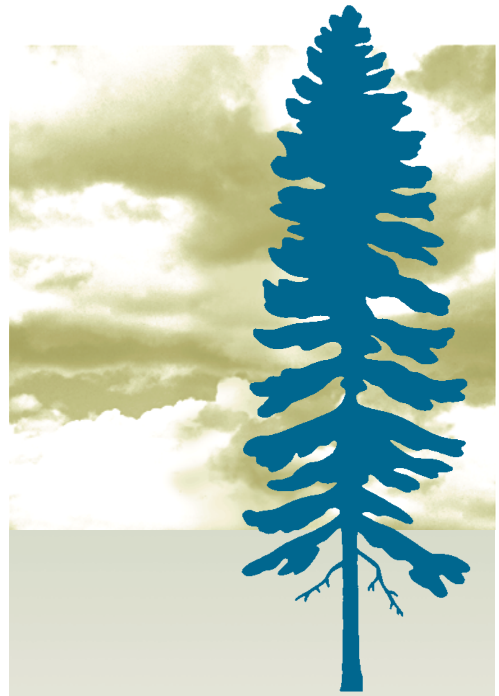
Report of the International Boreal Forest Genetic Resources Workshop



Toronto, Ontario, Canada

June 19–22, 1995

Food and Agriculture Organization of the United Nations and the Canadian Forest Service

Natural Resources Canada / Ressources naturelles Canada
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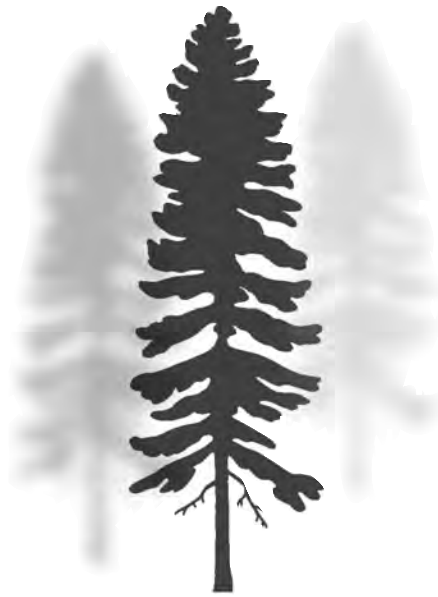
Canada



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Contents

Introduction

An international workshop on the conservation and management of boreal forest genetic resources was held in Toronto, Ontario, Canada, from June 19 to 22, 1995. It was jointly organized and sponsored by the Food and Agriculture Organization (FAO) of the United Nations and the Canadian Forest Service.

The workshop was originally intended to enable consideration of boreal forest genetic resources at the Fourth International Conference on Plant Genetic Resources held from June 17 to 23, 1996, in Leipzig, Germany. Although boreal forest genetic resources were not considered in detail at the Leipzig conference, the results of the workshop may stimulate other international fora to address the conservation and management of these important global resources.

The workshop brought together scientific experts on genetic conservation and management of boreal forest species from 20 countries. These experts presented reports, or "country studies," on the status of their national programs in this area. Individual country studies are not included in this publication but are available on request from the Canadian Forest Service (Appendix I).

The workshop participants are listed in Appendix II. Participants combined their findings from the country studies and prepared a State of the World Report on Boreal Forest Genetic Resources. Participants then prepared a series of recommendations for a Global Plan of Action for the Conservation and Management of Boreal Forest Genetic Resources.

Structure of the Workshop

The workshop agenda is outlined in Appendix III. Workshop organizer Dr. Gordon Murray (Canada) welcomed participants on behalf of the Canadian Forest Service and expressed his appreciation for the opportunity to collaborate with the FAO in organizing the workshop. He stressed the important contribution of boreal forests to the global economy, and the growing public awareness of the importance of conserving their genetic resources and biodiversity.

Dr. Gene Namkoong presented a keynote address in which he reviewed the biological aspects of boreal forest genetic conservation.

Dr. Jag Maini (Secretariat, Intergovernmental Panel of Forests, U.N. Commission on Sustainable Development, New York) provided an international context for the technical discussions taking place during the workshop. He challenged participants to address three issues:

- How do we sustain a flow of forest products while maintaining other forest benefits and values to meet future diverse needs?
- How do we manage natural, modified, and planted forests?
- How do we translate our scientific knowledge for the policy and political communities and the general public?

Dr. Oudara Souvannavong (FAO, Forest Resources Division, Rome) placed the workshop in the context of international plant genetic resource conservation activities. He gave (i) an overview of the structure of the FAO, (ii) a progress report on the Leipzig conference, (iii) a description of FAO's activities concerning forest genetic resources, and (iv) general suggestions for outputs from the workshop.

Dr. Jozef Turok (International Plant Genetic Resources Institute, Rome) described the scientific and technical activities of the European Forest Genetic Resources Programme (EUFORGEN) and the work it is doing with a major boreal species, Norway spruce (*Picea abies* [L.] Karst.).

Workshop facilitator Dr. Tim Boyle (Center for International Forestry Research, Bogor, Jakarta, Indonesia) described the international demands that are leading scientists to become involved in policy issues and welcomed the opportunity provided by the Leipzig conference to strengthen these science–policy links. Together with workshop coorganizer Tom Nieman, Dr. Boyle led participants through the series of country reports and discussion groups leading to the preparation of a state of the world report and a global plan of action for boreal forest genetic resources.

