PYRUS CROP GERMPLASM COMMITTEE REPORT AND GENETIC VULNERABILITY STATEMENT SEPTEMBER 2004

I. Introduction

Pears (*Pyrus*) and related genera are members of the subfamily Pomoideae and the family Rosaceae. All species are deciduous trees or shrubs. Pears are almost exclusively grown as a "compound genetic system", consisting of a rootstock, a scion or fruit-bearing cultivar, and in cases of graft-incompatibility between the rootstock and scion, a mutually compatible interstock. Because each component of the system has some unique characteristics and problems, the genetic vulnerability of scions and rootstocks will be considered separately. Within *Pyrus*, there is no graft-incompatibility among species. Quince (*Cydonia oblonga* L.) is the only non-*Pyrus* species which has been used commercially as a rootstock for pear. Additional genera which have been are potential rootstocks include *Amelanchier*, *Crataegus*, *Sorbus*, and *Mespillus*.

A. An Overview of the Genus *Pyrus*

The genus *Pyrus* has been classified, depending on the authority, into 21 to 26 primary species, which can be grouped together by geographic distribution and/or taxonomic relationships (Table 1). A number of non-primary species, which may be botanical varieties, subspecies, or interspecific hybrids also appear in the literature. The latter are, in a few cases, naturally occurring, but some are undoubtedly "arboretum hybrids", and are not known to occur in native populations. The genus probably evolved in the foothills of the Tian Shen mountains in Xinjiang Province in western China, and spread eastward and westward, with isolation and adaptation leading to speciation. Interspecific hybridization and introgression has probably been involved in the evolution of the various species, and no major barriers to hybridization between species are known to exist (Bell and Hough, 1986). The major edible species are *P. communis* for the European group, and *P. pyrifolia*, *P. ussuriensis*, and *P. x bretschneideri* (probably a subspecies of *P. pyrifolia,* although thought by some authorities to be an interspecific hybrid of *P. ussuriensis* with *P. pyrifolia*) for the East Asian group. Perry, a cider beverage produced primarily in England and France, is made from cultivars of *P. communis* cultivars which contain high concentrations of organic acids and leucoanthocyanins, the latter of which impart astringency, and sometimes from domesticated cultivars of *P. nivalis*, the snow pear.

Species used as seedling or clonal rootstocks around the world vary according to which species is indigenous, but include *P. communis* and its subspecies *P. communis* var. *pyraster* and *P. communis* var. *caucasica*, *P. nivalis*, *P. amygdaliformis*, *P. betulifolia*, *P.* x*bretschneideri*, *P. calleryana*, *P. elaeagrifolia*, *P. kawakamii, P. longipes, P. pashia*, *P. pyrifolia, P. salicifolia, P. syriaca, P. ussuriensis,* and *P. xerophila.*

Among *Pyrus* species, there is a wide range of adaptation to climatic and edaphic (i.e. soil type, moisture, and pH) conditions. General characteristics of the species have been reviewed by Bell (1990) and Lombard and Westwood (1987). The natural geographic range for each taxon is contained in the GRIN taxonomy database. The areas identified as also, presumably, the centers of genetic diversity.

B. An Overview of Related Rootstock Genera

One species of quince, *Cydonia oblonga* L., is used as a rootstock for pear. It is native to Iran, the Caucasus Mountains of Armenia, Azerbaijan, Georgia, and the Russian Federation, and Turkmenistan, and is naturalized elsewhere in Western Asia and southern Europe. It is adapted to regions with an annual rainfall of more than 800 mm, with regular summer rains, being somewhat drought sensitive because of a shallow root system. Optimum mean temperature should be about 15°C. The genus is moderately to highly tolerant of low soil pH, but high pH causes chlorosis due to poor uptake of iron. Because of graft-incompatibility with most *Pyrus* scion cultivars, chlorosis induced on high pH soils, poor cold hardiness, and susceptibility to fire blight, use of quince rootstocks is not favored, and most current breeding efforts are focused within *Pyrus.*

C. An Overview of the Industry

Annual average pear fruit production in the United States from 2001 through 2003 was estimated at approximately 836,000 metric tons, or 4.9% of the world production of all pears and 10.7% of European pears (*P. communis*), ranking 2nd among all nations in European pear production and 3rd for all pears (O'Rourke, 2004). This represents a 0.8% decrease since 1989-1991, although world production of European pears has increased 12.9% in the same period. When production of Asian species is included, world pear production has increased 78.4%, primarily due to a 253% increase in production by China (PRC). Pear production within the US ranks third among temperate tree fruit crops, after apples and peaches/nectarines. The seasonal average price for US fresh fruit was $288 per ton, for a total value for the utilized portion of production (917,577 tons) of $264 million, representing 3.2 % of the total value of all US non-citrus tree fruit crops (USDA-NASS, 2004).

The amount of fresh market pears in 2003 (564,350 tons) was much greater than the amount of processed pears (357,100 tons). Of the processed pears, almost all are canned; small amounts are pureed for baby food, dried, or juiced for use in pure or blended fruit juices, or in perry (i.e. pear cider) and wine products. 'Bartlett' is the cultivar used for canned halves, puree, and most pear juice and nectar, while the minor cultivars 'Winter Nelis' and 'Beurre Hardy', which are sometimes planted as pollinators in 'Bartlett' orchards, are used in fruit cocktail. Per capita consumption of canned pears has steadily decreased over the past 20 years, while consumption of fresh pears, which peaked in 1995-97, has declined slightly.

The United States exported an average of 176,416 metric tons of pears from 2000-2002, reflecting over a two-fold increase from 1982. Over 93% of these were exported as fresh pears. Imports of fresh pears totaled 83,838 metric tons, reflecting a substantial increase in the last decade. The industry is faced with increasing competition in late winter through early summer from imports from the southern hemisphere, primarily 'Bartlett' and 'Packham's Triumph' from Chile, Argentina, and South Africa, and 'Beurré d'Anjou' from Argentina. New Zealand exports of 'Taylor's Gold', a russeted mutation of ‘Doyenne du Comice’ are increasing, as are nashi, or Asian pears.

The United States ranked 2nd in the 1993/94 growing season among countries producing the European dessert pear, while Italy, which produced nearly one million metric tons, ranked first. The Peoples Republic of China (PRC) produced almost as much as Italy, although their production is almost exclusively of Asian species of pear.

There were at least 80,801 acres planted to pears for commercial production in the United States in 2002, of which 71,483 were bearing fruit. There has been a decrease of 773 acres since 1997 (USDA-NASS, 2002). Large scale commercial production is concentrated in Washington (48%), California (25%), and Oregon (23%), with New York (1.7%), Pennsylvania (0.6%), and Michigan (0.5%) contributing progressively smaller amounts. The three Pacific coast states accounted for 96% of the total reported US production in 2003. These data reflect estimates of commercial production only from the 9 states included in the annual USDA agricultural statistics reports (USDA-NASS, 2004), and thus underestimate the actual total national production. The 2002 Census of Agriculture (USDA-NASS, 2002) states that Washington accounts for 38% of the total acreage, California for 25.2%, Oregon for 24.8%, and New York for 2.5%, and all states but Hawaii reported farms growing pears. Organic production accounts for an estimated 3.5% of US pear acreage.

Specific information on production of pear rootstocks and trees by the nursery industry is not readily available.

II. Present Germplasm Activities

National Clonal Germplasm Repository. This facility of the NPGS, located in Corvallis, Oregon is the sole site for preservation activities for *Pyrus* and genera used or potentially useful as rootstocks (*Cydonia oblonga* L., *Amelanchier* sp., *Crataegus* sp., *Sorbus* sp., and *Pyronia vetchii*). The collection contains a total of 2,019 accessions of *Pyrus*, representing 26 primary species, 4 subspecies, and 5 interspecific hybrids. A total of 934 accessions are *P. communis*. Twelve taxa are represented by five or fewer accessions, and six are represented by single accessions. The collection consists of 1633 clonal accessions maintained as trees, and 289 accessions in the form of seed. The later are mainly wild-collected seed of natural populations of various species.

