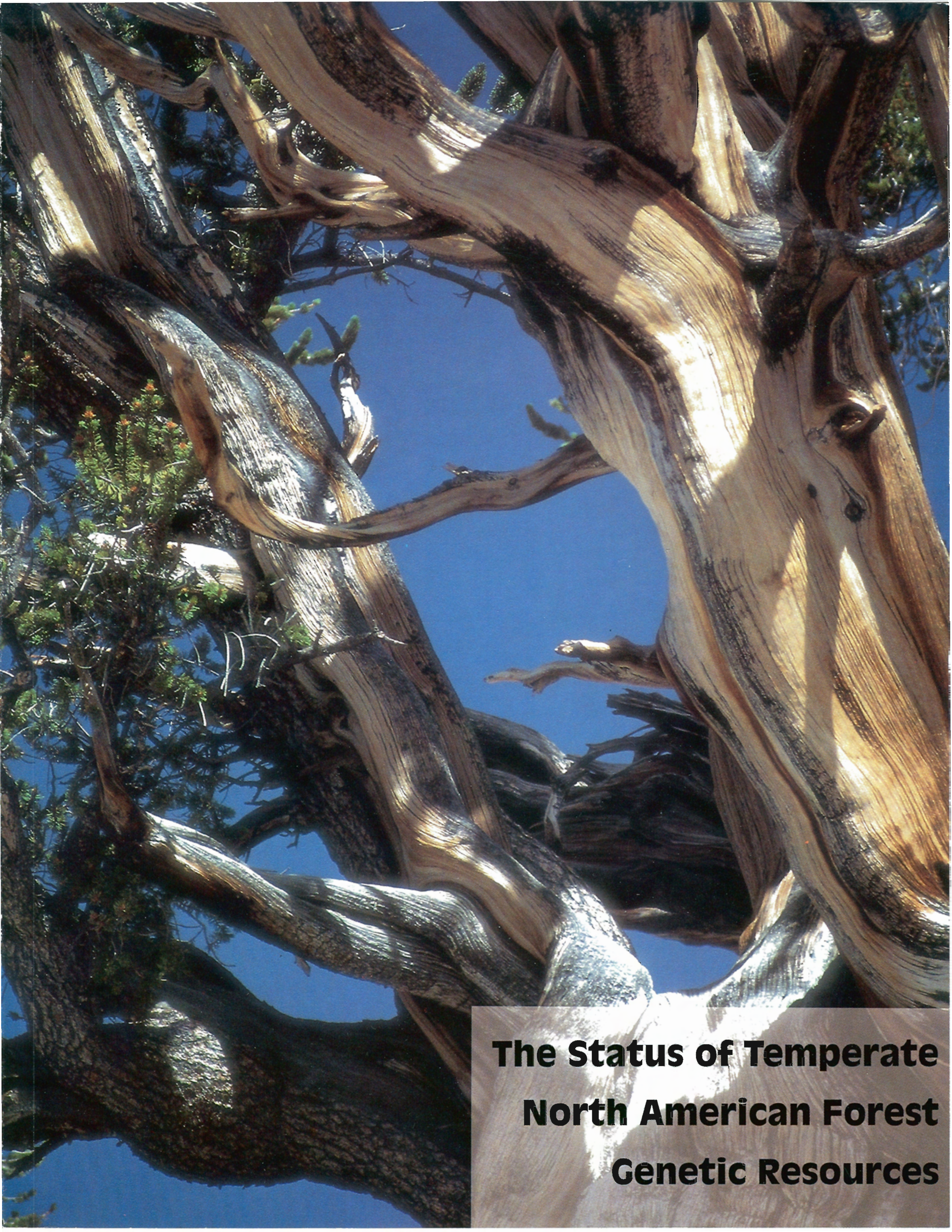

The Status of Temperate North American Forest Genetic Resources

Front cover. The bristlecone pine (*Pinus longaeva* D.K. Bailey), like most North American temperate tree species, has no commercial commodity value. However, it has aesthetic value and it literally changed the history of the world. Trees like the one pictured, from the Ancient Bristlecone Pine Botanical Area in the Inyo National Forest of California, U.S.A., provided a tree-ring chronology that extended several millennia back into prehistory. The chronology was used to calibrate the radiocarbon dating technique. The calibration revealed that radiocarbon dates deviated substantially from actual dates because they had been based on the false assumption of a constant $^{14}C/^{12}C$ ratio. In fact, the more-exact, bristlecone dendrochronology demonstrated that radiocarbon dates thought to represent 3100 B.C., for example, were really 1,100 years earlier (4200 B.C.) and that dates thought to be around 2400 B.C. were really from 3000 B.C. The only accurate radiocarbon dates were from the last 2,000 years. In a sense, correction of radiocarbon dates based on the bristlecone dendrochronology reversed the course of history, or at least reversed archaeological concepts regarding the sequence of historical events; e.g., megalithic structures of western Europe thought to have been constructed after the pyramids of Egypt actually predated them. For a more complete account see Hitch (1982).

The Status of Temperate North American Forest Genetic Resources

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An undertaking of the
Forest Genetic Resources Study Group
of the
North American Forestry Commission
of the
Food and Agriculture Organization of the United Nations

Deborah L. Rogers and **F. Thomas Ledig**
Editors

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Genetic Resources Conservation Program
University of California
Davis, CA 95616 USA
(916) 754-8501
FAX (916) 754-8505
e-mail: grcp@ucdavis.edu

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Deborah L. Rogers is a research geneticist with an appointment within the Office of the President, University of California, Oakland, California.

F. Thomas Ledig is senior scientist in the Pacific Southwest Research Station of the USDA Forest Service. He works at the Institute of Forest Genetics, Albany and Placerville, California on the genetics and evolution of conifers and teaches conservation genetics at the University of California, Davis.

PHOTOGRAPHY CREDITS: All photographs not otherwise credited are by **F. Thomas Ledig**.

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Preface

This report summarizes the results of a questionnaire on conservation and use of temperate North American forest genetic resources. It also presents recommendations on the management of forest genetic resources offered by participants in the Workshop on North American Temperate Forest Genetic Resources.

The workshop was held from June 12–14, 1995, in Berkeley, California in preparation for the Fourth International Technical Conference on Plant Genetic Resources, which will be organized by the Food and Agriculture Organization (FAO) of the United Nations, in June 1996 in Leipzig, Germany. One of the main outputs from the Technical Conference will be a Global Plan of Action for Plant Genetic Resources. The Global Plan will:

- Propose policies and actions;
- Set priorities for action;
- Strengthen national capabilities.

The recommendations formulated at the workshop will help ensure that forestry has a voice in the Global Plan of Action which will be adopted at the Technical Conference. This is crucial because the forestry enterprise is unique and does not fit well into the agricultural mold. We hoped that a workshop on North American forest genetic resources would identify the differences between forestry and agriculture and explore a conservation strategy appropriate to forestry.

We asked the participants to:

- Help clarify the conservation status of North American temperate forest genetic resources;
- Identify problems in the conservation of forest genetic resources;
- Recommend needs and assign priorities for the effective conservation and utilization of these resources.

Convening the workshop was a task undertaken by the Forest Genetic Resources Study Group (FGRSG) of the North American Forestry Commission (NAFC). The NAFC is one of several regional forestry commissions established by the FAO. The FGRSG is one of several study groups within the NAFC, and includes representatives from Canada, México, and the United States. The mission of the FGRSG is to: coordinate research activities on forest genetic resources of interest to North America; encourage international cooperation; and facilitate the exchange of information. It is in the spirit of encouraging international cooperation and the exchange of information that we organized this workshop. Several of the FGRSG members were participants.

The task of convening the workshop was actually urged upon the FGRSG in 1993 by Dr. Timothy J.B. Boyle, then of the Canadian Forest Service. Dr. Boyle would have been admirably suited to organize this gathering, but shortly thereafter he accepted a position with the Centre for International Forestry Research (CIFOR) of the Consultative Group on International Agricultural Research (CGIAR) in Indonesia.

The FGRSG was able to carry on with the assistance of several organizations. Because the U.S. Forest Service Research division, under the direction of Dr. Jerry Sesco, considers the conservation of forest genetic resources as one of the most important problems affecting forestry, agriculture, and the environment, it contributed substantial funding at an early stage.

The workshop was undertaken with the technical collaboration of the FAO through its Forest Resources Division. Oudara Souvannavong, Forest Genetic Resources Officer, and Christel Palmberg-Lerche, Chief of the Forest Resources Development Service, participated in planning the workshop from its inception.

The University of California's Genetic Resources Conservation Program (GRCP) cosponsored the workshop. The GRCP is a unique organization. California is the only state in the United States with a program for conservation of genetic resources ranging from the level of microbes to forest trees. The GRCP provided funding to offset costs of travel and to publish this report. Most importantly, Drs. Calvin O. Qualset, Director, and Patrick E. McGuire, Assistant Director, are to be recognized for their counsel in planning, for contributing to the workshop as both discussants and recorders, for providing a perspective from the agricultural viewpoint, and for directing the publication of this report.

The Department of Environmental Horticulture (EH) at the University of California at Davis was another cosponsor. Without the assistance of EH, particularly Dr. James A. Harding and Ms. Suzanne G. Melendy, this gathering would not have been possible. The Department took responsibility for leasing the meeting site, making travel arrangements for the participants, handling reimbursement, and the scores of tasks necessary to manage an international meeting.

Input from the Canadian Forest Service was invaluable. Thanks to the initiative of Gordon Murray, Tom Neiman, and Kurt Johnsen of the Canadian Forest Service, consultation was ongoing from the beginning of the planning process. We benefitted from the ideas that they raised during their planning for the Workshop on Boreal Forest Genetic Resources. The Workshop on Boreal Forest Genetic Resources took place in Toronto the week after this workshop.

The outcome of the workshop largely met our objectives. The workshop participants proposed and developed a set of recommendations that were then accepted by consensus. The recommendations were sent to the participants for review, and then transmitted to FAO for consideration in formulating the Global Plan of Action for Plant Genetic Resources. The specific recommmendations are listed in a separate section following the Executive Summary, and each appears individually in the body of the report so the reader can better appreciate its context.

This report also provides detail on the status of North American temperate forest genetic resources as plantation exotics outside North America. Our methods in gathering and summarizing data on the status of North American species are described in the Report Methodology section. While a wealth of information was provided by the workshop participants and survey respondents, the text of this report is largely our own, with the exception of the recommendations. It is not a proceedings of the workshop. We assume sole responsibility for errors in fact, omission, or misinterpretation.

Deborah L. Rogers and F. Thomas Ledig

Acknowledgements

A report of this size and scope has understandably drawn on the resources of many individuals. The workshop participants who developed the recommendations listed in this report and provided other information are gratefully acknowledged. Not only did they give freely of their ideas and enthusiasm during the workshop, but many participated in the workshop with support from their agencies or companies.

We heartily thank those individuals who made special contributions. Kenneth G. Eldridge and Rowland D. Burdon deserve special recognition for their multiple contributions as participants in the workshop, respondents to the questionnaire, authors of several case studies, and reviewers of the report. Calvin F. Bey, Patrick E. McGuire, Christel Palmberg-Lerche, and Oudara K. Souvannavong reviewed the entire report and made substantial improvements in its clarity and quality. Certain sections of the report received the constructive attention of W. Thomas Adams, Calvin O. Qualset, Peter J. Kanowski, Robert C. Kellison, J. Jesús Vargas Hernández, Nicholas C. Wheeler, and Alvin D. Yanchuk. Many other individuals contributed to the report with case studies and with questionnaire responses. Authors of the case studies are acknowledged in the boxes scattered throughout the report. Respondents to the questionnaires are acknowledged in Appendices A and B. We gratefully acknowledge the information provided by David B. Boomsma, José Luis Campo Diaz, Erich Haber, Shirley M. Sheppard, Gilles Villeneuve, and many others.

Executive summary

This report describes the status of North American temperate forest genetic resources, including their condition as exotic plantation species, and provides recommendations for their conservation. A workshop was convened in Berkeley, California from June 12–14, 1995 to address the problems and issues concerning the conservation of these resources. Participants in the workshop proposed and reached consensus on a series of 12 recommendations, which were subsequently submitted to FAO to assist in the formulation of the Global Plan of Action for Plant Genetic Resources. In addition, information concerning the status of these genetic resources was garnered from responses to a survey of individuals in Canada, México, and the United States, where these resources are native, and of others in countries where they are used as exotic plantation species. The responses to those surveys form the bulk of this report. The report also includes case histories relevant to the discussion of conservation of North American temperate forest genetic resources.

Central to any and all issues concerning conservation of genetic resources in North American temperate forest tree species is the lack of a comprehensive information base. Basic information such as species distributions, changes in distribution or health over time, effect of management practices, location and nature of *ex situ* and *in situ* reserves, etc. is not readily available. In some cases, the information simply does not exist, but more commonly it is not retrievable due to the diversity of land ownership and management agencies. Thus, the development of a comprehensive information base is one of the most compelling needs in conservation as it can serve to identify concerns and contribute to coordinated conservation efforts.

While forestry and agriculture have some common ground, conservation strategies for forest tree species generally will not follow agricultural models because:

- Even partially domesticated forest tree species are less differentiated from progenitor populations than are agricultural crops, whose ancestors are often lost in prehistory;
- Forest trees have values other than commodity values (e.g., ecosystem and esthetic values), in contrast to most agricultural crops;
- The long cycle between harvests in forest tree species (especially relative to annual crops) precludes all but exceptionally profitable investments in cultivation and protection;
- Most North American forest tree species with commercial value are managed and harvested *in situ* and regenerate naturally, whereas the agri-

cultural model is one of intensive *ex situ* cultivation and conservation;

- The domestication process for forest tree species began with the evaluation of genetic resources, whereas agriculturalists began the process with collection, distribution, and storage of resources.

As a result of these factors, conservation of forest tree species will rely heavily on *in situ* methods, and because evaluation of the genetic resources is well advanced, *ex situ* conservation in forestry can be practiced at a more economical scale than is customary in agriculture.

It is noteworthy that the existing reserves for North American forest tree species are almost exclusively defined on criteria other than genetic values. Furthermore, reserves follow land ownership and development patterns, leaving certain species more vulnerable than others. For example, the greater proportion of federally managed land in the United States is in the West, which means that there are more reserves for western species than for eastern.

Currently threatened or endangered tree species in Canada or the United States are few, six and seven, respectively. In general, species with commercial value in Canada and the United States have adequate genetic resources—in reserves, genebanks, or plantations. For these two countries, the concern is for the erosion and potential loss of populations—populations that may harbor valuable genetic resources. For example, some populations may be affected by loss and fragmentation of habitat; e.g., black walnut (*Juglans nigra*). Some species have been severely affected by introduced pests; among these are American chestnut (*Castanea dentata*) attacked by chestnut blight (*Endothia parasitica*), Port-Orford-Cedar (*Chamaecyparis lawsoniana*) attacked by *Phytophthora lateralis*, butternut (*Juglans cinerea*) affected by butternut canker (*Sirococcus clavigignenti-juglandacearum*), and western white pine (*Pinus monticola*) and sugar pine (*Pinus lambertiana*), both attacked by white pine blister rust (*Cronartium ribicola*).

Of the three countries that coexist in North America, México is the richest in species diversity. The United States and Canada together have about 650 tree species (Little 1979) while México has about 2,000 to 3,000. México is a center of diversity for pines, being home to over half the world's species. Unfortunately, an estimated 17% of Mexican plant species is considered endangered. In México, loss of habitat through deforestation is affecting the range of many species including Gregg pine (*Pinus greggii)*, Mexican weeping pine (*Pinus patula)*, Maximino pine (*Pinus maximinoi*), Chihuahua pine (*Pinus leiophylla)*, and Chiapas pine (*Pinus chiapensis*).

No systematic, coordinated national programs now exist for *in situ* or *ex situ* conservation of forest genetic resources in North America. Coordination of information and development of conservation plans at the national level is needed in Canada, México, and the United States. National-level plans and coordination should be used to ensure that species and supporting ecosystems are addressed in a comprehensive manner. For many species, international coordination is desirable. This does **not** imply top-down delivery of conservation policy (much of the forest land is not owned or managed by the federal government in these countries, especially in Canada and México), nor does it imply one model for conservation—the most appropriate models will vary according to local biological and social environments.

Effective conservation requires solutions acceptable to all stakeholders: landowners, government, environmental organizations, forest industry, the scientific community, and the public. Penalties and regulations regarding conservation of genetic resources on private land could possibly accelerate their loss. Education, recognition, and compensation to landowners who lose the value/use of their land to conservation are required for effective and long-term conservation of genetic resources.

At least 25 North American forest tree species are valued as plantation species in other countries. A minimum estimate of the total area they cover as exotic plantation species is over 15 million hectares. Some species, such as Douglas-fir (*Pseudotsuga menziesii*), are highly valued for commercial purposes both domestically and in other countries. Other North American species have a higher economic status as exotics on other continents than they do in their native range. For example, Monterey pine (*Pinus radiata*) is currently planted in plantations covering close to four million hectares outside of North America. The commercial value of this species, in countries such as Australia, New Zealand, and Chile, is immense. Yet the species is not valued for timber or fiber in North America, where native populations are managed for aesthetic value if they are managed at all. Members of the global community hope that species such as Monterey pine will be conserved *in situ* because it may be necessary to draw upon these genetic resources in the future.

International transfer of germplasm is beneficial, not only for commercial purposes, but for conservation. Plantations of North American species on other continents are themselves a mechanism for *ex situ* conservation of genetic resources. However, transfer of germplasm is fraught with the danger of introducing new pests.

After considering the problems and potentials for conserving North American temperate forest genetic resources, the workshop participants made twelve recommendations that were adopted by consensus in plenary session. It is recognized that many of the recommendations presented below extrapolate easily to regions outside the North American temperate zone.

Recommendations of the workshop

Workshop on North American Temperate Forest Genetic Resources, June 12–14, 1995, Berkeley, California

The following is a list of consensus recommendations developed by the participants in the Workshop on North American Temperate Forest Genetic Resources.

1. We **recommend** the development of national programs to address issues in the conservation of forest genetic resources. Due to the complexity of land ownership patterns and land management objectives within and among Canada, México, and the United States of America, coordination on the national level is necessary. All of those directly involved with forest land ownership and/or management should be actively involved with the national program—contributing to databases, participating in conservation planning, and implementing action plans for conservation of forest genetic resources. These programs should include the exploration, inventory, documentation, and monitoring of forest genetic resources, both *in situ* and *ex situ*. Both exotic forest tree species growing in North America and native North American species growing elsewhere should be considered in national programs. Furthermore, because species cross national borders, coordination and cooperation among nations will be required.

2. We **recommend** that conservation of forest genetic resources be addressed by multiple approaches, and that, whenever possible, they should include ecosystem reserves. We recognize, that for noncommercial species, ecosystem reserves may be the only economically practical method of conservation. We recognize that while biotechnology can be useful in many ways, it is not a substitute for an adequately funded, field-oriented genetic conservation program.

3. Recognizing that many North American temperate forest tree species are important plantation species on this and other continents, and that it may be necessary to draw upon these forest genetic resources in the future, we **recommend** that Canada, México, and the United States conserve these resources *in situ*. We assume that other countries outside North America will reciprocate with regard to their native genetic resources.

4. We **recommend** an increase in funding for research on conservation of forest genetic resources. This research should involve, when appropriate, interdisciplinary, interagency, and international collaboration.

Some (nonprioritized) examples of research needs are:

- Exploration and inventory of species' distributions and patterns of spatial genetic structure within species;
- Development of more efficient methods of evaluating genetic variation for adaptive traits;
- Evaluation of the relative utility of various types of genetic data in the development of sampling strategies for conservation;
- Analysis of the impacts of sociopolitical structures on the effectiveness of programs for the conservation of genetic resources;
- Analysis of factors influencing population viability;
- Analysis of the effects of habitat fragmentation, forest management practices, and environmental change on genetic resources.

5. Recognizing the high level of species and genetic diversity in México and the extreme lack of information on this resource, we **recommend** that research on Mexican tree species should receive special attention.

6. Recognizing that forest management practices may have positive or negative impacts on genetic diversity and population viability and, in fact, that some form of management will be necessary to maintain genetic resources, we **recommend** a research emphasis on the consequences of forest management practices. We encourage the use of reference populations within long-term ecological research sites, 'model forests', and research natural areas for studies on the effects of forest management.

7. We **recommend** that the FAO encourage the development of a centralized metadatabase of genetic resources. We see this as composed of local databases, coordinated through a network and designed to facilitate exchange within the international community.

8. We **recommend** that member countries request FAO, through their Regional Forestry Commissions, to promote and coordinate national forest genetic resource conservation programs, and their integration into forestry practices.

9. Recognizing that private-sector owners and managers play an important role in *in situ* conservation of forest genetic resources, we **recommend** that the FAO and conservation agencies explore a range of incentives and agreements (e.g., tax incentives, easements, and land trusts) to foster conservation of forest genetic resources by the private sector.

10. Recognizing that effective genetic conservation programs are very long term in nature, we **recommend** that the FAO encourage and assist in the education of natural resource professionals and the lay public to foster a conservation ethic.

11. Recognizing that species introductions affect native ecosystems and local cultures and economies, we **recommend** the development of guidelines for the introduction of species. These guidelines should include general procedures for conducting risk analyses for biological, social, and economic factors as well as general procedures for monitoring the species after introduction.

12. Recognizing the importance of the Convention on Biological Diversity, the benefits of unrestricted exchange of germplasm, and the distinction between forest genetic resources and those of domesticated crops, we **recommend** that the forest genetic community provide leadership in addressing the emerging issues of intellectual property rights, indigenous peoples' rights, and plant breeders' rights as they pertain to forest genetic resources.

North American temperate forests

F. Thomas Ledig

North American temperate zone

In trying to place bounds on the temperate forests, we could simply say that they occupy the area between the boreal forest and the tropical forest. However, it is not a simple matter to place limits on those plant associations either. Based on the Holdridge life zone system, the boreal zone lies north of an isotherm of 6°C mean annual temperature (Holdridge 1947). We took the limits of the boreal forest as given by Elliott-Fisk (1988): the southern limit approximates the 18°C July isotherm in eastern and central Canada, but is shifted to cooler, moister climates to the west. Latitude is a poor delimiter; in British Columbia, Canada, temperate and boreal forests intermingle because of the complex topography. Some species typical of the boreal forest, such as white spruce (*Picea glauca* (Moench.) Voss.), lodgepole pine (*Pinus contorta* Dougl.), and quaking aspen (*Populus tremuloides* Michx.) are also components of temperate forest associations, such as the Rocky Mountain forest.

A boundary between tropical or subtropical forests and temperate forests is even more difficult to draw than a northern boundary between boreal and temperate forest. Based on Holdridge life zones, the bounding isotherm would be about 18°C mean annual temperature. The astronomical divide between the temperate zone and the tropics, the Tropic of Cancer, is at 23°30' N latitude, but in Durango, México, spruce species—a genus characteristic of the boreal forests—occur south of the Tropic. Most of highland México is temperate, but subtropical forest extends far north of the Tropic of Cancer in Veracruz (Hartshorn 1988). One set of possible boundaries for the temperate forest is shown in Figure 1.

In the final analysis, the definition of boundaries for temperate forests seemed unimportant. The workshop participants entered discussions with the realization that hard and fast lines were not always possible between temperate, boreal, and tropical forests. In fact, much of the discussion was conducted without regard for the temperate forest boundaries. The discussions and the recommendations that emerged from the discussions often seemed broad enough to encompass boreal, temperate, or tropical species. We recognize that there are many similarities in management of tree species across the three major forest zones, and that genetic resource conservation practices have common themes across forest zones. However, the species most prevalent and most studied and, therefore, those that subconsciously guide our thinking, are monoecious and wind pollinated.

North American forest genetic resources

North America is a continent rich in climatic and topographic diversity and, therefore, rich in biological resources. The genetic resources in North American forests are the basis for plantation forestry in much of the rest of the world. Sitka spruce (*Picea sitchensis* (Bong.) Carr.), loblolly pine (*Pinus taeda* L.), Monterey pine (*Pinus radiata* D. Don.), and oocarpa pine (*Pinus oocarpa* Schiede) are planted on millions of hectares in Africa, Asia, Australia, Europe, and South America (Figure 2).

Of the three countries that coexist in North America, México is the richest in species diversity. The United States and Canada together have about 650 tree species (Little 1979) while México has about 2,000 to 3,000 (J. Rzedowski personal communication, 1989). Of a total 22,000 plant species in México, 11,000 are endemic, and certainly more will be discovered. México's many taxa represent a wealth of genetic diversity. One of México's gifts to the world is maize, of course, but another is pine. México is a center of diversity for pines, being home to about half the world's pine species. Of the (approximately) 50 pine species native to México, 17% are considered endangered (see "Status of Temperate Forest Tree Genetic Resources in North America—México", below).

The gravest danger to the forest resource may be the loss of populations and genetic resources within species—called the "secret extinctions" (Ledig 1993). Loss of forest genetic resources occurs largely as a result of conversion of forest land to other uses, primarily grazing and agriculture. The situation is worst in México. Deforestation in México is proceeding at a rapid rate; conservatively, about 0.65% (over 165,000

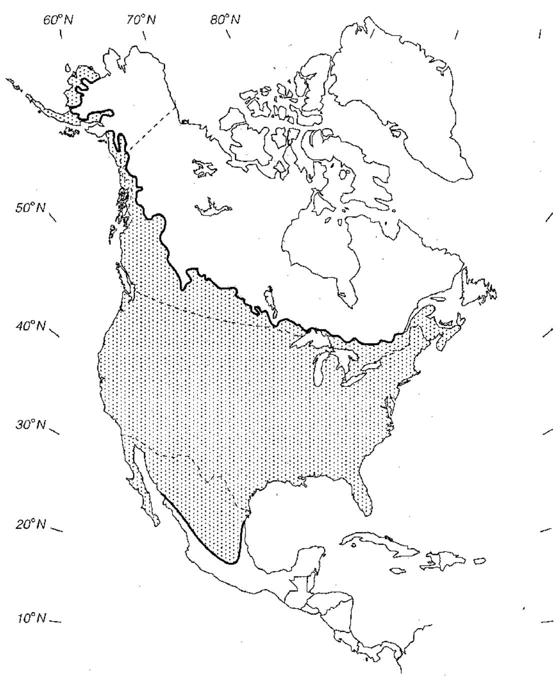

Figure 1. The temperate zone of North America as defined by the boundaries of the boreal forest in the north (after Elliot-Fisk 1988) and the subtropical and tropical forest in the south (after Hartshorn 1988). However, islands of temperate forest occur on high peaks as far south as the Central American republics.

Figure 2. A plantation of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in Scotland. Sitka spruce is a North American temperate species extensively planted in Europe.

ha) of the temperate forest area is converted annually (Cairns et al. 1995; Anonymous 1992). Conversion results in the elimination of local populations with, perhaps, unique genetic resources.

It is imperative that national leaders understand that a species, like ponderosa pine (*Pinus ponderosa* Laws.) or oocarpa pine, is not one, homogeneous population. A wide-ranging species is usually a collection of genetically distinct populations. Local populations are adapted to their environment, and if those populations were extirpated, or replaced with stock of nonlocal origin, forest productivity would be reduced. For example, if ponderosa pine sites at 825 m elevation in the Sierra Nevada of California had to be replanted with seed from 600 m lower in elevation, the reduction in volume at 50 years of age would be about 5% (see Figure 3). If replanted with seed from 600 m higher in elevation, the reduction would be about 20%. We find similar relationships for planting sites at other elevations. Thus, local genetic resources contribute to forest productivity which, of course, is a basic economic value, and if those resources were lost, it might be difficult or impossible to replace them.

The genetic diversity within individual populations serves other biological and potentially commercial purposes. This diversity provides some evolutionary flexibility, allowing species to respond to changes in the environment such as 'climate change'. Individual populations may be the source of specific adaptations such as resistance to particular diseases or insects, tolerance to certain soil conditions, or other attributes that may be of current or future value in domestic forest tree breeding programs.

Concern for genetic resources in North America should include forest species that we now do not consider as commercial species, because we may discover new uses for them in the future. Pacific yew (*Taxus brevifolia* Nutt.) was valueless ten years ago (see Box 1). But then taxol from bark extracts was found to be highly effective against cancer in tests conducted by the U.S. National Cancer Institute (Douros and Suffness 1980). In a matter of years, yew became so highly sought that conservationists were concerned it would be eliminated from forests in the Pacific Northwest.

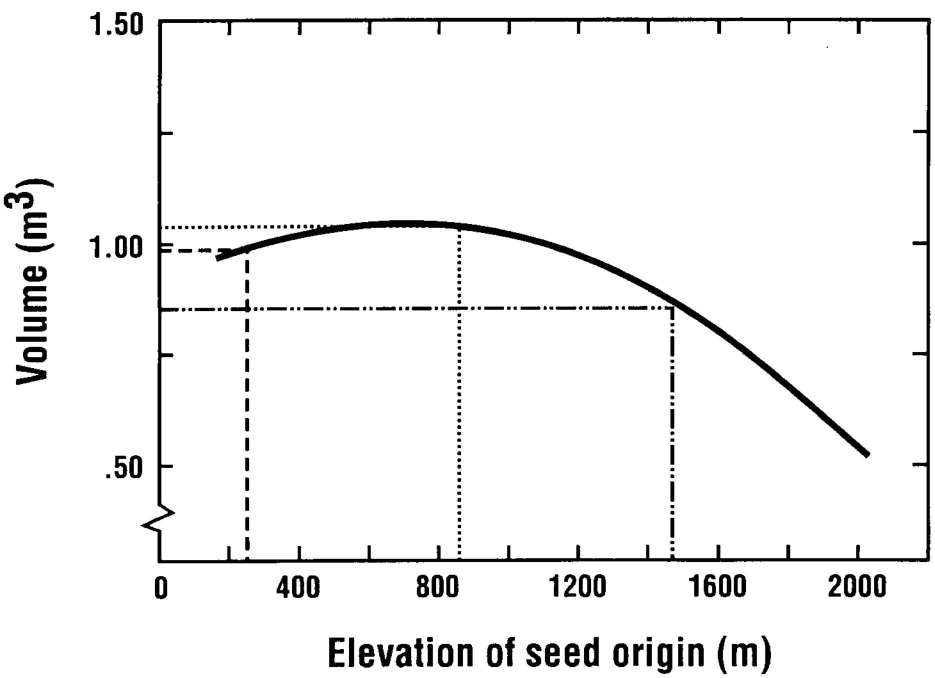

Figure 3. Fifty-year, per tree volume of ponderosa pine (*Pinus ponderosa* Laws.) as a function of elevation of the seed origin. Results are for a plantation at 825 m elevation and mean latitude 39°N in the Sierra Nevada of California. The central set of coordinates represents use of the local seed; the set on the left shows that a 5% reduction in volume is expected if seed originates from 600 m lower in elevation than the planting site; the set on the right shows that a 20% reduction in volume is expected if seed originates from 600 m higher in elevation. (M.T. Conkle, unpublished data).

Box 1
The Pacific yew: Minor species or cancer remedy?