State of the World Report for Boreal Forest Genetic Resources

Extent of Boreal Forest

For the purposes of this report, "boreal forest" encompasses all forests falling between the tundra zone at high latitudes or elevations, and temperate mixed forests at lower latitudes or elevations. The term “boreal forest genetic resources” is used broadly to encompass both characteristic boreal species occurring within the temperate zone and characteristic temperate species within the boreal zone.

Boreal forests occur as a circumpolar band extending across the subarctic latitudes of Russia, China, Mongolia, the Baltic Republics, Finland, Sweden, Norway, Canada, and the United States (Alaska). These countries collectively account for over 95% of the world’s boreal forests. The remaining boreal forests are found largely as discontinuous high elevation forests in parts of Asia (Japan, P.D.R. Korea), Europe (Poland, Ukraine, Romania, Hungary, Slovakia, Czech Republic, Austria, Switzerland, and Germany), and South America (Chile and Argentina).

Some wide-ranging boreal species are also common in temperate forests. Examples include Scots pine (*Pinus sylvestris* L.), which is found throughout Europe, and balsam fir (*Abies balsamea* [L.] Mill.), which occurs from northern Canada south into the (temperate) eastern United States.

The boreal forest covers 1.37 billion hectares, approximately 33% of the global forest area, and contains approximately 28% of the standing volume of the world’s forests. Boreal forests contribute significantly to the economies of many nations. Many boreal tree species are composed of diverse genotypes. Conservation of their genetic diversity represents a major component of national sustainable development strategies. This report reviews the status of conservation and related activities in boreal forest nations.

Commercial Boreal Species

In Table 1, 30 conifer species and 26 hardwood species are identified as commercially important by participating countries in the workshop. Commercial species have a major economic impact on a national or regional scale. *Abies, Betula, Larix, Picea, Pinus,* and *Populus* are the most widely represented genera.

In North America, five indigenous conifers are of major commercial importance (*Picea glauca* [Moench] Voss, *Picea mariana* [Mill.] B.S.P., *Pinus banksiana* Lamb., *Pinus contorta* Dougl. ex Loud., *Abies balsamea* [L.] Mill.). Three indigenous hardwood species (*Betula papyrifera* Marsh., *Populus balsamifera* L., *Populus tremuloides* Michx.) have major commercial importance.

In Chile, the only important commercial boreal forest species is *Nothofagus pumilio* (Poepp. & Endl.) Krasser. This hardwood forms monospecific forests that occupy most of the boreal zone.

Conifer species occupy most of the boreal forest in northern and central Europe. *Picea abies* (L.) Karst. and *Pinus sylvestris* (L.) are the two species most commonly identified by the participating countries as commercial species. The hardwood species *Betula pubescens* Ehrh. and *Betula verrucosa* Ehrh. are also important commercially throughout Europe.

In the immense boreal forests of Russia, the number of commercial species is relatively large. As in Europe, *Pinus sylvestris* (L.) is dominant except in the Far East. *Larix russica* (Endl.) Sabine ex Trautv. and related larch species, and *Picea obovata* Ledeb. are characteristic of eastern Siberia. Other conifers, such as *Pinus sibirica* Du Tour, *Abies nephrolepsis* (Trautv.) Maxim., *Abies sachalinensis* (Schmidt) Mast., and *Abies sibirica* Ledeb., are also important. Commercial hardwoods include several *Betula* spp., *Populus tremula* L., and *Alnus incana* (L.) Moench.

The number of commercially valuable conifer species in the boreal forests of China is also large. These occur in the genera *Abies*, *Larix*, *Picea*, and *Pinus*. *Betula platyphylla* Sukatchev. is the major commercial broadleaf species.

In Japan’s boreal forests, four coniferous species and five broadleaf species are commercially exploited. *Larix kaempferi* (Lambert) Carr. is an indigenous conifer from montane boreal forests on the island of Honshu that is widely planted elsewhere in the world as an exotic.

Significant Noncommercial Boreal Species

Noncommercial species have an economic impact locally or play important ecological roles (Table 2). The assignment of species to major commercial and noncommercial categories is not always clear, and distinctions may be arbitrary.

Workshop participants listed 24 genera and 68 species of noncommercial importance. These include species typical of boreal forests and species typical of temperate forests that grow into the southern parts of the boreal forest (for example, species of *Quercus*, *Fraxinus*, *Tilia*, and *Carpinus*).

Species within genera typical of the boreal forest zone (*Pinus, Picea, Larix, Betula, Populus, Juniperus,* and *Sorbus*) may be considered noncommercial owing to their slow growth or small dimensions (for example,

Table 1. Major commercial boreal species.