Germplasm was initially acquired from existing collections of Oregon State University, U. S. public breeding programs, and other domestic and Canadian sources. Foreign germplasm collections and explorations have become increasingly important sources for acquisition. Clonal germplasm which has virus-free phytocertification approved by USDA-APHIS can be imported from Canada, England, Germany, France, Netherlands, and Belgium under post-entry permits without passing through the joint USDA/APHIS indexing program. Characterization data are collected to verify identity and to provide basic descriptive information. Limited evaluation of traits that can be observed in the orchard are also being carried out. Research on micropropagation and cryopreservation of meristems supports the preservation function of the repository. The facility has the capability of indexing and producing virus-free clones through thermotherapy. A total of 81% of clonal accessions from domestic sources have been tested for common latent viruses, and 9% have undergone thermotherapy to produce virus-free clones. A small number of quarantined accessions have been indexed and passed through thermotherapy under a special permit from APHIS.

On-site backup for 164 accessions is provided as in vitro shoot cultures. Off-site backup is provided for 177 accessions at the National Center for Genetic Resources Preservation in Fort Collins, Colorado. These accessions are preserved in vitro as meristems. No backup is provided for most of the collection (2,098 of a total of 2,283 accessions in NPGS). The collection at NCGR-Corvallis consists of single trees of each clonal accession, most of which are in an orchard plots. A total of 339 non-winter hardy accessions are maintained in a screenhouse. Details about the management of the collection are available in the repository annual report through their website (www.ars-grin.gov/cor).

National Plant Germplasm Quarantine Center (NPGQC). Introduction of germplasm subject to quarantine and indexing for prohibited viruses and other disease etiologic agents are performed at the USDA's National Plant Germplasm Quarantine Center (NPGQC) at Beltsville, Maryland. This facility is jointly staffed by APHIS and ARS. The ARS personnel constitute the Plant Germplasm Quarantine Office (PGQO), a unit of the Fruit Laboratory, Plant Science Institute, Beltsville Agricultural Research Center. Thermotherapy of virus-infected accessions is part of the responsibility of this laboratory.

The National Research Support Project No. 5 (NRSP5) serves as an importation site for small numbers of commercial cultivars, or potentially commercial germplasm, which require quarantine and indexing. The collection serves as a repository of virus-free budwood of domestic and foreign cultivars of interest for commercial production. Budwood and seed has been distributed for a nominal fee, but for foreign cultivars, importation, indexing, and thermotherapy service is provided on a fee-for-service basis. The project is located at Washington State University's Irrigated Agriculture Research and Extension Center in Prosser, Washington, is staffed by university personnel, and receives funding from USDA-CSREES through state agricultural experiment stations. However, continued CSREES funding has been recommended for phase-out.

Breeding and Germplasm Evaluation Programs. Evaluation and enhancement activities have traditionally been part of breeding programs. Breeding programs maintain working collections which change in composition with the needs of the program. Only those characteristics of immediate interest to the breeder are usually evaluated. At various times, several state universities conducted pear breeding programs, but all have been officially terminated. Purdue University is still evaluating a small number of selections. The principle goal of most of these programs was the development of fire blight resistant cultivars for the eastern and southern states, or winter hardy cultivars for the northern plains states.

The only large scale breeding program in this country is that of the U. S. Department of Agriculture’s Agricultural Research Service located at the Appalachian Fruit Research Station in Kearneysville, West Virginia. It is national in scope and objectives, with cooperative test sites for advanced selections in most of the major commercial pear districts in the country. The major objectives of the program are the development of cultivars with improved post-harvest quality and storage life, dual purpose cultivars for fresh and processed markets, and cultivars with resistance to fire blight, pear psylla, Fabraea leaf spot, and pear scab. The principle focus is on European pears, but Asian pears have been incorporated into the program for specific traits, and breeding for Asian and Asian x European hybrid fruit types has been undertaken. This program has evaluated approximately 100 germplasm accessions, primarily from Eastern and Central Europe, for resistance to pear psylla (*Cacopsylla pyricola* Foerster), and is currently evaluating a smaller number of accessions for resistance to Fabraea leaf and fruit spot. The program is investigating genetic diversity and relationships among psylla-resistant and psylla-susceptible European pear cultivars using genetic marker systems.

There is apparently a very small amount of private breeding activity in the US, especially for Asian pears, but specific information is not readily available. Breeding programs for European pear are active at varying levels in Canada, France, Italy, Norway, Sweden, New Zealand, Australia, Romania, Moldavia, and the Russian Federation. Breeding programs for Asian pears are active in China, Japan, Korea, and New Zealand, and for Asian-European hybrids in New Zealand. Cultivars and selections from most of these programs are available through material transfer agreements that prohibit distribution to third parties.

There is no rootstock breeding program in the US, although Oregon State University is evaluating a series (i.e. ‘Horner’ rootstocks) of rootstocks derived from open-pollination of OHxF clones. The NC-140 regional project, “Rootstock and Interstem Effects on Pome and Stone Fruit Trees”, evaluates small numbers of new *Pyrus* rootstocks for commercial potential. Currently, there was a small trial planted in 2002, and plantings of additional rootstocks in 2005 and 2006 are planned. These rootstocks originated in England, Italy, Germany, and South Africa. Active pear rootstock breeding programs are being conducted in England, France, Italy, Sweden, the Soviet Federation, Romania, and several other countries.

III. Status of Crop Vulnerability

A. Scion cultivars

Degree of Genetic Uniformity. The degree of genetic uniformity of the standing US crop is extremely high, and thus, pear production in the United States is extremely vulnerable. All of the major cultivars belong to a single species, *Pyrus communis* L. Approximately 50% of commercial production reported to USDA-NASS is accounted for by a single cultivar, 'Bartlett' (syn. 'William's Bon Chretien'). An additional three cultivars, 'Beurre d'Anjou' (34%), 'Beurre Bosc' (10%), and 'Doyenne du Comice' (1%) account for the majority of the remaining production. Thus, 95% of reported commercial US production consists of four cultivars. Red-skinned mutant clones of 'Bartlett', 'Beurre d'Anjou', and ‘Clapp’s Favorite’, in addition to 'Seckel', 'Beurre Hardy', 'Winter Nelis', 'Butirra Precoce Morettini', 'Forelle', ‘Packham’s Triumph’, ‘Concorde’, 'Nijisseki' (syn. 'Twentieth Century'), and ‘Hosui’ are each produced in amounts of less than 1% of the national total. Statistics on tree sales indicate that the relative production of 'Beurre d'Anjou' and 'Beurre Bosc', and Asian pears are increasing. The Asian cultivars, such as 'Nijisseki' (syn. ‘Twentienth Century’), 'Hosui', 'Chojuro', and 'Shinseiki', belong to the species *Pyrus pyrifolia*. These have accounted for an increasing percentage of pear trees sold for planting in California, and to a lesser extent in Washington, and in the east and southeast during the past ten years. Two less popular cultivars, 'Ya Li' and 'Tsu Li', belong to *P.* x *bretschneideri*, a naturally occurring interspecific hybrid. The Asian cultivars at present appear to have only a limited or niche market, and some market analysts predict that the approximate 5000 acres which are or will be bearing fruit in the next few years could satisfy current large-scale market demand. New red-skinned mutant clones (i.e. "sports") of 'Bartlett' and 'Beurre d'Anjou', and fully russetted mutants of 'Beurre Bosc' are also being planted in increasing numbers because of higher market value. In spite of these trends, 'Bartlett' will continue to be the predominant cultivar, especially because it is the cultivar almost exclusively used for processing. It is unlikely that major changes in production or diversity will occur within the next decade. There are, however, approximately 150 other cultivars offered for sale by US fruit tree nurseries, but many are not suitable for large scale production.

