are not represented in the NCGR collection or are present in only very limited numbers. They should be given high priority for exploration activities although most countries where these are native now severely restrict or prohibit germplasm exchange.

2. Central Asia

Important sources of *J. regia* germplasm are being lost due to extensive logging and deforestation in Iran, Kyrgyzstan and other Central Asian areas of origin. Several characterized collections of material from this region were established in the past within the former Soviet Union but these collections are also at risk.

3. Far East

The current status of germplasm resources of species native to Japan, Korea, Manchuria, coastal China and southern China are not well known. As elsewhere, logging and population pressure are likely threats to forest populations as is replacement of native material in many areas with selected introductions for commercial production. Native material in Xinjiang Province has been the foundation of commercial selection and breeding programs both locally and throughout China, particularly as the primary source of lateral bearing and precocity. Limited material has been collected from these areas and is in the current collections.

IV. Germplasm Needs

A. NCGR collection maintenance

Additional space is urgently needed at the NCGR, Davis. Limited space availability for collections has required close planting of the *Juglans* accessions. While this is adequate for production and distribution of vegetative material, tight spacing increases annual management costs considerably, prevents normal canopy development and cropping, and severely impedes evaluation of accessions. In addition, there is not space to repropagate current accessions threatened with loss from crown gall, other root diseases, and TCD.

Attention needs to be given to protecting the collection and repropagating impacted trees. Many *Juglans* trees in this collection are in poor and declining condition, perhaps initiated by a variety of causes, but exacerbated by management issues, insufficient funding for maintenance, and overcrowding due to lack of land. Many have declined or died due to crown gall disease and have not been repropagated due to lack of funding and space.

There are currently a very limited number of accessions of *Juglans* species native to eastern North American in the NCGR, Davis collection. Restrictions on importation of *Juglans* germplasm into California due to bunch disease and concerns about butternut canker make expansion of the collections of native North American *Juglans* clonal material difficult.

Currently, the largest collection of *J. nigra* nut cultivars is located at the University of Missouri. A number of *J. cinerea* accessions and related hybrids are maintained at Purdue University.

A repository location with a subtropical climate is needed, and has long been requested, for species with insufficient cold-hardiness to survive at Davis.

Cryostorage of embryo axes from seeds, with subsequent successful germination and recovery of plants, has succeeded for butternut (7-year storage) and *J. nigra*, (20-year storage). Cryopreservation of *Juglans* somatic embryos has been achieved and one genotype has been stored at Ft. Collins. A procedure for cryopreservation of *in vitro* grown shoot tips with recovery of growth was published recently, but long-term storage was not evaluated. Attempts to cryopreserve dormant buds from field material have not been successful. Consideration should be given to developing cryostorage procedures at Ft. Collins to back up the NCGR *Juglans* accessions in the field.

B. Exploration

Exploration locations have been prioritized according to genetic diversity that is potentially available and according to the stability of the germplasm sources.

1. North, Central and South America

Approximately 11 species of black walnut are native to areas of Central and South America. Development of a representative collection of these species is a high priority of the committee.

Exploration for species native to Mexico, the Caribbean, South and Central America, most of which are not currently represented in the collection (e.g., *J. hirsuta, J. jamaicen*sis, and *J. pyriformis*), should be undertaken as a priority when and if there is access. Exploration in Mexico would also increase the geographic representation and genetic diversity of accessions of *J. major* in the collection. Collection of J*. pyriformis* is likely to be difficult since any remaining stands will be located in a few remote locations in southeastern Mexico, to which access is difficult. *J. australis*, native to Argentina, is thought threatened by hybridization with introduced species. Most of these species are tropical or semi-tropical, so some of them, including *J. olanchana, J. pyriformis,* and *J. jamaicensis*, will probably need to be maintained in a greenhouse or a location that is not susceptible to freezes. *J. hirsuta*, *J. australis, J. neotropica*, and *J. mollis* can be maintained at the more temperate Davis NCGR location.

2. *Juglans cinerea*

The Juglans CGC has given high priority to collection of germplasm of butternut (*J. cinerea*) in North America due to the immediate threat to many populations of this species posed by the butternut canker disease, combined with the relative ease of arranging collections within the U.S. where this species occurs.

*Juglans cinerea* is probably the most threatened North American species in the genus. The species was once widely distributed, and formerly had some commercial importance both as a nut tree and as a source of timber. As a native species, butternut also enjoys a place in Native-American cultures, folklore, ethnobotany for medicinal purposes, and in folk art. Since there have been very few scientific evaluations of the genetic or phenotypic diversity within butternut, the location of unique and/or unusual and valuable genotypes are poorly understood. In some cases, local experts (e.g., foresters, landowners, timber buyers, conservation biologists) have identified areas where butternut is, or was, an important part of the hardwood forest.