Conifer species	Countries
Abies alba Mill.	GER, POL, ROM, SWI, UKR
Abies balsamea (L.) Mill.	CAN
Abies delavayi var. *georgei* (Orr) Melville	CHN
Abies grandis (Dougl. ex D. Don) Lindl.	GER
Abies nephrolepsis (Trautv.) Maxim.	RUS
Abies sachalinensis (Schmidt) Mast.	JAP, RUS
Abies sibirica Ledeb.	RUS
Larix × *czekanowskii* Szafer = *Larix gmelinii* × *L. russica*	RUS
Larix decidua Miller	CHL, GER, POL, ROM, SWI, UKR
Larix gmelinii (Rupr.) Kuzeneva	CHN, RUS
Larix kaempferi (Lambert) Carr.	GER, JAP, CHN
Larix russica (Endl.) Sabine ex Trautv.	RUS
Picea abies (L.) Karst.	AUS, DEN, EST, FIN, GER, LAT, LTH, NOR, POL, ROM, RUS, SWE, SWI, UKR
Picea asperata Mast.	CHN
Picea engelmannii Parry ex Engelm.	CAN
Picea glauca (Moench) Voss	CAN
Picea glehnii (Fr. Schmidt) Mast.	JAP
Picea jezoensis (S. & Z.) Carr.	CHN, JAP, RUS
Picea mariana (Mill.) B.S.P.	CAN
Picea obovata Ledeb.	RUS
Picea sitchensis (Bong.) Carr.	ICE, NOR
Pinus banksiana Lamb.	CAN
Pinus cembra L.	AUS
Pinus contorta Dougl. ex Loud.	CAN, CHL, ICE, SWE
Pinus koraiensis L. & Z.	CHN, RUS
Pinus ponderosa Dougl. ex Laws.	CHL
Pinus sibirica Du Tour	RUS
Pinus strobus L.	CAN, GER
Pinus sylvestris L.	CHL, CHN, DEN, EST, FIN, LAT,LTH, NOR, POL, ROM, RUS, SWE, UKR
Pseudotsuga menziesii (Mirb.) Franco	CHL, GER

Hardwood species	Countries
Acer pseudoplatanus L.	ROM
Alnus glutinosa (L.) Gaertn.	EST, GER, LAT, LTH, POL, UKR
Alnus incana (L.) Moench	EST, RUS
Betula costata Trautv.	RUS
Betula davurica Pall.	RUS
Betula ermanii Cham.	RUS
Betula maximowicziana Regel	JAP
Betula papyrifera Marsh.	CAN
Betula platyphylla Sukatchev.	CHN
Betula pubescens Ehrh.	EST, FIN, GER, NOR, RUS, SWE
Betula verrucosa Ehrh.	EST, FIN, GER, LAT, LTH, NOR, RUS, SWE, UKR
Fagus sylvatica L.	ROM, UKR
Fraxinus excelsior L.	LTH
Fraxinus mandshurica Rupr.	JAP
Kalopanax pictus (Thunb.) Nakai.	JAP
Nothofagus pumilio (Poepp. & Endl.) Krasser.	CHL
Populus balsamifera L.	CAN
Populus tremuloides Michx.	CAN
Populus trichocarpa Torr. & Gray	ICE
Populus tremula L.	GER, LAT, LTH, RUS, SWE
Quercus mongolica var. *grosseserrata* (Bl.) Rehd. & Wils.	JAP
Quercus mongolica Fisch. ex Turcz.	CHN
Quercus petraea (Mattuschka) Liebl.	ROM, UKR
Quercus robur L.	LTH, ROM, UKR
Quercus rubra L.	GER
Tilia japonica (Miq.) Simonkai	JAP

Table 2. Significant noncommercial boreal species.

Conifer species	Countries (reasons for identification)
Abies fargesii Franch.	CHN (protection)
Abies delavayi var. *georgei* (Orr) Melville	CHN (protection)
Abies homolepsis S. & Z.	JAP (ecological)
Abies mariesii Mast.	JAP (ecological)
Abies sibirica Ledeb.	CHN (protection)
Abies veitchii Lindl.	JAP (ecological)
Araucaria araucana (Molina) K. Koch	CHL (cultural value/amenity wildlife)
Juniperus communis L.	EST, LAT, ROM (ecological/biodiversity/amenity)
Juniperus rigida S. & Z.	CHN (protection)
Larix decidua Miller	POL (ecological)
Larix laricina (Du Roi) K. Koch	CAN (ecological/biodiversity amenity)
Larix decidua ssp. *polonica* (Racib.) Domin.	UKR (ecological)
Larix potaninii Batal.	CHN (protection)
Larix russica (Endl.) Sabine ex Trautv.	CHN (protection)
Picea likiangensis (Franch.) Pritz.	CHN (ecological)
Picea meyeri Rehd. & Wils.	CHN (ecological)
Picea wilsonii Mast.	CHN (ecological)
Pinus armandii Franch.	CHN (protection)
Pinus albicaulis Engelm.	CAN (game habitat)
Pinus cembra L.	GER, ROM (soil stabilization)
Pinus flexilis James.	CAN (ecological/protection)
Pinus mugo Turra	AUS, DEN, GER, POL, ROM (erosion control)
Pinus parviflora S. & Z.	JAP (ecological)
Pinus pumila (Pall.) Regel	JAP (ecological soil protection)
Pinus resinosa Ait.	CAN (ecological)
Pinus sylvestris L.	UKR (ecological)
Pseudotsuga wilsoniana Hayata.	CHN (protection)
Thuja occidentalis L.	CAN (ecological)
Tsuga forrestii Downie.	CHN (protection)