The argument has often been made that biodiversity of our native ecosystems should be conserved to ensure that as-yet-undiscovered but potentially useful plant products are not lost to society. Although such discoveries are relatively infrequent, an outstanding example is that of the Pacific yew (*Taxus brevifolia* Nutt.).

The Pacific yew is a small, long-lived, shade-tolerant, dioecious gymnosperm native to the western United States and Canada. Though the species is widespread geographically, from coastal southeastern Alaska to northern California and as far east as western Montana, it occurs rather sporadically in that range. In the intensively managed, low-elevation forests of the Pacific Northwest, the yew has no doubt diminished in abundance because of its perceived lack of timber value and consequent neglect as the focus of reforestation efforts over the last 100 years.

In the 1960s, tissues of Pacific yew were discovered to contain an active ingredient that arrested cell division in cancerous cell lines. By the late 1980s, the Pacific yew had become the focus of considerable attention by medical and forest management communities because it was identified as the primary source of the compound taxol, a potent chemotherapeutic agent.

For a brief time, the discovery of taxol was feared to be detrimental to the viability of the species because there was a rush to obtain bark for clinical use. This led to the death of a large number of trees that were harvested for their bark alone. However, the discovery may ultimately be viewed as the milestone that galvanized a remarkable series of activities resulting in significant long-term protection for the species. Government agencies instigated immediate harvest and management protocols that limited access on national forests and BLM (Bureau of Land Management) lands. Universities and private companies sought to better understand the genetic diversity of this and related species, to aid in its management and to develop domesticated sources of taxol, cultivated outside the natural forests.

Today, less than five years after Taxol® was approved as a clinical drug, relatively small amounts of the compound are derived from Pacific yew. The majority is derived from a conversion of a related compound taken from domesticated, ornamental yews (semisynthesis). While the Pacific yew remains a minor species in the Pacific Northwest forests, it will no longer be viewed as an inconsequential component of the ecosystem. Furthermore, as a result of the attention given to this minor species, regional land managers appear to have a much deeper appreciation of the need to intelligently manage diversity.

Nicholas C. Wheeler

Agricultural models and forestry practice

F. Thomas Ledig

Much of forestry practice is simple exploitation of the resource, much as pre-agricultural, hunter-gatherer societies utilized native plants (Figure 4). Commercial timber species are often used as they are found, and natural reproduction is relied upon to regenerate the forest. Because much of forestry still depends on wild plants growing in naturally regenerated stands, the management of wild species is an aspect of conservation unique to forestry. In agriculture, once species were domesticated, agriculturists usurped the habitat of their wild progenitors by cultivation and displaced the native vegetation. This may often have had the effect of driving the progenitors of the domesticated crop to extinction. That seems to be the case with maize in México (Mangelsdorf et al. 1964).

The origin of most major agricultural crop species is lost in prehistory. As a consequence, *in situ* conservation of crop species is hardly ever considered by agriculturists, and they have rarely used *in situ* methods even for wild relatives of their domesticated crops. An exception is the new World Bank project in Turkey to protect wild relatives of crop species and forest trees in a system of *in situ* reserves (see Box 2). In forestry, virtually every important commercial tree species, with rare exceptions such as island endemics like Mauritius ebony (*Diospyros hemiteles* L.), can still be conserved *in situ* (Ledig 1992).

The agricultural model of conservation is one of *ex situ* conservation in huge seedbanks and in field plantations, especially for clonally propagated species and those having recalcitrant seeds. The number of wheat accessions in seedbanks alone is immense, 46,000 in the U.S. National Seed Storage Laboratory (Chang 1989). More recently, clonal archives *in vivo* or in *in vitro* tissue cultures maintained under slow-growth conditions have become a useful mode of conservation (Chavez et al. 1988).

Conversely, *ex situ* conservation is not usually as critical in forestry as it is in agriculture, nor need it be. In forestry, *ex situ* conservation can be considered a back-up, or insurance policy, to guard against the loss of especially critical or threatened populations. The main threat to forest species in North America is from deforestation that results from conversion of forest land to agricultural uses, primarily grazing, as in México. With the advent of widespread use of improved lines of commercial forest species, which is probably conceivable only in the southeastern United States or some parts of the Pacific Northwest, some *ex situ* conservation practices will be needed.

Genetic resource management of agricultural crop plants is divided into eight components: collection, documentation, characterization, storage, evaluation, multiplication, distribution, and utilization. The list fits the forestry situation poorly. In forestry, the process of genetic resource management began with evaluation (Keiding and Graudal 1989).

In agriculture, conservation followed transport and diversification of crop plants. The process of adaptation to new environments that followed human transport and the deliberate efforts of breeders over millennia to modify crop plants to human advantage resulted in a tremendous genetic radiation. For example, broccoli, Brussels sprout, cauliflower, collards, kale, kohlrabi, marrow-stem kale, and the savoy, leafy, and heading cabbages have all been selected from the single species *Brassica oleracea* L. introduced into cultivation 8,000 years ago (Janick et al. 1969). Within each of these crops, numerous cultivars have been developed. Bread wheats (*Triticum aestivum* L.) have diverged into countless varieties of hard, soft, winter, spring, red, and white wheats, and maize (*Zea mays* L.) into flour, dent, sweet, and popcorn types.

Evaluation of the genetic resource should be an important component of any conservation program. Because no accurate record of origin exists, genebanks for major crop species undoubtedly contain many essentially redundant accessions. The National Seed Storage Laboratory in Fort Collins, Colorado has over 46,000 accessions of wheat alone; the Vavilov Institute in Russia has 63,000; and the International Rice Research Institute in the Philippines has 83,000 accessions of rice (Chang 1989). Sampling the collections for evaluation is a daunting task. If the need arises to locate resistance genes for a new pest, screening (i.e., evaluating) these huge collections is a major problem (Spagnoletti Zeuli and Qualset 1993). Forestry has followed a different model.

Conservation efforts in forestry, in contrast to agriculture, began with the process of evaluation as forestry moved from the strictly exploitive to the early stages of domestication. That is, as tree planting began to supplement natural regeneration of forests in some areas, foresters began to plant provenance tests to determine appropriate seed sources for local planting (see Box 3). Because patterns of variation in naturally regenerated forests largely reflected underlying climatic variation, trends were often clinal and it was possible to interpolate between the provenances under test. Therefore, in most major commercial timber species, evaluation is well underway, and foresters are only now feeling the need to move into more formal conservation activities such as collection and storage of germplasm.

Figure 4. Mechanical felling of loblolly pine *(Pinus taeda* L.) forest in Florida, U.S.A. In the last century, natural stands of many tree species were harvested without regard to regeneration, and treated like other exploitive resources (e.g., oil, gold). At present, loblolly pine either is replanted after harvest or appropriate silvicultural methods are used to favor natural regeneration, treating it like a sustainable resource.

The genetic resources for forest tree species have a different geographic pattern than do crop plant resources. While the genetic resources for most crop plants are concentrated in centers of diversity in warm temperate areas, genetic resources for forest tree species are globally distributed, spanning the range from tropical to temperate to boreal regions. Furthermore, the genetic resources for forest tree species are still abundant, for the most part, on publicly owned land,

Box 2
Global Environment Facility supports *in situ* conservation of forest trees and wild crop relatives in a pilot project in Turkey

Turkey is a major center of biological and cultural diversity and it is highly appropriate that the country was chosen for the development of a pilot project of the Global Environment Facility (GEF). The project targets habitats which contain concentrations of biological resources of great importance for human use and for the maintenance of biological diversity. As a pilot project, it promises to show how complex conservation activities can be managed and will generate new information about biodiversity. The project is unique in addressing conservation of both forest and wild crop genetic resources in their native habitats. Turkey is the center of origin for many woody and bulbous species that are exploited by extractive harvests. The country has the most northern extension of the formerly great forests dominated by cedars of Lebanon (*Cedrus libani* A. Rich.) and harbors many plants of known or potential medicinal values. Its flora of wild crop relatives is truly amazing, including woody-horticulture progenitors of apple, plum, almond, pear, walnut, pistachio, chestnut, and others. Understory species in forest lands include wild relatives of numerous important world crop plants, including barley, wheat, chickpea, and lentil and many forage grasses and legumes.

The GEF project is funded for three years with the World Bank providing $5,500,000. The end date is March, 1997 which will be marked by an international conference in southern Turkey on *in situ* conservation. Ministries of the Government of Turkey are providing personnel and facilities to the project. Three areas were selected for study: 1) the Kazdagi National Park in the Aegean region of northwestern Turkey, a mountainous area containing many forest species and crop relatives; 2) the Amanos Mountains in southcentral Turkey which is the confluence of Euro-Siberian, Mediterranean, and Irano-Turanian flora and the northern extremity of the Fertile Crescent; and 3) the Ceylanpinar State Farm, a 1.69 million ha facility in southeastern Turkey which includes many annual crop relatives in its 48,000 ha of rangelands and in borders of cropped lands. Three ministries participate in the project, including the Ministry of Agriculture and Rural Affairs (MARA), the Ministry of Forestry (MOF), and the Ministry of Environment (MOE). MARA has overall management responsibility and conducts the work on agricultural crop plant relatives, MOF handles forestry, and MOE is involved in drafting a national plan for biodiversity conservation and public awareness.

The project has a strong element of human resources development through on-site training, short-courses, and external training. Funds are provided for institutional development, including laboratories and equipment. The first goal of the project was to undertake biological surveys in the targeted areas, using traditional inventory methods linked to geographical information systems. A major activity of the project is the development, from the survey data, of gene management zones (GMZs). These will be defined for the array of selected plant species and each will have its own management plan designed to maintain the natural genetic composition of the protected species. Each GMZ will have a scientific and technical team from the various government agencies responsible for carrying out the conservation activities on site. These initial GMZs will become the basis for a nationwide program to be initiated in the near future for a much broader *in situ* conservation of wild plants. Thus, this project has potential for great impact on conservation of Turkey's rich heritage of biological resources and will serve as a model for other countries. It is, perhaps, the first example of the comprehensive use of *in situ* resources for conservation of agricultural crop plants and their wild relatives.

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while the habitat of the wild relatives of crop plants has been largely eliminated by agriculture and urbanization.

Another way in which forestry differs from agriculture is in the inherent variation of tree species relative to annual crop species. In agriculture, cultivars have been bred for specific traits, soils, climates, and cultural regimes, and that has resulted in narrow genetic bases within cultivars or strains (U.S. Committee on Genetic Vulnerability of Major Crops 1972). Forest tree species have been relatively little influenced by selection of this sort, and genetic variation within populations is usually high. In fact, variation within populations of tree species is, on average, much higher than that in annual plants, even wild annuals (Hamrick and Godt 1990). One reason for greater within-population variation in forest species may be that trees are predominantly outcrossing (Schemske and Lande 1985) while many annuals are selfing. Another reason may be that trees must endure fluctuating environ-

Box 3
Evaluation of genetic resources in forestry

Even before Darwin had formulated his theory of natural selection, and while the typological concept of species still reigned, foresters knew that tree species graded into series of races that differed for economic characteristics, such as bole straightness. In 1759 the Royal Swedish Admiralty issued a communiqué about oak, which said that the farther north that acorns could be collected, the better would be the shape of the tree (Langlet 1971).

The earliest record of tests to evaluate a species' genetic resources are for Scots pine (*Pinus sylvestris* L.), a highly variable species with a wide range. Between 1745 and 1755, H.L Duhamel du Monceau grew plants from seeds from several regions in Europe together in France. In the next century, Pierre Philippe André de Vilmorin assembled a seed collection from several geographic areas and, beginning in the 1820s, planted them side by side on his estate at Les Barres in the Loire Valley. This experimental approach is the classic 'common garden' (or 'uniform garden') test used in all field evaluations of crop cultivars. Some of de Vilmorin's trees can still be seen in the Arboretum National des Barres. As the trees matured, it was obvious that the geographic variation observed in the forest was, in part, hereditary; i.e., when grown together, trees from different origins, called provenances, differed in growth rate, straightness, branching habit, and foliage color.

Early in this century, Cieslar (1907) demonstrated differences among seed sources that were much closer in proximity than the widely separated geographic races planted by de Vilmorin. Segments of more-or-less continuous populations of Norway spruce (*Picea abies* (L.) Karst.) drawn from an altitudinal transect in the Tyrol were adapted to their altitudinal zone of origin despite an apparent lack of major barriers to gene flow over the transect. Cieslar's test was a 'reciprocal transplant' study; in this case, replicate experiments with seeds from different elevational zones were planted back across the range at low, middle, and high elevation.

The concept of species as a series of populations adapted by selection to local climate and edaphic conditions was almost fully matured by 1925. The term 'genecology' was coined by Turesson (1923) to signify the study of racial variation resulting from the hereditary response of the population to the environment. In the United States, several evaluation trials (now called seed source or provenance tests) were established in the decades of the 1920s and 1930s. One of these (Wakeley 1944) convincingly demonstrated the loss of forest productivity that could accompany use of the wrong seed source in plantation forestry. Wakeley planted four provenances of loblolly pine (*Pinus taeda* L.) in Louisiana in 1926 and harvested part of the test in a thinning in 1948 (Figure 5; Wakeley and Bercaw 1965). The dramatic difference among provenances in timber yield was a graphic argument for conservation of local seed sources because provenances from Texas, Georgia, and Arkansas produced much less wood than those from Louisiana.

In California's classic ponderosa pine (*Pinus ponderosa* Laws.) elevational transect study planted in 1938, low-elevation seed sources grew well at the high-elevation planting site for many years (Mirov et al. 1952; also see Ledig and Kitzmiller 1992). They were overtaken by high-elevation sources only after the test had been subjected to a range of climatic conditions over two to three decades. By 29 years of age, low-elevation provenances were best at a low-elevation planting site, mid-elevation provenances were best at mid-elevation, and high-elevation provenances were best at high elevation (Conkle 1973).

The overwhelming result of provenance testing in North American forest tree species has been to demonstrate clinal patterns of variation (making interpolation possible) and the near-optimality of local races.

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Figure 5. Loblolly pine (*Pinus taeda* L.) pulpwood harvested in a thinning from a 22-year-old plantation at Bogalusa, Louisiana, U.S.A. The plantation provided an opportunity to evaluate performance of seed sources from Louisiana (LA), Texas (TEX), Georgia (GA), and Arkansas (ARK). The local, Louisiana seed source (i.e., the seed source closest to the planting site) obviously grew best, a common result in evaluation trials. (Photo from Wakeley and Bercaw 1965.)

mental conditions (and therefore, fluctuating selection pressures) over decades or centuries, which may maintain variability within the population. In addition, tree species may have a higher mutation rate per generation, which generates higher levels of variation than is possible in annuals (Ledig 1986, Klekowski and Godfrey 1989).

Because of the high levels of genetic variation available for selection, forest tree breeders have not given 'wild relatives' as much consideration as have agricultural breeders. The term has a broad range of meaning in forest tree species (see Box 4). Wild relatives could mean noncommercial congeners of commercial timber species; e.g., Table-Mountain pine (*Pinus pungens* Lamb.) could be considered a wild relative of the partially domesticated loblolly pine. Noncommercial tree species may have value for hybridization with commercial species by traditional sexual means, or through other techniques now being explored by biotechnologists. At the current stage of domestication in many forest tree species, noncommercial relatives (i.e., nondomestic, conspecific populations) are perhaps the most meaningful interpretation of wild relatives. Together with populations of noncommercial species of forest trees, they are recognized both as currently or potentially valuable, and yet are vulnerable to loss because they are not represented in breeders' collections.

The longevity of forest trees, especially as it determines the long rotation (i.e., interval between harvests), is significantly different from any situation in agriculture, even in orchard species such as apples (*Malus* spp.). Simple economics makes it very difficult to practice forestry on the level of intensity customary to agriculture. The necessity of compounding interest over a rotation of 20 or more years before any return is realized makes all but the most profitable investment impossible. Therefore, foresters are usually unable to provide the intensive inputs in cultivation, fertilization, and irrigation that are standard in agriculture. Foresters rely on genetic diversity within stands rather than cultural practices to buffer against environmental heterogeneity.

Perhaps, the most important way in which forestry differs from the agricultural model is in the 'slippery' or noncommodity values of forests. The noncom-

Box 4
The concept of 'wild relatives' as applied to temperate forest tree species

The concept of 'wild relatives' has its origin in agriculture, referring to the undomesticated conspecific or congeneric populations of modern crop plants. The application of the concept to forestry was addressed in workshop discussions, from which this text is extracted. Because of both the longer breeding cycles of forest tree species relative to agricultural crop species, and the shorter period of domestication of the former relative to the latter, domesticated forest trees are less differentiated from their progenitor populations than is the case in agriculture. Therefore, wild relatives have not attracted the same interest as in agriculture. If this concept is to be applied to forest tree species, it could provisionally be used in the following hierarchical sense:

1. Related species—this concept of wild relatives, although not a common term in forest biology or forest tree breeding, would most logically include undomesticated species that were congeneric to domesticated species;
2. Wild populations—populations from natural regeneration that have not been in any way incorporated into domestication programs. An example from forest tree species might be an unimproved, natural population of loblolly pine (*Pinus taeda* L.).
3. New germplasm from previously sampled wild populations—unsampled trees from populations that have been incorporated into domestication programs. These may be an important arena for natural selection for disease resistance, for example.

As domesticated forest trees are, for the most part, not genetically far-removed from their progenitor populations, wild relatives are a source of both potential opportunities and problems. While providing natural sources of genetic variation, they are also a source of genetic contamination (in seed orchards, for example) that may degrade gains achieved by breeding in domesticated populations. Conversely, domesticated populations, in plantations, for example, may affect the genetic diversity of natural populations (e.g., by vegetative spread into natural populations or gene flow by seed or pollen if the plantations are not harvested prior to reproductive maturity) (e.g., Millar and Libby 1989).

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modity values of forests may be more critical than the commodity values. Claire G. Williams, one of the workshop participants, was thinking of esthetic values when she noted: "What makes forest tree breeding different from agricultural breeding is that foresters are ambivalent about whether they want to domesticate trees at all or whether they want to save the wild forest." For some segments of the public, particularly in the United States and Canada, esthetic values and recreational use of the forest are inconsistent with harvest and with evenly spaced, cultivated, tree plantations.

Other slippery values are ecologic values. A field of maize is very efficient at carbon dioxide uptake during the months that it occupies the field. However, forest cover is continuous, and on an annual basis, forests are the most efficient vegetational form for offsetting carbon dioxide emissions (Ledig and Linzer 1978). Furthermore, carbon sequestering is immensely more effective in forestry than in agriculture because of the longevity of trees and the relatively permanent products to which they contribute, compared to the relatively rapid turnover (oxidation by metabolism) of agricultural products. Forests and forest cover are more effective at controlling erosion and reducing siltation of streams, reservoirs, and reefs than agricultural crops because forest cover may be disturbed only once every 20 to 100 years or longer, whereas agricultural crops such as forage or pastures persist for 3 to 15 years and most others are cultivated annually or even more frequently. Forests provide habitat for native wildlife, particularly threatened wildlife, whereas agricultural crops are relatively unimportant in this regard. Many other values of forests, ecological and cultural, might be mentioned, and all provide a rationale for conserving forests *in situ*. Foresters, especially those dealing with native forests, are hardly ever able to manage for commodity values alone, in contrast to agronomists.

The practice of forestry, which recognizes the diversity of forest values, suggests that *in situ* conservation will be the dominant strategy for conservation of forest genetic resources, compared to the reliance on *ex situ* conservation that has characterized agriculture. *Ex situ* conservation should be employed in forestry to ensure against loss of genetic resources, especially for species where natural ranges are small and populations are being lost.

The number of accessions needed to backup *in situ* methods of conservation will generally be orders of magnitude less in forestry than in agriculture because forestry has pioneered in provenance evaluation. Seedbanks of agricultural crops include many accessions from the same locality or even the same field. In the absence of prior evaluation, collectors of agricultural crop plants generally feel that more are better than fewer (Chang 1989). By contrast, collectors of forest tree seeds can be quite confident about encompassing the range of available variation in their species by systematically sampling populations based on a long history of provenance testing. Geographic and elevational patterns of variation are known for some forest tree species and can be extrapolated to others that have not been specifically tested.

Report methodology

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Developing a comprehensive description of the status of North American temperate forest tree species requires a variety of approaches. Unlike agricultural plants, forest tree species exist predominantly in natural settings, with varying states of inventory at the species level. In some areas of México, not even species composition is documented. Outside of plantation situations, natural regeneration is more common than artificial regeneration (Figure 6). Furthermore, genetic research on the amount and pattern of genetic variation in natural populations is patchy—resulting in only vague or incomplete descriptions of within-species genetic diversity. Moreover, the diverse array of land ownership for forest tree species, particularly in the United States and México, is a challenge to the provision of comprehensive, comparative data.

In view of this situation, the following approach was adopted as the most promising to document the status of North American forest genetic resources. First, questionnaires were prepared to solicit information on the status of temperate North American forest tree species—both within North America and in those countries where they are grown as exotic plantation species. For the countries where North American forest tree species are exotics, issues addressed were the level of information concerning geographic source of germplasm, amount of genetic diversity within reserves and plantations, investment in research, value of germplasm as breeding stock or wood source, transfer of germplasm internationally, and problems with and threats to these species. The questionnaire on exotic use of North American forest tree species was sent to forest geneticists or plantation managers in 13 countries where these species have a significant presence (Table 1, Appendix A). A comprehensive survey was beyond the scope of this undertaking, and normally there was only one respondent per country. Therefore, the landbase included in the response was not necessarily the entire landbase for each country in which North American temperate forest tree species are managed in plantations (Table 1). Furthermore, not every country in which North American temperate forest tree species are grown was surveyed. Undoubtedly, the results of our survey are an underestimate.

A questionnaire was also sent to several forest land managers and forest geneticists across the United States, Canada, and México to gain some information on the *in situ* status and plantation situation of North American forest tree species. Eleven responses were received from within the United States and one collaborative response from México (Appendix B). The information gained from the questionnaires provided case studies and general trends but is not a comprehen-

Figure 6. Prolific natural regeneration after timber harvest in an Arizona pine (*Pinus arizonica* Engelm.) forest near El Salto, Durango, México.

sive status report.

The second mechanism for gathering input for this report was to provide a forum for discussing conservation issues related to North American temperate forest tree species. A workshop was convened June 12–14, 1995 in Berkeley, California to help in interpreting the questionnaire responses, to provide informed opinions and approximations as proxies for missing information, and to discuss concerns, set priorities, and recommend actions appropriate to the conservation of genetic resources in North American temperate forest tree species. Workshop participants (Appendix C), represented countries of North America where these temperate forest genetic resources exist *in situ*, and countries where these species are important *ex situ* plantation resources.

What follows embraces, but is not limited to, both the responses from the questionnaires and the content of the workshop discussions. Detailed information on various topics is provided in boxes throughout the report. The information in boxes was extracted from questionnaire responses or solicited, often from workshop participants, to illustrate various uses of forest genetic resources, problems in their management, and specific efforts in conservation.

Table 1. Countries and areas within them represented in the questionnaire on the use of North American temperate forest tree species as exotic plantation species

Country	Land represented in questionnaire response
Argentina	All lands on which these species are managed
Australia[1]	All state-owned and private land (there is no federally owned forest land in Australia)
Brazil	All land with North American pines
Chile	All lands on which these species are managed
China	All lands on which these species are managed, both state-owned and collective land
France	All federally owned lands on which these species are managed
Germany	All lands on which these species are managed
Greece	All lands on which the major exotic species are managed (includes both state-owned and private land)
Hungary	All lands on which these species are managed
New Zealand	All lands on which these species are managed
South Africa	All forestry plantations in the country, both public and private ownership
Spain	All plantations with enough surface area to be identified in the Regional Forest Inventories (normally 2 ha)
United Kingdom	State-owned and private lands on which these species are managed in England, Scotland, and Wales

[1]In many of the subsequent tables, Queensland has been reported separately from the rest of Australia due to the availability of specific information for this area.

Status of temperate forest tree genetic resources in North America

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Canada

Canada contains a wealth of forest land, over 416 million hectares. Most of this, 88%, is recognized as falling within the boreal forest zone (Mosseler 1995). However, although only approximately 50 million hectares of the forest land is defined as temperate forest, most of the forest tree species in Canada are represented predominantly or exclusively in the temperate zone. Of the 135 tree species native to Canada, 123 of them are principally tree species of the temperate zone (Mosseler 1995). Most of the temperate zone tree species, over 80%, are angiosperms.

The Canadian section of this report is brief: a relatively small proportion of the forest land is within the temperate zone and most temperate species also occur in the United States, usually for most of their natural range. A separate report on the boreal forest zone of Canada has been prepared to address the status of those genetic resources. It also provides some description of the temperate zone resources (see Mosseler 1995).

Most of the forest land in Canada (ca. 71%) is owned and managed by the provincial governments. However, forests within the temperate zone have a higher percentage of private ownership than that in the country as a whole. The temperate zone in Canada, lying in the southernmost regions, was coincident with early and intense agricultural and urban development. Thus, habitat loss, forest fragmentation, and private land ownership coincide with high species diversity and the occurrence of marginal populations at the northern limits of their range, creating concerns for conservation.

The forest lands in Canada are expansive, and many of the temperate forest tree species are widespread in their distribution. However, land conversion and forest management activities have contributed to the loss of populations of temperate zone gymnosperms, including eastern white pine (*Pinus strobus* L.), red pine (*Pinus resinosa* Ait.), and white spruce, with probable genetic consequences (Mosseler 1995). Angiosperm species, which often have very restricted distributions in the southern regions of Canada, have experienced more severe population declines than gymnosperms, and genetic impacts are even more probable. Examples from the latter group of species are sugar maple (*Acer saccharum* Marsh), American beech (*Fagus grandifolia* Ehrh.), and black walnut (*Juglans nigra* L.).

With the exception of plants found on federal lands (e.g., National Parks), plant species in Canada are under provincial jurisdiction. Several provinces, including Québec, Ontario, and New Brunswick, have legislation that requires the listing and protection of plants that are at risk (Ministère des Ressources Naturelles du Québec 1996, Wallis and Allen 1987). Whether or not statutory protection exists, provincial agencies and nongovernmental organizations routinely take the presence of rare species into consideration in land management decisions; see Wallis and Allen (1987) for examples from Alberta, Canada.

Species 'at risk' in Canada are identified and assigned national status by a committee of representatives from federal, provincial, and private agencies—COSEWIC (Committee on the Status of Endangered Wildlife in Canada). As of 1995, six forest tree species, all of them in the temperate forest zone, had been identified as endangered or threatened, with a further three species identified as 'vulnerable' (Table 2). All of these species, with the exception of Tyrrell's willow (*Salix planifolia* ssp. *tyrrellii* (Raup) Argus), are members of the now highly fractured Carolinian forest of extreme southeastern Canada, mainly southern Ontario (see Box 5). As such, their at-risk status is somewhat related to their marginal natural occurrence, although six of the species listed—blue ash (*Fraxinus quadrangulata* Michx.), cucumber tree (*Magnolia acuminata* L.), American chestnut (*Castanea dentata* (Marsh.) Brokh.), hop tree (*Ptelea trifoliata* L.), dwarf hackberry (*Celtis tenuifolia* Nutt.), and Kentucky coffeetree (*Gymnocladus dioica* (L.) C. Koch)—are also at risk in other parts of their range.

Table 2. Temperate forest trees species in Canada that have been designated at risk (Source: Committee on the Status of Endangered Wildlife in Canada (COSEWIC), Ottawa, Ontario)

Species[1]	Status[2]	Date[3]	Comment
Fraxinus quadrangulata	Threatened	1983	Very small populations. Uncommon outside Canada; *F. quadrangulata* is dioecious and some populations in Canada include trees of only one sex. No significant seedling reproduction.[4]
Morus rubra	Threatened	1987	Only six populations known; only one of these has evident reproduction and success is low. The species hybridizes with introduced *M. alba* and is, therefore, subject to genetic swamping.[5]
Magnolia acuminata	Endangered	1984	Only three populations known; all endangered.[6]
Castanea dentata	Threatened	1987	Although 49 sites are known, most trees have blight cankers and viable seed is produced at only nine sites. Trees are still being lost through cutting and urban expansion.[7]
Ptelea trifoliata	Vulnerable	1984	Very limited distribution. Reproducing populations exist in low numbers.[8]
Quercus shumardii	Vulnerable	1984	Very limited distribution, but is reproducing well.[9]
Gymnocladus dioica	Threatened	1983	Only one sexually reproducing population in Canada; *G. dioica* is dioecious and most Canadian populations contain only male or female trees, not both.[10]
Salix planifolia ssp. *tyrrellii*	Threatened	1981	Subspecies has a restricted and sparse distribution on sand dunes in northern Saskatchewan. Current and projected human activity, accelerated by road construction, threatens its habitat.[11]
Celtis tenuifolia	Vulnerable	1985	Only three populations are known in Canada, all in southern Ontario.[12]

[1]The list includes all woody species. The last two species on the list are often considered to be shrubs.

[2]Endangered—A species facing imminent extirpation or extinction. Threatened—A species likely to become endangered if limiting factors are not reversed. Vulnerable—A species of special concern because of characteristics that make it particularly sensitive to human activities or natural events. It includes any indigenous species of fauna or flora that is particularly at risk because of low or declining numbers, occurrence at the fringe of its range or in restricted areas, or for some other reason, but is not a threatened species. (This category includes species that had previously been designated as rare. The rare designation was abolished by COSEWIC in 1990).

[3]Date that at-risk status was assigned by COSEWIC

[4]Ambrose and Aboud (1983)

[5]Ambrose (1987)

[6]Ambrose and Aboud (1984a)

[7]Ambrose and Aboud (1987)

[8]Ambrose and Aboud (1984b)

[9]Waldron (1984)

[10]Ambrose (1983)

[11]Argus (1981)

[12]Klinkenberg (1985)

Individual populations may receive national at-risk status even if the species as a whole is not at risk in Canada. Any population may be considered for designation when it meets one or both of the following criteria:

- There exists a significant genetic difference between the population and any other population based upon genetic analysis, taxonomic techniques, or other compelling evidence; and/or
- The population is the only representative of a species or subspecies within one of Canada's major biogeographic zones (Erich Haber, COSEWIC, personal communication, October, 1995).

Most forest tree species of the temperate zone in Canada, however, are probably not candidates for national at-risk status in the near future. Aside from the special case of the Carolinian forest species described above, most species reside primarily within provincial or federal ownership, facilitating the organization and implementation of conservation plans as they are developed. Over 90 million hectares of forest land in Canada (over 20% of all forest land) reside in 'protected areas', most of it managed by government agencies, with approximately one million hectares managed by nongovernmental organizations (NAFC 1994). However, it should be noted that, in Canada as in most other countries, protected areas have neither been defined nor managed specifically with genetic values in mind. Further, information on the genetic status and dynamics of most species is inadequate to determine whether they are currently or potentially experiencing significant and/or undesirable genetic impacts.

In addition to research on amounts and patterns of genetic variation in natural populations of forest tree species, considerable effort has been directed towards providing some insight into the effects of forest management practices on the genetic diversity of certain forest tree species. Completed studies have compared levels of genetic variation in natural and domesticated populations of white spruce (Stoehr and El-Kassaby 1996), Sitka spruce (Chaisurisri and El-Kassaby 1994), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) (El-Kassaby and Ritland 1995), and jack pine (*Pinus banksiana* Lamb.) (Knowles 1985).