Molecular studies of genetic diversity and relationships among limited numbers of *P. communis* cultivars have indicated a relatively high degree of genetic similarity, with Dice coefficients of approximately 0.8 (Monte-Corvao et al., 2001), and the degree of similarity among major *P. pyrifolia* cultivars was likewise relatively close (Kimura et al., 2002a; Kimura et al., 2002b).

***High Impact and Other Risks*.**

The major cultivars, both European and Asian, are susceptible to a number of potentially destructive diseases and pests. A comprehensive list of evaluation priorities that includes diseases and arthropod pests is given in Table 2.

Diseases

The highest impact diseases are identified and ranked in Table 3. The high impact diseases as well as other diseases of lesser importance are discussed below according to type of pathogen.

Fire blight. This disease, caused by the bacterium *Erwinia amylovora* Burrill (Winslow et al.), has been a major factor in the restriction of large scale commercial production to the drier interior valleys of the Pacific coast states. However, outbreaks have become more serious in recent years even in these areas. Development of strains of the bacterium which are resistant to streptomycin, an antibiotic used to prevent blossom and, to some extent, shoot infections, highlight the vulnerability of the industry. Streptomycin resistance has arisen under the pressure of widespread antibiotic use through selection of mutant bacteria in the Pacific Northwest, Michigan, Missouri, and California. The pathogen may also acquire resistance through transfer of plasmids from other non-pathogenic bacterial species, but this mechanism appears to occur rarely in orchards. Oxytetracycline is an alternative antibiotic, but is likewise, not as effective as streptomycin. Copper compounds used as dormant and delayed dormant sprays can reduced inoculum levels, and hence, reduce the risk of subsequent blossom infection. Biological control agents, such as *Pseudomonas fluorescens* A506 (Blight Ban) and *Erwinia herbicola* C9-1, are not as effective as streptomycin for control. Of the major European pear cultivars, only 'Seckel' is moderately resistant to this disease. Of the major cultivars of Asian pears, the *P.* x *bretschneideri* cultivars, 'Ya Li' and 'Tzu Li', are at least moderately resistant. The *P. pyrifolia* cultivars are almost uniformly as susceptible as *P. communis* cultivars. 'Shinko', 'Meigetsu', 'Seuri', and 'Immamura Aki' appear to be less severely infected than most Asian cultivars (Bell, 1990; van der Zwet and Beer, 1999).

Bacterial blossom blast or *Pseudomonas* blight. Incited by the bacterium *Pseudomonas syringae* pv. *syringae* Van Hall, this disease can significantly decrease the crop in all production regions. The pathogen infects blossoms and young leaves, and can spread into woody spurs and, infrequently, to branches. Most European and Asian pears are susceptible, although 'Forelle' and 'El Dorado' have been rated as moderately resistant. Red-skinned mutants of 'Beurre d'Anjou' and 'Bartlett' appear to be less susceptible than the green-skinned cultivar to canker (i.e. trunk) infections associated with cold temperature injury.

Postharvest fruit rot diseases. Several fungal pathogens which infect the fruit, either pre-harvest or post-harvest, can account for as much as 30% loss of fruit in storage. The major diseases of pears are blue mold (*Penicillium expansum*), gray mold (*Botrytis cinerea*), *Coprinus* spp. (especially in the Hood River and Wenatchee districts), Mucor rot (*Mucor piriformis*), side rot (*Phialophora malorum* and *Cladosporium herbarum*), and bull's-eye rot (*Neofabraea malicorticis* [syn. *Pezicula malicorticis*]). Other minor diseases that also cause fruit decay in the orchard include bot rot (*Botryosphaeria obtusa*), black rot (*Sphaeropsis malorum*), white rot (*Botryosphaeria dothidea*), bitter rot (*Glomerella cingulata*), brown rot (*Monilinia* sp.), and sprinkler rot (*Phytophthora cactorum*). All of our major cultivars are susceptible to these diseases. 'Beurre Bosc', in particular, in highly susceptible to side rot. Two new postharvest pathogens have been reported on 'Beurre d'Anjou' in Washington state. One is caused by *Phacidiopycnis piri* (Fucke;) Weindlymayr, is the anamorph of the *Potebniamyces pyri* (Berkeley & Broome) Dennis, which is associated with bark necrosis and twig cankers of pear in the Pacific Northwest (Xiao and Boal, 2003; Xiao and Boal, 2004). The second, caused by *Sphaeropsis pyriputrescens* sp. nov., occurs at a low level in some Washington orchards (Xiao and Rogers, 2004).

In the case of pathogens which produce incipient of quiescent symptoms after infection in the orchard or harvest bins (gray mold, bull's eye rot, white rot, black rot, bitter rot, brown rot, sprinkler rot, and probably Sphaeropsis rot), orchard sanitation and prophylactic fungicide sprays will significantly reduce the amount of fruit rot developing later during storage. Other pathogens (blue mold, Mucor rot) primarily infect wound caused by stem punctures and bruises during harvest or post-harvest handling and packing. Fruit loss to these diseases can be reduced by fungicide dips and the practice of wrapping individual fruit in copper sulfate impregnated papers. Both types of control measures may be effective against Phacidiopycnis rot.

Fungal leaf and fruit spot diseases. Fabraea leaf spot (*Fabraea maculata* Atk.) can cause severe defoliation and fruit spots on most major European pears, although 'Bartlett' is moderately resistant. Asian cultivars are generally more resistant, but not immune. A second pathogen, *Mycospharella sentina* (Fckl.) Schroet., causes a minor leaf spot which is primarily a problem in Europe. Both of these diseases can be controlled by frequent fungicide application, and they are not of concern in the dry Pacific coast production regions.

Powdery mildew. Objective studies of host resistance to powdery mildew, caused by the fungal species *Podosphaera leucotricha* (Ell. & Ev.) Salm., has not received much attention in the literature. 'Bartlett' and 'Beurre d'Anjou' are moderately susceptible and susceptible. respectively, while 'Winter Nelis' is reportedly moderately resistant (Fisher, 1922). One the basis of general tendencies of species (Westwood, 1982), the Asian cultivars are heterogeneous in their response (Kanato et al., 1982), although no detailed studies have been published.

European pear scab. The pathogen *Venturia pirina* Aderh. can cause severe infection in 7 of the 11 major cultivars for which reasonably reliable or repeatable observations have been made. 'Bartlett', 'Conference', and 'Dr. Jules Guyot' have been reported to be resistant. Again, no published data could be found for reaction of the Asian cultivars to this disease, although Westwood (1982) reports that *P. pyrifolia* is variable for resistance, and *P. ussuriensis* is resistant. Presumably, *P.* x *bretschneideri* will be heterogeneous. Control requires repeated applications of fungicide to control, especially in the more humid production areas.

Asian pear scab. In Asia, a pear scab caused by a related species, *Venturia nashicola* Tan. et Yam. affects almost all cultivars to some degree (Kanato et al., 1982). European pears are reported to be resistant.

Black spot. This disease is also known as alternaria blotch, and is caused by *Alternaria alternata* (Fr.) Keissler (previously designated as *A. kukuchiana* Tanaka). It is a serious disease of *P. pyrifolia* pears in Asia (Sanada et al., 1988). It does not known to exist in North America or Europe, and *P. communis* cultivars apparently have not been tested for susceptibility. While the most important cultivar, 'Nijisseiki', is susceptible, and 'Shinsui' is moderately susceptible, all of the other major *P. pyrifolia* cultivars are resistant.

Brown spot of pear. This disease has become economically important on *P. communis* pears in Europe during the past 30 years. Caused by a fungal pathogen, *Stemphylium vesicarium* (Wallr.) E. Simmons, it causes necrosis on leaves, fruit, and to a lesser extent on young shoots. Infected fruit are unmarketable. Control is through preventative sprays of dithiocarbamate fungicides. The major cultivars, especially ‘Passe Crassane’, ‘ Conference’, ‘Doyenne du Comice’ and ‘Abate Fetel’ are highly susceptible.