Hardwood species	Countries (reasons for identification)
Acer spp.	CAN, CHN (ecological/local consumption)
Acer platanoides L.	EST, FIN, LAT, POL (ecological/biodiversity/amenity)
Alnus glutinosa (L.) Gaertn.	DEN, NOR, SWE (soil & water protection)
Alnus hirsuta (Spach)	RUS (soil & water protection)
Alnus incana (L.) Moench	GER, LTH, POL, ROM, SWE (soil protection)

(Continued)

Table 2. Significant noncommercial boreal species. *(Continued)*

Hardwood species	Countries (reasons for identification)
Alnus japonica (Thunb.) Steud.	JAP (soil protection / erosion control)
Alnus maximowiczii Call.	JAP (soil protection)
Alnus viridis (Chaix.) DC.	AUS, GER, ROM (erosion control / protection)
Amelanchier spp.	CAN (wildlife)
Betula spp.	CHN (protection)
Betula lenta L.	RUS (water protection)
Betula platyphylla Sukatchev.	RUS (water protection)
Betula verrucosa Ehrh.	DEN, EST (ecological)
Betula pubescens Ehrh.	DEN, ICE, LAT, LTH, POL (soil protection / erosion control)
Carpinus betulus L.	LTH, POL (soil protection)
Chosenia bracteosa	RUS (soil & water protection)
Fraxinus excelsior L.	LAT, NOR (ecological / biodiversity / amenity)
Nothofagus antarctica (Forst.) Oerst.	CHL (firewood / ecological)
Populus spp.	CHN (local consumption)
Populus alba L.	RUS (soil & water protection)
Populus nigra L.	RUS (soil & water protection)
Populus tremula L.	DEN, ICE, ROM, RUS (amenity)
Prunus padus L.	EST (ecological / biodiversity / amenity)
Quercus spp.	CHN (local consumption)
Quercus dentata Thunb.	JAP (ecological)
Quercus petraea (Mattuschka) Lieb.	NOR, POL (ecological / biodiversity / amenity)
Quercus robur L.	EST, FIN, LAT, NOR (ecological / biodiversity / amenity)
Salix spp.	CAN (ecological)
Salix alba L.	LAT, RUS (soil & water protection / amenity)
Salix alaxensis (Anderss.) Coville	ICE (soil & water protection / shelterbelts)
Salix fragilis L.	LAT, RUS (soil & water protection / amenity)
Sorbus aucuparia L.	AUS, DEN, EST, GER, ICE, NOR, ROM, SWE (ecological / amenity)
Tilia spp.	CHN (protection)
Tilia cordata Mill.	EST, FIN, LAT, NOR, POL (ecological / biodiversity / amenity)
Ulmus carpinifolia Gleditsch.	POL (ecological / biodiversity / amenity)
Ulmus laevis Pall.	POL (biodiversity) EST, FIN, LAT (ecological / biodiversity / amenity)
Ulmus glabra Huds.	EST, FIN, LAT, NOR, POL (ecological / biodiversity / amenity)

Alnus spp., *Pinus pumila* [Pall.] Regel, *Juniperus communis* L., *Larix laricina* [Du Roi] K. Koch) or their limited distribution or very fragmented distribution (*Picea meyeri* Rehd. & Wils. in China or *Sorbus aucuparia* L. in northern Europe). Genera native to the "boreal" zone of the southern hemisphere in Chile and Argentina include *Nothofagus* and *Araucaria*.

Threats to Species and Populations

Boreal tree species typically exist in large populations characterized by open pollination and widespread gene flow. Such species would appear to be immune from threats to genetic diversity. However, even the most widespread species may have local populations that require protection (Table 3). Small populations affected by fire, blowdown, insect epidemics, or harvesting may suffer from inbreeding depression, leading to further declines. Rare species often have breeding systems that enable them to survive in small populations. They may be under different genetic and demographic pressures. Several rare and endangered species are also listed in Table 3.

Boreal forests are extensively exploited for fiber and timber. The manner in which harvested stands

Table 3. Threatened boreal species (S) and populations (P).

Country	Species/populations threatened
Iceland	*Populus tremula* (S), *Betula pubescens* (S)
Finland	*Taxus baccata* (S)
Estonia	*Taxus baccata* (S), *Crataegus laevigata* (S)
Canada	*Pinus strobus* (P), *Pinus resinosa* (P), *Betula alleghaniensis* (P), *Fraxinus nigra* (P), *Picea glauca* (P)
Chile	*Nothofagus pumilio* (P), *Araucaria araucana* (P)
Russia	*Pinus tabuliformis* (P), *Pinus brutia* (P), *Pinus sylvestris* var. *cretacea* (P), *Larix olgensis* (S), *Larix lubarsjuu* (P), *Abies holophylla* (P),*Taxus cuspidata* (P), *T. baccata* (P), *Betula maximowicziana* (P), *Betula schmidtii* (P), *Microbiota decussata* (S), *Picea glehnii* (P)
China	*Pinus koraiensis* (P), *Pinus sylvestris* var. *mongolica* (P), *Fraxinus mandshurica* (S), *Juglans mandshurica* (S), *Phellodendron amurense* (S), *Populus euphratica* (P)
Ukraine	*Picea abies* (P), *Larix decidua* ssp. *polonica* (P), *Pinus sylvestris* (P), *Pinus cembra* (P)
Japan	*Larix kaempferi* (P), *Picea glehnii* (P), *Picea koyamae* (S), *Picea maximowiczii* (S), *Picea polita* (P), *Picea shirasawae* (S), *Betula apoiensis* (S), *Betula ovarifolia* (S), *Salix hukaoana* (S), *Salix paludicola* (S), *Salix rupifraga* (S)
Romania	*Ulmus glabra* (P)
Germany	*Abies alba* (P), *Pinus sylvestris* (P), *Picea abies* (P), *Taxus baccata* (P) (all boreal species have threatened populations)
Switzerland	*Pinus cembra* (P), *Pinus mugo* var. *mugo* (P), *Pinus mugo* var. *uncinata* (P), *Betula pubescens* (P), *Betula nana* (S), *Alnus viridis* (P), *Ulmus glabra* (S)
Sweden	*Acer campestre* (S), *Ilex aquifolium* (S), *Tilia platyphyllos* (S), *Ulmus carpinifolia* (P), *Ulmus glabra* (P), *Ulmus laevis* (P)
Poland	*Picea abies* (P), *Larix decidua* (P), *Abies alba* (S), *Pinus sylvestris* (P)