One of Canada's provinces, British Columbia, has recently proposed a two-part strategy and implementation program for the genetic conservation of 23 of its conifer species (Yanchuk and Lester 1996). None of these species is currently at risk according to COSEWIC guidelines. The process underlying the conservation strategy identifies various factors related to a species' genetic vulnerability—including the extent of its natural range, its natural capacity for regeneration, the status of provenance-testing programs for the species, and the representation of the species in

Box 5
The decline of red mulberry (*Morus rubra* L.) in southern Canada

Red mulberry (*Morus rubra* L.) is an understory forest tree species of eastern North America. At the northern limits of its range it is a rare tree of moist, forested habitats, including floodplains and bottomlands. In Canada, it is confined to the Carolinian Zone, with extant populations known to occur at only six sites. These sites are centered in two regions: 1) between the Niagara Escarpment and the Lake Ontario shore, and 2) in Essex County, Ontario near Lake Erie. Red mulberry is morphologically similar to the introduced Asian white mulberry (*Morus alba* L.), and the latter species is well naturalized throughout the Canadian range of red mulberry. Therefore, the two species have often been confused. Red and white mulberry also appear to hybridize freely.

Although never a common species in Canada, in a few, local populations red mulberrys are significant members of their communities and, while fruiting, provide an abundant mid-summer food source for birds and small mammals. Historically, the inner bark of red mulberry was used by native people to make a coarse thread that was then woven into cloth.

In Canada, the distribution of red mulberry is becoming more restricted, possibly due to the continuing loss of suitable habitats. It no longer occurs in areas of historical collections, and recently could not be relocated in several Niagara Region valleys where it had been observed in the past 20 years.

Hybridization with the introduced white mulberry is evident in many of the extant populations. This hybridization presents a potential threat of undetermined magnitude to the genetic integrity of red mulberry and could result in the loss of red mulberry by genetic assimilation.

Deborah L. Rogers, adapted from Ambrose 1987 breeding programs (Table 3). According to this process, species such as whitebark pine (*Pinus albicaulis* Engelm.) and subalpine larch (*Larix lyallii* Parl.) should receive high priority for conservation efforts, while species such as Douglas-fir and lodgepole pine would not. Context is important for interpreting British Columbia's strategy. For example, jack pine receives a high priority for conservation mainly due to its marginal range and related lack of representation in provenance testing and breeding programs in British Columbia. However, jack pine has a very extensive range and is well represented in *ex situ* reserves and breeding programs across Canada.

In summary, few temperate forest tree species are at risk of extinction in Canada. The few that are in peril are marginal populations of deciduous species in the fragmented Carolinian forests of southern Canada. Many temperate forest tree species have not been sufficiently studied to determine their level of genetic diversity or vulnerability. The dominance of government ownership of forest lands in Canada

Table 3. Gene conservation scores for 23 forest tree species in British Columbia (adapted from Yanchuk and Lester 1996)[1]

Species	Presence[2]	Range[3]	Regeneration[4]	Tests[5]	Breeding[6]	Total
Reserve status 3[7]						
Juniperus scopulorum	2	2	2	3	3	12
Larix laricina	3	2	1	3	3	12
Larix lyallii	3	3	2	3	3	14
Pinus albicaulis	3	2	3	3	3	14
Pinus banksiana	3	3	3	3	3	15
Pinus flexilis+	3	3	?	3	3	12
Reserve status 2						
*Abies amabilis**	2	2	2	2	3	11
Abies grandis	2	3	2	2	3	12
Picea mariana	2	1	1	3	3	10
*Picea sitchensis**	3	2	1	1	1	8
Pinus monticola	2	2	2	2	1	9
Taxus brevifolia+	2	2	?	2	3	9
Tsuga mertensiana	2	2	1	3	3	13
Reserve status 1						
*Abies lasiocarpa**	1	1	2	3	3	10
*Chamaecyparis nootkatensis**	3	2	2	1	1	9
*Larix occidentalis**	2	3	2	1	1	10
*Picea engelmannii**	2	1	2	2	2	9
*Picea glauca**	1	1	2	2	1	7
*Pinus contorta**	1	1	1	1	1	5
*Pinus ponderosa**	2	3	2	2	3	12
*Pseudotsuga menziesii**	1	1	2	1	1	6
*Thuja plicata**	1	1	2	1	1	6
*Tsuga heterophylla**	1	1	1[8]	2	1	6-7

[1]High total scores indicate species with high current priority for conservation efforts within the province of British Columbia. Species of currently high economic value are marked with an asterisk (*). Species with little information regarding their natural regeneration are marked with a '+'. Their total scores are depressed by this missing information and their actual total scores are expected to be somewhat higher.

[2]Presence is an index composed of both the number of biogeographic zones in which the species occurs and its average frequency in each zone: 1 is quite common; 2 is moderately common; and 3 is not common.

[3]Natural range of the species within British Columbia: 1 indicates a large range—over 25% of the province; 2 indicates a moderate range, covering 5 to 25% of the province; and 3 indicates a small range, covering less than 5% of the province.

[4]Capacity of the species for natural regeneration: 1 indicates high potential for natural regeneration; 2 indicates moderate potential for natural regeneration; and 3 indicates infrequent or largely unsuccessful natural regeneration.

[5]Status of provenance testing for the species: 1 indicates that the species is well represented in provenance trials; 2 indicates moderate representation of the species in a provenance testing program; and 3 indicates no or little provenance testing is in progress.

[6]Representation within breeding programs: 1 indicates species which are in comprehensive breeding or selection programs within the province; 2 indicates species with a relatively small breeding program; and 3 indicates little or no breeding or selection activity for the species in British Columbia.

[7]Reserve status refers to the current representation of each species in protected areas—a species well represented in such areas was considered to be at lower risk than a species that is not. Thus, a reserve status of 3 indicates that the species is not sufficiently represented in protected areas, which contributes to a higher priority rating for that species. A species with a reserve status of 1 is currently well represented in protected areas.

[8]Pertaining to natural regeneration in maritime climates.

should facilitate the organization and implementation of conservation strategies as they are developed. British Columbia has recently proposed a conservation strategy for many of its coniferous species. The strategy is an attempt to recognize and correlate life history characteristics and management activities with priority for conservation.

México

México is rich in forest tree species diversity and intraspecific genetic variation. Conditions favoring this diversity include México's breadth of latitude, encompassing temperate, tropical, and subtropical regions; range in elevation; and mosaic of soil conditions. Indeed, nearly half of the 100 extant species of the genus *Pinus* are native to México (Caballero and Bermejo 1994). Some species and populations have become increasingly threatened in recent decades from population growth and economic pressures that involve land conversion, habitat degradation, population fragmentation, and dysgenic selection. However, there is little direct information on the genetic impacts of these pressures on Mexican forest tree species. This combination of a diversity of genetic resources, anthropogenic influences, and paucity of information led to a direct recommendation during the workshop that more support be provided for genetic research on Mexican forest tree species. Sixty gymnosperm and 99 angiosperm tree species and varieties in México were considered rare and endangered in that country (Table 4).

Recognizing the high level of species and genetic diversity in México and the extreme lack of information on this resource, we ***recommend*** *that research on Mexican tree species should receive special attention.* (Rec. no. 5)

The lack of information on temperate forest tree species in México thwarts our efforts to provide a comprehensive description of their genetic status. However, insight into the status of some of the more commercially valuable temperate forest tree species in México is offered below. The temperate forest represents 51% of the base, and the questionnaire response dealt only with that portion. This information pertains mainly to temperate-zone pines, the most economically significant species group in México at present, and refers to all lands in México on which these species are currently managed. As such, there is little information on the state of unmanaged forest lands or areas in which the commercially significant species are largely absent or economically inaccessible.

It must be emphasized that the reported activity for México excludes tropical species, such as Tecun Uman pine (*Pinus tecunumanii* (Schw.) Eguiluz et Perry) and Caribbean pine (*Pinus caribaea* Morelet). Tropical forest land represents 24.1 million ha or almost 49% of the total forest land in México according to 1992 figures released by the Secretaría de Agricultura y Recursos Hidráulicos. The major tropical states of Campeche, Veracruz, and Yucatan submitted reports on the status of their forest genetic resources to FAO. FAO is currently entering those reports into an information system which will be accessible electronically as early as the end of 1996.

Twelve of the thirteen species that are the dominant commercial temperate forest tree species in México are pines (Table 5). Mexican cypress (*Cupressus lindleyi* Klotsch) is the one exception, currently managed in plantations that total over 2,000 ha. In natural areas, there is evidence of fragmentation and reduction in population sizes of several endemic forest species such as spruce species, Gregg pine (*Pinus greggii* Engelm.), Chihuahua pine (*Pinus leiophylla* Schl. et Cham.), Maximino pine (*Pinus maximinoi* H.E. Moore) Chiapas white pine (*Pinus chiapensis* (Mart.) Andresen), Mexican weeping pine (*Pinus patula* Schl. et Cham.), and Apache pine (*Pinus engelmannii* Carr.), and there is too little information about the loss of genetic diversity in these species or populations to draw conclusions.

Fragmentation of habitat seems to be the most serious threat affecting the genetic integrity of Gregg pine, Mexican weeping pine, Maximino pine, etc. The second most severe threat is loss of habitat—particularly for Chihuahua pine, *Pseudotsuga* species, and Chiapas white pine. Other threats to genetic integrity, in increasing order of importance, are pathogens, insects, and selective removal of trees. There are some problems with stem canker in planted Monterey pine and Mexican weeping pine, and bark beetles in other

Table 4. Native species and varieties of trees in México that are considered rare and endangered (Vera 1990)[1]

— Gymnosperms —

Abies concolor (Gard. et Glend.) Lindl. ex Hildebr.	*Pinus culminicola* And. et Beam.
Abies durangensis var. *coahuilensis* (Johnston) Martinez	*Pinus flexilis* James
Abies guatemalensis Rehd.	*Pinus jeffreyi* Grev. et Balf.
Abies hickeli Flous et Gauss.	*Pinus juarezensis* Lanner
Abies mexicana Martinez	*Pinus lambertiana* Dougl.
Abies vejari Martinez	*Pinus maximartinezii* Rzedowski
Abies vejari var. *macrocarpa* Martinez	*Pinus monophylla* Torr. et Frém.
Calocedrus decurrens (Torr.) Florin	*Pinus muricata* D. Don
Ceratozamia mexicana Brogn.	*Pinus pinceana* Gord.
Ceratozamia spp.	*Pinus ponderosa* Laws.
Cupressus benthami Endl.	*Pinus radiata* var. *binata* Lemm.
Cupressus forbesii Jepson	*Pinus reflexa* Engelm.
Cupressus guadalupensis Wats.	*Pinus remorata* Manson
Cupressus lindleyi Klotsch	*Pinus rzedowski* Madrigal et Caballero
Cupressus montana Wiggins	*Pinus strobus* var. *chiapensis* Martinez
Dioon edule Lindl.	*Pinus quadrifolia* Parl. ex Sudw.
Dioon purpusii Rose	*Podocarpus guatemalensis* var. *pinetorum* Bartl.
Dioon spinulosum Dyer.	*Podocarpus matudai* Lund.
Juniperus californica Carr.	*Podocarpus matudai* var. *macrocarpus* Buch.
Juniperus comitana Martinez	*Podocarpus oleifolius* D. Don
Juniperus deppeana var. *pachyphlaea* (Torr.) Martinez	*Pseudotsuga flahaulti* Flous
Juniperus erythrocarpa Cory	*Pseudotsuga guinieri* var. *mediostrobus* Flous
Juniperus gamboana Martinez	*Pseudotsuga macrocarpa* (Vasey) Mayr
Juniperus standleyi Steyermark	*Pseudotsuga macrolepis* Flous
Picea chihuahuana Martinez	*Pseudotsuga rehderi* Flous
Picea mexicana Martinez	*Taxus globosa* Schl.
Pinus attenuata Lemm.	*Zamia cycadifolia* Dyer
Pinus cembroides var. *edulis* Voss	*Zamia furfuracea* L.F.
Pinus contorta var. *latifolia* Engelm.	*Zamia loddigesi* Miq.
Pinus coulteri D. Don	*Zamia spartea* DC.

— Angiosperms —

Acer brachypterum Wooter et Stand.	*Carya ovata* C. Koch
Acer grandidentatum Nutt.	*Cedrela oaxacensis* C.D.C.
Arbutus laurina Mart. et Gal.	*Cedrela occidentalis* Rose
Arbutus peninsularis Rose	*Cedrela odorata* Roem.
Bactris acuminata Liebm. ex Mart.	*Cedrela poblensis* Mir.
Beilschmiedia riparia Mir.	*Cedrela salvadorensis* Stand.
Brosimum costarricanum Liebm.	*Ceiba acuminata* (Wats.) Rose
Brosimum panamensis Stand. et Steyem.	*Ceiba parvifolia* Rose
Brosimum terrabanum Pitt.	*Cercidium sonorae* Johnston
Bursera aloëxylon Engl.	*Chamaedorea lindeliniana* H. Wendl
Byrsonima bucidaefloia Stand.	*Cherrosteman platanoides* Hurrt. et Gonpl.
Calocarpum viride Pittier	*Chrysobalanus icaco* L.
Carpinus caroliniana Walt.	*Cordia elaeagnoides* DC.
Carya myristicceformis (Michx. f.) Nutt.	*Dalbergia cubilquitzensis* Pitt.

Table 4. (continued)	
— Angiosperms (continued) —	
Dalbergia granadillo Stand.	*Ocotea bernoulliana* Mez.
Didymopanax morototoni Planch.	*Olneya tesota* (L.) Gray
Dioscorea convolvulacea Schl. et Cham.	*Orbignya cohune* (Mart.) Dalgr.
Dioscorea floribunda Mart. y Gal.	*Orbignya guacoyule* Liemb. et Mart.
Eugenia fragrans (Swarte) Willd.	*Phoebe effusa* Meissn.
Fagus mexicana Mart.	*Platanus chiapensis* Stand.
Fraxinus berlandierana A. DC.	*Platanus lindeniana* Mart. et Gall.
Fraxinus velutina Torr.	*Platanus oaxacana* St.
Guarea bijuga DC.	*Platymiscium dimorphandra* D. Srm.
Guarea chichon DC.	*Prosopis pubescens* Benth.
Guarea excelsa H.B.K.	*Pseudolmedia spuria* Griseb
Hampea integerrima Schl.	*Pterocarpus acapulcensis* Rose
Hampea tomentosa (Presl) Stand.	*Pterocarpus hayesii* Hemsl.
Hampea trilobata Stand.	*Quararibe funebris* (Llave) St. Quararibea
Inga belicensis Stand.	*Robinsonella mirandai* G. Pompa
Inga laurina Willd.	*Swartzia cubensis* Britt et Wils.
Inga michelina Harms.	*Sweetia panamensis* Benth.
Juglans hirsuta Mann.	*Swietenia cirrata* Blake
Juglans major (Torr.) Heller	*Swietenia humilis* Zucc.
Juglans mexicana Wats.	*Swietenia macrophylla* Kins.
Juglans microcarpa Berland.	*Tabebuia rosea* (Bertol.) DC.
Juglans mollis Engelm.	*Terminalia amazonia* (Gmel.) Exell.
Licania arborea Seem.	*Theobroma bicolor* Humb. et Bonpl.
Licania capitata (Cham. et Schl.) Kost.	*Theobroma pentagona* Bern.
Licania platypus (Hemsl.) Fritsch	*Tilia mexicana* Benth.
Litsea glaucescens H.B.K.	*Trichilia havannensis* Jacq.
Lonchocarpus cruentus Lund.	*Trichilia pringlei* Rose
Lonchocarpus longistylus Pitt.	*Trophis chorizantha* Stand.
Magnolia dealbata Zucc.	*Trophis chiapensis* Brand.
Magnolia schiedeana Schl.	*Ulmus divaricata* C.U. Muller
Magnolia sharpii Mir.	*Vitex hemsleyi* Brig.
Mirandaceltis monoica (Hemsl.) Sharp	*Washingtonia filifera* (Linden ex André) H.A. Wendl.
Myrica pringlei Greenm.	*Washingtonia sonorae* Wats.
Myroxylon balsamum var. *pereirae* (L) Harms.	*Zanthoxylum belizense* Lund.
Nectandra globosa (Aubl.) Mez.	*Zanthoxylum mayanum* St.
Ochroma lagopus Sw.	

[1]Not every species listed in the table is necessarily a temperate zone speies. All species listed in the original source, even if from tropical or subtropical zones, have been included for the readers' information.

Table 5. Plantation area for dominant commercial temperate forest tree species of México

Species	Area[1]	Approximate age of oldest planting
	(ha)	(years)
Pinus patula	5,000	30
Pinus radiata	2,500	25
Cupressus lindleyi	2,000	25
Pinus greggii	1,500	10
Pinus pseudostrobus	1,000	20
Pinus montezumae	1,000	20
Pinus arizonica	<1,000	
Pinus engelmanii	<1,000	
Pinus durangensis	<1,000	
Pinus ayacahuite	<1,000	
Pinus maximinoi	<1,000	
Pinus herrerae	<1,000	
Pinus oocarpa	<1,000	

[1]Most plantings, even those made for commercial purposes, are scattered in small plantations (from a few up to several hundred hectares). In some cases, species were planted in a mix.

pine species, but they are not a serious threat at present. Recently, a problem has emerged with an introduced pest (wood borer) in exotic poplars which may spread to México's native poplars.

The pattern of land and germplasm ownership has implications for the development of policy and the practice of conservation. For many of the major species, the majority are grown on lands owned by ejidos (see Table 6 and Box 6). Private landowners own only a small plantation area (1 to 5%) and only a few species are represented. There has been an increasing interest in forest plantations both for industrial and protection purposes during the last decade, coupled with a better knowledge of the most important species. In addition, changes in federal policies have allowed a larger allocation of lands to forest plantations (see Box 6).

Contrary to the pattern of forest land ownership, most germplasm reserves are maintained by federal or state agencies and by universities and research institutions. There is little genetic variation represented within the plantations of the major commercial species (Table 7). More (intraspecific) genetic diversity is represented in reserves, although for Monterey pine and Mexican cypress even the reserves represent only a few provenances or seed sources.

Several of the commercially significant forest tree species have been the focus of tree improvement programs, resulting in genetic reserves in seed orchards, provenance tests, and seedbanks (Table 8). Very little advanced activity in tree improvement, such as the production of controlled crosses, is evident for any of the temperate forest tree species. None are propagated by vegetative means for commercial reforestation or plantation establishment. For the six pine species listed in Table 8, over 90% of the propagules for planting purposes derive from seeds collected in natural stands. In the cases of Mexican weeping pine, Apache pine, and false-Weymouth pine (*Pinus pseudostrobus* Lindl.), 10% of the propagules come from seeds collected from seed production areas.

One conservation-related concern is the genetic integrity of nursery stock and plants propagated from this material. Because of frequent changes in technical

Table 6. Pattern of land ownership and management for plantations of commercially significant temperate forest species in México

Owner (manager)[1]	*Pinus patula*	*Pinus radiata*	*Cupressus lindleyi*	*Pinus greggii*	*Pinus pseudostrobus*	*Pinus montezumae*
	(Approximate percentage of a species' total plantation area by ownership)					
Communal lands (federal government)	25	60	60	50	30	30
Ejidos	50	20	15	25	40	40
Private landowners	5	5	1	5	–	–
Ejidos (state government)	20	15	24	20	30	30

[1]See Box 6 for further explanation.

Table 7. Genetic diversity represented in plantations and reserves of the major temperate forest tree species of commercial interest in México

Species	Plantations	Reserves[1]
	(Genetic diversity represented)[2]	
Pinus patula	A	D
Pinus radiata	A	A
Cupressus lindleyi	A	A
Pinus greggii	C	D
Pinus pseudostrobus	A	C
Pinus montezumae	A	C

[1]Here, a reserve refers to any collection of genetic resources, such as an archive, breeding orchard, hedge orchard, seedbank, etc.

[2]A=Only a few provenances or seed sources, B=Only a few clones, C=Provenances or clones representing most of the natural range for the species that is considered similar (and adaptive) to the range in which the species in planted and/or managed, D=Provenances or clones representing most of the natural range of the species.

personnel within the federal or state agencies where germplasm reserves are maintained or propagated, the maintenance of records on geographic origin is in jeopardy. Indeed, for the principal six species of commercial interest (Table 7), only the general geographic region is known for most of the germplasm currently in use, and for some proportion of the germplasm, the source is entirely unknown. The records are least precise for Mexican cypress, where most of the germplasm in use is of unknown seed source.

National parks and other large reserves at present cover most of the major forest ecosystems throughout México, and there are policies on protection of native, endemic forest species in natural forests, particularly for those at high risk of loss. These policies are established at both the federal and state level. Several thousand hectares are designated as 'conservation areas', in addition to the traditional national parks or other large reserves (i.e., Biosphere Reserves). Conservation areas are scattered throughout natural forests to protect rare, threatened, or endangered species and some unique populations. Harvesting is forbidden in these conservation areas, but seed collections are permitted for valid research or ex situ conservation activities. However, most of these areas are still vulnerable to natural (destructive) disturbances as well as human encroachment and may not be large enough to maintain viable populations in the long term. Until recently, there have been no specific conservation policies for plantations.

Specific laws about germplasm introduction and some recent regulations about the use and planting of exotic forest species have been en-

Box 6
Forest land ownership and management in México

There are four situations that generally describe forest management and ownership in México: 1) Communal lands that are managed by the federal government; 2) Land that is owned and managed by ejidos; 3) Land that is owned by ejidos and managed by the state government; and 4) Land that is privately owned and managed. The difference between communal lands and ejidos is very subtle, since in both cases the land can be used in common (i.e., no individual owner). 'Communal' lands refer to lands 'owned' by villages (most of them native people), dating back to colonial times. 'Ejidos' refer to lands given to groups of peasants after the 1910 revolution. Moreover, lands of ejidos have the option to be used and owned individually if the members of the ejido decide that this is appropriate. In the ejido class in Table 6, both types of use (communal and individual) have been included. Originally, the ejido lands could not be sold to anyone else. Recent changes in the law give ownership rights to members of ejidos that are similar to those of private land-owners, so they can sell their land. The communal lands, on the other hand, cannot be sold.

J. Jesús Vargas Hernández

Table 8. Genetic reserves within tree improvement programs for Mexican temperate forest tree species

Species	Seed orchards No.	Seed orchards Area	Provenance tests No.	Provenance tests Range[1]	Seedbanks[2]
		(ha)		(%)	
Pinus patula	2	1.0	8	50	2 years
P. radiata	0	0.0	0	0	1 year
P. greggii	2	1.0	10	90	5 years
P. leiophylla	1	0.5	8	30	None
P. engelmannii	0	0.0	10	90	3 years
P. pseudostrobus	2	1.0	8	40	2 years

[1]Approximate percentage of the species' total range that is represented in provenance tests.

[2]Approximate supply currently in storage (relative to current demand for seed).

Table 9. Exports of temperate forest genetic resources from México

Species	Scale of transfer	Country	Intended use in receiving country
Pinus patula	Major	South Africa, South America	Provenance trials, small-scale plantings
P. greggii	Major	South Africa, South America	Provenance trials, small-scale plantings
P. radiata	Minor	Chile, U.S.A., New Zealand, Australia	Genetic testing, research, genetic conservation
P. maximinoi	Minor	South Africa, South America	Provenance trials
P. maximartinezii	One event	U.S.A.	Research, genetic conservation
Picea spp.	One event	U.S.A.	Research, genetic conservation

acted. However, they are not completely effective against introduction of potential pests.

The genetic richness of México's forests is internationally recognized. There are significant seed exports of several temperate species, most notably of Mexican weeping pine and Gregg pine, for genetic testing (Table 9), and even greater seed export of tropical species. However, the contribution of forest plantations in México to the domestic market of wood products is currently nominal. Investment in temperate forest genetic resources, via basic research or tree improvement programs, is modest.

In summary, México is rich in temperate forest tree species. Little genetic information is available for these species: in most cases even distribution maps are incomplete. Anthropogenic pressures, leading to habitat loss and population fragmentation and degradation, are great and increasing. The delineation of conservation areas is recent, and it is unknown whether the current areas are adequate to protect the genetic integrity of populations or whether they can be enforced. Compared to Canada and the United States, the management of commercially significant forest tree species in México is a recent phenomenon. However, several pine species are being tested for commercial plantations in other countries, particularly in South Africa and countries of South America.

United States of America

The complex and obscure picture of the genetic status of temperate forest tree species (i.e., nearly all forest tree species of any substantial area) within the United States is presented here by means of case studies, survey responses, and federal statistics. Geographic distributions of the forest resource at the species level are well known: genetic diversity of the resources is imperfectly known. Amounts and patterns of genetic variation have been outlined for many U.S. species; nevertheless, genetic diversity of most taxa is imperfectly known and the impacts of anthropogenic influences are not well understood. The diversity in land ownership and management, coupled with the lack of a dedicated agency responsible for conservation-related statistics or a structure for data sharing, enables us to provide only a sketch of the full picture.

The most accessible information on the amount of land in the United States with conservation restrictions is from the federal land management agencies. The four major land management agencies—the Department of Agriculture's Forest Service, and the Department of the Interior's Bureau of Land Management, Fish and Wildlife Service, and National Park Service—manage over 250 million hectares (620 million acres) of land, over 40% of which has some conservation-related land use restrictions (Table 10). Most of the federal land with conservation restrictions is located in 13 western states. Conservation restrictions do not preclude all activities that could have genetic impacts, nor have the protected areas been selected with conservation of the genetic resources in mind. For example, although the Wilderness Act of 1964 prohibits most development within the designated 'wilderness areas', it still allows "the development of minerals and the grazing of livestock in those instances where valid rights exist, access to private lands inside wilderness areas, and use of nonmotorized recreational vehicles" (USA/GAO 1995). Similarly, the 'Wild and Scenic River' designation protects rivers from water resource projects that may divert or hinder the flow of the river, yet such activities as road construction, hunting, fishing, and mining may be permitted in these areas under some circumstances.

Table 10. Area managed by the major federal land management agencies in the United States and percentage with conservation restrictions as of September 30, 1993[1]

State	Area managed (100 ha)[2]	Area with conservation restrictions (100 ha)[3]	(%)[4]	State	Area managed (100 ha)[2]	Area with conservation restrictions (100 ha)[3]	(%)[4]
Alabama	3,231	309	9	Nebraska	2,134	740	35
Alaska	969,272	610,219	63	Nevada	230,049	38,578	17
Arizona	120,871	34,282	28	New Hampshire	2,975	474	16
Arkansas	13,029	2,682	21	New Jersey	418	418	100
California	173,967	134,992	78	New Mexico	92,756	16,614	18
Colorado	94,847	23,369	25	New York	349	295	84
Connecticut	27	27	100	North Carolina	8,109	4,028	50
Delaware	97	97	100	North Dakota	6,856	2,140	31
Florida	15,526	11,518	74	Ohio	1,018	136	13
Georgia	5,632	2,830	50	Oklahoma	1,661	596	36
Hawaii	2,140	2,140	100	Oregon	129,926	28,720	22
Idaho	131,272	39,147	30	Pennsylvania	2,382	443	19
Illinois	1,374	402	29	Rhode Island	6	6	100
Indiana	859	136	16	South Carolina	3,001	838	28
Iowa	162	160	99	South Dakota	10,669	1,792	17
Kansas	549	112	20	Tennessee	4,126	1,896	46
Kentucky	3152	560	18	Texas	9,305	6,401	69
Louisiana	5,517	2,202	40	Utah	131,307	29,958	23
Maine	682	516	76	Vermont	1,475	446	30
Maryland	396	396	100	Virginia	8,453	2,737	32
Massachusetts	264	264	100	Washington	46,938	19,399	41
Michigan	15,094	3,714	25	West Virginia	4,387	772	18
Minnesota	14,675	5,939	40	Wisconsin	8,106	1,495	18
Mississippi	6,066	1,217	20	Wyoming	121,826	30,218	25
Missouri	6,479	733	11				
Montana	108,237	29,999	28	**Total**	**2,521,678**	**1,097,102**	**44**

[1]Source: General Accounting Office analysis of data provided by the Departments of Agriculture and the Interior, U.S.A. Area totals may not equal the total given due to rounding. For the analysis, the District of Columbia was not included.

[2]Areas were originally presented in acres. These have been converted to hectares, rounding to the nearest 100 ha.

[3]Restricted areas include: Wilderness, Wilderness Study Area, Wild and Scenic River, Area of Critical Environmental Concern, Research Natural Area, National Conservation Area, National Monument, National Primitive Area, National Recreation Area, National Game Refuge, National Scenic-Research Area, National Natural or Historic Landmark, Scientific Research Area. Areas were originally presented in acres. These have been converted to hectares, rounding to the nearest 100 ha.

[4]Figures were calculated from the original (acres) data and rounded to the nearest percent.

The U.S. Fish and Wildlife Service maintains a list of species that are designated as 'threatened' or 'endangered' under federal legislation. Similar to the situation in Canada, where there is only one tree species listed as 'endangered' at the federal level, only a few U.S. tree species are listed as endangered (Table 11). One additional species, Catalina island mountain mahogany (*Cercocarpus traskiae* Eastw.), has been proposed for listing as endangered but is not yet officially listed. Gowen cypress (*Cupressus goveniana* ssp. *goveniana* Gord.) has been proposed for listing as threatened. Individual states may list additional species at the state level.

In the United States, the concern is for the erosion and potential loss of populations—populations that may harbor valuable genetic resources. For example, some populations may be affected by loss and fragmentation of habitat (e.g., black walnut). Atlantic white cedar (*Chamaecyparis thyoides* (L.) B.S.P.) has experienced 80% loss of habitat in the last two centuries (R.C. Kellison, personal communication, 1995).

Certain management practices, particularly those that alter natural disturbance or successional patterns, may have substantial genetic impacts, including shifts in species representation. For example, fire protection practices favor some species over others. On many sites in the southern Appalachians, eastern white pine, being intermediate in fire tolerance, encroaches on hardwoods in fire-protected areas. When those hardwood stands break up, the white pines grow up between them and take over the site (Timothy LaFarge, personal communication, May, 1995). Fire suppression practices on federal lands in Montana and northern Idaho have contributed to much replacement of ponderosa pine with Douglas-fir (George E. Howe, personal communication, 1996).

Some private companies have established conservation areas on the forest lands they own and manage. For example, a company in the Pacific Northwest has set aside over 35,000 ha to protect critical wildlife and/or plant habitats. Examples of the latter include rocky knobs that are habitat for Oregon oak (*Quercus garryana* Dougl. ex Hook.) and golden chinquapin (*Chrysolepis chrysophylla* (Hook.) Hjelmq.), and wetlands for Oregon ash (*Fraxinus latifolia* Benth.). Many of the protected areas represent ecologically marginal populations of tree species and are perhaps not suitable for intensive forestry. Most of the areas are restricted from harvest activity, although in some cases thinning or salvage logging might be permitted. None of the areas in this example were set aside specifically to conserve genetic variation, but rather, conservation is a currently recognized and valued additional benefit of the original restriction designation.