Asian pear rust. Incited by *Gymnosporangium haraeanum* Syd., pear rust is a serious disease of all major *P. pyrifolia* cultivars in Japan (Kanato et al., 1982), and has become more widespread because of the ornamental use of the Chinese juniper, *Juniperus chinensis* Ant., an alternate host. The pathogen infects foliage and petiole tissue of all cultivars now grown in Japan, but does not cause serious damage to the *P. communis* cultivars.

Valsa canker. This disease, caused by *Valsa ceratosperma*, is common in Japan, Korea, and China, and has also been observed in North America. It affects the bark, resulting in branch girdling and death. No curative fungicides are available, some fungicides may provide preventative control. It is widespread on *P. ussuriensis* and *P.*x *bretschneideri* cultivars, but is less severe on *P. pyrifolia* cultivars. For the purposes of this report and assessing impact, *P. communis* will be assumed to be susceptible. The disease was reported to cause serious damage to pear in Italy in 2001.

Brown rots. There are three species of brown rot pathogens that cause fruit rots of pear. *Monilinia fructicola* is present in the US, whereas *M. fructitgena* is the most common species in Europe, and is the one of quarantine significance. A third species, *M. laxa*, rarely causes fruit rot on pear. All European pear cultivars are presumed to be susceptible to these pathogens. No information on Asian cultivars could be found.

Leaf, branch, and fruit disease. This exotic pathogen, *Guigardia piricola* (syn. *Botryosphaeria berengeriana* f. sp. p*iricola* or *Physalospora piricola*) *,* exists in the Japan, and is related to apple ring rot. It is presumed that European and Asian pear cultivars are susceptible. It may be subject to control by the same fungicides used to control white rot (i.e. bot rot), caused by *Botryosphaeria dothidea,* a common disease in the US.

Pear decline. This disease is caused by a phtyoplasma, transmitted primarily by the pear psylla, *Cacopsylla* spp. (Hibino and Schneider, 1970). It causes sieve-tube necrosis below the graft union, and is particulary severe when cultivars of the generally tolerant species, *P. communis*, are grafted onto rootstocks of the sensitive species, *P. pyrifolia or P. ussuriensis*. Use of these later rootstocks has been rare since the problem was recognized. All of the major *P. communis* cultivars are apparently moderately tolerant to varying degrees, with the exception of ‘Clapp Favorite’ and 'Conference', which are susceptible (Graf, 1977). The disease occurs throughout North America.

Apple proliferation. This is an exotic pathogen, not known to exist in the US, and has been tentatively designated *Phytoplasma mali.* It is vectored by various species of leafhoppers, but is also graft transmissible. The principle control would be quarantine indexing and certification. It is sensitive to tetracycline antibiotics. All pears are presumed to be susceptible.

Viruses and other unknown pathogenic agents. There are other disease organisms which are graft-transmissible. While they can cause deleterious effects on pear trees, they are not insect-vectored, and therefore, while or quarantine significance, are not considered to be as high in risk as the other other pathogens listed in Table 1. Pear bud drop virus and quince yellow blotch agent are exotic, and pear blister canker virus is an endemic pathogen on the APHIS regulated plant pest list. Quince sooty ringspot virus and quince stunt virus are also on the list. Once of unknown etiology, they are now thought to be caused by either apple stem pitting or apple chlorotic leaf spot virus, both of which exist in the US. Since all of these are not insect-vectored, control through quarantine, indexing, and certification of nursery stock should make control relatively easy.

Arthropod Pests.

The pear psylla, *Cacopsylla pyricola* Föerster, is the single most expensive pest to control in North America. Typical labor and insecticide costs can amount to $350 per acre for this insect alone. While some progress in biological control and integrated pest management, including the development of more selective pesticides, has been made, the level of control necessary still requires the use of substantial amounts of insecticide. In addition, codling moth (*Laspeyresia pomonella* L.), plum cucurlio (*Conotrachelus nenuphar* Herbst), San Jose scale (*Aspidiotus perniciousus* Comstock), mealy bugs (*Pseudococcus maritimus* Ehr. and *P. obscurus* Essig.), various aphids (*Myzus* and *Aphis* species), and at least four species of mites can result in either downgraded fruit or damage to leaves. The European apple sawfly, *Hoplocampa testudinea* (Klug), has been spreading throughout New England

and the Mid-Atlantic. It is not known is have spread to the major pear production areas. Although primarily known as a pest of apples, it does infest and cause serious damage to young pear fruit. No commercial cultivar is known to possess resistance to any of these arthropod pests.

Availability of resistant cultivars and germplasm.

This section assesses the amount of genetic diversity "in reserve", e.g. known resistant cultivars and other germplasm that could replace highly susceptible current cultivars. The issue of "replacement" must be informed by the knowledge that pear fruit is not a generic commodity, but that each cultivar has unique, readily identifiable and distinguishing characteristics that are, at least currently, important in marketing and consumer acceptance. Because pears are genetically highly heterozygous and self-incompatible, and have a long juvenile period that results in long generation cycles for breeding, development of, for example, a new fire blight-resistant cultivar with the unique flavor of 'Bartlett', along with similar texture and appearance, is difficult and time consuming. However, breeding programs are succeeding in producing new cultivars that are similar in some important traits. Acceptance of new cultivars has been long-term process in apples, but the growth in the number of cultivars in the marketplace over the past decade shows what is possible for pears, given the new cultivars are of high quality and profitable for the growers and distributors.

Fire blight. Resistance in *P. communis* is relatively rare, with only 5-10% being rated as at least moderately resistant (Oitto et al., 1970; van der Zwet and Oitto, 1972; Thibault et al., 1987; van der Zwet and Bell, 1990). Old dessert cultivars most consistently rated as resistant are 'Alexander Lucas', 'Tyson', 'Seckel', and 'Maxine'; resistant cultivars developed by recent breeding are 'Harrow Delight', 'Harrow Sweet', 'AC Harrow Crisp', 'AC Harrow Gold', 'Moonglow', 'Honeysweet', 'Magness', 'Potomac', 'Blake's Pride', and 'Shenandoah'. Therefore, sources of moderate to high resistance, although not immunity, do exist in European pears. With the exception of 'Seckel', and to a lesser extent 'Magness', these cultivars have not, to our knowledge, been extensively planted or evaluated in commercial size trials. There is a small amount of commercial production of 'Magness', primarily in the eastern and southeastern US. The newer cultivars have not yet been widely planted or evaluated, and thus, it is not certain whether they can be considered to be suitable replacements for susceptible cultivars. Additional resistance is available for use by the breeding program within introduced *P. ussuriensis* and *P.* x *bretschneideri* germplasm and hybrid selections from breeding programs.

Brown rot. There have been reports of resistance to M*onilinia* fruit rots, but they appear to involve *M. fructicola* rather than *M. fructigena*. The one exception to the general susceptibility to fruit rots was reported for 'Passe Crassane' (syn. 'Edelcrassane'), 'Clapp's Favorite', 'Beurre Hardy', and 'Louise Bonne d'Avranches' (syn. 'Louise Bonne de Jersey'.) (Mittman-Maier, 1940). Kock (1911) listed 39 cultivars of *P. communis* as free from infection by *Monilinia* (*Sclerotinia*), including some of the currently popular cultivars. The accuracy or repeatability of these observations has not been determined. Kovalev (1940) states that all species of *Pyrus* from the humid regions of eastern Asian are resistant to *Monilinia*, while those from the arid areas of western China and Soviet Central Asia are susceptible, and populations in the transitional zone are variable in resistance. The Asian species are susceptible to a variety of pathogens either not common or endemic to the West. All of this germplasm may provide resistance to *M. fructigena*.

Other major postharvest fruit rots. Other than for *Monilinia* (discussed above), there are no published reports of high levels of resistance to the major postharvest fruit rots. This is certainly an area which warrant further research.

Brown spot. The most commercially important cultivar in the US, 'Bartlett', as well as 'Blanquilla' (important in Spain), and 'Louis Bonne' are resistant to fruit infection. Other resistant cultivars of acceptable quality are 'Beurre Hardy', Grand Champion', and 'Highland'. Upon further evaluation for production traits, these could also be used for commercial fruit production or for breeding new resistant cultivars.