are regenerated greatly influences genetic diversity. Planting of stock that has been artificially selected through breeding or nursery practices is unlikely to cause significant losses of genetic diversity for most common boreal species. Differences between wild and cultivated varieties are small, and high gene migration rates from naturally regenerated stands will tend to conserve rare alleles.

Workshop participants noted that small and disjunct populations are subject to genetic drift and inbreeding and are vulnerable to local extinction through natural catastrophes and forest harvesting. Additional concerns included threats from agricultural conversion and grazing, air pollution, pest and disease problems, and the interactions among these factors.

Nordic and Baltic Countries—Concerns were limited to the status of small, disjunct populations at the northern margins of a species' range.

Russia, China, and Japan—In Japan, there is a danger that climate warming will cause population declines in relict populations of rare species, particularly in mountainous areas. In China, there may be cases of excessive harvesting of rare, high value species. In Russia, there are areas where severe air pollution is causing forest declines.

Central Europe—The major threat in central Europe is air pollution, leading to forest decline and associated damage from wind, pest, and diseases. Drought induced by climate warming and associated problems with stress and disease is also a significant threat, particularly in the boreal–temperate ecotone.

Chile—Forest burning for agriculture and grazing by cattle has reduced native forests and caused local extinction of populations. Harvesting practices such as selective cutting of superior phenotypes may also be causing losses of genetic diversity.

Canada—The genetic and demographic effects of small population size, particularly in disjunct populations, were cited as a concern. Particularly vulnerable are temperate zone species found in the boreal zone, and boreal species found in the temperate zone. Clearcutting of late successional species such as white spruce (*Picea glauca* [Moench] Voss) represents a special concern across the southern boreal zone.

Constraints to Genetic Conservation

Workshop participants identified several barriers to the design, development, and implementation of effective programs for genetic conservation in boreal forests. These include:

- inadequate knowledge of patterns of genetic variation, reproductive biology, and (in some cases) species distribution (these problems are more serious for noncommercial species);
- a lack of cooperation in designing conservation programs for widespread species, either among different nations or among jurisdictions within nations;
- no national strategy or program for conservation of forest genetic resources;
- insufficient awareness of the importance of genetic conservation and sustainable use among decision makers, forest managers, and the general public;
- difficulty in coordinating efforts of large numbers of forest landowners;
- dependence of users/owners on forests for economic activity and/or subsistence; and
- a failure to integrate genetic conservation in routine forest planning and management (for example, overuse of artificial regeneration).

Inadequate funding was identified as a major constraint to the design and implementation of effective conservation programs in all countries. Public funding was seen generally as insufficient, and private funding was viewed as hard to attract owing to the long-term nature of conservation benefits. Lack of trained specialists was also cited as a constraint in some countries.

Gaps in Knowledge

Significant gaps in knowledge have a negative impact on conservation of boreal forest tree species. Information is lacking on mechanisms of adaptation and population dynamics in the face of complex and interactive threats, including global change, air pollution, and harvesting.

Knowledge of reproductive biology, genetic structure and variation, physiology, and ecological roles is inadequate for most boreal species. Site requirements are often not well known, particularly for exotic species in plantations. In general, more information is available for commercial species than for noncommercial species, for common species than for rare species, and for conifers than for broadleaved species.

Workshop participants also cited gaps in knowledge of morphological, biochemical, and karyotype variation; effective population sizes; and genotype–environment interactions.

In situ Conservation

In situ conservation of genetic resources requires both establishment of forest reserves and legislated or policy-driven conservation measures in managed forests outside reserves.

Reserve networks should represent the range of genetic variation of species and populations to be conserved. It is often assumed that a network that is representative of ecosystem variation will capture most genetic variability. This approach is appropriate in most circumstances. However, genetic information is generally lacking to assess its effectiveness, particularly for noncommercial species.

Most countries in the boreal forest zone have ecological reserve networks. Of the six countries that identified inadequacies in their reserve networks, two have plans in place to complete the networks. Some countries have explicitly addressed genetic variation in designing these networks; in other countries, genetic resource conservation is incidental to other objectives.