There is a collection of butternut and butternut hybrid seedlings at Purdue University but this and other ex situ collections in the Eastern US are generally short duration collections not intended as repositories, have high maintenance costs, and are not formally part of the NCGR system. There is currently no viable plan to maintain this valuable germplasm.

3. China

China has vast and diverse wild *J. regia* germplasm resources available for Chinese selection and breeding programs. Germplasm from Xinjiang province in Northwestern China is the primary source the lateral bearing trait associated with enhanced and precocious yield. This resource is widely exploited within Chinese breeding and selection programs and has resulted in development of improved Chinese varieties, several of which are competing in international trade, but, as with Chinese germplasm generally, availability outside China is very limited. A limited amount of germplasm collected from this region in 1990 and elsewhere in China in 1995 is included in the NCGR collection. *J. cathayensis*, a species native to eastern China, has been of interest for possible resistance to lesion nematodes (*Pratylenchus vulnus*), the key nematode pest of walnut. The NCGR collection currently contains only 2 accessions of this species. Inclusion and evaluation of additional Chinese germplasm is highly desirable.

4. Central Asian locations

Large-scale commercial logging of native walnut forests, loss to grazing and replacement with selected varieties has occurred in Iran, Kyrgyzstan, Kashmir, and other central Asian locations, reducing or eliminating locally adapted seedling forests. Kyrgyzstan offers, in addition to China, a source of the valuable lateral bearing trait, and Iran is known to have extremely precocious wild germplasm and native walnuts growing in areas of high salt and very low chill. These important native sources of *J. regia* genetic diversity are at serious risk. Deterioration of established and characterized Soviet-era collections from this region is an additional concern.

C. Evaluation

1. Description of NCGR *Juglans* collection

There is need for continuing description of the phenology, flowering, yield, and nut characteristics in existing accessions, particularly the more recent introductions. There is a need for continued evaluation of resistance to soilborne pests (plant parasitic nematodes, *Phytophthora* spp., Lethal Paradox Canker, and *Armillaria* spp.) among accessions of many species represented in the collection. In addition, the chilling requirements and resistance to scion pests and diseases, including husk fly, bacterial blight, and Botryosphaeria should be evaluated.

Phased, long-read genome assemblies have been constructed for *J. regia* cv. ‘Chandler’ and are underway for *J. hindsii* cv. ‘Rawlins’ and several other scion and rootstock cultivars. High coverage, short-read Illumina data have been generated for six *Juglans* species *(J. regia, J. sigillata, J. hindsii, J. microcarpa, J. nigra, and J. cathayensis)* as well as an outgroup *(Pterocarya stenoptera).* Work to characterize the genetic diversity of several species in the collection has been initiated, and should be continued as a priority. In particular, the collection contains several thick-shelled accessions of *J. regia* from northern Pakistan that appear from molecular data to be truly wild, undomesticated walnuts. Characterization of these accessions could help identify genes and genomic regions important for walnut improvement.

2. Species hybrids for rootstocks

“Paradox” hybrids *(J. hindsii x J. regia)* are widely used in California due to their superior vigor and documented resistance and tolerance to several soilborne pests. There has been a concerted effort to study the effects of *Juglans* wild relatives to produce disease resistant rootstock. Of the wild species tested, *J. microcarpa* and *J. major* have proven to be the most promising sources of disease resistance for crown gall, Phytophthora, and nematodes. One commercially available rootstock, ‘RX1’ is a *J. microcarpa x J. regia* hybrid with the highest level of resistance available for Phytophthora, and many more *J. microcarpa x J. regia* hybrids are currently at the advanced testing stage. “Royal” hybrids *(J. hindsii x J. nigra*) are thought to provide resistance against waterlogging but have received little recent attention. As noted, *J. australis x J. regia* hybrids have been used as rootstocks in Argentina and Chile but have not been tested in the US.

D. Enhancement

1. *Juglans regia*

a. Improved Persian walnut cultivars

To develop Persian (English) walnut cultivars with improved precocity, lateral bearing, and short-season crop development, the Walnut Improvement Program continues its main approach, which includes hybridization between existing English cultivars and individuals with desired traits followed by backcrossing. Continued introgression is also required for development of English cultivars with tolerance or resistance to walnut blight and hypersensitivity to CLRV.

b. Rootstock improvement

Intensified interdisciplinary efforts are underway for continued development of improved rootstocks. Improvements that are especially needed in walnut rootstocks include tolerance to CLRV, resistance or tolerance to *Phytophthora* spp., *Armillaria* spp., and parasitic nematodes and resistance to crown gall. Improvements in responses to pests must be accompanied by horticultural acceptability.