Although forest lands with conservation restrictions are generally not selected or managed with genetic criteria in mind, there is at least one exception. On state-managed lands in Washington, approximately 900 hectares of forest land have been designated as *in situ* conservation areas for Douglas-fir. The conservation areas were chosen on the basis of elevational and ecological criteria that could serve as proxies of representative genetic variation within the species (Wilson 1990). One of the objectives of the federally designated Research Natural Areas (RNAs) is "to preserve and maintain genetic diversity" (USDA Forest Service 1994). The areas are located so as to preserve representative plant communities. As of 1985, the USDA Forest Service had established 150 RNAs, and the USDI Bureau of Land Management 326 more (Ledig 1988).

Table 11. Tree species on the federal 'Endangered Species' list for the United States (Source: World-wide Web-site directory of endangered species (http://www.fws.gov), U.S. Fish and Wildlife Service, Division of Endangered Species, Sacramento

Species	Common name	Date first listed	Status[1]
Gymnosperms			
Cupressus abramsiana	Santa Cruz cypress	1987	E
Torreya taxifolia	Florida torreya	1984	E
Angiosperms			
Betula uber	Virginia round-leaf birch	1978	T
Chionanthus pygmaeus	Pygmy fringe tree	1987	E
Prunus geniculata	Scrub plum	1987	E
Quercus hinckleyi	Hinckley's oak	1988	T
Rhus michauxii	Michaux's sumac	1989	E

[1]T = threatened, E = endangered. "The term 'endangered species' means any species which is in danger of extinction throughout all or a significant portion of its range..."; "The term 'threatened species' means any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range."; "The term 'species' includes any subspecies of fish or wildlife or plants, and any distinct population segment of any species of vertebrate fish or wildlife which interbreeds when mature." (Endangered Species Act of 1973)

Most land-management agencies and private companies have internal policies that guide artificial reforestation, regeneration, or restoration activities to maintain genetic variation and adaptation within commercial forest tree species. These policies are often framed as minimum number of parental trees to be included in seed orchards, minimum number of clones per breeding population, maximum number of related families to be used within a planting unit, maximum amount of land that can be reforested with individual families within a specific time-frame, and the designation and use of 'local' seed sources (see Box 7).

Much of the natural genetic diversity in managed, commercial native species is well represented in plantations and genetic reserves. Survey respondents indicated that germplasm from most of the natural range of their commercial species was included in planta-

Box 7
Management of genetic resources by controlling seed movement

Replanting after timber harvest, or reforestation, became an increasingly common practice in forest management during the last century. Often, nonlocal, or exotic, seed sources were planted. Although provenance differences had been recognized as early as the eighteenth century, reforestation with nonlocal seed sources continued well into the twentieth century. As a result, biodiversity may have been lost and the genetic structure of species was likely modified. More than a century of research on the nature of species and populations eventually led to the practical conclusion that for reforestation, it was usually best to conserve and use 'local' seed sources. This realization culminated in laws and policies that restricted the so-called 'transfer' of seed.

In Germany, where forest planting was much more widely practiced at the turn of the century than in the United States, the ill effects from planting maladapted provenances became so obvious by 1934 that a forest seed law was passed (Baldwin and Shirley 1936). Of all the Scots pine (*Pinus sylvestris* L.) plantations established between 1890 and 1910, 25% were so poor that the law required their destruction so they would not serve as progenitors for the next generation. At least 50% of the stands were so poor that it was illegal to collect seed from them.

In the United States the same mistakes were repeated. Records were poorly kept, so statistics on 'off-site' planting are not available. However, by 1939 plantation failures had become so obvious that the U.S. Department of Agriculture established policy on seed transfers (McCall et al. 1939). The policy statement, whose signatories included Francis A. Silcox, Chief of the Forest Service, and Henry A. Wallace, Secretary of the Department of Agriculture, said that plantings on national forests should be established with seed collected no more than 100 miles north or south and 1,000 feet higher or lower in elevation.

Defining seed transfer rules is one of the most important tasks in conserving and managing forest genetic resources. Usually, the rules take the form of seed zone boundaries, which are drawn to facilitate management. Seed zones should be areas with relatively uniform genetic composition. Before results of provenance tests are available, seed zones are based on expert opinion, using latitude, elevation, physiography, and generalized knowledge of adaptive patterns as a surrogate for specific knowledge about genetic diversity in the taxa of interest. Seed zones are modified as the resource is evaluated in provenance tests.

In the southeastern United States, seed can be moved rather long distances, based on the results of an extensive series of field tests (Wells and Wakeley 1966, Schmidtling 1996). Seed zones are fairly large in the Southeast because changes in topography and climate are gradual over much of the region (Figure 7). Near the limits of a species' ecological tolerances, however, the zones become narrower.

In the western United States, mountainous topography is accompanied by abrupt changes in temperature, rainfall, and growing season. As a result of selection, populations differ over short distances. Therefore, seed zones must be narrow and are particularly constrained along elevational gradients. On the national forests in California, seed collectors record elevation to the nearest 500 feet (152 m) and the seedbank maintains these records in storage, the nursery maintains them in raising the seedlings, and the National Forests maintain them in planting. In addition to controlling the origin of the seed used in planting, National Forest policy recognizes the wisdom of maintaining genetic diversity within the seed zone (Kitzmiller 1976).

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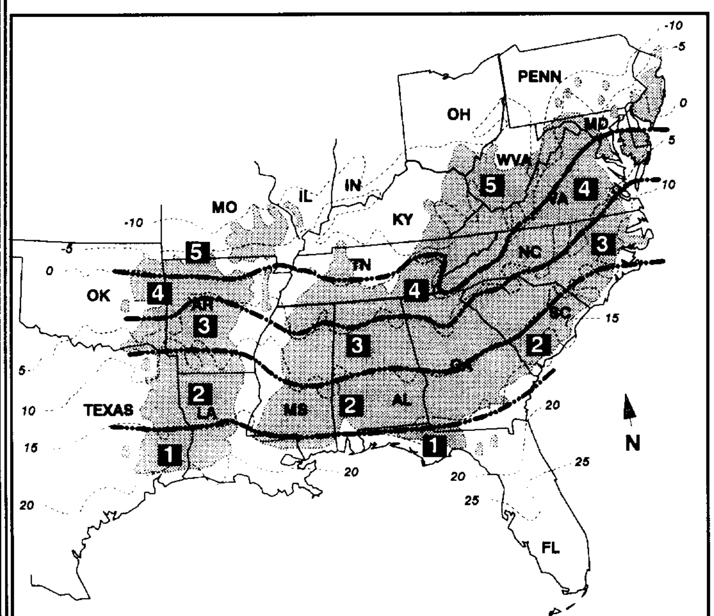

Figure 7. Seed zones established for shortleaf pine (*Pinus echinata* Mill.) based on provenance tests conducted at several locations throughout the species' range (from Ronald C. Schmidtling, unpublished data, 1996). Range of shortleaf pine is shaded; seed zone numbers are in squares; seed zone boundaries –· · –; minimum temperature isotherms (°F) ---. For planting in zone 1, seeds should be collected in zone 1; for planting in zone 2, seeds may be collected in zones 1 or 2; for zone 3, seeds may be collected in zones 2 or 3; for zone 4, seeds may be collected in zones 3 or 4; for zone 5, seeds should come from zones 4 or 5.

tions, with additional genetic diversity represented in genetic reserves.

The identity (by geographic source) of the general seed source in the majority of reforested areas or plantations is well documented, although this is not the case for some of the oldest plantings. For example, seed lots collected prior to the mid-1960s on Forest Service lands in Montana and northern Idaho were not identified by source. Thus, the genetic source is unknown for some of the older plantings in this region, primarily western white pine (*Pinus monticola* Dougl.) and ponderosa pine (George E. Howe, personal communication, 1996). For most recently established plantations, the specific seed source is known. In only a few cases, such as a small percentage of the pine plantations in the southeastern United States, including slash pine (*Pinus elliottii* Engelm.), loblolly pine, sand pine (*Pinus clausa* (Chapm.) Vasey) and longleaf pine (*Pinus palustris* Mill.), is the seed source unknown.

Certain insects and diseases, many of them introduced, have affected temperate U.S. tree species (Campbell and Schlarbaum 1994). Dutch elm disease *(Ophiostoma* spp.) has caused severe decline in the American elm populations (*Ulmus americana* L.) of central and eastern United States. Pitch canker, an indigenous fungal disease caused by *Fusarium subglutinans* f. sp. *pini*, is a sometimes-serious problem in pines (subsection Australes) in the southeastern United States. It is common on slash and loblolly pines, and there is some evidence of genetic impact on shortleaf pine (*Pinus echinata* Mill.) from this canker. Pitch canker is now established in California where it has caused conspicuous damage in plantings of Monterey pine and several other pines (Eldridge 1995). There is some evidence of genetic variation in susceptibility of Monterey pine to this pathogen (Schultz and Gordon 1996). American chestnut has been severely affected by chestnut blight (*Endothia parasitica*) and butternut (*Juglans cinerea* L.) by butternut canker (*Sirococcus clavigignenti-juglandacearum*). White pine blister rust (*Cronartium ribicola*), considered to be an Asiatic fungal species, has particularly affected sugar pine (*Pinus lambertiana* Dougl.), western white pine, and whitebark pine. Fusiform rust and tip moth attack are specific to some families of eastern U.S. pine species (R. C. Kellison, personal communication, 1995). Fusiform rust has had a genetic impact on eastern pines, most notably loblolly and slash pine: breeding for resistance is ongoing (Timothy LaFarge, personal communication, 1995). Port-Orford-cedar (*Chamaecyparis lawsoniana* (A. Murr.) Parl.) has been significantly affected by a root rot (*Phytophthera lateralis*) which has been moved into the range of the species by human activities.

There is much international transfer of germplasm of domestic forest tree species (Table 12). With some species, such as Douglas-fir, loblolly pine, and slash pine, germplasm is marketed on a large scale for commercial purposes, with significant economic benefit to

Table 12. Examples of international transfer of forest tree germplasm from the U.S.A. to other continents[1]

Species	Recipient country	Comment
Abies grandis	Belgium, Germany	Minor, but ongoing, transfer
Abies procera	UK, Belgium, Germany	Minor, but ongoing, transfer
Alnus rubra	UK	Minor, but ongoing, transfer
Picea sitchensis	UK	Minor, but ongoing, transfer
Pinus contorta	Argentina, Sweden	Minor, but ongoing, transfer
Pinus elliottii	China, Argentina, Brazil, South Africa	Large amounts sold annually, especially to China
Pinus ponderosa	Argentina, Chile, New Zealand	Minor, but ongoing, transfer
Pinus taeda	China, Brazil, New Zealand, Argentina, South Africa, Zimbabwe	Large amounts sold annually, especially to China
Populus deltoides	Italy, France, Belgium, New Zealand, Argentina, India, UK, Germany, Netherlands	Minor, but ongoing, transfer
Pseudotsuga menziesii	Chile, Argentina, Belgium, France, UK, Germany, New Zealand	Major amounts are sold annually (primarily seeds and seedlings)
Sequoia sempervirens	New Zealand	Minor sale of cuttings
Tsuga heterophylla	France, Belgium	Minor, but ongoing, transfer

[1]This list is not a comprehensive one of all species marketed internationally, and the scale of transaction described may underestimate the actual transfer.

the domestic supplier. In other cases, small amounts of germplasm are provided for research or test plantatations.

Much investment has been made in genetic analyses of the major commercial forest tree species within the United States. One major effort has been in understanding patterns of genetic variation within and among populations at various spatial (primarily macrogeographic) scales. A second major effort, associated with tree improvement programs, has been to understand the genetics of quantitative traits influencing growth and adaptability. This has involved estimating the amounts of genetic variation in these traits and their heritabilities. Some of the recent research efforts have compared natural populations with managed stands and breeding populations using allozyme markers (e.g., loblolly pine in the Southeast, and Douglas-fir in the Northwest). This approach may help to quantify management-related impacts on genetic variation in these forest tree species, if they occur.

Status of temperate forest tree species of North America in countries where they are grown as exotic plantation species

Deborah L. Rogers and F. Thomas Ledig

The role of exotics in conservation of forest genetic resources is problematic; it has many aspects. Plantation forestry of exotic species plays an economic role, without doubt. Sometimes exotics also play an ecologic role, restoring degraded sites so that native vegetation may eventually reinvade. However, the danger is that introduced species may become invasive, displacing native species, disrupting ecosystems, and in some cases, hybridizing native congeners out of existence (e.g., Box 5).

On balance, however, intensive forest management of exotics may make it easier to conserve native forest. Dr. Rowland D. Burdon, one of the workshop participants, said that:

> We have more of our native forests left [in New Zealand] as a result of the presence of [*Pinus*] *radiata* than we would have otherwise. These industrial plantations take tremendous pressure off the natural populations.

We **recommend** *the development of national programs to address issues in the conservation of forest genetic resources. ...Both exotic forest tree species growing in North America and native North American species growing elsewhere should be considered in national programs. Furthermore, because species cross national borders, coordination and cooperation among nations will be required.* (Rec. no. 1)

In the absence of plantation forestry, harvesting and grazing, both of which are more extensive uses of the land, would have resulted in clearing of native forest on a larger scale than has occurred.

Fast-growing exotic species and active plantation management can increase forest-product yields to levels well above those attained in natural forest. If needs for forest products can be met from plantation forests, then natural forest can be allocated for the *in situ* conservation of genetic resources, the protection of biodiversity, and esthetic enjoyment. For example, Brazil has 396,000,000 ha of natural forest and only 6,500,000 ha of industrial plantations (only 2% of its total forest area). Nevertheless, Brazil obtains 60% of its industrial wood supply from its plantations; i.e., 60% from only 2% of the forest landbase (Anonymous 1993). The introduction of the rapidly growing Australian blue gum (*Eucalyptus globulus* Labill.) to Peru is credited with a reduction in the rate at which native forest was cleared in the Peruvian Andes (Rocca Caliennes 1985). Intensive forest management can benefit conservation indirectly through increased commodity yields and increased employment (Gladstone and Ledig 1990).

Exotics may be able to withstand new conditions that natives cannot and, therefore, can be used to reforest degraded sites with an economically useful crop until the sites are restored sufficiently to support native vegetation.

Plantations of North American species on other continents are themselves a mechanism for the *ex situ* conservation of genetic resources. They may be a means to store germplasm for a century or more, and in some cases (species with seeds that do not store for long periods, such as oaks and poplars), they are the only method of *ex situ* conservation presently available. Plantations of exotics should be considered in the design of any program for the conservation of forest genetic resources, although their value in this role will depend on their origin and level of domestication.

Some participants felt that sustainability should be considered in risk analysis when considering the large-scale introduction of exotic species; e.g., will the differential in production between natives and exotics be maintained? In fact, sustainability may not be a concern if the potential threats to sustainability are the diseases and insect pests left behind in the country of origin. Although the potential introduction of a new pest is also a consideration, this is less of a concern in situations where an alternate host is involved, and that host species is absent in the country of importation. If there is a pest problem, then the solution is to convert back to a native species or to a new exotic. If the concern for sustainability is one of reduced soil productivity, then a real problem exists and this should be considered in risk analyses.

Significance and scope of North American temperate forest tree species as exotic plantation species

Some North American temperate forest tree species are well represented in other countries where they are managed in commercial plantations. This situation has implications for the conservation of these species. In some cases, the exotic plantations or reserves could be considered and employed as genetic reserves, potentially valuable in restoration efforts within the species' native range (see Box 8). Conversely, native sources of germplasm could be important to breeding efforts in other countries. Given their international economic value, the global community should consider support for *in situ* conservation programs for these species.

A modest number of species are responsible for the majority of North American-origin exotic plantations (Table 13). Some of these species are also highly valued for timber and/or fiber within their native ranges (e.g., Douglas-fir, slash pine, and loblolly pine), while others are much more highly valued in their role as exotics (e.g., Monterey pine). Cultivation of these temperate zone species in nonnative countries is both geographically and historically significant, with some countries having several million hectares devoted to exotic plantations which, in some cases, were first established over a century ago (Table 14). New Zealand, in particular, has taken advantage of the genetic wealth of many North American species and pursued genetic and silvicultural investments in domesticating them (see Box 9).

The description of the scope and nature of North American temperate forest tree species in their capacity as exotic plantation species derived from responses to our questionnaire in 1995 is a snapshot of a dynamic pattern. Recent changes and emerging trends in the species grown, the area covered, and the ownership of plantations are presented in Table 15. Species with increasing plantation area in one or more countries include Caribbean pine, Mexican weeping pine, pitch pine, Monterey pine, *Populus* species and Euramerican hybrids, Mexican cypress, Douglas-fir, grand fir, Sitka spruce, and Port-Orford-cedar. While the area planted to slash pine has been increasing in countries such as China and South Africa, slash pine is being replaced in other countries, such as Argentina, Australia, and Brazil, with faster-growing *P. elliottii* × *P. caribaea* hybrids or other species. Some species have shown a dramatic drop in popularity, such as lodgepole pine in the United Kingdom and ponderosa pine in New Zealand. Ponderosa pine was once the second most widely planted species in New Zealand, but now assumes a very minor role there.

The value of the germplasm of these species as exotics is considerable, principally because of their contribution to commercial forestry in countries

Box 8
The preservation of shipmast locust in Hungary

Shipmast locust (*Robinia pseudoacacia* var. *rectissima* Raber) differs in several respects from the species type, black locust. Most importantly, shipmast locust has a more erect stem and narrower crown than black locust and a wood that is even more durable in contact with the soil than black locust. Shipmast locust is sterile or nearly so. It produces few flowers and pollen germination is poor to nonexistent (Raber 1936). Therefore, it propagates by vegetative means, usually from root suckers.

Shipmast locust was first described from Long Island, New York, an area far from the native range of black locust. By tradition, Captain John Sands (1649-1712) was credited with finding the shipmast locust in Virginia and planting it at his home on Sands Point, Long Island in 1683 (Detwiler 1937). Captain Sands was engaged in the coastal trade in colonial America. After its initial introduction to Long Island, shipmast locust was spread rapidly in the area of Glen Cove and Roslyn because of its desirable characteristics (Raber 1936).

Shipmast locust is not presently known from Virginia. In the once-rural areas on western Long Island, where it was extensively propagated, it has been urbanized out of existence. Other known localities (in New Jersey, Massachusetts, and New York) for shipmast locust were associated with areas settled by the Society of Friends (Quakers), who apparently transported and propagated the variety. However, it is likely that shipmast locust has disappeared from those areas as well as western Long Island because of urbanization and because shipmast locust is a cultivar that depends largely on humans for propagation. The use of untreated posts for fencing and, therefore, the need for shipmast locust, vanished many decades ago in the United States. However, shipmast locust can be obtained from *ex situ* plantings, for example, those in Hungary.

Black locust occupies 18.8% of the forested area in Hungary, where it is extensively planted as a commercial species and has been used to reclaim spoil banks. It has proven unusually adapted to such low-nutrient, droughty sites. Black locust is reported to have been the first North American tree species imported into Europe (in 1601, according to Keresztesi 1980). It is difficult to imagine its source: Jamestown, Virginia, the first more-or-less permanent English colony in America, was not settled until 1607, and Jamestown was 100 km from the natural range of black locust (see range map in Roach 1965). The older, Spanish settlement of Saint Augustine, Florida, dates to 1565, but it is several hundreds of kilometres from supposed southern outliers of black locust in Geor-

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Figure 8. A 23-year-old clone trial of shipmast locust (*Robinia pseudoacacia* var. *rectissima* Raber) in the Arboretum Gödöllő, near Budapest, Hungary. (Photo courtesy of Hungarian Forest Research Institute.)

Box 8 (continued)

gia and Alabama. However, even the original, pre-Columbian range of black locust cannot be determined precisely. Therefore, the history of black locust is obscure.

Within the extensive black locust resource in Hungary, shipmast locust appears spontaneously. We know of no record of the specific import of shipmast locust into Europe. However, about a dozen clonal groups of shipmast locust have been selected and approved as varieties in Hungary (Figure 8).

Shipmast locust and black locust illustrate two points. The first is that plantations of North American forest trees on other continents represent an *ex situ* resource for conservation. If it were desirable to reintroduce shipmast locust to the United States, Hungary would be the most accessible source. The second point, illustrated by the use of black locust in general, is that exotic species may serve an ecological function. In the case of black locust, it is used to stabilize degraded sites in Hungary and elsewhere and improve site quality (black locust is a legume that fixes atmospheric nitrogen), perhaps to the extent that native species may one day be reintroduced.

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Table 13. North American temperate forest tree species that are major plantation species outside of North America[1]

Species	Approximate area in exotic plantations[2] (ha)
Pinus radiata	3,846,000
Robinia pseudoacacia	2,047,000*
Populus spp./hybrids	2,016,000*
Pinus taeda	1,986,600*
Pinus elliottii	1,983,600*
Amorpha fruticosa[3]	1,000,000*
Pseudotsuga menziesii	578,000
Picea sitchensis	571,000
Pinus patula	343,000
Taxodium distichum	200,000*
Pinus contorta	131,000
Cupressus lusitanica	130,000*
Juniperus virginiana	80,000*
Salix spp.	60,000
Liriodendron tulipifera × *chinensis*	50,000*
Pinus ponderosa	31,000
Pinus rigida	30,000*
Abies grandis	29,000
Quercus rubra	21,000
Pinus lusitanica	15,000
Pinus banksiana	15,000*
Pinus caribaea × *P. elliottii*	6,000
Cupressus macrocarpa	5,000

[1]Includes only figures provided from those countries listed in Table 1, and as such, underestimates the actual plantation area. Species with total reported plantation areas of less than 5,000 ha are not included in this list.
[2]Figures marked with an asterisk are heavily influenced by figures for China. In some cases, the species total is for China exclusively.
[3]A shrub.

Table 14. Main North American species grown as exotics, by country

Country	Total area managed as exotic plantations[1] (ha)	Date of oldest plantation[2]	Main species (by area planted)
Argentina	550,000	1845	*Pinus elliottii*
Australia[3]	850,000	1876	*Pinus radiata*
Brazil	1,600,000	1950	*Pinus taeda*
Chile	1,515,000	1900	*Pinus radiata*
China	7,000,000	1897	*Robinia pseudoacacia*
France	750,000	–	*Pseudotsuga menziesii*
Germany	150,000	1890	*Pseudotsuga menziesii*
Greece	29,240	1950	*Populus* spp.
Hungary	310,000	1770	*Robinia pseudoacacia*
New Zealand	1,320,000	1868	*Pinus radiata*
South Africa	616,000	1857	*Pinus patula*
Spain	250,000	–	*Pinus radiata*
United Kingdom	700,000	1860	*Picea sitchensis*

[1]Total plantation area of all North American temperate forest tree species.
[2]The age of the oldest plantation of any North American temperate forest tree species, not necessarily the major one listed in the following column. The date is approximate in some cases.
[3]Includes the plantation area in the state of Queensland.

where they are grown in plantations. In the countries surveyed, North American temperate forest tree species provided over 40% of the domestic demand for wood and wood products (from plantations within each country) in Argentina, Chile, New Zealand, and South Africa (Table 16). In Argentina, Brazil, China, France, and New Zealand, the sale of locally produced seeds, seedlings, and/or cuttings of North American native tree species has significant value (Table 17). With the exception of France, most of this market is in the form of seeds from slash pine, loblolly pine, or Monterey pine.

Genetic reserves

Conservation of native North American sources of germplasm is of interest to those who cultivate the species as exotics. *In situ* conservation efforts are particularly germane to exotic plantations when local reserves are judged inadequate for current and/or predicted uses, and/or vulnerable to natural demise or human error. Whether exotic reserves are perceived as adequate varies greatly by country and by species. Only in Hungary, France, and Chile are the germplasm reserves of exotic species considered adequate (Table 18).

Inadequacy of genetic reserves may result from several conditions, the most obvious of which is insufficient genetic diversity in the original collections. For many of the species grown as exotics, the genetic diversity currently represented in reserves or plantations in the host country does not cover the species' range or even that portion of the range that is most similar in environment to the growing range in the host country (Table 19). In this lexicon, a 'genetic reserve' has been given broad interpretation, including any collection of germplasm from clone banks to seed orchards to provenance trials (Table 20).

A second factor affecting adequacy of genetic reserves is the precision of records on geographic origin of the germplasm. If records are missing or vague, as was the case for many early introductions, it is difficult to ascertain the proportion of the species' range represented, and thus the adequacy of the reserves. Also, the development of models for growth or adaptability of exotics based on the origin of material (which can indicate the most desirable native populations for more intensive sampling) will be severely hampered by lack of records. Although there is some possibility of using molecular techniques to determine origin, their efficacy depends on the existence of very distinctive affinities of molecular markers with geographic origin.

Box 9
North American temperate forest tree species planted in New Zealand

North American temperate forest tree species dominate commercial forest tree plantations in several countries outside their native ranges. In New Zealand, for example, approximately 1.4 million hectares are covered with plantations of these 'exotic' species. Some of these tree species, such as Monterey pine, Douglas-fir, and Monterey cypress, have been managed as plantation species in New Zealand for over 100 years.

Rowland D. Burdon

Species	Area[1] of oldest plantation (ha)	Approximate date
Pinus radiata	1,320,000	1868
Pseudotsuga menziesii	65,000	1875
Cupressus macrocarpa	5,000	1875
Pinus ponderosa	3,000	1890
Pinus contorta	3,000	1905
Pinus muricata	2,000	1905
Cupressus lusitanica	1500	1938
Sequoia sempervirens	500	1899
Pinus taeda	500	1912
Pinus strobus	200	1905
Pinus patula	150	1910
Juglans nigra	50	1970
Abies grandis	20	1905
Pinus attenuata	1	1905
Pinus pseudostrobus	1	1962

[1]The areas in plantations for all but the first two species in the list are questionable as there is currently no effective national inventory for the minor species. Also, the task is compromised by recent, significant changes in area committed to plantations (mainly reductions in area, with the exception of *Pinus radiata*). Not included are *Populus* species which, although widely planted, are used primarily for controlling soil erosion, etc.

A survey of the status of pedigrees of North American forest tree germplasm in use in plantations in other countries shows that in many cases the geographic origin is either unknown or only known by general region (Table 21). This may be less of a problem in the future if harvested plantations are replaced with better-identified stock. However, if the current plantation materials persist, for example, due to the confidence they inspire from their production records, the situation may remain as it is—many vaguely defined genetic resources—or even worsen.

A further consideration in determining the adequacy of genetic reserves is the pattern of ownership of the germplasm. The information presented in Table 20 is a generalization for each species, irrespective of germplasm ownership. However, various types of ownership imply various kinds of restrictions on the use of genetic reserves: in extreme cases, genetic reserves may be inaccessible to prospective users of the germplasm for proprietary reasons. In South Africa, for example, the genetic reserves for the four widely used North American pine species in the ownership of private industry are much more restricted than those in the government-owned landbase (see Box 10).

Exotic (*ex situ*) genetic reserves are potential reserves for the country of origin as well as serving the needs of exotic plantation management. Classic examples of this are the genetic reserve of the Guadalupe Island population of Monterey pine recently established in Australia (Box 11) and shipmast locust (*Robinia pseudoacacia* var. *rectissima* Raber) in Hungary (Box 8).

Table 15. Recent or emerging trends in use of North American forest tree species where they are grown as exotics

Country	Comment
Argentina	More *Pinus taeda*, *P. caribaea*, and *P. elliottii* × *P. caribaea* hybrids are being planted, and less *P. elliottii* in fertile soils of subtropical areas due to the growth superiority of the former species and hybrids.
Australia	The rate of increase of *Pinus radiata* plantations has declined in recent years. Clearing of eucalypt forests for *P. radiata* plantations greatly diminished after 1970; thereafter, the use of marginal farm land for this purpose prevailed.
Australia) (Queensland)	Both *Pinus elliottii* and *P. taeda* are rapidly being harvested and virtually no replanting has occurred since 1990. The plantation areas are being replanted instead with the *P. elliottii* × *P. caribaea* hybrid developed in Queensland.
Brazil	Areas with *Pinus patula* increased quickly and should continue to increase as well-suited sites are located. The area of *P. elliottii* is decreasing due to the preference for planting faster-growing tropical species.
China	The area of plantations with *Pinus elliottii*, *P. taeda.*, *P. rigida*, *Populus euramericana*, *Populus deltoides*, *Cupressus lusitanica*, *Juniperus virginiana*, and *Liriodendron tulipifera* × *chinensis* has significantly increased.
France	The area used for growing *Pseudotsuga menziesii* has increased by 50% in the last decade. *Abies grandis* and *Picea sitchensis* have also increased, but to a lesser extent. The area with *Quercus rubra* has increased dramatically, while the area used for growing *Robinia* and *Populus* has decreased slightly.
Germany	No significant changes in the former West Germany, but the process of reassigning land ownership in the former East Germany is ongoing—with uncertain consequences for tree plantations.
Greece	Since 1992, wood production on previously farmed lands has been subsidized by the government. As a consequence, the amount of *Robinia pseudoacacia* grown has been increasing dramatically—by 1,500 ha in the past three years.
Hungary	*Robinia pseudoacacia* is the predominant exotic plantation species (at present, 19% of the total forest area), but there is pressure to decrease its area. However, lack of funds to subsidize conversion means that little change has occurred. Much of plantation forestry has been re-privatized (land of collective farms) from large units into small-scale woodlots, with resulting constraints on individual management.
New Zealand	Large and continuing drop in role of *Pinus ponderosa* (once the no. 2 species—now minor); *Pseudotsuga menziesii* dropped in importance relative to *Pinus radiata*, but is showing a modest resurgence; *Cupressus* species are making modest gains at present; with *Pinus muricata* there has been an increase in area for preferred provenances despite large drop in overall area.
South Africa	The area used for growing *Pinus taeda* has been somewhat decreasing in favour of other species. *Pinus elliottii* plantings increased after 1945.
Spain	*Pseudotsuga menziesii* and *Chamaecyparis lawsoniana* are increasing yearly in area grown, mainly on private land. *Pinus radiata* and *Populus* plantations have increased over the past few years.
United Kingdom	*Pinus contorta* plantations have been reduced dramatically due to planting/environmental policy. There has been a small increase in the amount of *Pseudotsuga menziesii* grown.