Black spot. Many cultivars are resistant to this disease, including the major cultivars 'Chojuro', 'Hosui', 'Kikusui', ''Kosui', 'Niitaka', 'Shinko', 'Shinseiki', and 'Suisei, and other minor (Kanato et al., 1982). The predominant Japanese cultivar 'Nijkisseiki' is susceptible, but an irradiation-induced mutant, 'Oja-Nijisseiki', has been developed and is being used in breeding. European pears are generally considered to be resistant (Banno et al., 2002), although many have not been evaluated.

Japanese pear rust. All of the major cultivars grown in Japan are susceptible to this pathogen, but it does not cause serious damage to European pears (Kanato et al., 1982).

Asian pear scab. There are reports from China of some moderately resistant Asian pear germplasm, but none of the major commercial cultivars are resistant. In addition, however, there is considerable interest in hybridizing with European pears to transfer resistance genes.

Valsa canker. Moderate levels of resistance are apparently available within *P. pyrifolia* cultivars that could be used in breeding. There are no reports of resistance in *P. communis.*

Leaf, branch, and fruit disease. There is little literature on relative resistance to this disease. There is apparently some variability in resistance among *P. communis* cultivars, since in a report on evaluation of 65 cultivars for suitability for production in Japan, 'General LeClerc' was been reported to be too susceptible, while no comment was made on the other cultivars.

European pear scab. There are several *P. communis* cultivars with moderate to high levels of resistance to pear scab. 'Conference', 'Jules Guyot', and 'Beurre Hardy', major cultivars in Europe, are resistant, and 'Bartlett' and 'Doyenne du Comice' are reported to be moderately resistant. There are several new scab resistant cultivars developed by European pear breeding programs, but they have either not been introduced or evaluated in the US for commercial suitability.

Powdery mildew. Minor cultivars and other germplasm with at least moderate levels of resistance do exist, but commercial suitability would need to be determined. Generally, pears are less susceptible to powdery mildew and the disease is easily controlled, and therefore, the disease has not received extensive attention in breeding programs.

Apple proliferation. There is no documented resistance in pears to this disease.

Pear decline. Most *P. communis* cultivars, with the exception of 'Conference' and 'Clapp Favorite', are fairly tolerant of this disease, as are the major *P. communis* rootstocks, including the 'Old Home' x 'Farmingdale' rootstocks.

Viruses. Varying degrees of resistance or tolerance to pear bud drop virus has been reported from Bulgaria. Resistance to the other of the viruses listed in Table 3 has not been documented.

Outlook and Needs. A few cultivars of pear with resistance to fire blight are available, but most are not grown commercially on a large scale, either because of deficiencies in fruit quality, yield or other important characteristics, or because of insufficient evaluation and promotion. In addition, gaining market acceptance in a retail trade which limits the number of cultivars marketed is difficult. Selections with promising fruit quality and fire blight resistance are being tested throughout the country. Little is known about the range of susceptibility to *Pseudomonas syringae*. Cultivars with reduced susceptibility to pear scab have been identified, primarily by Hungarian and Soviet researchers on the basis of long-term observations under orchard conditions, but most have either not been imported or have not been evaluated for commercial acceptability in this country. Resistance to eight major fruit rot fungi is unexplored.

Host plant resistance to many insect and mite species has not received adequate attention. Resistance to the pear psylla has been identified in *Pyrus ussuriensis* and some of its hybrids with *Pyrus communis*, as well as in 15 cultivars (most presumably *P. communis*) from Eastern Europe. This germplasm does not have acceptable fruit quality, but the long-term prospects for breeding cultivars with resistance to this insect are promising. Resistance to a number of diseases and insects appear to exist within the East Asian germplasm pool of *P. ussuriensis*, *P. calleryana*, *P.* x *bretschneideri*, and *P. betulifolia*.

A reduction in the genetic vulnerability of the pear industry might be attained through several paths. Introduction of new germplasm, either as foreign cultivars or wild germplasm, and the evaluation, breeding, and introduction of new selections would all contribute to the reduction in genetic vulnerability. An increase of the number of cultivars, as well as replacement of the vulnerable cultivars, would reduce the risk to total national production. Breeding of new cultivars could also be augmented by genetic transformation of existing cultivars with genes conferring enhanced resistance to major diseases and insect pests.

B. Rootstocks

Status of Genetic Diversity and Risks. The genetic base of pear rootstocks is even more narrow than that for scions. While seedling rootstocks were used almost exclusively in the United States until about 20 years ago, clonal rootstocks have become preferred. Because the seedling rootstocks are derived from parent cultivars which are highly heterozygous and self-incompatible, the rootstocks are not genetically identical, although they are usually sufficiently uniform in all important characteristics. Seedlings of 'Bartlett' predominate in older plantings, with seedlings of 'Winter Nelis' probably being the next most widely used seedling rootstock. Both of these are *P. communis* cultivars, and are highly susceptible to fire blight. Seedlings of *P. calleryana* are sometimes used in areas with mild winters, such as the southern states, California, and southern Oregon. Where high vigor is needed in clay or poorly drained soils, seedlings of *P. betulifolia* are used. Certain seedling selections of *P. betulifolia* (i.e. "Reimer" selections) are also resistant to fire blight. These are also the predominant choice for Japanese (*P. pyrifolia*) cultivars. ‘Winter Nelis’ seedlings are also used to some extent for Asian pears, predominantly the Chinese cultivars.

Clonal, or asexually propagated, genetically identical rootstocks have been used to a lesser degree in the United States than in Europe. Clonal rootstocks of quince, *Cydonia oblonga* L., which are the dominant rootstock throughout the milder climates of Western Europe, are used to a limited degree in California and southern Oregon. These rootstocks are not as winter-hardy as *P. communis* rootstocks. Graft-incompatability of most of the major cultivars with quince rootstocks necessitates the use of a mutually compatible interstock, making trees more expensive to produce. Quince is also highly susceptible to fire blight. For these reasons, quince rootstocks have not attained the popularity achieved in Europe. They can, however, induce both precocious and productive fruit yields, and dwarfed tree stature. The number of different quince rootstocks in commercial US production is small: EMLA A, EMLA C, Provence, and BA29.

Efficient growth-controlling clonal rootstocks selected from seedling populations of *P. communis* parentage have become commercially available and have been more widely planted in the last 20 years. Named for their parents, these 'Old Home' x 'Farmingdale' clonal rootstocks are moderately resistant to fire blight, and, depending on the clone, exhibit tree size control in a range of somewhat larger than the most vigorous quince (approximately 60% of the size produced on 'Bartlett' seedlings), to 20% more vigorous than the 'Bartlett' seedling rootstocks. Although commercial propagation of most of these rootstocks is controlled by a single nursery, they are becoming increasingly popular and available, and in fact, have become the preferred rootstocks in most production districts. This is due to some improvement in precocity and the many advantages of smaller trees planted at higher densities, factors which have led to the widespread use of size-controlling rootstocks in apples. A reduction in root suckering contributes to the decreased risk of infection. Genetic vulnerability of pear rootstocks to fire blight can, therefore, be seen as becoming less of a threat as trees on 'Old Home' x 'Farmingdale' clonal rootstocks replace those grown on the susceptible rootstocks. Many of the 'OHxF' rootstocks are still considered to difficult to propagate by usual methods (hardwood and semi-hardwood cuttings, and stooling). While ‘OHxF 333’, perhaps the most easily propagated clone, was once the most widely planted, it has been surpassed by ‘OHxF 87’ and ‘OHxF 97’, with increased interest in ‘OHxF 40’. There are 4 other clones in limited commercial production and use (‘OHxF 51’, ‘OHxF 69’, ‘OHxF 217’, and ‘OHxF 513’).

