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Status of temperate forest tree genetic resources in North America

Deborah L. Rogers

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. *tyrellii*	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).

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

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

— Angiosperms —

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

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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	Area with conservation restrictions		State	Area managed	Area with conservation restrictions	
	(100 ha)[2]	(100 ha)[3]	(%)[4]		(100 ha)[2]	(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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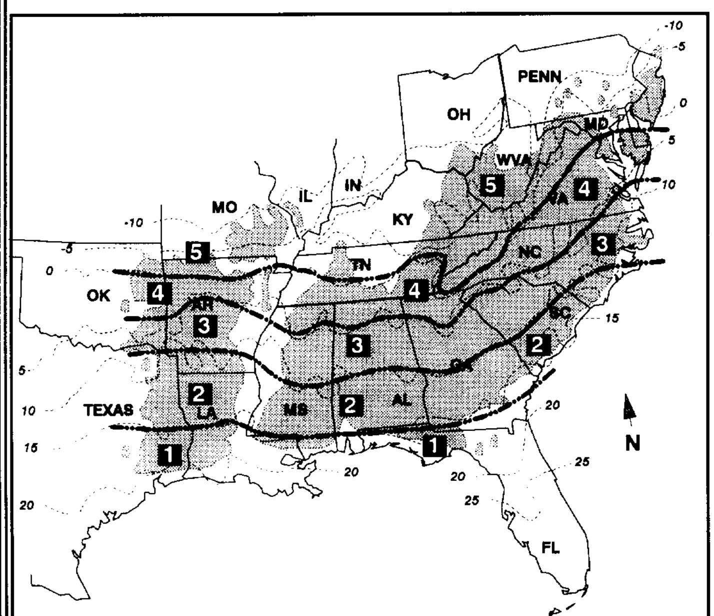

Figure 7. Seed zones established for shortleaf pine (*Pinus echinata* Mill.) based on provenance tests conducted at several locations throughout the species' range (from Ronald C. Schmidtling, unpublished data, 1996). Range of shortleaf pine is shaded; seed zone numbers are in squares; seed zone boundaries – · · –; 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.