Laws and policies concerning genetic conservation of exotics

Management of exotic genetic resources is becoming institutionalized in some countries. Five respondents from the thirteen countries surveyed reported having domestic laws or policies concerning genetic diversity and/or conservation of exotic forest tree species, including those of the North American temperate zone. These range in complexity and formality from seed zone designations in Hungary affecting black locust (*Robinia pseudoacacia* L.), red oak (*Quercus rubra* L.), Douglas-fir, and black walnut, to specific laws in Germany (see Box 12). In Australia, the emphasis is on policies rather than laws. For example, the Queensland Forest Service subscribes to the maintenance of genetic diversity in exotic plantations and has a deliberately designed suite of seed orchards, clone banks, multiple breeding populations, and conservation populations. France has a national forest genetic conservation program, applied now to autochthonous species such as European silver fir (*Abies alba* Mill.), European beech (*Fagus sylvatica* L.), elm (*Ulmus* spp.), mazzard cherry (*Prunus avium* L.), and provisionally to North American species. All countries belonging to the European Union are also subject to pan-European regulations. In New Zealand,

Table 16. Contribution of North American forest tree species to domestic supply of wood and wood products in countries where they are grown as exotics

Country	Comment (percentage of domestic demand supplied by North American forest tree species grown in the responding country)
Argentina	ca. 42%—mainly *Pinus elliottii* and *P. contorta*.
Australia	*Pinus radiata* and *P. elliottii* are major contributors to Australia's wood production. Australia is a net importer of forest products, in value. A significant proportion of imports are *P. radiata* sawn timber, pulp, and paper from New Zealand. Sawn timber production from Australian *Pinus radiata* plantations has increased steadily while production from native eucalypt forests has decreased. For example, in 1992 saw and veneer log production of eucalypts was 4,098,000 m^3 and for pine plantations (90% *P. radiata*) production was 4,562,000 m^3 (source: ABARE 1994).
Australia (Queensland)	*Pinus elliottii*—small but significant amount.
Brazil	Temperate *Pinus* spp.—ca. 20% of domestic wood and wood product demand.
Chile	Chile is self-sufficient in wood supply and a net exporter. Of the domestic supply, *Pinus radiata* contributes 70%, eucalypts 20%, and native species 10%.
China	Much—especially *Populus euramericana, Populus deltoides, Pinus elliottii,* and *Robinia pseudoacacia*.
France	ca. 7% (*Pseudotsuga menziesii*—600,000 m^3; Euroamerican poplars—2,850,000 m^3; total French wood production = 52,064,000 m^3).
Germany	*Pseudotsuga menziesii*—provides 2 to 3%; other species—less than 1%. Locally, the production of Christmas trees and branches for ornamental purposes of *Abies* spp., *Picea pungens, Pseudotsuga menziesii, Pinus strobus,* and *Quercus rubra* is of importance.
Greece	Poplars contribute ca. 12.5% of domestic wood production, but this figure includes native and non-American spp. as well.
Hungary	Out of the annual cut of 5,700 thousand m^3, *Robinia pseudoacacia* takes a share of 1,172 thousand m^3 (21%). It is, however, a low-value timber, so the value share is less than 15%.
New Zealand	*Pinus radiata* satisfies nearly 90% of domestic roundwood equivalent demand, of which a rapidly rising proportion (now nearly 60%) serves export markets (total current receipts: 1.8 billion USD = 500 USD per capita). *Pseudotsuga menziesii* also makes an appreciable contribution (ca. 5%).
South Africa	40% or less (most is supplied by eucalypts).
Spain	Approximately 17% of the domestic wood supply is provided by *Pinus radiata*. Hybrid poplar clones (*Populus deltoides* × *P. nigra*) contribute approx. 6%. There is a timber deficit in Spain.
United Kingdom	Across all species, 10% of domestic wood demand is met from home-grown sources. *Picea sitchensis* provides over half of this (i.e., 5% of domestic demand), but detailed figures are not available.

policies concerning genetic diversity in forest plantations are being developed or modified in keeping with the changes in land ownership (Box 13).

Patterns in ownership of the land resources and the genetic resources

Conservation interests and activities are influenced by the ownership patterns of both the plantation landbase and the germplasm reserves. In countries where North American temperate forest tree species are grown as exotics, much of the land used for such plantations is owned by private interests (Table 22). Exceptions are Australia and China where most of the exotic plantations are on publicly owned land. In Germany and the United Kingdom, the division between private and public ownership of these plantations is approximately equal. In several countries, the ownership pattern is species-specific (e.g., Hungary and South Africa).

While much of the forest plantation landbase is in the private sector, germplasm reserves in most of these same countries are more often in the public domain. One exception is Chile, where each company owns its own breeding material. The situation is more complicated for New Zealand and South Africa (see Box 14 and Box 15, respectively). In New Zealand, cooperatives are substantially involved in germplasm ownership and management. In South Africa, the situation is changing, mainly in the direction from public to private ownership.

Table 17. Trade in North American forest tree germplasm reported for various countries where North American species are grown as exotics[1]

Country	Comment
Argentina	*Pinus elliottii* and *Pinus taeda*—500 to 2,500 kg of seeds sold per year.
Australia	*Pinus elliottii*—small amount marketed from Queensland.
Brazil	Approximately $100,000 earned annually from first-generation clonal seed orchards of *Pinus taeda*.
Chile	None.
China	*Robinia pseudoacacia*—seed, cuttings; *Pinus elliottii*—seed in large quantity.
France	*Pseudotsuga menziesii*—annual seed need represents 1 ton/year, 3/4 imported from the natural area corresponding to 14 million seedlings produced. *Populus*—2 million cuttings from local production. *Quercus rubra*—5 million seedlings produced and sold. *Picea sitchensis*—2 million seedlings produced and sold. *Abies grandis*—777,000 seedlings produced and sold.
Germany	Export of germplasm of North American species produced in Germany is without importance.
Greece	No details available.
Hungary	None at present (years ago, *Robinia pseudoacacia* material had some value).
New Zealand	*Pinus radiata*—seed sold to Australia annually (1,000 kg of unimproved stock from Canterbury, Wairarapa, and central North Island after 1983; 1,000 to 2,000 kg/year of highly improved orchard seed 1989–93; 400 kg/year of more intensively improved orchard seed). Smaller amount of highly improved seed sold opportunistically to Chile and Spain.
South Africa	None.
Spain	No details available.
United Kingdom	Very small amount of *Picea sitchensis* and *Pinus contorta* sold to Republic of Ireland.

[1]Questionnaire responses included both domestic and export sales.

Table 18. Adequacy of gene pool reserves in countries where North American forest tree species are grown as exotics

Country	Comment
Argentina	In general, the gene pool reserves for most of the North American, Central American, and Mexican conifers are precarious. There is much concern about the availability of these resources because exploitation of pines in México and Central America is causing what is known as 'genetic impoverishment'. Federal regulations (influenced by 'naturalists', as is the case in México) are also becoming a problem as they lead to policies which do not allow one to make tree seed collections in threatened populations. The existence of cooperative tree improvement programs, funded by private companies in the U.S.A., is also a barrier as their members are reluctant to allow collections from their land or share genetic resources from their *ex situ* collections (i.e., *Pinus elliottii* and *P. taeda*). International cooperatives such as CAMCORE are making progress with testing and improving the Central America and México conifers on an international scale but this is expensive and exclusively for those who can afford it (i.e., big pulp companies).
Australia	Australia has taken steps which allow it to rely mainly on existing *ex situ* plantations for germplasm. The opportunity to return to native stands as sources of resistance to pests and diseases not yet established in Australia is important. Therefore, the continued availability of native germplasm may be of great value in the future. The population of *Pinus radiata* on Guadalupe Island, México, appears to be threatened with extinction and there seems to be little prospect of further procurement of germplasm from that native source.
Australia (Queensland)	Current reserves of *Pinus elliottii* are considered adequate having been consciously broadened and protected.
Brazil	Not known whether present reserves are adequate; further procurement is essential to maintain a high level of genetic diversity.
Chile	Genetic base is sufficient; all the natural populations of *Pinus radiata* have been sampled for future breeding.
China	There are inadequate gene pool reserves for most of the exotic temperate zone tree species—the genetic bases need to be broadened.
France	*Pseudotsuga menziesii*—adequate gene pool reserves. *Populus*—adequate. *Quercus rubra*—adequate.
Germany	No details available.
Greece	Not adequate.
Hungary	For *Robinia pseudoacacia*, reserves are adequate even if of unknown origin. *Pseudotsuga menziesii* is planted irregularly, using mostly imported seed from the U.S.A., not always the best possible sources. All others are locally regenerated. No concerns.
New Zealand	Main gaps exist in sketchy genetic bases (geographically and numbers-wise) for *Cupressus lusitanica* and some minor species, viz. *Sequoia sempervirens*, *Abies grandis*, *Pinus attenuata*. Future maintenance and management likely to be a more important issue than existing gaps for most species. In some cases, immediate supplies of appropriate seed are more of a problem than long-term availability of germplasm.
South Africa	Fairly adequate. The CAMCORE program helped a lot. Some exchange was done with U.S.A. breeding programs. However, additional species from México are currently being evaluated and if they are found to have commercial value, additional germplasm will need to be procured from native sources.
Spain	Genetic base of all species should be extended. There are not adequate gene pool reserves yet.
United Kingdom	*Picea sitchensis*—need additional provenances from the southern portion of its range for breeding, otherwise adequate. *Pinus contorta*—adequate. *Pseudotsuga menziesii*—additional U.S.A. material needed to boost home supply and for breeding purposes. Other species (*Abies grandis, Abies procera, Tsuga heterophylla, Thuja plicata*) normally adequate but demand is currently low.

Table 19. Genetic diversity in plantations and reserves of North American forest tree species in those countries where they are grown as exotics

Country/species	Plantations (Genetic diversity)[1]	Reserves (Genetic diversity)[1]
Argentina		
Araucaria angustifolia	A	A
Pinus caribaea	A	A
Pinus elliottii	A	A
Pinus ponderosa	A	A
Pinus taeda	A	A
Populus spp.	B	C
Salix spp.	B	C
Australia		
Hybrid pines	A	D
Pinus elliottii	A	D
Pinus muricata	A	D
Pinus radiata	A	D
Pinus taeda	A	A
Populus spp.	B	C
Brazil		
Pinus elliottii	C	C
Pinus patula	E	C
Pinus taeda	C	C
Chile		
Pinus radiata	C	D
Pseudotsuga menziesii	A	A
China		
Amorpha fruticosa	Unknown	Unknown
Cupressus lusitanica	A	A
Juniperus virginiana	E	E
Liriodendron tulipifera × *chinensis*	B	B
Pinus banksiana	A	A
Pinus elliottii	C	D
Pinus rigida	A	A
Pinus taeda	C	D
Poplar hybrids	C	E[2]
Populus deltoides	C	D
Robinia pseudoacacia	C	D
Taxodium distichum	D	D
France		
Abies grandis	A	D
Picea sitchensis	A	D
Populus spp.	B	D
Pseudotsuga menziesii	C	D
Quercus rubra	A	D
Robinia pseudoacacia	E	A
Germany		
Abies grandis	C	–
Picea sitchensis	C	–
Pinus strobus	B	D
Germany (continued)		
Populus spp.	B	D
Pseudotsuga menziesii	C	D
Quercus rubra	C	C
Greece	No details available	
Hungary		
Acer negundo	E	None
Fraxinus pennsylvanica	E	E
Juglans nigra	E	E
Pseudotsuga menziesii	A	A
Quercus rubra	E	E
Robinia pseudoacacia	C	C
New Zealand		
Abies grandis	A	A
Cupressus lusitanica	A	C
Cupressus macrocarpa	D	D
Juglans nigra	A	D
Pinus attenuata	–	D
Pinus contorta	C	C
Pinus muricata	C	F[3]
Pinus ponderosa	C	C
Pinus radiata	A	D
Pinus strobus	A	C,D
Pinus taeda	A	–
Pseudotsuga menziesii	C	C
Sequoia sempervirens	A	B,C
South Africa		
Pinus elliottii	C	C
Pinus patula	C	C
Pinus radiata	C	D
Pinus taeda	C	C
Spain		
Chamaecyparis lawsoniana	A-B	D
Pinus radiata	A	A
Populus spp.	B	F[4]
Pseudotsuga menziesii	A	C
Quercus rubra	A	–
Sequoia sempervirens	A	D
United Kingdom		
Abies grandis	C	D
Abies procera	E	D
Picea sitchensis	C	D
Pinus contorta	C	D
Pseudotsuga menziesii	C	D
Thuja plicata	A	D
Tsuga heterophylla	A	D

[1]This is an average or generalization for the country. The genetic base also varies by plantation ownership. For example, see Box 10. A = Only a few provenances or seed sources; B = Only a few clones; C = Provenances or clones representing most of the natural range for the species that is considered similar and adaptive to the range in which it is planted in the country; D = Provenances or clones representing most or all of the natural range of the species; E = unknown sources; F = Other (see footnotes below). The minor species are not necessarily listed for each country.

[2]More than 300 clones from 10 countries.

[3]Southern half of range virtually lost.

[4]Hybrid collections.

Table 20. Gene pool reserves of North American forest tree species in countries where they are managed as exotics

Country/species	Type of reserve
Argentina	
Pinus contorta	Provenance tests
Pinus elliottii	Provenance tests
Pinus patula	Provenance tests
Pinus ponderosa	Provenance tests
Pinus taeda	Provenance tests
Populus spp.	Clonal tests
Salix spp.	Clonal tests
Australia	
Pinus attentuata	Provenance trials
Pinus elliottii	Seed orchards, clone banks, seedbanks, provenance trials
Pinus muricata	Provenance trials
Pinus radiata	All types of reserves
Pinus taeda	Archives, provenance trials
Populus spp.	Archives, provenance trials
Pseudotsuga menziesii	Provenance trials
Brazil	
Pinus elliottii	Seed orchards
Pinus patula	Seed orchards
Pinus taeda	Seed orchards
Chile	
Pinus radiata	Seed orchards, clone banks, family trials, hedge orchards
China	
Pinus elliottii	Clonal gene pools (5 sites); 5 seed orchards, seed production areas; hedge orchard
Pinus taeda	Clonal gene pools—5 sites
Populus deltoides	2000 clones in gene pool
Robinia pseudoacacia	Clone bank, seed orchards, seed production areas
France	
Picea sitchensis	Clone banks, seed orchards
Populus spp.	Clone banks
Pseudotsuga menziesii	All types except tissue culture
Quercus rubra	Clone banks
Germany	
Abies grandis	Some registered seed stands
Picea sitchensis	Some registered seed stands
Pinus strobus	Some registered seed stands
Populus spp.	Clonal archives
Pseudotsuga menziesii	Some registered seed stands
Quercus rubra	Some registered seed stands
Greece	
Populus spp.	Clonal hedge orchards
Hungary	
Pseudotsuga menziesii	Provenance collections
Robinia pseudoacacia	Clone banks, seed orchards, hedge orchards
New Zealand	
Abies grandis	Provenance trials
Cupressus macrocarpa	Progeny trials, gene resource plantings, archived selected clones
Juglans nigra	Provenance and progeny trials, selected progenies
Pinus attenuata	Provenance trial, a few archived clones
Pinus contorta	Provenance trials, progeny trials, clonal orchard, seedling seed orchards
Pinus muricata	Provenance trials, progeny trial, archived selected clones, gene resource plantings
Pinus patula	Provenance collection
Pinus ponderosa	Provenance trials, single provenance seed stand
Pinus radiata	All types
Pinus strobus	Provenance trial
Pseudotsuga menziesii	Provenance trials, progeny trials, archived clones, seed orchards
Sequoia sempervirens	Provenance trial, tissue-cultured clones
South Africa	
Pinus elliottii	Seed orchards, family trials, provenance trials, seedbanks
Pinus patula	Seed orchards, family trials, provenance trials
Pinus radiata	Seed orchards, family trials, provenance trials
Pinus taeda	Seed orchards, family trials, provenance trials, clonal archives
Spain	
Pinus radiata	Seed orchards
Populus deltoides	Clonal banks
Pseudotsuga menziesii	A small, noncommercial seed orchard
Sequoia sempervirens	Small, noncommercial hedge orchard
United Kingdom	
Abies procera	Provenance collections
Abies grandis	Provenance collections
Picea sitchensis	Seed orchards, clone banks, clonal hedges, tissue culture, provenance collections
Pinus contorta	Seed orchards, clone banks, provenance collections
Pseudotsuga menziesii	Seed orchards, clone banks, provenance collections
Thuja plicata	Clone banks, provenances
Tsuga heterophylla	Provenance collections

Table 21. Status of records on geographic origin of North American temperate forest tree germplasm used in exotic plantations

Country/species	Proportion of germplasm	Precision of record
Argentina		
Pinus contorta	Some	Unknown source
	Most	Region known
Pinus elliottii	Most	Unknown source
	Some	Specific seed source
Pinus patula	All	Specific seed source
Pinus ponderosa	Half	Unknown source
	Half	Region known
Pinus radiata	All	Unknown source
Pinus taeda	All	Specific seed source
Populus spp.	Most	Known clones
Pseudotsuga menziesii	Most	Unknown source
	Some	Region known
Salix spp.	All	Known clones
Australia		
Pinus radiata	Most	General region
	Some	Specific source
Populus spp.	Most	Unknown source
	Some	Specific source
Australia (Queensland)		
Pinus elliottii	Some	General region
Pinus taeda	Some	General region
Brazil		
Pinus elliottii	Most	Region unknown
	Some	General region
	Few seedlots	Specific provenance
Pinus patula	Most	Region unknown
Pinus taeda	Most	Region unknown
	Some	General region
	Few seedlots	Specific provenance
Chile		
Pinus radiata	Most	Specific seed source
	Few	Unknown
Pseudotsuga menziesii	Most	Unknown source
China[1]		
Amorpha fruticosa	All	Unknown source
Cupressus lusitanica	Some	Specific seed source
Juniperus virginiana	Most clones	Unknown source
Liriodendron tulipifera	Few clones	Specific source
Pinus banksiana	Some	Specific seed source
Pinus elliottii	Most	Specific seed source
Pinus rigida	Some	Specific seed source
Pinus taeda	Most	Specific seed source
Populus deltoides	Some	Specific seed source
Populus euramericana	Some	Specific seed source
Robinia pseudoacacia	Some	Specific seed source
Taxodium distichum	Some	Specific seed source
France		
Abies grandis	Most	Unknown
	Some	General region
Picea sitchensis	Most	Unknown
	Some	General region
France (continued)		
Populus spp.	Most	Specific seed source of clone's parents
	Some	Unknown source
Pseudotsuga menziesii	Most	Unknown source
	Some	General region
Quercus rubra	All	Unknown origin
Robinia pseudoacacia	All	Unknown seed source
Germany		
	All	In older plantations, the seed source is generally unknown or known only by region. In newer plantations, seed zone is known.
Greece		
Populus clones	Most	Varied
Hungary		
Pseudotsuga menziesii	Most	Unknown source
	Few	General region
Robinia pseudoacacia	Most	Unknown source
	Most clones	Unknown origin
	Some clones	Known origin
Other hardwoods	All	Unknown
New Zealand		
Abies grandis	All	Origin unknown
Juglans nigra	Most	General origin
	Some	Specific origin
Pinus contorta	Half	General region
Pinus muricata	All	Provenance known
Pinus patula	Almost all	Origin unknown
Pinus ponderosa	Some	General region
	Most	Specific origin
Pinus radiata	Most	General region
	Some	Specific origin
Pinus strobus	Most	General region
	Some	Specific origin
Pinus taeda	All	General region is 'suspected'
Pseudotsuga menziesii	Half	General region
	Half	Specific origin
Sequoia sempervirens	Almost all	General region
South Africa		
Pinus elliottii	Most	General region
	Some	Specific seed source
Pinus patula	Most	Unknown
	Some	Specific seed source is on file
Pinus radiata	Most	General region
	Some	Specific seed source
Pinus taeda	Most	General region
	Some	Seed source

[1]Early introductions, before 1970s, were made mostly of unknown sources.

Table 21. (continued)

Country/species	Proportion of germplasm	Precision of record	Country/species	Proportion of germplasm	Precision of record
Spain			**Spain** (continued)		
Chamaecyparis lawsoniana	Most	Unknown source	*Quercus rubra*	Most	Specific secondary source (from European stands)
	Some	Known clones			
Pinus radiata	Most	General region	**United Kingdom**		
	Some	Seed orchard source	All species, all plantations less than 40 years old	Most	Specific seed source
Populus deltoides hybrids	All	Known clones		Some	Only general region
Pseudotsuga menziesii	Most	Unknown source		Few	Origin unknown
	Some	Specific provenance			

Ecosystem effects of exotic plantations

North American temperate forest tree species could affect ecosystem properties in other countries where they are grown as exotics through the mechanisms of displacement and/or invasiveness (including hybridization). Displacement is a complicated issue, not unique to the use of North American temperate forest tree species as exotics. Many exotic plantations have been established on marginal or converted agricultural land so exotics have not displaced native vegetation directly. In addition, the growth potential of fast-growing commercial tree plantations can be strongly supportive of conservation of native ecosystems. (Refer to the introduction of this section for further commentary on this topic.)

The factors determining whether a species is likely to become invasive have been well discussed in other venues (e.g., Richardson et al. 1994). Invasive characteristics can be advantageous when natural regeneration of the exotic species is desired, or the species is being used in land reclamation efforts (see Box 16). For example, native tree species cannot tolerate the high levels of industrial pollution characteristic of the 'black triangle' in Europe. However, Sitka spruce and blue spruce (*Picea pungens* Engelm.), both North American species, can be used to provide cover and an economic crop until the environmental problem is corrected (see Box 17). Nevertheless, the natural spread of exotics into natural areas, disrupting or competing with native vegetation, may be undesirable. Thus, invasiveness has a spectrum of possible impacts, from benign to threatening.

Recognizing that species introductions affect native ecosystems and local cultures and economies, we **recommend** *the development of guidelines for the introduction of species. These guidelines should include general procedures for conducting risk analyses for biological, social, and economic factors as well as general procedures for monitoring the species after introduction.* (Rec. no. 11)

Workshop participants suggested that temperate forest tree species tend to exhibit fewer characteristics typical of invasiveness than do tropical tree species. Nevertheless, examples of North American forest tree species that exhibit some level of invasiveness in other countries are numerous (Table 23). Generally, the invasiveness is described as natural regeneration in plantations and marginal spread from plantations. While long distance and/or troublesome spread of an exotic species is rare, modest levels of invasiveness have been reported in numerous cases, a small sample of which includes black locust in Greece, lodgepole pine and Douglas-fir in New Zealand, and Monterey pine in Australia.

In a study of pine invasions in the Southern Hemisphere, Richardson et al. (1994) found that of the 16 pine species identified as 'invasive' (i.e., the species regenerated naturally and recruited seedlings more than 100 m from parent plants) nine are North American temperate forest species. As an example, Monterey pine is a troublesome invader in the Western and Eastern Cape Provinces along the coastal zone in South Africa (see Box 18).

Box 10
Genetic diversity within plantations and reserves of North American species managed in South Africa

Based on questionnaire responses, the amount of genetic diversity represented in commercial plantations outside of the native range varies by species, by country of plantation, and by ownership of landbase within the host country. In South Africa, for example, there is a good sample of provenances from much of the natural range of the four major pine species that are grown there as exotics: *Pinus patula* Schl. et Cham., *P. elliottii* Engelm., *P. radiata* D. Don, and *P. taeda* L. However, the genetic sample varies with land ownership—being somewhat more restricted in plantations and genetic reserves belonging to private industry (e.g., Sappi, HL&H, Mondi) than in government-owned (SAFCOL) plantations. In this particular case, there is little difference between the amount of genetic diversity in the plantations and that residing within genetic reserves (e.g., seed orchards, provenance tests, seedbanks, etc.).

	Plantations			Reserves		
Ownership[1]	SAFCOL	HL&H	Sappi	SAFCOL	HL&H	Sappi
	(Amount of genetic diversity)[2]					
Pinus patula	–	–	C	–	–	C
Pinus elliottii	C	B	A	C	B	B
Pinus radiata	C	–	–	C	–	–
Pinus taeda	C	B	A	C	B	A

[1]SAFCOL, the South African Forestry Company Limited, is a 'government company', the state being the only shareholder. Sappi and HL&H are two of the three largest private companies with exotic plantations. Together with a third company, Mondi, they collectively own and manage over 80% of the area of South Africa's private forest plantations.

[2]A = Only a few provenances or seed sources; B = Provenances or clones representing most of the natural range of the species that is considered similar to the range in which it is planted in South Africa; C = Provenances or clones representing most of the natural range of the species.

Deborah L. Rogers

Cases of natural hybridization between native species and North American temperate forest tree species in countries where they are grown as exotics are rare. The known exceptions are among native and exotic *Populus* species in Europe, where poplar cultivation is important. Generally, such poplar hybrids have been utilized to good advantage in the domestication of the genus. There are a few examples of hybridization with natives among species of *Cupressus* and *Larix*, but to a lesser degree.

As the degree of invasiveness is specific to the species and the situation, and the effect of invasiveness varies from benign or desirable to ecologically threatening, guidelines for the introduction and management of exotic species that encourage carefully considered and responsible management are preferable to potentially limiting, ill-suited, or even counter-productive laws.

The choice of plantation species and genetic source are critical, not only to avoid the negative impacts of invasiveness or hybridization with natives, but to ensure the survival and intended productivity of the plantation. Otherwise, the beneficial effects of the exotics, as wood producers in lieu of native species, are lost. During the workshop Dr. Rowland D. Burdon of New Zealand commented:

> There is one problem with *Pinus radiata*: it is such an attractive species commercially that there are always great temptations to grow it in environments that turn out to be submarginal. There have been many cases in the literature of successful establishment of *P. radiata*, but after four or five years it very often fails and that is hardly ever reported in the literature. There are certain fairly restricted environments where it will perform well. And it can **start** well in many other environments and then, later on, it can fail disastrously.

Biological threats to exotic reserves/plantations

North American temperate forest tree species do not entirely escape insect and disease impacts when grown as exotics. Most species are subject to at least mild attacks from one or more insect species or diseases in almost every country where they are grown (Table 24). However, in most cases, the problems are not serious, but do have genetic implications. If the genetic basis of the exotic plantations is too restricted, insect and disease problems might become more serious. Where there is a genetic basis for resistance to the insect or disease, the pest exerts a selection pressure on the exotic species. Such selection could be turned to commercial advantage, but also further restricts the genetic base.

International transfer of germplasm

In addition to the original and continuing export of North American temperate forest tree species to other countries, two additional types of international trade activity exist. The first is the export of these materials among nonoriginating (i.e., non-North American) countries for commercial and/or research purposes. Every country surveyed, except Chile, China, and Argentina, exports some North American temperate forest tree germplasm to other countries (Table 25). The commercial implications are apparent, but there

Box 11
Ex situ conservation reserve of the Guadalupe Island population of *Pinus radiata* D. Don

An important and successful *ex situ* conservation planting was made in Australia in 1994 to conserve the Guadalupe Island population of *Pinus radiata* D. Don which is threatened with extinction (Figure 9). The Southern Tree Breeding Association Inc. (STBA) planted 23 hectares of Guadalupe seedlings, at 5.0 x 5.0 m spacing, near Tantanoola, north of Mount Gambier, in the state of South Australia. The seed came from 44 families collected on Guadalupe in 1978 and 76 families collected in 1992. Basilio Bermejo Velázquez found only about 150 native trees alive on Guadalupe Island when he collected there in 1992 with CAMCORE. Bill Libby and I (and several other enthusiasts for conservation of forest genetic resources) counted 378 in 1978 (Libby 1978). Libby et al. (1968) counted 383 in 1964. So the population is definitely on the way to extinction—there is no regeneration, due to the grazing pressure of numerous goats.

It is planned that seeds for the next generation will be collected in the center of the *ex situ* block when the adjacent routine plantation of radiata pine is felled and regenerated at about age 30 years. There will be a 'window of opportunity' for a few years when unwanted pollen from routine plantations is at a minimum. The Tantanoola planting is intended as a long-term replacement for the native forest on Guadalupe Island.

The *ex situ* reserves in South Australia may be a source of seed for restoring Guadalupe Island pine should the dire prediction of extinction be fulfilled.

Kenneth G. Eldridge

Figure 9. Monterey pine (*Pinus radiata* D. Don) native to México's Guadalupe Island is a significant but endangered genetic resource. (Photo courtesy of Constance I. Millar, Pacific Southwest Research Station, USDA Forest Service, Berkeley, California, U.S.A.)

are also management and genetic considerations. This type of activity creates a greater record-keeping challenge in maintaining the original geographic identity of the germplasm. It also potentially compounds selection pressures on the germplasm, modifying it from the original populations.

The second type of export activity now occuring to a small degree is the export back to North America from a country where the species was grown as an exotic. For example, germplasm from loblolly pine and slash pine has been exported from South Africa to the United States. Small-scale transfers of Monterey pine have been made from Australia to the United States for genetic trials. Similarly, repeated seed sales of Monterey pine from New Zealand have been made to nurserymen in the United States for commercial use. Minor donations have been made to others for genetic trials.

Recognizing the importance of the Convention on Biological Diversity, the benefits of unrestricted exchange of germplasm, and the distinction between forest genetic resources and those of domesticated crops, we **recommend** *that the forest genetic community provide leadership in addressing the emerging issues of intellectual property rights, indigenous peoples' rights, and plant breeders' rights as they pertain to forest genetic resources.* (Rec. no. 12)

The 'repatriation' of native species may benefit research, commercial interests, and conservation (through reforestation) in the future. During the workshop, William S. Dvorak commented that: "Generally, the transfer of genetic material for the management of genetic resources is something **very positive.**" Historically, however, some transfers have

Box 12
Laws and policies concerning the conservation of genetic resources in the Federal Republic of Germany (FRG)

In the FRG, policies concerning genetic conservation of forest tree species, including exotics, are influenced by edicts from several levels: 1) European Union; 2) Federal Government; 3) Governments of the Federal States of Germany; and 4) by other organizations (communities, private institutions, etc.). The lower levels are always influenced by laws and regulations of the higher levels.

The main federal laws pertaining to genetic conservation are:

1. *Gesetz über forstliches Saat- und Pflanzgut* (Law on forest seed and planting material)—from September 25, 1957; new ed. July 26, 1979. This law applies to 18 species and the genus *Populus*, including the main North American species grown in FRG, such as grand fir (*Abies grandis* (Dougl.) Lindl.), Sitka spruce (*Picea sitchensis* (Bong.) Carr.), eastern white pine (*Pinus strobus* L.), *Populus* spp., Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and red oak (*Quercus rubra* L.). The law specifies the minimum requirements concerning basic reproductive material, which has to be selected or tested. Further details are specified in additional regulations.

2. *Gesetz zur Erhaltung des Waldes und zur Förderung der Forstwirtschaft* (Law on the conservation of forests and the promotion of forestry)—from May 2, 1975.

3. *Gesetz zu dem Übereinkommen vom 3. März 1973 über den Internationalen Handel mit gefährdeten Arten freilebender Tiere und Pflanzen* (Law to the convention from March 3, 1973 on the international trade with endangered species of wild-living animals and plants)—from May 22, 1975.

4. *Gesetz über Naturschutz und Landschaftspflege* (Law on the protection of nature and landscape management)—from December 20, 1976; new ed. March 12, 1987.

5. *Gesetz zu dem Übereinkommen vom 19. September 1979 über die Erhaltung der europäischen wildlebenden Pflanzen und Tiere und ihrer natürlichen Lebensräumen* (Law to the convention from September 19, 1979 on the preservation of European wild-living plants and animals and their natural habitats)—from July 17, 1984.

6. *Gesetz zu dem Übereinkommen vom 5. Juni 1992 über die biologische Vielfalt* (Law to the convention from June 5, 1992 on biological diversity)—from August 30, 1993.

Furthermore, there exists an important working document called '*Konzept zur Erhaltung forstlicher Genressourcen in der Bundesrepublik Deutschland*' (Concept for the preservation of forest gene resources in the FRG)—from January, 1987. This document is mainly implemented by the Federal States which decide on the protection of species, populations, and areas; make collections; issue special management or protection regulations, etc.