2. *Juglans nigra*

a. Nut Production

The bulk of current black walnut nut production is from unimproved natural stands. Selections for improved yield, annual bearing and more desirable nut traits exist and have been characterized. The University of Missouri breeding program is directed towards improved tree yield, precocity, lateral and annual bearing habits, anthracnose resistance and greater kernel yield per nut.

b. Timber production

Landowners typically have several objectives when they plant *J. nigra* for timber production. The two most important objectives are forest regeneration and plantation establishment. These objectives require distinct management schemes and distinct genetic stocks. Forest regeneration requires improved seed of relatively low cost that will produce trees that grow well with little maintenance. Traditional seed orchards containing a large number of genetically diverse but select progeny are well suited to meet the large demand for improved seed used in forest regeneration.

Plantation establishment or clonal forestry requires genotypes that respond well to management. These genotypes are usually produced by intercrossing a few elite individuals followed by stringent selection and extensive testing. This approach has also been used to create populations with unusual and valuable wood quality traits such as figured wood. The HTIRC at Purdue University has selected and evaluated *J. nigra* genotypes with both forest regeneration and plantation establishment objectives in mind.

c. Rootstock development

Due in part to the hybrid vigor of inter-specific crosses of *Juglans*, Paradox hybrids are often the rootstock of choice for J*. regia* in California. Seedling *J. nigra* rootstocks are the only option currently available for propagating black walnut scions. There is a need for vigorous, adapted rootstocks that can be propagated by rooting. The potential of interspecific hybrids as rootstocks for *J. nigra* needs further investigation.

3. *Juglans cinerea*:

There is not a formal breeding program for *J. cinerea* (butternut), but there has been an ongoing effort at Purdue/HTIRC to identify and propagate historically important selections and to identify new selections that appear to be resistant to, or tolerant of, butternut canker. There is currently an organized effort, run jointly by Purdue, the USFS, and Canada, to use the few available disease resistant selections, and primarily hybrids with *J. ailantifolia*, to restore butternut populations and to maintain this species on the landscape.

E. Importation Protocols

Current guidelines for germplasm importation were developed by the relevant State and Federal regulators. Most significant are the Animal Plant Health Inspection Service (APHIS) and the California Department of Food and Agriculture (CDFA). Imported bud or graft wood is subject to APHIS inspection on entry.

The California Plant Quarantine Manual states:

(1) All species of *Juglans* (walnut, butternut) trees and parts capable of propagation, except nuts, are:

(a) Prohibited entry into California from any state east of the eastern borders of Idaho, Utah, and Arizona.

(b) Admissible into California from Idaho, Nevada, Oregon, Utah and Washington provided each lot is accompanied by a certificate issued by the Department of Agriculture of the state of origin affirming (1) The material was grown in the state of origin, (2) Brooming disease is unknown in the state of origin, and (3) The amount and kind of commodities covered.

There are no current limitations on the importation of seeds although these may potentially harbor important diseases and pests, and caution is strongly advised. It is known that the pathogen causing butternut canker, *Ophiognomonia clavigignenti-juglandacearum*, can be seed borne in butternut and potentially in other *Juglans* species.

V. Recommendations

A. Additional land and sites

Additional space is urgently needed for the NCGR-Davis collections. Limited space availability has required close planting of the *Juglans* accessions. While this is adequate for production and distribution of vegetative material, tight spacing increases annual management costs considerably, prevents normal canopy development and cropping, and severely impedes evaluation of accessions. Many *Juglans* trees in this collection are in poor and declining condition, severely stressed, and threatened by a variety of problems including crown gall disease. *Juglans californica* trees have failed to thrive in the collection in the A and B blocks for many years and over time many have died. Losses are now extending to other species as well. Land is a limiting factor and there is no space to repropagate accessions threatened with loss. Thousand cankers disease has likely exacerbated decline. Attention needs to be given to protecting the current germplasm and repropagating impacted trees, finding land for re-establishing the collection on reasonable spacing, developing methods of alternate storage, and examining approaches to curating the collection that reduce space requirements.

A repository location with a subtropical climate is needed, and has long been requested, for *Juglans* species with insufficient cold-hardiness to survive at Davis.

A method also needs be developed to better identify and monitor the viability of independent collections. Careful consideration should be given to continue *ex situ* maintenance of *J. nigra* and *J. cinerea* collections in the eastern United States. There are current plant quarantine obstacles and legitimate disease concerns regarding introductions of these species into California. The University of Missouri collection is the largest assemblage of *J. nigra* nut cultivars currently existing and has been well characterized using both phenological descriptors and microsatellite markers to form the basis of an active nut-breeding program. The long-term maintenance of this collection and the *J. nigra* collection at the Hardwood Tree Improvement Center at Purdue, which is oriented towards timber, and the *J. cinerea* collection should be carefully monitored and ensured.