Some countries have legislation or policies addressing genetic conservation in managed forests outside protected areas. Most of the countries that identified gaps in reserve networks, or that have only incidental protection of genetic resources, also lack legislation or policy measures to address gene conservation in managed forests outside reserves.

Ex situ Conservation

Conservation of genetic material in artificial settings such as seed banks is referred to as ex situ conservation. For those boreal forest tree species that are long-lived, wild, outcrossing species with high levels of genetic diversity, in situ conservation is most important for genetic conservation. However, ex situ conservation is a valuable supplement to in situ conservation for:

- conservation of rare, vulnerable, or endangered species or populations under threat;
- decreasing the level of risk associated with sparse or inadequately protected in situ reserve networks;
- preserving highly valued families or clones, usually of commercial species subjected to improvement programs; and
- implementation of restoration and rehabilitation programs for species and ecosystems that have been degraded by past activities.

Ex situ conservation may involve plantations, seed orchards, seed banks, and facilities for cryopreservation of seed, pollen, and embryogenic tissue. Ex situ measures can be designed to achieve specific genetic conservation objectives or they can be incidental by-products of tree improvement programs.

Most countries indicated a need for planned ex situ conservation of both commercial and noncommercial species, including rare and endangered species. Many have established clonal archives, botanical gardens, arboreta, seed or pollen banks, seed orchards, or off-site plantations to achieve that goal. Countries that have few or no species/populations under threat were less interested in these approaches.

All countries but one (where boreal forest regeneration is almost strictly natural) reported incidental or planned conservation measures for some major commercial species, mostly conifers. Incidental measures may be quite effective although their adequacy as formal conservation measures (for example, involving planned sampling strategies) would not be ideal.

Research Priorities

Research priorities listed by different countries participating in the workshop were classified by level of importance (medium, high, very high). Priorities refer to boreal species generally, and reflect a mixture of priorities for individual species.

Very high priorities include:

- conservation strategies (in situ and ex situ), their impacts and their costs;
- improved methods for characterization of genetic variation;
- impacts of forest management and other human activities on genetic diversity and structure; and
- greater knowledge of reproductive biology.

High priorities include:

- studies of genetic variability between and within populations;
- genetic diversity and climatic change; and
- major threats and dangers.

Medium priorities include:

- sampling strategies;
- long-term germplasm storage; and
- factors generating and maintaining genetic variability.

Information Management

Information to support genetic resource management programs was identified as essential by all countries. The level and sophistication of existing information systems varies widely among countries. Most countries have national forest inventories and information on tree breeding programs. Historical records are generally available on seed collection and distribution activities. Some data bases are available in computerized form, while many remain as paper records.

In general, these data bases were not originally designed in support of genetic conservation programs. Additional efforts may be needed to identify and obtain information to optimize genetic resource conservation efforts. Establishing or upgrading information systems for managing forest genetic resources is a major goal for some countries' national programs. Sophisticated new data management technologies (including geographic information systems) can be used to attain this goal.

National Plans/Strategies for Genetic Conservation

Some countries that have boreal forests have formal genetic conservation strategies. These include Denmark, Sweden, Germany, Japan, Ukraine, Russia, and Poland. Other countries, such as Lithuania, Estonia, and Chile, have general legislation under which genetic conservation is covered.

Most remaining countries that lack formal strategies are in the process of rectifying this situation. An unofficial genetic conservation strategy in Finland will soon be formalized, while China has embarked on a process leading to a formal strategy, and Canada has a framework strategy in place. In some countries (for example, Poland), existing strategies are limited to federal or state lands. If significant forest genetic resources are on private lands, this can represent a serious gap in a comprehensive national strategy.

There is universal acceptance among countries in the boreal zone of the need for and value of national plans or strategies for genetic conservation. Because the elements of a genetic conservation strategy depend on the biophysical, socioeconomic, and political conditions of a country, there is a limit to the extent to which strategies in different countries may be harmonized. Nevertheless, countries currently lacking strategies can benefit from those that have already developed strategies. Furthermore, harmonization of the goals for such strategies would be beneficial, even if the details of implementation may differ. It is generally accepted that a biologically based ecosystem approach to genetic conservation is essential.

Global Plan of Action for the Conservation and Management of Boreal Forest Genetic Resources

Recognizing that some countries already have in place a forest genetic resource management plan;

Recognizing that the development of such a plan is the logical framework for genetic conservation; and

Recognizing further that in situ conservation of forest genetic resources is compatible with, and indeed an essential element of, sustainable management of forests, we recommend:

- that all countries should develop a national strategy for conservation of forest genetic resources and ensure its effective implementation. Elements of the strategy should include methods to be applied, species of concern, and organizations involved. Furthermore, the strategy should address, among other things, in situ conservation, ex situ conservation, forestry practices, land ownership patterns, and conflicting land use policies.

Recognizing that policies and actions in the agricultural and other sectors affect forest genetic resources, and that a variety of scientific competencies can contribute to effective conservation, we recommend:

- that multidisciplinary approaches to forest genetic resources conservation be enhanced, including coordination among government ministries responsible for forests, agriculture, parks, and the environment.

Recognizing the need to strengthen the understanding of genetic conservation and the role of genetic diversity in ecosystem function, we recommend

- the promotion and integration of conservation genetics into university curricula and into programs for the continuing education of land managers and landowners.