Hans-J. Muhs and Armin König

Box 13

Policies concerning the maintenance of genetic diversity in New Zealand

In New Zealand, tree breeders within the New Zealand Forest Research Institute (NZFRI) emphasize genetic diversity, particularly in size and base of breeding population and genetic resources. When State Forests were corporatized (which has been followed by ongoing privatization), certain restrictions on land use were conditions of the handover and subsequent sales. These restrictions, called covenants, often included the protection of pre-existing experiments, designated seed stands, and other materials that rated as significant genetic resources. The covenants, overseen by NZFRI, are not without their problems. Some of the existing covenants are currently under review in anticipation of further privatization of state-owned forests. Industrial plantation owners are beginning to express interest in developing voluntary codes for minimum levels of genetic diversity within plantation estates. Another commitment to the maintenance of genetic diversity is an increase in government funding for research on alternative species (i.e., alternatives to Monterey pine (*Pinus radiata* D. Don)), and the work places considerable emphasis on species for complementary utilization niches. There is also an initiative within the NZFRI to address the issue of 'contingency species' (i.e., species that might be used in the event of serious biological problems affecting Monterey pine in all or part of the country).

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proven disastrous for North America. The importation of eastern white pine seedlings from Europe was the source of introduction of the white pine blister rust into Canada and the United States. The effects of that introduction have not yet culminated. New infestations of the fungus have recently been found in Arizona and the disease may yet spread to México (see Box 19).

Even current policies and practices related to international transfer of forest genetic resources are not entirely successful in preventing the introduction of exotic pests. One reason is that the infrastructure to enforce standards and screen for potential disease problems is frequently inadequate—sufficient funds for enforcement are often lacking (see Box 20). In the long term, exclusion of any pest may prove impossible.

Current policies regarding international transfer of germplasm may require review in many countries in view of the changing attitudes towards natural resources. Under the Convention on Biological Diversity, countries with high forest biodiversity are being encouraged to conserve these resources and to seek an appropriate share in any benefits, if only to defray the substantial costs associated with *in situ* conservation (Fryer 1994).

In some cases, proprietary issues and funding problems can restrict exchange of genetic materials beyond what is required for biological protection. Proprietary questions often apply to improved materials where the concern is how to receive compensation for the investments in selection and breeding. However, it might also apply to natural populations and to government-owned resources, as well as to private industries' holdings. It has been suggested, for example, that: "Australia, in seeking to develop new rural industries and to enhance the competitiveness of those existing industries, might similarly question the open access it has granted to forest genetic resources in the past" (Fryer 1994). Lack of funds for germplasm collection may also limit the exchange of genetic resources (see Box 21).

Emerging issues that will affect the exchange of genetic resources are: agreements for bio-prospecting rights; the question of intellectual property rights and plant patents; the Convention on Biological Diversity; the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES); and political problems between countries and civil chaos within.

Global interests in *in situ* conservation of North American temperate forest tree species

"The value of North American forest tree genetic resources to numerous people outside North America needs strong emphasis" (Kenneth G. Eldridge, personal communication, June 22, 1995). Regardless of the amount of area covered in exotic plantations, the

Table 22. Land ownership patterns where North American forest tree species are grown as exotics

Country	Ownership of plantation land
Argentina	Private ownership of virtually all. In the south, provincial governments are planting via semi-private corporations.
Australia	Most of the conifers are grown on public land (1/3 of *Pinus radiata* is grown on private land). Almost all poplars (mainly *Populus deltoides*) are grown on private land.
Australia (Queensland)	Public ownership (State of Queensland) of all *Pinus elliottii* and *P. taeda*
Brazil	Private ownership of almost all. Very small amount (4 to 6%) owned by federal and state governments.
Chile	All privately owned. Forest industry owns 70% of the *Pinus radiata* plantations and 40% of the *Pseudotsuga menziesii* plantations. Private land owners account for the rest.
China	In northern China, all forest plantations are owned by the state. In southern China, however, most of the forest plantations (85 to 90% of plantation area) are owned by collectives—townships or villages. Overall, approximately 80% of the plantation land is state-owned, and 20% is collectively owned. Germplasm reserves are owned and managed by the state. Regardless of ownership, forest bureaus determine management practices.
France	Almost all owned by private owners. Some (2 to 17%, by species) owned by villages and some (1 to 13%, by species) by the federal government.
Germany	In the states of the former West Germany, 30% of the forests were owned by the state, 24% by communities, and 46% by private owners. In the new states (formerly East Germany), the process of rearrangement is not complete, but percentages will be similar.
Greece	For almost all of these species, approximately 2/3 is privately owned and 1/3 is state-owned. For *Robinia pseudoacacia* 3/4 is state-owned and 1/4 is privately owned.
Hungary	For *Robinia pseudoacacia*, *Quercus rubra*, and *Fraxinus pennsylvanica*, most (60 to 70%) is grown on private land, the remainder on state forest land and land of other government agencies. The situation is reversed for *Juglans nigra*, *Pseudotsuga menziesii*, and *Pinus strobus*, where most (80 to 100%) is grown on state forest land, and a small amount of *Juglans nigra* is grown on private forest land and land of other government agencies.
New Zealand	Most plantations are owned by large private companies (e.g., Carter Holt Harvey and Tasman Forestry). Unsold state forest and a state-owned enterprise (Forestry Corporation of New Zealand) host approximately 15% of the plantations. Maori land hosts approximately 3 to 4%. The most rapidly expanding sector for forest plantations is individual owners and small private companies.
Spain	Land ownership varies by species. For *Populus* species, most of the plantations are privately owned. For *Quercus rubra*, 30 to 40% of the land is privately owned; 60 to 70% is owned by local administration. For *Pinus radiata* in the Basque country, 80% is privately owned and 20% is owned by local administration. In the rest of Spain, local administration owns 60 to 70% of the *P. radiata* plantation area; 30 to 40% is privately owned.
South Africa	For *Pinus patula* and *P. taeda*, approx. 2/3 is owned by private companies (mainly three big companies—Sappi, Mondi, and HL&H), with the remainder owned by government and SAFCOL—a government company. For *Pinus elliottii*, the split is approximately 50:50 (government:private industry). For *Pinus radiata*, approximately 2/3 is government-owned, and 1/3 private industry.
United Kingdom	For most species, approximately half the plantation area is state-owned and half is in the private sector. For *Pinus contorta*, 80% is state-owned and 20% is in the private sector.

native populations of commercially important North American forest tree species are valued by other countries. This condition is dramatically demonstrated for Monterey pine, a species with large international, but negligible domestic, value for timber and fiber (see Box 22). Even though the genetic reserves in New Zealand and Australia contain considerable diversity, these countries are still interested in conserving the native genetic sources because: 1) *ex situ* conservation plantings are ephemeral in the long term; and 2) *ex situ* conservation plantings are contaminated more and more in successive generations (i.e., from pollen from other provenances when generations advance by open pollination), thereby increasing the interest in 'pure' native populations. Indeed, the entire coastal fog belt of California, Oregon, and Washington is an area of

Box 14
Ownership of exotic forest tree germplasm in New Zealand

In New Zealand, the ownership of select genetic material of Monterey pine (*Pinus radiata* D. Don) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) is vested in New Zealand Forest Research Institute (NZFRI)/Industry Cooperatives, even though most of the material is physically on the forest holdings of industry members. Other genetic material of interest, especially of the minor species, which includes some collections of considerable international significance (i.e., Douglas-fir, Monterey cypress (*Cupressus macrocarpa* Hartw.), ponderosa pine (*Pinus ponderosa* Laws.), lodgepole pine (*Pinus contorta* Dougl.), bishop pine (*Pinus muricata* D. Don), Mexican cypress (*Cupressus lindleyi* Klotsch)) is subject to covenant protection, with NZFRI supervision. This covenant protection, however, is often fragile; in some cases because the material is no longer of great economic interest within New Zealand, in other cases because of managerial confusion largely associated with changes in forest ownership and corporate reorganization, and occasionally through omissions in drawing up covenant schedules. There are, however, some positive influences that may enhance conservation of genetic resources, regardless of land ownership: the New Zealand Resource Management Act; signatory status to International Convention on Biodiversity; and growing company awareness of public relations.

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special conservation concern among 'user' countries. It harbors a combination of many important gene pools, it is subject to great human population pressures, and many of the best seed sources are not under federal control on public lands. In addition to Monterey pine, other temperate North American forest tree species that are more valued as exotics than they are in their native countries are Mexican weeping pine, bishop pine (*Pinus muricata* D. Don) and, to a lesser extent, black locust and Port-Orford-cedar. The latter species is of special concern due to the losses it is suffering from *Phytophthora lateralis* in natural populations. Black locust, while having only modest commercial value at present in the United States, plays an important role in land conservation and rehabilitation efforts in China, Hungary, and Greece (e.g., Box 16).

Recognizing that many North American temperate forest tree species are important plantation species on this and other continents, and that it may be necessary to draw upon these forest genetic resources in the future, we **recommend** *that Canada, México, and the United States conserve these resources* in situ. *We assume that other countries outside North America will reciprocate with regard to their native genetic resources.*
(Rec. no. 3)

Current commercial value in the country of origin, however, does not guarantee conservation of native populations (e.g., due to historical practices) or necessarily ease the concerns of those countries where the species is managed as an exotic. For example, Douglas-fir has

Box 15
Ownership of exotic forest tree germplasm in South Africa

In South Africa, the ownership of exotic forest tree germplasm is both complicated and variable. According to questionnaire responses, historically, most of the germplasm came from state plantations, and later, seed orchards established by the state. More recently, companies have started their own tree improvement programs. However, the gene flow from one to the other is free, so South African populations of exotic forest species all have the same genetic base, more or less. Recent introductions of Mexican weeping pine (*Pinus patula* Schl. et Cham.) provenances from the Central America and Mexico Coniferous Resources Cooperative (CAMCORE) have added significantly to the gene pool of that species. Within private industry, the pattern depends on the importance of the species to the particular company. For example, Sappi has a small slash pine (*Pinus elliottii* Engelm.) breeding population but purchases all loblolly pine (*Pinus taeda* L.) seed from other organizations because they plant almost 38,000 ha of the former and only ca. 8,000 ha of the latter. Sappi and many other companies have their own sources of germplasm for Mexican weeping pine.

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Box 16
The role of exotics in restoring ecosystems

Where sites have been degraded by human activities, native species may be unable to reinvade. Sometimes, the site is too impoverished to reforest naturally and, sometimes, seed sources of crucial native species are lacking. Exotic species may be useful in ameliorating conditions or filling the role of native species for which no seed source is available.

In Korea, extremely eroded, barren sites were reforested with pitch pine (*Pinus rigida* Mill.), a North American species native to sterile sand plains. Over a period of decades, soil formation was enhanced, and native, Korean species were able to establish (Choi et al. 1988). Both the thickness of the organic horizon and the cation exchange capacity increased under pitch pine planted on eroded sites. Serrate-leaf oak (*Quercus serrata* Thunb.) and the native Korean red pine (*Pinus densiflora* Sieb. et Zucc.) naturally invaded under the pitch pine after soil properties had improved.

In Hungary and elsewhere, the North American black locust (*Robinia pseudoacacia* L.) serves a similar purpose on mine spoils. Because black locust is a legume and fixes atmospheric nitrogen, site quality is improved, which allows native species to reinvade.

Another example of exotics that facilitate restoration is flooded gum (*Eucalyptus grandis* Hill ex Maiden) in the Atlantic Forest of Brazil, one of the most endangered forest associations in the world. Brazil's Atlantic Forest once occupied more than 1,000,000 km², but today only 8.8% of that area has forest cover and less than 1% is primary, uncut forest (World Wide Fund for Nature 1992). It is now a priority to reestablish native vegetation with the aim of protecting water sources and sheltering local fauna. Flooded gums act as nurse-trees, assuming a role that would be taken by native pioneer species in less disrupted environments. After only 10 years, a young community, characteristic of an advanced stage of succession, is present under flooded gum plantations. Thus, natural regeneration of late successional species is facilitated and succession is accelerated, promoting the recovery of tropical forest in Brazil (Cláudio et al. 1995).

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high commercial value in its native country, has been sampled extensively, and has considerable genetic reserves, both *in situ* and *ex situ*. This species is also commercially important as an exotic in such countries as Spain, France, Germany, Chile, New Zealand, and France. However, for Douglas-fir, or any widespread species, the populations of domestic interest may not be those of foreign interests. Domestic genetic reserves may be biased in favor of the populations that are of most interest to domestic commercial interests, and these might not meet the needs of those employing the species as an exotic. Furthermore, *in situ* genetic reserves may have been established after substantial human impact. For example, based on the results of provenance studies of Douglas-fir established in several European countries and New Zealand during the 1960s, European foresters returned to certain desirable populations in the United States for additional collections only to find that they had been harvested. Also, *ex situ* genetic reserves are subject to environmental stochasticity and catastrophes, just as *in situ* reserves. Even when a host country has assembled what it considers an adequate genetic base, the reserves may be lost (see Box 23).

In summary, due to the use of North American temperate forest tree species as exotics, their genetic conservation is of international concern. When there is a major difference between the commercial value of a species grown domestically versus as an exotic, the concern for genetic conservation of native populations might be greater outside than within the country of origin. Formal and coordinated efforts among all of those concerned with conservation of genetic resources is desirable. Investments that could be made by the country of origin towards conservation of species of international importance include:

1. Replacing felled trees with autochthonous open-pollinated seed (i.e., to maintain subpopulation integrity);
2. Keeping good records of seed origin over the long term; and
3. Developing a list of species, ranked by level of 'endangeredness', with an associated plan of action. Guadalupe Island Monterey pine would be near the top of such a list.

Box 17
The use of North American species for site protection

Widespread mortality of Norway spruce (*Picea abies* (L.) Karst.) in the 'black triangle' of Central Europe is attributed to industrial pollution, mainly of sulfur dioxide. North American spruces, such as Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and blue spruce (*Picea pungens* Engelm.) seem to tolerate the conditions better than the native Norway spruce. Sitka spruce is one of the species used to reforest seriously affected, high-elevation (550-750 m) sites in Saxony, and blue spruce is used in the Czech Republic. In Figure 10, dead Norway spruce can be seen in the background of a vigorous blue spruce plantation.

Csaba Mátyás

Figure 10. A plantation of the North American blue spruce (*Picea pungens* Engelm.) in the Ore Mountains, Czech Republic. Dead snags of Norway spruce (*P. abies* (L.) Karst.), a European native, killed by atmospheric pollution, can be seen in the background. (Photo courtesy of I. Hamplová, Czech Forest Research Institute.)

Table 23. Invasiveness of North American temperate forest tree species in countries where they are managed as exotics

Country/species	Description
Argentina	
Pinus elliottii	Spreads from plantations easily.
Pinus ponderosa	Minor escape from plantations.
Pseudotsuga menziesii	Spreads from plantations to disturbed habitats (e.g., roadsides).
Australia	
Leucaena leucocephala	A small tree or tall shrub, and, while employed in some land use, often forms weed thickets.
Pinus radiata	Has spread as a weed species in many places in southern Australia; not particularly aggressive, but is an unacceptable invader of native forests and is costly to control.
Prosopis juliflora	Very troublesome because it forms thorny thickets in parts of north Australia.
Australia (Queensland)	
Pinus elliotti, P. taeda	Both species regenerate profusely and spread vigorously but are not considered invasive yet.
Brazil	
Pinus taeda, P. elliottii	Spread easily from plantations onto disturbed habitats.
Chile	No known cases.
China	
Amorpha fruticosa, Robinia pseudoacacia	Evidence of natural reproduction.
France	
Quercus rubra, Robinia pseudoacacia	These species frequently regenerate naturally and are invasive around plantations.
Germany	
Prunus serotina, Robinia pseudoacacia	Both species are becoming invasive in some regions.
Greece	
Robinia pseudoacacia	Fully naturalized all over the country and has spread from sea level to 2,000 m. Easily spreads by root sprouts.
Hungary	
Acer negundo, Fraxinus pennsylvanica	Invasive in riverine forests.
Robinia pseudoacacia	Invasive in mesic forest types.
New Zealand	
Abies grandis	Can be vigorously invasive but only over very short distances.
Pinus contorta	Extremely invasive, in many situations that are highly sensitive both ecologically and politically.
Pinus muricata, Pinus radiata	Sometimes vigorously invasive, although not usually in highly sensitive situations.
Pinus ponderosa	Appreciably invasive, not spreading over long distances but situations can be sensitive.
Pinus strobus	Can be appreciably invasive, but not used in sensitive situations.
Pseudotsuga menziesii	Strongly invasive in some quite sensitive situations.
South Africa	
Pinus patula, P. elliottii, P. taeda, P. radiata	Germination of all of them in plantations is prolific; normally removed in thinning and harvesting operations, they do spread into protected areas; mostly invasive around plantations. *P. radiata*, in particular, is invasive in the mountain fynbos in the western cape.
Spain	
Pinus radiata, Quercus rubra, Pseudotsuga menziesii, Chamaecyparis lawsoniana	All spread from plantations.
United Kingdom	
Picea sitchensis, Tsuga heterophylla	'Volunteer' following harvest creating spacing problems in plantations.

Box 18
Monterey pine invasiveness in the coastal zone of South Africa

Monterey pine (*Pinus radiata* D. Don) and maritime pine (*Pinus pinaster* Ait.) invasiveness is a problem in the Western Cape Province and the western part of the Eastern Cape Province, along the coastal zone of South Africa. The main problems related to this invasion are the reduction in local biodiversity in areas occupied by alien pines, and the water consumption of the species in catchment areas—which could be between 30 and 60% of total run-off, depending upon the degree of occupation.

The invasion in the Western Cape Province represents approximately 90% of the total invasion in the Fynbos Biome (i.e., Cape Plant Kingdom = *Regio Capensis*). In the protected water catchment areas of this province, approximately 1.14 million ha, it is estimated that a total area of 390,000 ha has been invaded by alien pines. The most widespread of these are maritime pine and Monterey pine. The latter would contribute an estimated 40% to the total occupied area. Figures reported in the early 1990s suggest that maritime pine is by far the most widespread invasive pine in South Africa (Richardson et al. 1994, Macdonald 1991). However, the current trend is that Monterey pine is increasing its proportion of the occupied land, as it both has a shorter life cycle than maritime pine (and therefore, reaches reproductive maturity sooner) and seed sources for maritime pine are being reduced as it is being phased out of the forestry management regimes. There is still, however, a large seed source and invasion potential for maritime pine.

A measure of invasion density is 'percent invasion' which is equal to the percentage of the area that will be covered by pines if the plants in an area were grouped to form a closed-canopy stand. The method of estimation is based on canopy diameters and the distance between canopies. The number of stems per hectare for a young stand of pines would therefore be much higher than it would for a mature stand of the same density.

The invasion density in areas occupied by alien pines in the protected water catchment areas of the Western Cape Province has been estimated as shown in the accompanying table.

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Invasion density (Percent invasion)	Area (100 ha)
<1	2,650
1-5	600
6-25	430
26-50	110
51-75	58
76-100	52
Total	**3,900**

Table 24. Major insect or disease problems of North American forest tree species in countries where they are managed as exotics

Country/species	Insect or disease[1]
Argentina	
Pinus elliottii	*Sirex noctilio*
Pinus radiata	*Rhyacionia buoliana*, *Sirex noctilio*, *Dothistroma pini*
Pinus taeda	*Sirex noctilio*, *Rhyacionia buoliana*
Populus spp.	*Septoria musiva*, *Melampsora* spp., *Phomopsis macrospora*
Salix spp.	*Cerocospora salicicola*, *Marssonina salicicola*, *Melampsora epitea*
Australia	
Cupressus macrocarpa	Cypress canker fungi
Pinus radiata	*Sirex noctilio*, bark beetles, *Dothistroma pini*, *Cyclaneusma minus*, *Diplodia pinea*, (Others imminent: western gall rust, *Fusarium* pitch canker, pine wood nematode, Asian gypsy moth, European shoot moth)
Populus spp.	Leaf rusts
Australia (Queensland)	No major problems
Brazil	
Pinus taeda	*Sirex noctilio*
Chile	
Pinus radiata	*Rhyacionia buoliana*, *Dothistroma septospora*
China	Many problems
France	
Populus spp.	Leaf rusts, *Septoria musiva*
Quercus rubra	American oak wilt (possibly)
Germany	
Picea sitchensis	*Dendroctonus micans*
Pinus strobus	*Cronartium ribicola*
Populus spp.	*Melampsora* spp., *Marssonina brunnea*, *Pollaccia radiosa*
Pseudotsuga menziesii	*Rhabdocline pseudotsugae*, *Phaeocryptopus gäumannii*
Quercus rubra	*Pezlcula cinnamomea*
Greece	
Pinus radiata	*Thaumetopoea pityocampa*, *Blastophagus piniperda*, *Diplodia pinea*, *Cenangium ferruginosum*
Populus spp.	*Melanophila picta*, *Aegeria apiformis*, *Saperda populnea*, *Sciapteron tabaniformis*, *Cossus cossus*, *Dothichiza populea*, *Marssonina brunnea*, *Cytospora chrysosperma*
Greece (continued)	
Robinia pseudoacacia	*Phomopsis oncostoma*, *Aglaospora profusa*, *Cucurbitaria elongata*
Hungary	
Pseudotsuga menziesii	Woolly aphids, etc.
Robinia pseudoacacia	Mosaic virus
New Zealand	
Cupressus macrocarpa	Cypress canker fungi
Pinus attenuata	*Dothistroma pini*
Pinus ponderosa	*Dothistroma pini*, *Diplodia pinea*
Pinus radiata	*Dothistroma pini*, *Cyclaneusma minus*, *Armillaria* spp.
Pseudotsuga menziesii	*Phaeocryptopus gäumannii*, Geometrid larvae defoliation
South Africa	
Pinus spp.	Not disastrous, but serious, e.g., *Cinara pini*, *Armillaria* spp., *Pissodes* spp., *Sirex noctilio*, *Diplodia pinea*, *Rhizina undulata*, etc. However, they pose a threat as the problems can intensify easily when the genetic base is restricted.
Spain	
Chamaecyparis lawsoniana	*Seiridium cardinale*
Pinus radiata	*Thaumetopoea pityocampa*, *Dothistroma pini*, *Evetria*, *Blastophagus*
Populus spp.	*Aegeria apiformis*, *Venturia* spp. *Paranthrene tabaniformis*, *Dothichiza* spp.
Quercus rubra	*Phytophthora* spp.
United Kingdom	
Picea sitchensis	*Dendroctonus* spp., *Heterobasidion annosum*, *Elatobium abietinum*, *Hylobius abietis*
Pinus contorta	*Panolis flammea*, *Ramichloridium pini*
Pseudotsuga menziesii	*Hylobius abietus*, *Adelges abietus*, *Rhabdocline pseudotsugae*, *Potebniamyces coniferarum*, *Heterobasidion annosum*
Thuja plicata, *Tsuga heterophylla*, *Abies procera*, *Abies grandis*	*Heterobasidion annosum*

[1]When reported in the questionnaire response, the Latin name for the species (and not the common name) has been given. Otherwise, only the common name is used.

Table 25. Transfer of germplasm from North American forest tree species between countries where they are managed as exotics

Country/species	Transferred to
Argentina	None.
Australia	
Populus spp., *Pinus radiata*	Several countries (minor, ongoing transfer for breeding and wood production).
Australia (Queensland)	
Pinus elliottii, *Pinus taeda*	Several countries (tens of kilograms of seed).
Brazil	
Pinus elliottii	Limited transfer to Paraguay.
Pinus taeda	Limited transfer to Paraguay and Uruguay.
Chile	None.
China	None.
France	
Pseudotsuga menziesii	Mainly among European countries.
Germany	
Several species	Export to countries within the European Union for planting purposes.
Greece	None.
Hungary	
Robinia pseudoacacia	South Korea, China, Bulgaria, etc. (clonal tests).
New Zealand	
Pinus muricata	Australia (seed), Chile.
Pinus radiata	Australia (seeds and clones for commercial plantations), South Africa, Kenya, Chile.
South Africa	
Pinus patula	A small amount of seed has been sold to Bolivia. SAFCOL sells seed from its seed orchards to any interested buyer.
Spain	
Populus deltoides	Commercial plantations.
United Kingdom	
Picea sitchensis, *Pinus contorta*	Republic of Ireland (small amount for wood production).

Box 19
The introduction of white pine blister rust to North America

Exchange of genetic resources may result in exchange of pest organisms as well. Shipments of eastern white pine (*Pinus strobus* L.) seedlings from Europe, where the species is an exotic, to North America, its continent of origin, resulted in the introduction of white pine blister rust (*Cronartium ribicola*) to Canada and the United States, and potentially, to México. The fungus infects the needles of all white pines and may grow into the stem where it causes death by girdling the trunk. White pine blister rust may have been endemic to Asia: evidence comes from the observation that many of the Asian white pines are relatively resistant to the fungus.

The rust arrived at New York on eastern white pine seedlings imported from a nursery in Germany (Boyce 1948). These seedlings were widely distributed throughout the northeastern United States. In 1906 the disease was found on gooseberries (*Ribes* spp.), its alternate host, in upper New York State and in 1909 was found on native eastern white pine. A second introduction of the fungus occurred in 1910 on eastern white pine seedlings imported from France. By the early 1940s, the rust had spread throughout the range of eastern white pine in the United States, as far south as North Carolina and as far west as Minnesota, and into Canada.

On the West Coast, blister rust was apparently introduced about 1910 near Vancouver, British Columbia, Canada (Mielke 1943). It entered Canada on eastern white pine seedlings purchased from a nursery in France. It expanded southward slowly at first, but with devastating effects on western white pine (*Pinus monticola* Dougl. ex D. Don). By 1927 it was observed on inland populations of western white pine (Hoff et al. 1976). Mortality in locations favorable to the rust exceeded 95% (Hoff and McDonald 1977). As it moved southward, the fungus came into contact with sugar pine (*Pinus lambertiana* Dougl.) and became chronic and severe in northwestern California about 1936 (Mielke 1938). For several decades it appeared that it was not adapted to the warmer, dryer conditions of the Sierra Nevada and that its southern progress would be stopped. However, by 1980 it had reached epidemic proportions in some areas of the southern Sierra Nevada (Kinloch and Dulitz 1990). Recently, it has spread to high-elevation species like whitebark pine (*Pinus albicaulis* Engelm.), and in 1990 was found on southwestern white pine (*Pinus strobiformis* Engelm.) in the Sacramento Mountains of New Mexico, having somehow jumped a gap of at least 1000 km (Hawksworth 1990). There is fear that it may move southward into México's white pine resource.

White pine blister rust is not the only example of an introduced threat to North American forests. The dangers of unrestricted movement of biological materials are also illustrated by the introduction of chestnut blight, Dutch elm disease, poplar leaf rust, gypsy moth, woolly adelgids, and many other diseases and pests (see Campbell and Schlarbaum 1994).

F. Thomas Ledig

Box 20
The effectiveness of plant quarantine

The exchange of forest genetic resources increases the threat of introducing pathogens and insect pests. Adequate laws against movement of plant materials and quarantine may slow the spread of pathogens and insects, but regulations can be circumvented by the unscrupulous or the merely ignorant. The volume of international travel is so immense that enforcement of restrictions is extremely difficult and it is virtually impossible to exclude forest pests forever. The USDA Plant Protection and Quarantine's Animal and Plant Health Inspection Service (APHIS) is responsible for intercepting imported plant materials (fruits, seeds, seedlings, cuttings) at international airports, border crossings, and shipping terminals. Restricted materials are destroyed, others are inspected for obvious signs of pests. Although APHIS does a Herculean job, perhaps only a small percentage of materials entering the country are actually inspected. Funding is simply inadequate to the task and, in any case, 100% search and inspection would probably create a public outcry because of the delays it would cause at entrance points.

Experiences with the import of cork oak (*Quercus suber* L.) demonstrate how 'leaky' the system may, at times, be. In 1993, I initiated a collection of cork oak acorns as part of a program to improve the species by selection and breeding and to conserve its genetic resources. The range of cork oak has shrunk by half in the last century because of loss of habitat. Then, beginning about 1987, heavy mortality was noted in the Iberian Peninsula. Apparently, a nonnative fungus, *Phytophthora cinnamomi*, was responsible (Brasier 1992; Philip M. Wargo, personal communication, 1992), and posed an economic threat to cork production and, perhaps, a biological threat to cork oak. Moving a sample of cork oak's genetic resources to California, which has a suitable climate for the species, was planned as part of a survey of genetic diversity in the species and as an *ex situ* conservation measure.

However, cork oak acorns may carry four insects (*Curculio elephas*, *C. nuncum*, *Cydia splendana*, and *Hemimene juliana*) that are potential pests and, therefore, imported acorns must be fumigated with methyl bromide. Methyl bromide will, of course, kill the acorns as well as the pests, so that in essence it is impossible under law to import cork oak acorns. At the inception of the program, I did not know of the pests or the restrictions. Neither did all the APHIS inspectors. One inspector checked his regulations when we received an early shipment of acorns by air freight and concluded that they were not subject to restrictions. The regulations are voluminous, not always clear, and change frequently, so the inspector's error was human.

Other shipments were received with import labels attached that directed U.S. customs officers to send the package to APHIS for inspection, but for some reason customs forwarded them directly to our laboratory. In another case, I carried several boxes of acorns as part of my luggage from Portugal to the U.S., and after telling the customs inspector that they were acorns for research, was passed without being sent to APHIS for further inspection. Many plant materials probably enter the United States in travellers' baggage: for example, several years ago a traveller who had been impressed by cork oak while on vacation in another country brought acorns to the Institute of Forest Genetics to see whether we were interested in growing them. Apparently, the traveller had not been inspected when he entered the United States. In the end, we destroyed all the imported acorns but found that we could accomplish our objectives by importing cork oak seedlings, which are permitted entry under quarantine and do not require fumigation.

One lesson learned from the experience with cork oak is that scientists and breeders should give serious consideration to the dangers of importing propagating materials. Another lesson is that enforcement of plant quarantine is difficult, given the high volume of international travel and trade. In the long term, exclusion of any pest may prove impossible, and this may have disastrous effects on North American forest genetic resources. In the reverse direction, from North America to user countries, the lesson is that native pests probably will overtake their hosts in time.

The experiences with cork oak illustrate another point: in some cases it may be necessary to move populations or species to protect them from threats in their native range, but we do not know how to handle this problem without moving pests as well.

F. Thomas Ledig

Box 21
Funding constraints on the exchange of genetic resources

During the two decades between 1960 and 1980, México received hundreds of requests for extensive provenance and progeny collections of seeds, mainly of Mexican pines but also of hardwoods. México assisted many countries with seed requests but was handicapped by insufficient funding and the lack of a seed center. In 1963-64 the Food and Agriculture Organization of the United Nations (FAO) sent a New Zealand geneticist, the late Ib J. Thulin, on assignment to México for one year to study the problem and make recommendations.

As early as 1967, the Forest Genetic Resources Study Group (FGRSG, at that time called the Study Group on Forest Tree Improvement) of the North American Forestry Commission urged the FAO to strengthen México's seed bank. The request was repeated in subsequent years. National seed centers to fill requests from the global community were established by the United States at Macon, Georgia, and by Canada at Petawawa, Ontario.