Recently, two new German rootstocks, ‘Pyrodwarf’ and “Pyro 2-33’, which produce trees approximately 40 and 70% the size of trees on seedling rootstocks, which induce earlier yield, and are tolerant of fire blight, have become commercially available. They were selected from a cross of ‘Old Home’ and ‘Louise Bonne d’Avranche’.

Seedling rootstocks of *P. ussuriensis* and *P. pyrifolia* were used until pear decline occurred during the late 1950's and 1960's. This phytoplasma disease requires an insect vector, the pear psylla, a tolerant scion, and a susceptible rootstock. Rootstocks of *P. betulifolia*, *P. communis*, and *P. calleryana* are relatively tolerant of the pathogen, as is quince.

In other parts of the world, wild seedlings of locally adapted species are extensively used as rootstocks. Because of the wide distribution of pear species, adaptation to a wide range of soil and climatic conditions exists within the genus. Some of the genetic variability among *Pyrus* species has been documented. In addition to *Cydonia*, various other related Rosaceae are candidates for rootstocks for pear. Selected clones of *Amelanchier* (serviceberry) and *Crataegus* (hawthorn) possess sufficient graft-compatibility with *Pyrus* to be considered as dwarfing rootstocks. Sources of tolerance or resistance to many diseases and insects affecting rootstocks have been identified among *Pyrus* or its related genera. There is also genetic variability in the ability of rootstocks to influence the scion cultivar in such traits as bloom date, fruit size and quality, tree size, precocity, and yield efficiency (yield corrected for tree size).

High Impact Diseases and Available Resistant Germplasm.

Fire blight. As stated above, ‘Bartlett’ and ‘Winter Nelis’ seedling rootstocks and quince clonal rootstocks are highly susceptible, but the ‘Old Home’ x ‘Farmingdale’ rootstocks and the new ‘Pyrodwarf’ rootstock are at least moderately resistant. These are rapidly replacing the susceptible seedling rootstocks. In addition, resistant *P. betulifolia* seedlings are extensively used for Asian pears and on orchard sites that require vigorous trees.

Pear Decline. The newer *P. communis* rootstocks and *P. betulifolia* possess sufficient resistance or tolerance to this disease. Additional new rootstock selections currently under evaluation also appear to be at least moderately tolerant. Even Cydonia (quince) rootstocks are moderately tolerant to resistant.

Outlook. Because of the known variability, it appears possible to breed a number of rootstocks for general or special use. Particularly lacking for North American production are adapted rootstocks which can result in tree size as small as or smaller than the quince (*Cydonia*) rootstocks, and which induce precocious and productive yields. Unfortunately, little is known about the physiological basis of size control, and specifically dwarfing, or of precocious fruit bearing, and correlated traits which could be used to select prospective rootstocks are not well established. Experience in some of the Malling and Malling-Merton genotypes of apple indicates that the bark-to-xylem or phloem-to-xylem ratio in roots is related to dwarfing ability, but it is not clear whether this trait is generally applicable to pears, or even to other apple germplasm. Additional research is needed to support selection and breeding of rootstocks which induce dwarfness and precocity.

C. Threatened Wild Germplasm

The International Union for the Conservation of Nature (IUCN) Red List currently contains only 5 *Pyrus* taxa, all in Turkey. Included in the "Low risk/near threatened" category are *P. salicifolia*, and three taxa not recognized by GRIN: *P. anatolica* Browicz, *P.oxyprion* Woronow, and *P. serikensis* Güner & Duman. One taxon, *P. hakkiarica* Browicz, is listed as "data deficient", but is presumably included because of concern. Güner and Zielinkski (1996), in their account of the status of Turkish woody flora, also list *P. elaeagrifolia* ssp. *bulgarica* and *P. yaltirikii* as low risk/near threatened, but list *P. elaeagrifolia* ssp. *elaeagrifolia* and spp. *kotschyana*, *P. pyraster* ssp. *caucasica* and ssp. *pyraster*, *P. spinosa*, and *P. syriaca* as "low risk/least concern". *According* to Browicz (1972), *P. anatolica* is probably *P*. elaeagrifolia subsp. *kotschyanae* or an interspecific hybrid of *P. elaeagrifolia, P. communis, and P. amygdaliformis.* Güner and Zielinkski (1996) state that *P. serikensis* is "known until recently as *P. boissieriana* subsp. c*renulata*", which GRIN recognizes as a synonym of *P. cordata*. The taxon *P. hakkiarica* is probably *P. syriaca* (Davis, 1972).

The International Dendrological Society also lists *P. magyarica* (probably a synonym of *P. communis* ssp. *pyraster*, and only described in Hungary) as either endangered, vulnerable, or rare (Lear, 1996). Wild populations of additional taxa in other countries are more than likely threatened. In Germany and the Czech Republic, wild populations of *P. pyraster* are threatened (Sindelar, 2002; Endtmann, 1999), although there are efforts to maintain those genetic resources by in situ and ex situ preservation (Kleinschmidt et al., 1998; Wagner, 1999; Paprstein et al., 2002). Other such efforts at in situ conservation have been planned for the Middle East (Amri et al., 2002). Wild populations in Kyrgyzstan (Blaser, 1998), the Kopet Dag woodlands of Turkmenistan (World Wildlife Fund, 2001), and elsewhere in Central Asia are threatened by logging and fuelwood gathering and other activities in previously protected forests. Among Asian species, *P. calleryana* is listed as a vulnerable endemic species in Japan (Ohba, 1996), and *P. kawakami* is listed as vulnerable in Taiwan (Lear, 1996).

IV. Germplasm Needs

A. Collection

The current NCGR *Pyrus* collection of pear cultivars may not provide an adequate genetic sample of the variability within the genus. This is because some cultivars may be similar, arising from the same genetic pool, while other genetic types may not yet be included. This may be especially true of the *P. communis* cultivars, which form the majority of this group. Unique clones of other species are inadequately sampled. The Asian pear species may be especially under-represented. No adequate method has been devised for selecting accessions for maximum genetic diversity. Work on the verification of clones will help to reduce duplications. The collection of information related to verification and evaluation will help identify gaps, as will assistance from cooperating scientists and CGC members.

The species collection includes most of the accepted species. However, most are represented by relatively few geographic sites, and many accessions are of unknown origin. In addition, work needs to be done to determine whether *P. koehnei* (syn. *P. kawakamii*) of southern China and Taiwan is extinct in the wild. Further work is needed to collect (and in some cases, to translate) pertinent literature in order to identify cultivars with unique characteristics. Biochemical characterization of phenolics has previously been used as a taxonomic tool in *Pyrus*. The techniques of protein electrophoresis and isoelectric focusing of isozymes were also previously used to "fingerprint" genotypes. Genetic marker methods based upon random (for example, RAPD, AFLP) or unique DNA primers (SSR, ISSR, SCAR, CAPS, etc.) and/or DNA restriction fragment length polymorphisms (RFLP) have begun to be used to assess genotypic diversity genetic relationships, and to identify unique genotypes.

Existing collections in Europe and Asia need to be reviewed and germplasm acquired, if necessary, to prevent losses and to fill gaps in our collection. Some of this has already been done. Acquisition of information from collections as a first priority will be helpful in making future decisions. For species, opportunities for obtaining information and material are limited by the few active breeding programs, and by the fact that no *Pyrus* species are native to North America. Although many samples may be obtained by exchange with other countries, much collection will have to be done directly by exploration in areas of diversity. The extent of needs, priorities, quantities, and sources of species material are only now being developed. A summary is included in Table 1. Recent collections by the *Pyrus* curator in Armenia and Georgia have been very important in expanding the amount of wild and cultivated *P.communis* germplasm from the Caucasus.

B. Evaluation

Since the repository responsible for the national collection of *Pyrus* germplasm was established in the early 1980s, evaluation has not been given a high priority. The basic functions of collection, preservation, verification of identity, determination of virus status and production of virus-free plants, and distribution have received emphasis. Collection of descriptive characteristics needed to verify identity, while not being neglected, needs to be expanded and the data entered into GRIN.