Recognizing that insufficient funding is a constraint to genetic resource management and research;

Recognizing the long-term nature of such research;

Recognizing further the connection between public support and funding opportunities, we recommend:

- that national and international organizations emphasize and promote public awareness of the importance of forest genetic resource conservation;
- that existing international organizations (for example, FAO and its regional forestry commissions, CGIAR and others) be used to foster collaboration on information exchange, training, and species-based networks to support genetic conservation efforts; and
- that forest genetic resource conservation be promoted in appropriate international fora such as the International Undertaking on Plant Genetic Resources and the Convention on Biological Diversity.

Recognizing that air pollution and global warming represent major and widespread threats to natural populations in the boreal zone, we recommend:

- that measures to reduce emissions that cause air pollution and climate change be supported nationally and internationally.

Recognizing that small populations are vulnerable to localized extinction, inbreeding depression, and genetic drift, we recommend:

- that species and populations that have patchy distributions, particularly rare and vulnerable species, should be evaluated regarding genetic and demographic viability, and assigned priority for conservation efforts.

Recognizing that the changes in the genetic constitution of forest tree populations may be caused by both natural and anthropogenic factors, we recommend:

- that an international network be established, including reference plots, for long-term observations to assess changes in the genetic systems of forest tree populations.

Recognizing that a lack of scientific information is a major constraint to the design and implementation of effective conservation and utilization programs, we recommend:

- that the following research topics be assigned high priority for financial support:
  - genetic structure and variation of wide-ranging boreal species, with particular attention to regions containing glacial refugia;
  - ecological genetics, including metapopulation dynamics and studies on both adaptive and neutral genes;
  - impacts of forestry practices on genetic diversity;
  - reproductive biology and ecology;
  - population viability analysis;
  - conservation methodology; and
  - monitoring methodology;
- that biological and genetic information be compiled and summarized in a form that facilitates genetic conservation efforts in boreal forests; and
- that international collaboration and coordination of research efforts on forest genetic resources be promoted, especially through the activities of IUFRO.

Discussion

Boreal tree species occur in large, continent wide, continuous forests. Vast tracts of boreal forest are commercially exploited. They provide a significant part of the world's supply of solid wood and paper products, and thereby contribute to national and global economic development. Boreal forest genetic resources ensure the continuance of these activities and are thus of inestimable value.

The boreal zone is receiving increasing attention by scientific and environmental groups. Boreal forests are important global sinks and reservoirs of carbon. They have a considerable ability to respond to global climate changes, and in turn moderate these changes. This ability rests on the genetic diversity of their constituent tree species.

Organizations dedicated to selecting and developing tree genotypes for specific applications share a common interest in boreal tree gene conservation with nature conservation groups. For both groups, a main objective is to maintain the adaptability of boreal tree populations. However, conservation groups caution about the extent to which native boreal tree populations are being replaced by genetically improved or exotic material following large-scale harvesting.

Agricultural genetic research provides powerful models for managing and modifying boreal tree genetic resources. These include breeding multiple populations, breeding for greater genetic variance, and new developments in biotechnology. However, financial constraints limit this work to tree species of high commercial value or those under threat. Research funding agencies must also take into account the following significant differences between forestry and agriculture:

- forests are often owned publicly or communally while crop lands are often privately owned;
- trees have many values, whereas agricultural crops are valued mainly as commodities and for their nutritional properties;
- trees often exist as wild populations in complex natural ecosystems across a broad range of environmental conditions, whereas agricultural systems are simplified;
- trees have long generation times relative to agricultural crops;
- conservation of forest genetic resources is heavily based on in situ strategies, whereas genetic conservation of agricultural crops relies primarily on ex situ strategies;
- ex situ conservation of forest resources is often ephemeral (that is, tests are lost, destroyed), whereas agricultural crops are conserved and rejuvenated more easily;
- trees may be regenerated naturally, whereas agricultural crops are mostly planted by humans;
- trees are often replaced with locally adapted seed sources following harvest, whereas agricultural varieties are often self-incompatible and must be artificially regenerated; and
- varietal development is at a very early stage for most tree species compared with food crop species.

The nature of adaptation—general versus local—is one of the main issues concerning boreal tree genetic resource conservation. Most boreal tree species are widely and openly pollinated and can be viewed as a single, large, intermating population. But not all species and genes follow this pattern. A dynamic tension exists between selective forces favoring local adaptation and forces that homogenize gene frequencies throughout a species' range. Forest resource managers must recognize the need to conserve evolutionary systems.

Populations of many boreal species cross national boundaries. This highlights the importance of a unified international approach to conservation and management of boreal forest genetic resources.

Conclusions

Conservation of genetic resources of boreal forest tree species is less complex than conservation of temperate or tropical tree species. Boreal forests are relatively intact compared with temperate and tropical forests, and in situ conservation methods can readily be applied. The current status of many boreal species is satisfactory. Priority must be given to rare and endangered species, and populations at the margins of more wide-ranging and commercially important species.

The challenge is to build on current efforts to conserve forest genetic resources in the boreal zone. Existing in situ reserve networks must be expanded. Research programs and ex situ facilities must be maintained and strengthened. These provide educational and training opportunities for scientists and managers from other forest regions. If we cannot conserve the genetic resources of the boreal forest, we will surely be unable to conserve those of the temperate or tropical zones.