The Mexican delegates of the FGRSG used the FGRSG recommendations to work for greater support from their government. As a result, the Mexican government increased funding for seed work and genetic studies at the Instituto de Nacional Investigaciones Forestales (INIF).

However, FAO itself did not fund the seed center and México's resources were limited. Therefore, in 1973, the study group again recommended that FAO fund seed collections in México. As a result, FAO began to support INIF's efforts with an annual stipend of 5,000 USD for a 3 to 4 year period. The FGRSG recognized this as an inadequate sum and recommended that the FAO provide the necessary resources to establish a regional tree-seed center in México:

> The Study Group reaffirms the 1967 recommendation that a Regional Tree-Seed Center be established in México and points out that the establishment of such a Center is in accordance with the worldwide concern for the conservation of endangered gene resources as expressed at the Stockholm Conference in June, 1972.

In May 1974, Jag S. Maini, Canadian delegate to the FGRSG, prepared "Briefing Notes for the Chairman, North American Forestry Commission, FAO." This 13-page document provided background information and described the actions needed to facilitate the collection and study of forest genetic resources in México.

At the Ninth Session of the FGRSG in 1976, the subject was again discussed. The minutes record that:

> The Study Group on Forest Tree Improvement recognizes the tremendous progress that the Government of México has made in establishing a Tree Seed Center. It further recognizes the assistance that the Seed Center has furnished to other nations. However, to effectively meet the increasing demands of numerous Afro-Asian and Latin-American nations, the Center needs further support.

The United Nations Development Program was approached for assistance, but all efforts were in vain.

Fortunately, two organizations entered the picture, taking pressure off INIF and assuring access to the genetic resources of valuable Mexican species. The Oxford Forestry Institute (OFI) began research and development activities with tropical tree genetic resources in 1963. Caribbean pine (*Pinus caribaea* Morelet) from Central America was the initial focus of attention, but by 1976 when the FGRSG had exhausted its possibilities for encouraging collection of forest genetic resources in México, the OFI expanded its interests beyond Caribbean pine to other Mexican and Central American conifers. By 1988, OFI had collected and distributed over 22,000 separate seedlots of 108 species to 122 countries (Barnes and Burley 1990).

The other organization was the Central America and Mexico Coniferous Resources Cooperative (CAMCORE), organized in 1980. By 1988, CAMCORE had collected seeds from 5,203 trees in 187 provenances representing 21 species, mostly conifers. This material was distributed to cooperators in South America and South Africa (Dvorak 1990).

F. Thomas Ledig

Box 22
The importance of *Pinus radiata* D. Don as an exotic plantation species

Monterey pine (*Pinus radiata* D. Don), while not valued for timber or fiber in its native country, is highly valued as a commercial plantation species in countries such as Chile, New Zealand, Australia, and Spain. Existing as only five small disjunct populations in its natural range, collection and breeding efforts have resulted in close to 4 million ha of the species in plantations worldwide (according to questionnaire responses).

In Chile, the species has been planted for over 80 years, with 80,000 to 100,000 ha current annual planting. Propagules for these plantations are provided by over 300 ha of seed orchards in Chile.

In New Zealand, the area covered by Monterey pine now totals over 1.3 million ha, with the oldest plantation having been established in 1868. New plantations are being planted at the rate of over 60,000 ha per year. Although there is a wide range in level of genetic improvement and type of propagule, the most common plantation propagules are seedlings derived from open-pollinated seed orchard or unimproved landrace collections.

In Australia, the species now covers over 700,000 ha, and the first plantation was established in 1876.

In Spain, Monterey pine is the most widely planted species from the North American temperate zone, covering almost 240,000 ha in plantations. Seeds for regenerating plantations come from both Spanish and New Zealand secondary sources.

Deborah L. Rogers

Box 23
The Ash Wednesday Fires of South Australia

The Ash Wednesday Fires began on February 16, 1983. They were accompanied by winds that gusted to over 100 km/hr, making the fires virtually unstoppable. During the first four hours, some of the fire fronts moved at 17 km/hr. Before the wind subsided and the fires were contained, they burned 210,000 ha (Figure 11), destroyed 383 houses, and took 28 lives in South Australia (Keeves and Douglas 1983).

Included in the area burned were 21,000 ha of pine plantations on state forests in the Southeastern and Central Regions of South Australia. This represented 24 to 29% of the total plantation area of Monterey pine (*Pinus radiata* D. Don). The proportion of older, more-valuable plantations was much higher, perhaps 49% of the plantations 45 years and older.

Not only were pine plantations destroyed, which represented the base population for future breeding efforts, but all local sources of seed were lost. Two of three Monterey pine seed orchards were burned. The Wepar Seed Orchard had been producing progeny with 10 to 20% realized gain (David B. Boomsma, personal communication, 1983). It was anticipated that 8 to 10 years would be needed before the seed orchards could be replaced. Not only were the producing seed orchards lost, but South Australia's seed storage facility at the Mount Burr Forest went up in flames. Much of the progress that had been made by the Southern Forest Tree Breeding Association in selecting, testing, and breeding Monterey pine was wiped out.

Prior to the fires, planting programs for Monterey pine were extensive. For example, Softwood Holdings Limited alone was planting 2.5 thousand ha annually. Following the fire, the rate of planting was necessarily increased to 3.5 thousand ha to put the burned areas back into production as rapidly as possible (John H. Sedgley, personal communication, 1983). However, because seed stores for accomplishing this feat had been destroyed along with the production orchards, South Australians found it necessary to purchase seed from New Zealand and from other states in Australia.

South Australia's program represented a valuable *ex situ* collection of Monterey pine germplasm. The lesson is that *ex situ* reserves are no safer from catastrophic loss than *in situ* reserves. Redundancy is a valuable conservation strategy. The fires were a setback to South Australia, but in the case of Monterey pine, redundancy was built-in by market forces, because the species was domesticated in several states in Australia and in many other countries.

F. Thomas Ledig

Figure 11. A Monterey pine (*Pinus radiata* D. Don) plantation near Mount Gambier, South Australia, Australia, only 10 months after the Ash Wednesday Fires of 1983. The winds that accompanied the fire were so strong that many trees were snapped in two.

Approaches to conservation

F. Thomas Ledig, Deborah L. Rogers, and workshop participants

> It is as if man had been suddenly appointed managing director of the biggest business of all, the business of evolution—appointed without being asked if he wanted it, and without proper warning and preparation. What is more, he can't refuse the job. Whether he wants it or not, whether he is conscious of what he is doing or not, he is in point of fact determining the future direction of evolution on this earth. That is his inescapable destiny, and the sooner he realizes it and starts believing in it, the better for all concerned.
>
> *—Julian Huxley (Anderson 1987)*

The overall objective of genetic resource conservation, as expressed by workshop participants, is "to conserve the adaptive, evolutionary, commercial, and amenity potential of trees and the ecosystems in which they exist". A secondary stated objective was "to ensure access to genetic resources".

The approach(es) taken to genetic resource conservation will depend upon a variety of biological and social factors (Figure 12). Levels and patterns of biological variation, including phylogenetic relationships, may be useful in determining priorities for conservation of genetic resources. The spatial distribution of a species is a contributing factor to its degree of vulnerability and determines the scale available and appropriate to conservation activities. The reproductive biology of species (mating system, etc.) determines the means by which they respond to new environments, migrate, become domesticated, and thrive or falter under various conservation methods. The complexity of relationships among species and with the physical environment underlies, in particular, the success of *in situ* versus *ex situ* conservation methods. The patterns and rates of environmental

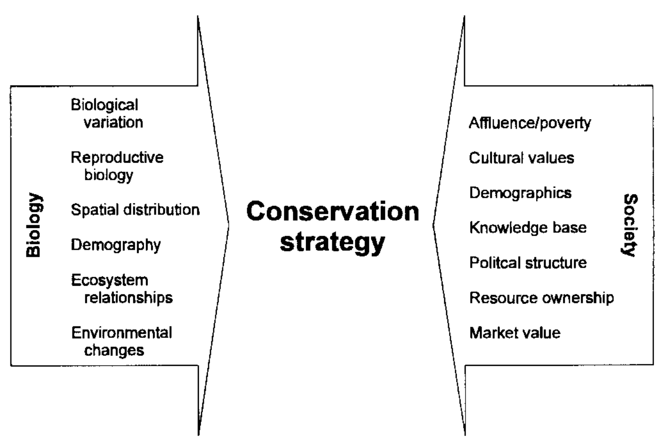

Figure 12. Biological and social factors affecting the approach to conservation

change determine the temporal and spatial scales that are necessary for conservation efforts. Finally, the demography of specific populations will influence the choice of conservation methods.

Social factors also affect the opportunities for conservation and help determine the most effective approach. Underlying the social factors is a tension between the drives to utilize and to preserve resources. The relative levels of societal affluence and poverty may provide or deny opportunities for conservation. The market value of a particular species is an important influence on its perceived social value. The resident political and administrative structures, their stability, and their level of accountability will influence the capacity to conserve and the efficacy of any conservation efforts. Similarly, the pattern of resource ownership will directly impact conservation options. Cultural values, independent of affluence or politics, may shape attitudes towards genetic resources. The sense of stewardship will determine the social will for conservation investment. Finally, the knowledge base available, including information from local to global levels, and from scientific to cultural realms, will determine the tools available for conservation.

> *We* **recommend** *that conservation of forest genetic resources be addressed by multiple approaches, and that, whenever possible, they should include ecosystem reserves. We recognize, that for noncommercial species, ecosystem reserves may be the only economically practical method of conservation. We recognize that while biotechnology can be useful in many ways, it is not a substitute for an adequately funded, field-oriented genetic conservation program.* (Rec. no. 2)

Conservation methods

In situ conservation is dynamic and provides for coevolution of the target species, its predators and pests, its symbionts, and its competitors. For passive *in situ* conservation, viable populations must be maintained, which will invariably mean large numbers distributed over sufficient area to accommodate spatial and temporal dynamics of all the key elements of the ecosystem. Participants generally accepted the argument that conservation of species by conserving ecosystems was desirable because it offered the least expensive means for conserving large numbers of species and, perhaps, the only economically feasible method for noncommercial species. However, strict preserves are problematic because the requirements of conservation must be balanced with the needs of local people to use forests.

Management of reserves is often passive. National parks and designated wilderness areas in the United States are examples of reserves largely under passive management. The policy in these areas can be described as 'letting nature take its course', formally known as the philosophy of natural regulation (see Bonnicksen 1989). Ecological processes are allowed full sway, but individual species are not actively protected. (National parks and wilderness areas are only one component of the lands that could be considered 'reserves' in the United States: other federal, state, and private lands are managed under a variety of stewardship philosophies.)

In fact, strict reserves, such as the national parks in the United States, may be of limited value for conservation of genetic resources unless they are very large. Active management of forests may be a better form of *in situ* genetic resource conservation than passively managed, strict reserves, though this is not to say that strict reserves do not have their own values. Many species are typical of early stages in succession, form even-aged stands, and will not replace themselves except in the wake of catastrophic disturbance; e.g., aspens (*Populus* spp.). Generations migrate across the landscape. The current term for the migration of species in time and space is patch dynamics. Management can create conditions that reduce the element of chance and encourage the replacement of targeted species.

Forest management must be part of any solution to the conservation of biodiversity in general and genetic resources in particular. Passive management will become ever more ineffective as fragmentation of habitat continues. Development outside reserve boundaries affects populations within the reserves (Schonewald-Cox 1988, Dasmann 1988) and these influences will continue or increase in intensity. Because private lands are subject to changes in management goals and philosophy, it imposes a responsibility on federal, provincial, and state governments to actively manage the resources on public lands to counterbalance influences originating beyond their boundaries. Management on public lands, it is hoped, will be consistent and stable over time, as contrasted to the vagaries of private tenure.

> *Recognizing that forest management practices may have positive or negative impacts on genetic diversity and population viability and, in fact, that some form of management will be necessary to maintain genetic resources, we* **recommend** *a research emphasis on the consequences of forest management practices. We encourage the use of reference populations within long-term ecological research sites, 'model forests', and research natural areas for studies on the effects of forest management.*
> (Rec. no. 6)

In the future, effective conservation of genetic resources will depend increasingly on a better understanding of the impacts of human activities and management practices on the resource. Research is needed to prescribe the best management procedures to maintain and optimize genetic diversity. Conservation should not, and cannot, be considered in isolation from any aspect of forest management or culture. As Teobaldo Eguiluz Piedra said: "Conservation should not be an isolated tree in the great woods of forestry" (Notes from the Tenth World Forestry Congress, Paris, 1991).

Timber harvest is not incompatible with conservation of genetic resources as long as stands are logged in such a way that protection and perpetuation of the genetic resource is the primary consideration. In California, Constance I. Millar and Robert D. Westfall are working with the national forests to establish Genetic Conservation Areas (GCAs). GCAs are open to timber harvest (see Box 24). The shelterwood system employs a method of harvest and regeneration that, in theory, should have negligible effects on the genetic resource. Conservation of genetic resources can be effective even when artificial regeneration is used, if forest managers use one standard rule: replant with the local seed source. Local seed could mean seed from the stand being harvested, or it could have a broader definition (Ledig 1988).

For *ex situ* conservation, one of the first questions to address is the goal—whether to save genes or genotypes. If the objective is to restore populations *in situ*, (i.e., 'salvation collections'), then the goal is to save genotypes; fitness is important. In this case, a great number of populations should be conserved. National forest seedbanks in the U.S. store tons of seeds to restore sites that have burned or been logged (Figure 13). If the objective is to obtain or preserve genes for breeding, through either conventional hybridization or through biotechnology, then the goal is to save genes. In this case, far fewer populations are required.

Provenance and progeny tests, if properly maintained and protected, are also a mechanism for the *ex situ* conservation of genetic resources. They may be a means to store germplasm for a century or more, and in some cases (species with 'recalcitrant' seed, seed that does not maintain viability in storage for long periods of time), they are the **only** method of *ex situ* conservation presently available.

As the practice of forestry becomes more sophisticated and species become domesticated, conservationists will have to decide what to conserve among the array of materials assembled during the domestication and breeding process. Should provenance samples be preserved? Early progeny tests? Clonal archives of early selections? Interspecific and intraspecific hybrids?

One criterion might be to consider the difficulty of replacing the material in question. It could require decades to reconstitute hybrids in tree species (Figure 14), which argues that they should be included in conservation schemes. Selections from an early stage of a breeding program, and their progeny, on the other hand, could be easily replaced from *in situ* reserves.

Economics and long-term conservation

Effective conservation of genetic resources requires long-term commitment. How can short-term economic needs be reconciled with the long-term commitment to genetic conservation? Workshop participants expressed the view that three groups, in general, are best suited to this long-term endeavor: 1) National governments—under the philosophy that governments at this level are best equipped, and have the responsibility, to carry and administer this type of 'social burden'; 2) Nongovernmental organizations, including land trusts and partnerships between private and public groups; and 3) User consortia—wherein the 'user' of genetic resources pays for them accordingly.

Box 24
Integrated management and monitoring of Genetic Conservation Areas on National Forests in California

Maintenance of genetic diversity in designated Genetic Conservation Areas (GCAs) is increasingly being promoted as a supplement to resource protection practices in timber management programs. GCAs are parcels of land chosen to encompass representative genetic diversity in target species and designated for long-term genetic management. In addition to their conservation function, GCAs play important monitoring roles. They provide opportunities both for monitoring long-term trends in natural genetic diversity and as control sites for monitoring effects of timber management on genetic diversity.

In the western United States, GCA networks exist for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in Washington state and are being developed for Pacific yew (*Taxus brevifolia* Nutt.) and Port-Orford-cedar (*Chamaecyparis lawsoniana* (A. Murr.) Parl.) in the Pacific Northwest. On the Placerville Ranger District of the Eldorado National Forest in California, a research demonstration project has proposed seven GCAs for the mixed forest type of the District. The Sierra mixed-conifer type includes five conifer species. This GCA project is unique not only in taking a multi-species approach to conservation, but in developing management approaches in which timber harvest and genetic conservation are compatible. Whereas established and proposed GCA networks elsewhere are managed as strict set-asides, the Placerville District would develop GCA management standards that achieve genetic conservation standards while allowing for timber harvest and artificial regeneration.

The proposed GCAs have been located in pairs, with members of a pair spaced along two transects 4 to 6 minutes of latitude apart. Each pair is located approximately 1000 feet (approx. 300 m) in elevation apart, starting at 3000 feet (approx. 910 m). There is a single GCA at the highest elevation, 6000 feet (approx. 1830 m). The spacing of locations was determined using a measure of transfer risk (Campbell 1986) applied to available data from allozyme and common garden studies. Sizes of the GCAs (including a buffer) were determined using dispersal distance estimates (see Wright 1978).

Phases in the development of the Placerville District GCA network included: (1) Genetic analysis—Geneticists developed a potential set of GCAs based on analysis of genetic diversity in Douglas-fir, sugar pine (*Pinus lambertiana* Dougl.), ponderosa pine (*Pinus ponderosa* Laws.), incense-cedar (*Calocedrus decurrens* (Torr.) Florin), and white fir (*Abies concolor* (Gord. et Glend.) Lindl.); (2) Gap analysis and site nomination—A candidate set of areas with defined boundaries was determined by integrating the genetically based maps delimiting practical opportunities with constraints. Candidate sites included the proper mix of species and desired ecological conditions and were acceptable from the standpoint of land-use allocations; (3) Ecological data collection—Candidate GCAs were inventoried for ecological data. This effort will be coordinated with Eldorado National Forest and Pacific Southwest Regional inventory and classification approaches; (4) Development of GCA management and monitoring plans—Integrated management plans for GCAs that take a bioregional perspective will be developed. These will be coordinated with working groups for surrounding areas and resources. Included in this effort will be a focus on developing objectives for GCA management, desired future conditions, and management of adjacent as well as GCA lands. Silvicultural and regeneration standards and fire management plans will be developed that provide for maintenance of genetic diversity. Seed collection plans will be developed, with the joint purposes of genebanking (Institute of Forest Genetics seedbank), providing material for monitoring the genetic status, and preparing for artificial regeneration; (5) Implementation of management and monitoring plans—Coordinated with other activities in the area, management and monitoring actions will be carried out and information from monitoring would feed back to management of the individual GCA and other GCAs in the network. The initial focus of management is to develop management objectives and compatible silvicultural standards, and to collect seeds for genebanking and monitoring.

This project is still in the implementation phase, and the efficacy of this approach (relative to others) as a management tool is constantly being reviewed in light of new genetic information. However, the value of Genetic Conservation Areas for studying the impact of *in situ* genetic management systems remains.

Constance I. Millar and
Robert D. Westfall

Workshop participants were adamant in their views that effective conservation requires solutions that consider all stakeholders, including landowners, governments, lobbyists, forest industries, and the scientific community. In particular, penalties and regulations requiring conservation on private land are less effective than the provision of positive incentives. Workshop participants expressed the view that much more could be done to promote a conservation ethic and reward conservation practices through public education and recognition, respectively.

> *Recognizing that private-sector owners and managers play an important role in* in situ *conservation of forest genetic resources, we* **recommend** *that the FAO and conservation agencies explore a range of incentives and agreements (e.g., tax incentives, easements, and land trusts) to foster conservation of forest genetic resources by the private sector.*
> (Rec. no. 9)

Institutionalizing gene pool reserves

A quandry exists in the conservation of forest genetic resources: the time-frame for conservation is the indefinite future, while the threat of loss is immediate. Here we will address the first need—how to ensure long-term conservation. By 'institutionalization' we refer to the means of maintaining or stabilizing conservation activities. The social stage is a dynamic one: land ownership, political leadership, legal requirements, and social values change over time. How can we incorporate genetic conservation into social processes and norms such that it is an abiding institution, and not a momentary fad?

Currently existing methods range from the 'passive' (i.e., incidental set-asides of land) to the 'active' (i.e., dedicated genetic reserves that are selected and maintained for that purpose). *In situ* reserves could be passive, such as many national monuments and parks in the U.S.A. and private reserves. When genetic considerations are integrated into management policy and practice, the reserves can be classified as active (Figure 15). Examples of the latter are 'Genetic Conservation Areas' (GCAs)—a new designation within the U.S. Forest Service, proposed in California; some Canadian reserves, with a similar philosophy to GCAs; and some reserves of The Nature Conservancy, a nongovernmental organization.

Ex situ genetic reserves are by nature active, having been established with genetic characteristics in mind. They are collections designed to maintain genetic parameters in population samples, and are intensively managed.

The requirements or mechanisms to implement or enforce conservation over time are numerous and include: subsidies and endowed funds; contractual obligations; volunteer efforts; land management policies; legislation, international treaties, and conventions; research on ecosystem management; development of a networking structure for conservation;

Figure 13. Interior of the U.S. Forest Service's Pacific Southwest regional seedbank on the Eldorado National Forest, California, U.S.A. Over 100,000 pounds (45,400 kg) of conifer seed are stored at 0°F (-18°C) for use in reforesting national forests in California in the wake of catastrophe or timber harvest. Identity of seed origin is maintained by species, seed zone, 500 ft (approx. 150 m) elevational band, national forest district, and national geodetic survey coordinates.

Recognizing that effective genetic conservation programs are very long term in nature, we **recommend** *that the FAO encourage and assist in the education of natural resource professionals and the lay public to foster a conservation ethic.*
(Rec. no. 10)

cultural commitment (e.g., religion); influencing social values; and education.

The 'social machinery' or organizations vested with the ability to make use of these mechanisms currently include: foundations and conservancies; concerned citizens; government agencies (federal, state, provincial, local); private industry (forest industries, banks, etc.); international agencies (e.g., FAO, IUFRO, CAMCORE, CGIAR); academic institutions; and collaborations of the foregoing.

In conclusion, long-term conservation of gene pools requires that a conservation ethic, suitable conservation mechanisms, and the acquisition and incorporation of knowledge be embraced by society. More specifically:

1. For any given species, multiple approaches to conservation are necessary, preferably including passive and active;
2. Success and stability of conservation measures require the incorporation of a conservation ethic into cultural values;
3. Sound and comprehensive methods for data acquisition and management are required;
4. Genetic resource management should be a part of all approaches to conservation.

The role of national governments in genetic conservation

The role that can be effectively played by national governments in conservation of forest genetic resources depends on the constitutional organization and social history of each country. This role typically includes passing legislation (e.g., import/export laws on traffic in endangered species), funding programs and projects (e.g., research), maintaining inventories (documentation of reserves), and providing leadership (determining guidelines for regional governments).

We **recommend** *the development of national programs to address issues in the conservation of forest genetic resources. Due to the complexity of land ownership patterns and land management objectives within and among Canada, México, and the United States of America, coordination on the national level is necessary. All of those directly involved with forest land ownership and/or management should be actively involved with the national program—contributing to databases, participating in conservation planning, and implementing action plans for conservation of forest genetic resources. These programs should include the exploration, inventory, documentation, and monitoring of forest genetic resources, both in situ and ex situ. Both exotic species growing in North America and native North American species growing elsewhere should be considered in national programs. Furthermore, because species cross national borders, coordination and cooperation among nations will be required.*
(Rec. no. 1)

Some components of a national genetic conservation program would typically, although not necessarily, include the following:

1. Monitoring of resources—i.e., the level of diversity
2. Research (in particular, examining the relationship between conservation objectives and forestry practices)
3. *In situ* programs
4. Genebanks
5. Databanks
6. Documentation
7. Public education

The role of international organizations in genetic conservation

International organizations, such as the North American Forestry Commission (NAFC) can play an important role in conservation of forest genetic resources. Workshop participants expressed the view that the NAFC could provide leadership in the realm of conservation of genetic resources. Some of the roles this organization could play include:

1. Coordinating working groups to assess the nature of impacts on individual species;
2. Monitoring and documenting the status of genetic resources, conservation goals, and programs among countries.

An international conservation organization in Europe, EuForGen, plays such a role for participating countries in Europe. Based on a voluntary agreement, EuForGen works towards the conservation of genetic resources in Norway spruce (*Picea abies* (L.) Karst.), cork oak (*Quercus suber* L.), black poplar (*Populus nigra* L.), and the noble hardwoods.

We **recommend** *that member countries request FAO, through their Regional Forestry Commissions, to promote and coordinate national forest genetic resource conservaton programs, and their integration into forestry practices.* (Rec. no. 8)

Figure 14. A test of knobcone × Monterey pine (*Pinus attenuata* × *P. radiata*) hybrids at City Creek, San Bernardino National Forest, California, U.S.A.

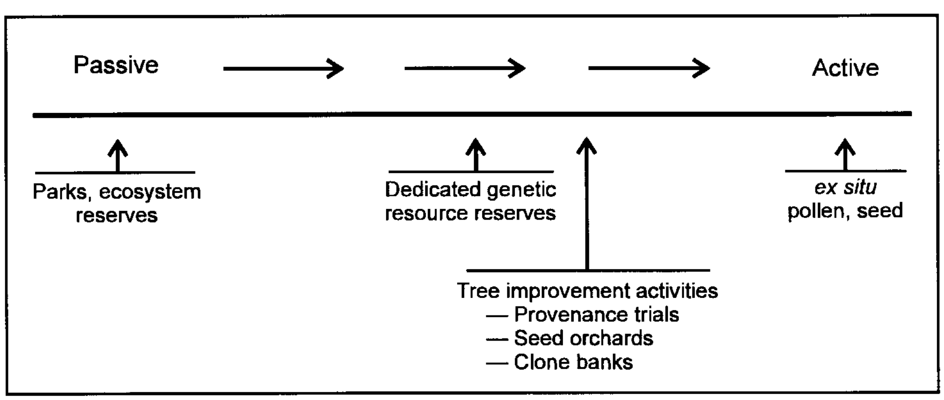

Figure 15. Conservation methods on the passive to active scale

Information needs

Deborah L. Rogers and workshop participants

Information management

Improvements in communication are necessary to better manage forest genetic resources. These improvements could help to prevent redundancy in conservation efforts and to improve efficiency through the sharing of information. Improving communications technology, and communications among scientists, will allow new information to be quickly accessed, allow coordination of conservation activities, accelerate decision-making, and enhance conservation objectives.

Workshop participants offered the following suggestions for improving communications:

1. Develop a genetic resources metadatabase and improve links among components (WWW/ Gopher, computer to computer).
2. Increase the level of awareness of genetic resource conservation and improve communication at the social (general public), political (decision makers, administrators), and technical (scientists) levels.
3. Encourage, through FAO regional forestry commissions, information gathering and strategy implementation for conservation of forest genetic resources.

> *We* **recommend** *that the FAO encourage the development of a centralized metadatabase of genetic resources. We see this as composed of local databases, coordinated through a network and designed to facilitate exchange within the international community.* (Rec. no. 7)

Research

"Genetic conservation is not only a genetic question, but a social challenge" (Discussion Group IV-2, Workshop on the Status of North American Temperate Forest Genetic Resources). A discussion of the research needed to support conservation of genetic resources would ordinarily start with, and perhaps be limited to, the biological questions. However, participants in workshop discussion groups that were requested to address research needs emphasized the need for social research—for example, how social groups feel about conservation, and the impacts of sociopolitical structures on the effectiveness of programs for the conservation of genetic resources.

One theme that emerged in the discussions was that there was a spectrum of research needs—ranging from simple inventories of species and populations in some geographic areas to analysis or re-analysis of existing data, to assessment and synthesis of exisiting information, to basic scientific research. In addition, participants confirmed the nature of research as iterative and incremental—the next step is not necessarily obvious but depends on the findings from the preceding step.

Given the large numbers of species involved, and the large number of possible research directions, one approach to organizing conservation-directed research is to develop a matrix of species versus threats to their survival. The species list could be divided into 'guilds' (subgroups of species with functional similarity within the subgroup, Clements 1905), with guild membership based on vagility, geographic, demographic, and genetic population structure, patterns of distribution (e.g., geographic, edaphic), and taxonomic status. Framing research in this way might help to determine when results could be extrapolated to other species or situations, and might illuminate connections between biological features and vulnerability.

*We **recommend** an increase in funding for research on conservation of forest genetic resources. This research should involve, when appropriate, interdisciplinary, interagency, and international collaboration.*

Some (nonprioritized) examples of research needs are:

- *Exploration and inventory of species' distributions and patterns of spatial genetic structure within species;*
- *Development of more efficient methods of evaluating genetic variation for adaptive traits;*
- *Evaluation of the relative utility of various types of genetic data in the development of sampling strategies for conservation;*
- *Analysis of the impacts of sociopolitical structures on the effectiveness of programs for the conservation of genetic resources;*
- *Analysis of factors influencing population viability;*
- *Analysis of the effects of habitat fragmentation, forest management practices, and environmental change on genetic resources.* (Rec. no. 4)

Population viability analysis (PVA) is high on the list for conservation-related research. What are criteria and indicators of a healthy population? Finding connections between molecular markers and adaptive traits would be a major contribution to PVA. Life history characteristics are likely to play a strong role in population viability, necessitating the study of representative species with various life history characteristics. However, this is unlikely to be a question that can be addressed for all species using one or two model species.

Improving our understanding of the relationships between various molecular markers and adaptive traits is important not only to PVA but a compelling issue in its own right. Knowledge of these relationships is critical to effective strategies for sampling and monitoring genetic diversity.

Finally, research is required on conservation management systems—what systems have been tried, what systems seem to work, what alternative systems exist, what are the impacts of social and political structures on management systems? Social scientists must participate in the research program.

Emerging issues

Workshop participants

Society is in an era of rapid global change. We were not able to analyze the effects of various political, economic, and social changes on conservation of genetic resources but their impact is certain. Shifting political alliances, in particular those creating common markets, will affect conservation of forest genetic resources. Some of the effects of new trade policies and agreements may have unintended impacts on the conservation of forest genetic resources (see Box 25). The North American Free Trade Agreement (NAFTA) will probably result in greater exploitation of resources. In forestry, NAFTA may have the result of intensifying logging and shortening rotations. Shorter rotations may conflict with dynamic evolution of local races. Increased competition in formerly protected national markets, particularly in México, may result in conversion to short-rotation exotics, such as eucalypts, potentially reducing habitat for native North American species. The increasing demand for forest-derived consumer goods may outstrip the ability to design and implement conservation strategies in that country.

Another effect of free trade agreements and common-market conditions may be the freer exchange of materials, including forest genetic resources. Therefore, it is important to focus on issues relating to exchange of germplasm. In particular, there is a need for identification of materials; i.e., where they are from and where they are distributed, plus the genetic characterization of the source populations and how that affects the extent and context for their cultivation. The anticipated increase in germplasm exchange also increases the need for *in situ* conservation programs. Conversely, there is also a need to increase attention on the potential of exotic gene pools as sources of genes for diminished natural populations.

With expanding global market connections, there is a need to further consider the role and importance of nongovernmental organizations (NGOs) in developing conservation strategies, recognizing that these organizations have, in part, driven the international conservation agreements now in place.

To achieve the objectives of the Convention on Biological Diversity, concerns that must be addressed include policy compliance on privately owned forests and policies directed at nonforest issues (e.g., those concerned with agriculture, regional or industrial developments, or trade), both of which affect the success of forest policies (Kanowski 1995). Finally, there is a need to resolve any conflicts between the Rio Convention on Biological Diversity and conventions to enhance the exchange of genetic materials. These emerging and potentially conflicting issues include bioprospecting agreements, breeders' rights, patents on life forms, and protection and conservation regulations (e.g., CITES).