It is our opinion that any research done at the repository should initially support the basic functions. Current research on *in vitro* micropropagation and cryopreservation are good examples, as is the use of DNA marker (SSR or microsatellite) techniques for the "fingerprinting" of species and clones. Such work should be expanded to study genetic diversity within the entire collection and in germplasm from past and future explorations.

As the first operational clonal repository, funding was available for research. Evaluation of cold hardiness of the *Pyrus* collection was undertaken. This research was of great value, since cold hardiness has been identified as a high priority for evaluation by the *Pyrus* CGC. When funding is available, additional in-house evaluation of characteristics identified as of high priority by the CGC could be initiated by a number of mechanisms: 1) graduate student or facility research at Oregon State University, 2) visiting scientists or ARS post-doctoral associates at the repository, and 3) research by cooperators at other institutions. The curator and the CGC should both actively seek cooperators to fulfill the evaluation needs. Relatively little objective data has been collected on the genotypes in the repository collection for the high priority characteristics (Table 2). General characteristics of the major species are known from studies of relatively few genotypes, and variability within all species has not been adequately explored for most characteristics. Host resistance among species to fire blight, pear psylla, pear scab, and fruit characteristics, all major concerns, have received the most attention. Even these traits need further investigation. Evaluation will be somewhat inhibited by the small number of interdisciplinary breeding teams. Interest in examining genetic diversity must be stimulated from the national research community.

C. Enhancement

For the purposes of this report, enhancement is defined as the initial generation(s) of breeding, in which germplasm collected from wild populations or local cultivars or landraces are hybridized to cultivars or advanced breeding selections. As outlined in Section II, present enhancement activities in *Pyrus* in the United States are carried out primarily by a single breeding program of the U. S. Department of Agriculture. Enhancement and breeding for fruit quality, productivity, and host resistance to fire blight and pear psylla are current goals of this scion cultivar development program. There are no longer any active university breeding programs, and no private commercial enterprise is currently involved in large scale pear breeding. The entire enhancement-breeding continuum must be encompassed in the existing USDA program. No enhancement activity is currently recommended for the clonal repository. The efforts of the U.S.D.A. program are augmented by interactions with active breeding programs in France, Italy, and Romania. Exchange of germplasm, including advanced selections, is a major part of this relationship. This may reduce the need for enhancement and early generation breeding for certain characteristics by this program.

There is currently no pear rootstock breeding program in the United States or Canada. (I believe efforts of Agriculture Canada at Summerland, British Columbia, were terminated.) In Europe, there are active programs in France, Italy, Romania, and other countries, while programs in England and Germany are relatively inactive. The most promising selections have been imported for evaluation by collaborators in the NC-140 project. The most dwarfing rootstocks from the French program are deficient in fire blight resistance and ease of propagation, and are probably unsuitable for direct use by our industry. Oregon State University has conducted the only sizable pear rootstock evaluation program in this country with non-commercial rootstocks. This program deserves more adequate funding. Tree size control, induction of precocious bearing, high yield, disease and insect resistance, and ease of propagation are characteristics for which improved rootstocks should be bred. The genus *Pyrus* and several graft-compatible genera possess sufficient genetic diversity for these and other characteristics to warrant expanded evaluation and enhancement efforts. Evaluation of rootstocks, however, require considerable time, land, and other resources, and would require the allocation of additional funding.

It is difficult to rank collection, evaluation, and enhancement, as each is important. The NPGS and the repository should stress collection and exploration. Preliminary evaluation for those priority characteristics identified by the CGC should be done as permitted by available funds. Enhancement and breeding of scion cultivars should be continued by the present USDA breeding program for fire blight and pear psylla resistance, while evaluation of the germplasm for other characteristics by additional cooperators should be encouraged.

D. Preservation

The "base" collection for *Pyrus* and related genera of potential use as rootstocks, is at the National Clonal Germplasm Repository at Corvallis, Oregon. There are no "working" collections other than those of breeding and cultivar evaluation programs previously mentioned. Most of the species and cultivar germplasm from these collections has been transferred to the repository. Additional germplasm imported into the country for these other programs may also be sent to the repository, if deemed appropriate. The initial decisions on what germplasm to include in the base collection at the repository was made by the curator acting upon the advise of scientists in charge of the working collections, the National Technical Advisor for Clonal Repositories (at that time, M. N. Westwood, Professor Emeritus at Oregon State University), and members of the Technical Committee for the repository.

The current system for getting appropriate materials into the base collection is adequate. However, evaluation of the germplasm may determine that cultivars of *P. communis* of western European origin, for example, are more than adequately represented on the basis of uniformity. Because of restrictions on the size of collection, it may become necessary to eliminate certain clones from the collection. The criteria for elimination have yet to be determined and may prove difficult to establish or implement until thorough evaluations are complete.

The facility is rapidly becoming filled. While collections of seed from wild populations of species may be stored on site and/or at the National Center for Genetic Resources Preservation in Fort Collins, Colorado, it is anticipated that additional clonal material will seriously strain the available space in the screenhouses and orchard. The one tree maintained on semi-dwarfing clonal rootstock in the orchard is the primary clone, and is used for verification of identity and evaluation. Small trees of cold-tender germplasm and germplasm undergoing virus indexing are stored in screenhouses. The needs of the other genera housed at the same repository must also be considered. Cold storage of shoot-tip cultures and cryopreservation of meristem cultures may reduce the screenhouse and orchard requirements to one plant in each location, assuming that the distribution needs can be adequately met. The issue of long-term security of the various preservation options needs to be more thoroughly explored.

V. Recommendations

A. Priority of Actions

The primary responsibilities of collection, preservation, determination of virus status and production of virus-free plants for sources of budwood, verification of identity, and distribution should receive the highest priority. Research and other activities which support these primary functions should receive the next highest priority for funding. Specific actions are outlined as follows:

1. International exploration for *Pyrus* germplasm and related genera identified as inadequately represented in the present collection should be vigorously pursued (see Table 1). To this end, contacts with appropriate persons or agencies in countries with native germplasm should be made to determine the degree to which these populations are endangered and to arrange for exploration and exchange of mutual benefit. Our activities should be coordinated as closely as possible with those of the International Plant Genetic Resources Institute (IPGRI).

2. Acquisition from existing foreign collections should be actively pursued.

3. Germplasm exchange and related scientific activities for all genera in the NPGS should be pursued and coordinated to enhance our access to information and germplasm.

4. Database activities should be as compatible as possible with those of the IPGRI to enhance access and exchange of vital information on collections and characteristics of accessions.

5. Basic botanical and pomological descriptive data are needed to determine the degree of diversity in the collection. Descriptive information on fruit quality would be especially as selective data useful to scientists and extension workers who wish to conduct cultivar evaluations.

B. Level of Support

The current funding level for the repository (~$1.4 million) is adequate to carry out the primary functions, some supporting research activity, and a small amount of basic evaluation. Some additional funding for exploration and characterization activities is needed. Cooperative scientific exchange and research activities, such as those programs administered by UN-FAO, should be encouraged to give high priority to germplasm activities. Scientists and curators should be made aware of these and other sources of funding for exploration and evaluation activities.

VI. Sources of Funding

In addition to ARS funds specifically allocated to the repository and the Plant Exploration Office, cooperative programs with scientists in countries with native *Pyrus* germplasm may be initiated with funds from other national and international agencies, such as USDA's OIRP and UN-FAO. Industry sources, such as the Washington Tree Fruit Research Commission, may be willing to support short term evaluation programs for high priority needs, and should be approached by the repository or by cooperating scientists at institutions within the major pear growing states.

Table 1. *Pyrus* species, geographic distribution, and collection needs (2004 List).