Delays in conservation actions would be costly. Restoration of damaged areas is a secondary activity in the boreal forest at present but it may become more important in the future. Effective ecological restoration requires maintenance of adaptive genetic variation.

Benefits of systematic action to conserve boreal forest genetic resources are considerable. These include opportunities to breed for enhanced growth; resistance to drought, insects, and diseases; and tolerance of pollutants. Boreal forests are also globally significant in maintaining air and water quality, and climate stability.

A renewed long-term commitment to conserve genetic resources is needed at both the national and international levels. The most tangible evidence of this commitment will be the preparation of national strategies by all boreal forest nations. Interagency coordination in land use planning, and sustained efforts in science, public awareness, and information management will be required. International organizations such as FAO, CGIAR, and IUFRO can play an important facilitating role in this effort.

Appendix I

Country Studies[1]

Boreal Forest Genetic Resources: Country Report, Finland
Veikko Koski and Hannu Kukkonen

Boreal Forest Genetics and Conservation
Gene Namkoong

Canada's Boreal Forest Genetic Resources
Alex Mosseler

Chile's Boreal Forests
Hans Grosse

Conservation of Genetic Resources of Boreal Forest Tree Species in Switzerland
Erwin Hussendörfer

Conservation of Romanian Forest Genetic Resources
Ministry of Waters, Forests, and Environmental Protection

Country Report of China on Boreal Forest Genetic Resources
Hong Jusheng and Zhang Shougong

Country Report of Japan
Hiroshi Hoshi

Country Report on Boreal Forest Genetic Resources—Norway
Tore Skroppa

Country Report: Sweden
Lennart Ackzell

Current Status of Genetic Conservation of Norway Spruce (*Picea abies*) in Austria
Thomas Geburek and Ferdinand Müller

Estonian Forests and Conservation of Their Gene Pool
Malle Krum and Ülo Tamm

Forest Gene Resources Conservation and Management in Poland
Jan Matras

German National Report on Forest Genetic Resources

Latvia's Forest, Forestry and Genetic Resources
Janis Birgelis

Lithuanian Forest Genetic Resources: Country Report
Albertas Vasiliauskas

Russian Boreal Forest Genetic Resources: Country Report
Anatoly I. Iroshnikov, Stanislav A. Mamaev, Iliodor V. Rutkovskiy, and Andrey E. Prokazin

Situation of the Conservation of Boreal Forest Gene Resources in the Ukraine
Ihor Shvadchak, Ihor Patlaj, Jatsyk Roman, and Kaletnik Mykola

Status of Forest Genetic Resources in Denmark

The European Forest Genetic Resources Programme (EUFORGEN) and its Contribution to the Conservation of Norway Spruce Genetic Resources in Europe
Jozef Turok and Emile A. Frison

[1] Reports presented at the International Boreal Forest Genetic Resources Workshop, Toronto, Ontario, Canada, June 19–22, 1995. Available on request from Dr. Ole Hendrickson, Natural Resources Canada, Canadian Forest Service, Science Branch, 580 Booth St., 7th Floor, Ottawa, Ontario, K1A 0E4. Telephone 613-947-9026; fax 613-947-9090; e-mail ohendrickson@am.ncr.forestry.ca

Appendix II
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Appendix III

Workshop Agenda

Sunday, June 18

1300—1600	Registration
1900—2100	Registration

Monday, June 19

0830—0845	Welcoming Remarks Gordon Murray, CFS
0845—0915	Boreal Forest Genetics Conservation—Gene Namkoong, UBC
0915—0945	International Dialogue on Forests—A Boreal Perspective J.S. Maini, CFS
0945—1000	FAO and the ICPPGR Process Oudara Souvannavong, FAO
1000—1030	Refreshment Break
1030—1100	EUFORGEN Programme Jozef Turok, IPGRI
1100—1130	Overview of Workshop Format and Objectives Tom Nieman, CFS
1130—1200	General Discussion—Participant Concerns
1200—1300	Lunch—On your own
1330—1500	Country Report Presentations Norway, Sweden, Finland, Denmark, Iceland
1500—1530	Refreshment Break
1530—1700	Country Report Representations China, Japan, Russia, Romania, Ukraine

Tuesday, June 20

0830—1000	Country Report Presentations Austria, Germany, Poland, Switzerland, Estonia
1000—1030	Refreshment Break
1030—1200	Complete Country Report Presentations Latvia, Lithuania, USA, Chile, Canada
1200—1330	Lunch—On your own
1330—1700	Regional Discussion Groups—Session I
1800—2100	Dinner Reception Guest Speaker—Yvan Hardy, Assistant Deputy Minister, CFS

Wednesday, June 21

0830—0930	Rapporteur Summary of Tuesday Discussion Groups
0930—1200	Regional Discussion Groups—Session II
1200—1330	Lunch—On your own
1330—1700	Regional Discussion Groups—Session III

Thursday, June 22

0830—0930	Rapporteur Summary of Wednesday Discussion Groups
0930—1200	Nonregional Discussion Groups—Session IV
1200—1300	Lunch—On your own
1300—1600	Rapporteur Summary of Morning Sessions Workshop Wrap-up and Discussion

Workshop Facilitator: Tim Boyle, CIFOR, Indonesia