The program at Purdue is not a germplasm repository and cannot function as one. As the germplasm of pure butternut declines, some solution is needed. One option is land owned by ARS or BLM or other agencies in the western US but east of the Rockies. This land would have to be irrigated. The climate there is dry enough that butternut canker is not a threat. Trees in western Iowa, planted by the State of Iowa, are reportedly doing well, with minimal loss to disease.

Consideration should be given to cryostorage of accessions when feasible as a backup for the existing collection. Methods for cryopreservation of seed embryo axes and *in vitro*-grown shoot buds have been developed. Cryostorage of dormant field-grown buds would be the most desirable and efficient option but has not been successful to date.

B. Movement, export, and quarantine protocols

The current guidelines for movement of *Juglans* germplasm and walnut wood within the United States include many restrictions. Germplasm curated at either Davis, CA or Corvallis, OR currently cannot be shipped east into the native range of *J. nigra* without a special permit and vegetative germplasm from the eastern US should likely not be sent to the current repositories.

In addition, the general risk of pest and pathogen introduction into California via seed and scion wood should continue to be assessed based on the most current information from pathologists and those experienced with germplasm acquisition. Importation guidelines should be updated to minimize the risks to existing germplasm resources. Pathogens of note that should be restricted from California orchards include bunch disease, butternut canker, and any new strains of cherry leafroll virus or *Geosmithia*. Importers should be aware of, and watchful for, newly emerging potential pests including spotted lantern fly (*Lycorma delicatula*) and Asian walnut moth (Garella musculana).

Current US import permit rules have made importation of *Juglans* scionwood prohibitively difficult. Diameter restrictions on imported wood make grafting of walnuts nearly impossible and imported material, if grafted, must be held long-term in a screenhouse, a condition that makes evaluation of any imported walnut scionwood nearly impossible. These restrictions, on top of the restrictions placed on exports by other countries, have made importation of characterized walnut clonal germplasm (scionwood) very difficult to impossible. This is a serious impediment to US walnut breeding.

C. Evaluation of horticultural traits

The lack of adequate alternatives to methyl bromide and regulatory pressure on the alternative fumigant 1,3-D (Telone) have increased the urgency of identifying resistance to soil-borne pests, including parasitic nematodes, *Phytophthora* spp., *Agrobacterium tumefaciens*, and *Armillaria* spp. Absence of adequate fumigants, changes in water availability and use, and accelerating commercialization of methods for producing clonal rootstocks all increase the need to evaluate a wider set of *Juglans* germplasm for rootstock-related traits, including disease and pest resistance, Lethal Paradox Canker, drought and salt tolerance, and height control. Most of the *Juglans* accessions at Davis should be evaluated more extensively and in greater detail for these traits.

Expected global warming and the recent frequency of low-chill winters indicate a need to evaluate the chilling requirements of *J. regia* accessions. Further evaluation for traits related to scion breeding, including yield, harvest date, nut quality, oil composition, blight resistance, husk fly resistance, *Botryosphaeria*, and pistillate flower abscission, are needed.

D. Butternut

The collection and evaluation of butternut should continue to receive a high priority, since this species may be extremely endangered and many of the necessary resources for collection and evaluation are already in place. Identifying the most threatened *J. cinerea* populations and determining the best conservation strategies for these populations is critical in preventing the complete loss of this species’ commercial potential.

The germplasm of *J. cinerea* is poorly understood. Germplasm collection and evaluation is critical to preservation. Efforts to collect *J. cinerea* germplasm with resistance or tolerance to butternut canker should be in conjunction with a program to perform disease resistance screens on candidate genotypes. Genetic and phenotypic characterization of the germplasm can then be used in breeding and as a means to understand patterns of diversity within the species. This would require identification of a location for *ex situ* conservation and evaluation of *J. cinerea* germplasm within its natural range.

The best long-term strategy for species enhancement will be based on the introduction of genotypes that are resistant or tolerant to butternut canker, into state and private nurseries and seed orchards.

E. Central and South American species

Approximately 11 species of black walnut are native to areas of Central and South America. US development of a representative collection of these species is a high priority.

Exploration for species native to Mexico, the Caribbean, South and Central America, most of which are not currently represented in the collection, should be undertaken whenever possible. Remaining stands of many of these are thought to be remote and access is likely to be difficult and restricted. Many of these species are thought to be endangered and are likely to have potential use in both scion and rootstock development.

F. Evaluate diversity of *J. nigra* and other native *Juglans*.

The genetic diversity of the *Juglans* species native to North America is still insufficiently understood. We recommend further genetic and phenotypic evaluation of all the native *Juglans* with the goals of understanding the relationship between genetic and geographic distance, evaluating the relative importance of various threats, including global climate change, to the *in situ* germplasm, identifying threatened or critical populations, and contributing to crop enhancement by current breeding efforts. The value of additional in situ conservation efforts should be determined by characterizing diversity for the species in National Parks, wilderness areas and on other public and private lands.

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