Geographic Group and Species	Centers of diversity	Priority Needs
European		
P. communis L.[z]	Western and Southeast Europe, Turkey	Wild forms and cultivars from the Caucasus, Turkey, and western Asia
P. caucasica Fed.	Southeast Europe	
P. nivalis Jacq.	South Central Europe	Seed of true wild forms
P. cordata Desv.	France, Spain, Turkey	
Circum-Mediterranean		
P. amygdaliformis Vill.	Southeast Europe Turkey	
P. elaeagrifolia Pall.	Southeast Europe Russia, Turkey	
P. syriaca Boiss.	Tunisia, Libya Middle East	Seed from entire range
P. longipes Coss. & Dur.	Algeria	Seed of wild form
P. gharbiana Trab.	Morocco	Seed of wild form
P. mamorensis Trab.	Morocco	Seed of wild form
Mid-Asian		
P. salicifolia Pall.	North Iran Southern Russia	Seed of wild form
P. regelii Rehd.	Afghanistan	Seed of wild form
P. pashia D. Don.	Pakistan, India, Nepal	
East Asian		
P. armenicafolia	Northwestern China Kazakhstan	Seed of wild form

P. aromatica Kik. & Nak. (syn. P. hondoensis)	Northern Japan	Seed of wild form; species status uncertain
P. betulifolia Bunge	Central and Northern China Southern Manchuria	Seed from northern range
P. x bretschneideri	China	Cultivars
P. calleryana Dcne.	Central and Southern China	
P. dimorphophylla Mak.	Japan	
P. fauriei Schneid.	Korea	
P. hondoensis Kik. & Nak.	Japan	Seed of wild form
P. kawakamii (syn. P. koehnei)	South China, Taiwan	Seed of wild form (if not extinct in wild)
P. pseudopashia (syn. P. kansuensis)	China (Kansu)	Seed of wild forms; species status uncertain
P. pyrifolia (Burm.) Nak.	China, Japan, Korea, Taiwan	Improved clones
P. sinkiangensis	Northwestern China	Clones and seed
P. ussuriensis Max.	Siberia, Manchuria Northern China Korea	Clones of true species and hybrids
P. xerophila	Northwestern China	Seed of wild form

[z] Includes several taxa listed as valid species names for GRIN, but for which species status is uncertain. Also includes several taxa not recognized as valid species by GRIN.

Table 2. *Pyrus* Descriptor List for GRIN and Priorities for Evaluation

I. Scion Cultivars:

Priority	Category	Priority	Trait
Primary	Diseases of tree/foliage	High	Fire blight
			Pseudomonas blight
			Pear scab
			Powdery mildew
		Moderate	Fabraea leaf and fruit spot
		Low	Mycosphaerella leaf spot
			Pear decline phytoplasma
			Pear vein yellows virus
			Pear ring pattern mosaic virus
			Apple stem grooving
			Blister canker
			Apple rubbery wood
			Pear rough bark
Primary	Arthropod Pests	High	Pear psylla
			European red mite
			Rust mite
		Moderate	Codling moth
			European apple sawfly
		Low	Plum curculio
			San Jose scale
			Grape mealy bug
			Blister mite
Primary	Environment/ Climatic	High	Winter-hardiness
		Moderate	Chilling requirements to break dormancy
			Heat requirement for bud break
			Drought and heat tolerance
Primary	Fruit Quality	High	Fruit traits: flavor, grit, texture, size, and appearance
			Storage life

Table 2. (cont.)

Priority	Category	Priority	Trait
			Shelf life
			Texture type (crisp vs. melting or buttery)
		Moderate	Processing quality
Primary	Production/ Tree traits	High	Yield efficiency
			Precocity
			Bloom date
			Secondary bloom
		?	Harvest date
			Growth habit
			Fruiting habit
			Vigor
			Pollen sterility
			Parthenocarpic fruit set
Secondary	Fruit diseases	High	Blue mold
			Brown rot
			Bull's eye rot
			Gray mold
			Mucor rot
			Side rot
		Moderate	Bitter rot
			Black rot
	Physiological	High	Black-end (of Asian pears)
			Cork spot
			Alfalfa greening, green stain
			Core breakdown
			Superficial and senescent scald
		Low	Boron-deficiency pitting

Table 2. (cont.)

II. Rootstocks

Priority	Category	Priority	Trait
Primary	Diseases	High	Crown gall Collar rot Fire blight
		Low	Oak root fungus
	Environmental Adaptation	High	Cold-hardiness Heat tolerance Drought resistance Range of pH tolerance Soil type adaptation
	Arthropod & Nematode Pests	Moderate	Wooly pear aphid Root lesion nematode
	Production	High	Size control

Table 3. Ranking of Highest Impact Diseases of Pear[1].

Rank	Disease	Type	Pathogen	Endemic/ Exotic	Comments
1	Fire blight	bacterium	*Erwinia amylovora*	Endemic	Streptomycin-resistant strains pose a high risk.
2	Apple proliferation	phytoplasma	*Phytoplasma mali*	Exotic	Leafhopper transmission
3	Brown spot	fungus	*Stemphylium vesicarium*	Exotic	Economically important in Euro Europe; fungicidal control exists.
4	Brown rot	fungus	*Monilinia fructigena*	Exotic	Fungicidal control exists.
5	Postharvest fruit rots:	fungi		Endemic	High potential for fruit loss; fungicidal control available
	Blue mold		*Penicillium expansum*		
	Gray mold		*Botrytis cinerea*		
	Mucor rot		*Mucor piriformis*		
	Side rot		*Phialophora malorum* and *Cladosporium herbarum*)		
	Bull's-eye rot		*Neofabraea malicorticis*		
	Phacidiopycnis rot		*Phacidiopycnis pyri*		Newly reported in US
	Coprinus rot		*Coprinus psychromorbidus*		
	Sphaeropsis rot		*Sphaeropsis pyriputrescens*		Newly reported in US
6	Leaf, branch, and fruit disease	fungus	*Guignardia piricola* (syn. *Botryosphaeria berengeriana* f. sp. *piricola*)[2]	Endemic?[2]	Fungicidal control exists.
7	Black spot	fungus	*Alternaria alternata* pv. *kikuchiana*	Exotic	Affects Asian pear species.

Table 3. (cont.)

Rank	Disease	Type	Pathogen	Endemic/ Exotic	Comments
8	Japanese pear rust	fungus	*Gymnosporangium asiaticum*	Exotic	Affects most *P. pyrifolia* cultivars
9	Valsa canker	fungus	*Valsa ceratosperma*	Endemic[3]	No curative fungicides, although there are preventative fungicides. Less severe on *P. pyrifolia* than other Asian pear species.
10	Pear decline	phytoplasma	*Phytoplasma pyri*	Endemic	Transmissible by pear psylla
11	Asian pear scab	fungus	*Venturia nashicola*	Exotic	Most *P. communis* are resistant: most *P. pyrifolia* are susceptible.
12	Blossom blast	bacterium	*Pseudomonas syringae* pv. *syringae*	Endemic	Copper-containing fungicides somewhat effective.
13	European pear scab	fungus	*Venturia pirina*	Endemic	Fungicidal control exists
14	Powdery mildew	fungus	*Podosphaera leucotricha*	Endemic	Fungicidal control exists
15	Pear bud drop	virus	-	Exotic	Only graft-transmissible
	Pear blister canker	viroid	-	Endemic	Only graft-transmissible
	Quince sooty ringspot	virus	ASPV[4]	Exotic?[4]	Only graft-transmissible
	Quince stunt	virus	ASPV[4] & ACLSV[5]	Exotic?[4, 5]	Only graft-transmissible
	Quince yellow blotch	unknown	-	Exotic	Only graft-transmissible

[1] Rank is based upon potential for significant tree loss, crop loss, or loss of marketability of fruit, mode of transmission (insect vectored or graft transmission), ease of control, and susceptibility of common European or Asian cultivars.

[2] Identical to *Botryosphaeria dothidae*, which is present in the US (see Farr et al., 1989; Slippers et al., 2004).
[3] It is not certain whether this pathogen is present in the Pacific Northwest and California.
[4] ASPV = apple stem pitting virus. Virus is known to exist in US.
[5] ACLSV = apple chlorotic leafspot trichovirus. Virus is known to exist in US.

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