Box 25

Some negative aspects of European Community policy on management of forest genetic resources in Spain

European Community regulation 2080/92 promotes the conversion of agricultural lands to forest. Ironically, the maintenance of forest species diversity in Spain has been negatively affected by this regulation, whose basic purpose was to reduce excess agrarian production and improve competitiveness by removing marginal agricultural lands from production. The regulation provides funding to cover the costs of site preparation, tree planting, and maintenance for the first five years after plantation establishment, and compensates the loss of agricultural rents during the next 20 years. However, the level of support depends on the species used in the plantations.

The way in which the regulation is applied in Spain has resulted in the planting of nonnative seed sources of native species. The level of support for planting autochthonous tree or shrub species (endemic, valuable wood producers, or endangered), is more than double that for planting trees for wood production that have rotations longer than 18 years. Fast-growing species (such as eucalypts) are not even considered. Consequently, during the last two years, the demand for planting stock of yew, holly, juniper, arbutus (*Taxus*, *Ilex*, *Juniperus*, *Arbutus*), etc. has increased beyond any precedent. The result is that commercial nurseries have collected plants all over Europe, without any regard for their origin and without maintaining any record, for planting on agricultural lands throughout Spain.

Afforestation of agrarian lands without proper regard to the match between species and site will be compounded by problems peculiar to these sites, such as soil compaction, lack of mycorrhizal fungi, improper soil pH and nutritional imbalances, etc. Worse, from the standpoint of conserving forest genetic resources, the use of uncontrolled, nonnative genetic material near the natural populations of rare or endangered species will result in genetic contamination that compromises future preservation or conservation programs. Most local populations of native forest and shrub species have not been genetically described, so we cannot even gauge the extent of the problem.

European Communities Council Directive 66/404 supports the use of forest sexual-reproductive material of 13 species and vegetative-reproductive material of poplars. This directive also has adversely affected forestry. The directive fixed the use of forest reproductive material for the 13 'noble' species that it named at only two selection levels: 1) selected reproductive material (i.e., from desig- ➤

Box 25 (continued)

nated seed stands); and 2) controlled reproductive material (i.e., from tested seed orchards). It excluded the use of material that was merely identified by source (i.e., of known provenance).

When this directive was applied in Spain, no selected seed stands or production seed orchards existed for any of the species involved. The forest administration was forced to request annual exemptions from the directive to maintain its forest planting program (other countries in Europe decided to identify all their forests as selected stands). However, the exemptions did not cover the entire seedling demand. Therefore, it was necessary to import and plant material that had been selected under other environmental conditions and from nonnative genetic bases. This was done without the benefit of records or controls, and, in some cases, plantations were established in close proximity to native Spanish populations.

A special situation was created with regard to Douglas-fir (*Pseudotsuga menziesii*). Douglas-fir is one of the directive's 13 'noble' species. The performance of Douglas-fir in northern Spain is excellent, and its use, by both the forest administration and by private owners, is increasing year after year. However, the possibility of building a good genetic base is threatened if it is not possible to assemble a broad sample of the native North American populations (especially those from northern California and southern Oregon) that have proven most adapted in provenance tests in Spain (Figure 16). These populations are of minor interest to the rest of Europe, and there is no adequate European base in select seed stands or seed orchards to draw upon.

Guillermo Vega Alonso

Figure 16. Fourteen-year-old Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) from southern Oregon, U.S.A. in a seed source test in Orense Province, Galicia, Spain. (Photo courtesy of James L. Jenkinson, Pacific Southwest Research Station, USDA Forest Service, Berkeley, California, U.S.A.)

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Appendix A

Respondents to questionnaire on the use of North American temperate forest tree species as exotic plantation species

Michel Arbez
INRA Centre de Recherches de Bordeaux
B.P. 45 Gazinet
Pierroton 33610 Cestas
FRANCE

Claudio L. Balocchi
Bioforest S.A.
Edificio Prales
Casilla 347
Valdivia
CHILE

Rowland D. Burdon
Genetics and Tree Improvement
New Zealand Forest Research Institute Ltd.
P.B. 3020, Rotorua
NEW ZEALAND

Hennie Coetzee
Department of Water Affairs
Parliamentary Office
Private Bag 9052
Cape Town
SOUTH AFRICA

Helmut Dörflinger
Bundesministerium für Ernährung, Landwirtschaft und Forsten
Postfach 14 02 70
53107 Bonn
FEDERAL REPUBLIC OF GERMANY

Kenneth G. Eldridge
CSIRO Forestry and Forest Products
P.O. Box 4008 QVT
Canberra, A.C.T. 2600
AUSTRALIA

Alan M. Fletcher
Forestry Authority
Northern Research Station
Roslin
Midlothian EH25 9SY
UNITED KINGDOM

Waldo Hinze
South African Forestry Company Ltd.
P.O. Box 428
Pretoria, 0001
SOUTH AFRICA

Martin A. Marcó
National Institute of Agronomic Research (INTA)
Estacion Experimental Agropecuaria Concordia,
C.C. No 34
(3200) Concordia - Entre Rios
ARGENTINA

Sonia Martin Albertos
Servicio de Material Genetico, ICONA
Gran Via de San Francisco 4
28005 Madrid
SPAIN

Csaba Mátyás
Department of Plant Sciences
University of Sopron
H-9401 Sopron
P.O.B. 132
HUNGARY

Hans-J. Muhs
Institute of Forest Genetics
Federal Research Center for Forestry and Forest Products
Sieker Landstrasse 2
D-22927 Grosshansdorf
FEDERAL REPUBLIC OF GERMANY

D. Garth Nikles
QFRI, Forest Service
P.O. Box 631
Indooroopilly, Queensland 4068
AUSTRALIA

C.J.A. Samuel
Forestry Commission
Northern Research Station
Roslin
Midlothian EH25 9SY
UNITED KINGDOM

Jarbas Y. Shimizu
Centro Nacional de Pesquisa de Florestas - CNPF/EMBRAPA
Caixa Postal 319 Colombo, Parana
BRAZIL CEP 83411-000

Helen Skarmoutsos
National Agricultural Research Foundation
Forest Research Institute
570 06 Vassilika
Thessaloniki
GREECE

Terence K. Stanger
Sappi Forests Research
P.O. Box 473 Howick
Natal 3291
SOUTH AFRICA

J. Tew
Forest Research
HL & H Timber Products
P.O. Box 137
Pietermaritzburg
SOUTH AFRICA

Gerrit van Wyk
Faculty of Forestry
University of Stellenbosch
Private Bag X1, Matieland 7602
SOUTH AFRICA

Guillermo Vega Alonso
Centro de Investigaciones Forestales
Conselleria de Agricultura, Ganderia e Montes
Xunta de Galicia
Apartado de Correos num. 127
36080 Pontevedra
SPAIN

Wang Huoran
Division of Exotic Forestry
Research Institute of Forestry
Chinese Academy of Forestry
Wan Shou Shan, Beijing 100091
PEOPLE'S REPUBLIC OF CHINA

Appendix B

Respondents to questionnaire on the domestic status of North American temperate forest tree species

Basilio Bermejo Velázquez
Division de Ciencias Forestales
Universidad Autonoma Chapingo
Apartado Postal No. 37
Chapingo, México, C.P. 56230
MÉXICO

Mark A. Diegan
Simpson Timber Company
Tree Improvement Program
P.O. Box 68
Korbel, California
U.S.A. 95550

George E. Howe
USDA Forest Service
P.O. Box 7669
Missoula, Montana
U.S.A. 59807

Robert C. Kellison
Forestry
North Carolina State University
P.O. Box 8008
Raleigh, North Carolina
U.S.A. 27695

Current address:
Champion International Corporation
1316 Dixie Trail
Raleigh, North Carolina
U.S.A. 27607

Jay H. Kitzmiller
USDA Forest Service
Genetic Resource Center
2451 Cramer Lane
Chico, California
U.S.A. 95926

Timothy LaFarge
USDA Forest Service
1720 Peach Tree Road, N.W.,
Atlanta, Georgia
U.S.A. 30367

Sheila R. Martinson
USDA Forest Service
333 SW 1st Street
P.O. Box 3623
Portland, Oregon
U.S.A. 97208

Gregory L. Powell
Florida Cooperative Forest Genetics
Research Program
School of Forest Resources and Conservation
University of Florida
Gainesville, Florida
U.S.A. 32601

George Rink
Forest Sciences Laboratory
USDA Forest Service
Southern Illinois University
Carbondate, Illinois
U.S.A. 62901

Warren Roberts
USDA Forest Service
P.O. Box 7669
Missoula, Montana
U.S.A. 59807

Marc Rust
Inland Empire Tree Improvement Cooperative
Department of Forest Resources
College of Forestry, Wildlife and Range Sciences
University of Idaho
Moscow, Idaho
U.S.A. 83843

J. Jesús Vargas Hernández
Programa Forestal
Colegio de Postgraduados
Montecillo, México, C.P. 56230
MÉXICO

Nicholas C. Wheeler
The George R. Staebler Research Center
Weyerhaeuser Company
505 North Pearl Street
Centralia, Washington
U.S.A. 98531

Tim L. White
School of Forest Resources and Conservation
University of Florida
Gainesville, Florida
U.S.A. 32601

Boyd C. Wilson
Department of Natural Resources
Forest Research Center
P.O. Box 47018
Olympia, Washington
U.S.A. 98504-7018

Appendix C

Workshop participants

W. Thomas Adams
Department of Forest Science
Oregon State University
Corvallis, Oregon
U.S.A. 97331

Michel Arbez
INRA Centre de Recherches de Bordeaux
B.P. 45 Gazinet
Pierroton 33610 Cestas
FRANCE

Basilio Bermejo Velázquez
Division de Ciencias Forestales
Universidad Autonoma Chapingo
Apartado Postal No. 37
Chapingo, México, C.P. 56230
MÉXICO

Calvin F. Bey
Forest Management Research INW
USDA Forest Service
P.O. Box 96090, Washington, D.C.
U.S.A. 20090-6090

J.P. van Buijtinen
Department of Forest Science
Texas A&M University
College Station, Texas
U.S.A. 77843-2136

Rowland D. Burdon
Genetics and Tree Improvement
New Zealand Forest Research Institute Ltd.
P.B. 3020, Rotorua
NEW ZEALAND

Miguel Caballero Deloya
Unidad de Cooperacion Internacional
Sub-Secretaria de Recursos Naturales
SEMARNAP
Avenida Progreso No. 5, Edif. 1
Colonia del Carmen, Coyoacan
México, D.F. 04100
MÉXICO

Helmut Dörflinger
Bundesministerium für Ernährung,
Landwirtschaft und Forsten
Postfach 14 02 70
53107 Bonn
FEDERAL REPUBLIC OF GERMANY

William S. Dvorak
North Carolina State University
Raleigh, North Carolina
U.S.A. 27695-7626

Kenneth G. Eldridge
CSIRO Forestry and Forest Products
P.O. Box 4008 QVT
Canberra, A.C.T. 2600
AUSTRALIA

Glenn R. Furnier
Department of Forest Resources
University of Minnesota
1530 N. Cleveland Avenue
St. Paul, Minnesota
U.S.A. 55108-1027

Matthew A. Gitzendanner
Department of Botany
Washington State University
Pullman, Washington
U.S.A. 99164-4238

Peter J. Kanowski
Department of Forestry
Australian National University
Canberra, ACT 0200
AUSTRALIA

Jay H. Kitzmiller
USDA Forest Service
Genetic Resource Center
2451 Cramer Lane
Chico, California
U.S.A. 95926

F. Thomas Ledig
Institute of Forest Genetics
USDA Forest Service
2480 Carson Road
Placerville, California
U.S.A. 95667

William J. Libby
Forest Products Laboratory, Bldg 478
University of California
1301 South 46th Street
Richmond, California
U.S.A. 94804

Jorge Lopez H.
Director Centro de Semillas Forestales
Corporación Nacional Forestal
P.O. Box 203, Chillán
CHILE

Martin A. Marcó
National Institute of Agronomic Research (INTA)
Estacion Experimental Agropecuaria Concordia,
C.C. No 34
(3200) Concordia - Entre Rios
ARGENTINA

Sonia Martin Albertos
Servicio de Material Genetico, ICONA
Gran Via de San Francisco 4
28005 Madrid
SPAIN

Csaba Mátyás
Department of Plant Sciences
University of Sopron
H-9401 Sopron
P.O.B. 132
HUNGARY

Patrick E. McGuire
Genetic Resources Conservation Program
University of California
Davis, California
U.S.A. 95616

Alexander J. Mosseler
Canadian Forest Service
P.O. Box 4000
Fredericton, New Brunswick
CANADA E3B 5P7

Hans-J. Muhs
Institute of Forest Genetics
Federal Research Center for Forestry and Forest Products
Sieker Landstrasse 2
D-22927 Grosshansdorf
FEDERAL REPUBLIC OF GERMANY

David B. Neale
Institute of Forest Genetics
USDA Forest Service
P.O.Box 245
Berkeley, California
U.S.A. 94701

Calvin O. Qualset
Genetic Resources Conservation Program
University of California
Davis, California
U.S.A. 95616

Deborah L. Rogers
Institute of Forest Genetics
USDA Forest Service
P.O. Box 245
Berkeley, California
U.S.A. 94701

Oudara K. Souvannavong
Forest Resources Development Service
Forest Resources Division
Food and Agriculture Organization of the United Nations
Viale delle Terme di Caracalla
00100 Rome
ITALY

Jarbas Y. Shimizu
Centro Nacional de Pesquisa de Florestas - CNPF/EMBRAPA
Caixa Postal 319 Colombo, Parana
BRAZIL CEP 83411-000

Nathan Stephenson
Research Office
Sequoia National Park
Three Rivers, California
U.S.A. 93271

J. Jesús Vargas Hernández
Programa Forestal
Colegio de Postgraduados
Montecillo, México, C.P. 56230
MÉXICO

Guillermo Vega Alonso
Centro de Investigaciones Forestales
Conselleria de Agricultura, Ganderia e Montes
Xunta de Galicia
Apartado de Correos num. 127
36080 Pontevedra
SPAIN

Wang Huoran
Division of Exotic Forestry
Research Institute of Forestry
Chinese Academy of Forestry
Wan Shou Shan, Beijing 100091
PEOPLE'S REPUBLIC OF CHINA

Robert D. Westfall
Institute of Forest Genetics
USDA Forest Service
P.O. Box 245
Berkeley, California
U.S.A. 94701

Nicholas C. Wheeler
The George R. Staebler Research Center
Weyerhaeuser Company
505 North Pearl Street
Centralia, Washington
U.S.A. 98531

Claire G. Williams
Department of Forest Science
Texas A & M University
College Station, Texas
U.S.A. 77843

Gerrit van Wyk
Faculty of Forestry,
University of Stellenbosch
Private Bag X1, Matieland 7602
SOUTH AFRICA

Alvin D. Yanchuk
Research Branch, Ministry of Forests
31 Bastion Square
Victoria, British Columbia
CANADA V8W 3E7

Zhou Guolin
Division of International Programs
Department of International Cooperation
Ministry of Forestry, 18 Hepingli Dongjie
Beijing 100714
PEOPLE'S REPUBLIC OF CHINA

Financial Administrator:

Ms. Suzanne G. Melendy
Department of Environmental Horticulture
University of California
Davis, California
U.S.A. 95616

Appendix D

List of forest tree species mentioned in the text of the report[1]

— Alphabetized by common name —

American beech	*Fagus grandifolia* Ehrh.
American chestnut	*Castanea dentata* (Marsh.) Brokh.
American elm	*Ulmus americana* L.
Apache pine	*Pinus engelmannii* Carr.
Arizona pine	*Pinus arizonica* Engelm.
Asian white mulberry	*Morus alba* L.
Atlantic white cedar	*Chamaecyparis thyoides* (L.) B.S.P.
Bishop pine	*Pinus muricata* D. Don
Black locust	*Robinia pseudoacacia* L.
Black poplar	*Populus nigra* L.
Black walnut	*Juglans nigra* L.
Blue ash	*Fraxinus quadrangulata* Michx.
Blue gum	*Eucalyptus globulus* Labill.
Blue spruce	*Picea pungens* Engelm.
Bristlecone pine	*Pinus longaeva* D.K. Bailey
Butternut	*Juglans cinerea* L.
Caribbean pine	*Pinus caribaea* Morelet
Catalina Island mountain-mahogany	*Cercocarpus traskiae* Eastw.
Cedar of Lebanon	*Cedrus libani* A. Rich.
Chiapas white pine	*Pinus chiapensis* (Mart.) Andresen
Chihuahua pine	*Pinus leiophylla* Schl. et Cham.
Chihuahua spruce	*Picea chihuahuana* Mart.
Coast redwood	*Sequoia sempervirens* (D. Don) Endl.
Cork oak	*Quercus suber* L.
Cucumber tree	*Magnolia acuminata* L.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Dwarf hackberry	*Celtis tenuifolia* Nutt.
Eastern white pine	*Pinus strobus* L.
European beech	*Fagus sylvatica* L.
European silver fir	*Abies alba* Mill.
False-weymouth pine	*Pinus pseudostrobus* Lindl.
Flooded gum	*Eucalyptus grandis* Hill ex Maiden
Golden chinquapin	*Chrysolepis chrysophylla* (Hook.) Hjelmq.
Gowen cypress	*Cupressus goveniana* ssp. *goveniana* Gord.
Grand fir	*Abies grandis* (Dougl.) Lindl.
Gregg pine	*Pinus greggii* Engelm.
Hop tree	*Ptelea trifoliata* L.
Incense-cedar	*Calocedrus decurrens* (Torr.) Florin
Jack pine	*Pinus banksiana* Lamb.
Kentucky coffeetree	*Gymnocladus dioica* (L.) C. Koch
Knobcone pine	*Pinus attenuata* Lemm.
Korean red pine	*Pinus densiflora* Sieb. et Zucc.
Loblolly pine	*Pinus taeda* L.
Lodgepole pine	*Pinus contorta* Dougl.
Longleaf pine	*Pinus palustris* Mill.
Maritime pine	*Pinus pinaster* Ait.
Mauritius ebony	*Diospyros hemiteles* L.
Maximino pine	*Pinus maximinoi* H.E. Moore
Mazzard cherry	*Prunus avium* L.
Mexican cypress[2]	*Cupressus lindleyi* Klotsch
Mexican weeping pine	*Pinus patula* Schl. et Cham.
Monterey cypress	*Cupressus macrocarpa* Hartw.
Monterey pine	*Pinus radiata* D. Don
Norway spruce	*Picea abies* (L.) Karst.
Oocarpa pine	*Pinus oocarpa* Schiede
Oregon ash	*Fraxinus latifolia* Benth.
Oregon oak	*Quercus garryana* Dougl. ex Hook.
Pacific yew	*Taxus brevifolia* Nutt.
Pitch pine	*Pinus rigida* Mill.
Ponderosa pine	*Pinus ponderosa* Laws.
Port-Orford-cedar	*Chamaecyparis lawsoniana* (A. Murr.) Parl.
Quaking aspen	*Populus tremuloides* Michx.
Red mulberry	*Morus rubra* L.
Red oak	*Quercus rubra* L.
Red pine	*Pinus resinosa* Ait.
Sand pine	*Pinus clausa* (Chapm.) Vasey

Scots pine	*Pinus sylvestris* L.
Serrate-leaf oak	*Quercus serrata* Thunb.
Shipmast locust	*Robinia pseudoacacia* var. *rectissima* Raber
Shortleaf pine	*Pinus echinata* Mill.
Sitka spruce	*Picea sitchensis* (Bong.) Carr.
Slash pine	*Pinus elliottii* Engelm.
Southwestern white pine	*Pinus strobiformis* Engelm.
Subalpine larch	*Larix lyallii* Parl.
Sugar maple	*Acer saccharum* Marsh
Sugar pine	*Pinus lambertiana* Dougl.
Table-mountain pine	*Pinus pungens* Lamb.
Tecun Uman pine	*Pinus tecunumanii* (Schw.) Eguiluz et Perry
Torrey pine	*Pinus torreyana* Parry ex Carr.
Tyrrell's willow	*Salix planifolia* ssp. *tyrrellii* (Raup) Argus
Western white pine	*Pinus monticola* Dougl.
Whitebark pine	*Pinus albicaulis* Engelm.
White fir	*Abies concolor* (Gord. et Glend.) Lindl.
White spruce	*Picea glauca* (Moench.) Voss.

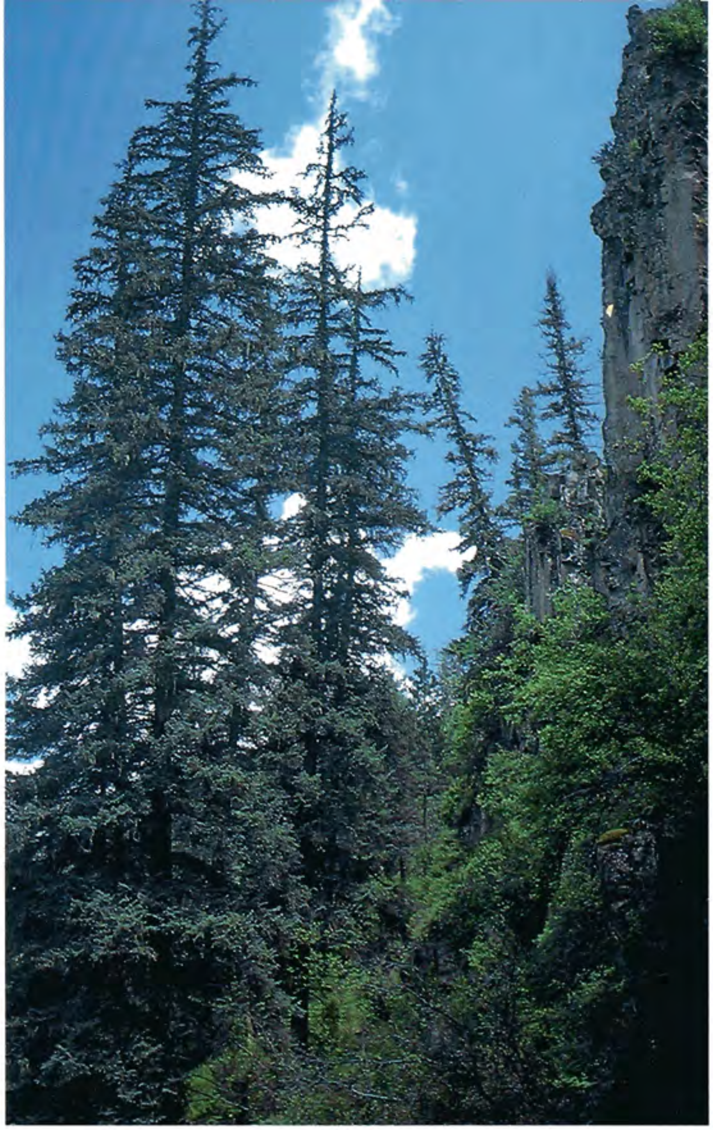
— Alphabetized by scientific name —

Abies alba Mill.	European silver fir
Abies concolor (Gord. et Glend.) Lindl.	White fir
Abies grandis (Dougl.) Lindl.	Grand fir
Acer saccharum Marsh	Sugar maple
Calocedrus decurrens (Torr.) Florin	Incense-cedar
Castanea dentata (Marsh.) Brokh.	American chestnut
Cedrus libani A. Rich.	Cedar of Lebanon
Celtis tenuifolia Nutt.	Dwarf hackberry
Cercocarpus traskiae Eastw.	Catalina Island mountain-mahogany
Chamaecyparis lawsoniana (A. Murr.) Parl.	Port-Orford-cedar
Chamaecyparis thyoides (L.) B.S.P.	Atlantic white cedar
Chrysolepis chrysophylla (Hook.) Hjelmq.	Golden chinquapin
Cupressus goveniana ssp. *goveniana* Gord.	Gowen cypress
Cupressus lindleyi Klotsch[2]	Mexican cypress
Cupressus macrocarpa Hartw.	Monterey cypress
Diospyros hemiteles L.	Mauritius ebony
Eucalyptus globulus Labill.	Blue gum
Eucalyptus grandis Hill ex Maiden	Flooded gum
Fagus grandifolia Ehrh.	American beech
Fagus sylvatica L.	European beech
Fraxinus latifolia Benth.	Oregon ash
Fraxinus quadrangulata Michx.	Blue ash
Gymnocladus dioica (L.) C. Koch	Kentucky coffeetree
Juglans cinerea L.	Butternut
Juglans nigra L.	Black walnut
Larix lyallii Parl.	Subalpine larch
Magnolia acuminata L.	Cucumber tree
Morus alba L.	Asian white mulberry
Morus rubra L.	Red mulberry
Picea abies (L.) Karst.	Norway spruce
Picea chihuahuana Mart.	Chihuahua spruce
Picea glauca (Moench.) Voss.	White spruce
Picea sitchensis (Bong.) Carr.	Sitka spruce
Picea pungens Engelm.	Blue spruce
Pinus albicaulis Engelm.	Whitebark pine
Pinus arizonica Engelm.	Arizona pine
Pinus attenuata Lemm.	Knobcone pine
Pinus banksiana Lamb.	Jack pine
Pinus caribaea Morelet	Caribbean pine
Pinus chiapensis (Mart.) Andresen	Chiapas white pine
Pinus clausa (Chapm.) Vasey	Sand pine
Pinus contorta Dougl.	Lodgepole pine
Pinus densiflora Sieb. et Zucc.	Korean red pine
Pinus echinata Mill.	Shortleaf pine
Pinus elliottii Engelm.	Slash pine
Pinus engelmannii Carr.	Apache pine
Pinus greggii Engelm.	Gregg pine
Pinus lambertiana Dougl.	Sugar pine
Pinus longaeva D.K. Bailey	Bristlecone pine
Pinus leiophylla Schl. et Cham.	Chihuahua pine
Pinus maximinoi H.E. Moore	Maximino pine
Pinus monticola Dougl.	Western white pine
Pinus muricata D. Don	Bishop pine
Pinus oocarpa Schiede	Oocarpa pine
Pinus palustris Mill.	Longleaf pine
Pinus patula Schl. et Cham.	Mexican weeping pine
Pinus pinaster Ait.	Maritime pine
Pinus ponderosa Laws.	Ponderosa pine
Pinus pseudostrobus Lindl.	False-weymouth pine
Pinus pungens Lamb.	Table-mountain pine
Pinus radiata D. Don	Monterey pine
Pinus resinosa Ait.	Red pine
Pinus rigida Mill.	Pitch pine
Pinus strobiformis Engelm.	Southwestern white pine
Pinus strobus L.	Eastern white pine
Pinus sylvestris L.	Scots pine
Pinus taeda L.	Loblolly pine
Pinus tecunumanii (Schw.) Eguiluz et Perry	Tecun Uman pine
Pinus torreyana Parry ex Carr.	Torrey pine
Populus nigra L.	Black poplar

Populus tremuloides Michx.	Quaking aspen	*Robinia pseudoacacia* L.	Black locust
Prunus avium L.	Mazzard cherry	*Robinia pseudoacacia* var. *rectissima* Raber	Shipmast locust
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir		
		Salix planifolia ssp. *tyrrellii* (Raup) Argus	Tyrrell's willow
Ptelea trifoliata L.	Hop tree		
Quercus garryana Dougl. Ex Hook.	Oregon oak	*Sequoia sempervirens* (D. Don) Endl.	Coast redwood
Quercus rubra L.	Red oak	*Taxus brevifolia* Nutt.	Pacific yew
Quercus serrata Thunb.	Serrate-leaf oak	*Ulmus americana* L.	American elm
Quercus suber L.	Cork oak		

[1]Includes forest tree species in the main body of the text and in boxes, but not necessarily all species mentioned in tables. Whenever possible, Little's (1979) checklist was used as the authority on nomenclature and authorship. However, we retained respondents' nomenclature in tables and boxes.

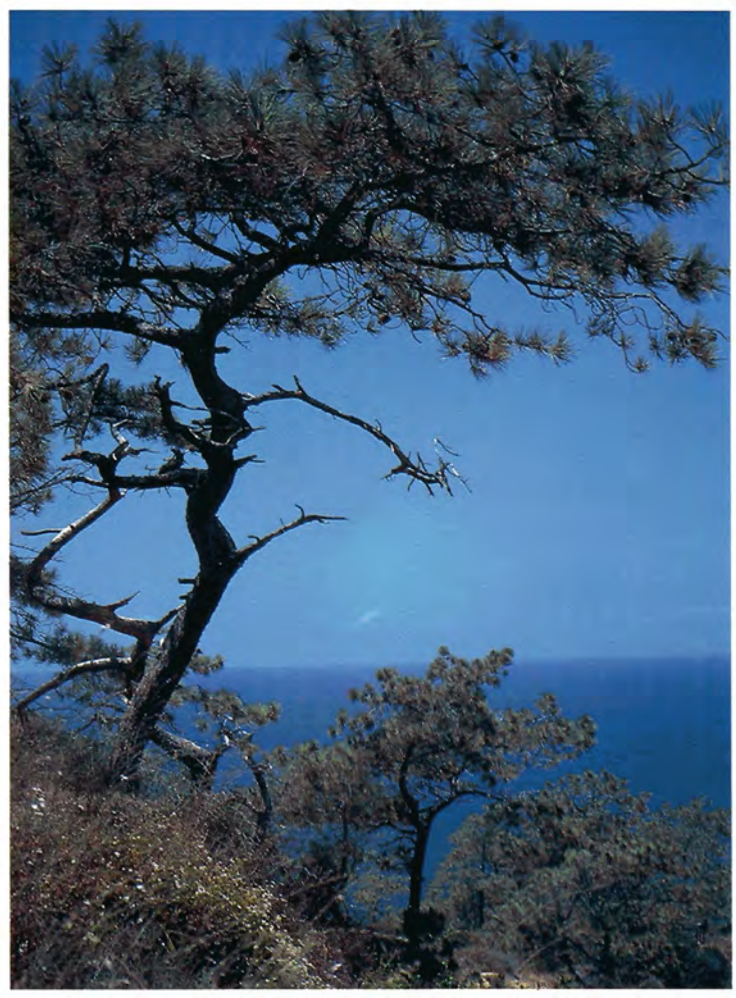
[2]Also known as Portuguese cypress or *Cupressus lusitanica* Mill.



Upper left. Chihuahua spruce (*Picea chihuahuana* Mart.) is a rare and endangered species of México's western mountains and might one day have utility to breeders as a 'wild relative' of the commercially important spruces.

Upper right. Threatened Canadian tree species, with the exception of blue ash (*Fraxinus quadrangulata* Michx.), shown here, are northern outliers of species that are in no present danger in their central populations in the United States. (Photo courtesy of Dr. John Ambrose, Metro Toronto Zoo)

Right. Torrey pine (*Pinus torreyana* Parry ex Carr.) is protected in the U.S.A. in Torrey Pines State Reserve and Channel Islands National Park but is vulnerable because of its restricted range and genetic uniformity.



North American Forestry Commission

FIAT PANIS

FOREST SERVICE U S DEPARTMENT OF AGRICULTURE

University of California Genetic Resources Conservation Program

Environmental Horticulture UC Davis