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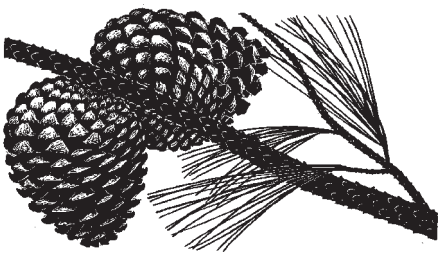
Status of conservation for Monterey pine



The range of genetic conservation activities is traditionally divided into two basic approaches: *in situ* and *ex situ* methods. *In situ* conservation has been defined as the continuing maintenance of an existing, wild population within the community of which it forms a part, in the environment to which it is adapted (Plucknett and Horne 1992). *In situ* genetic conservation is conservation of genetic resources on site—in the natural and original population, on the site formerly occupied by that population, or on the site where genetic resources of a particular population developed their distinctive properties. Thus, this approach involves preserving not only associated flora, fauna, and ecosystem processes but maintaining the populations within a dynamic environment in which the genetic variation can continue to respond to natural influences. *Ex situ* conservation refers to the suite of activities that involve removing genetic material from the natural populations and maintaining it outside of the natural habitat in such conditions as seed banks, clone banks, seed orchards, or plantations. Both types of conservation are dynamic—the genetic resources change over time—but differ in the degree and influences of change. *In situ* genetic conservation favors genetic changes that are related to natural selection and regeneration. Genetic changes in *ex situ* reserves may be more artificial (e.g., loss of seed viability over time in seed banks, artificial selection in nurseries). However, this distinction is not absolute. For example, a plantation that is allowed to regenerate naturally could be considered an *ex situ* reserve yet still respond to natural selection.

A critical feature of the *in situ* approach is the conservation of those associated populations and species, those natural disturbances, and those underlying processes that work to maintain genetic structure and diversity within a normal range of variation. Not only is an understanding of these coevolved organisms and processes important to the effective genetic conservation of the target species, but, by safeguarding the opportunity to understand the web of ecological interactions similar to those under which Monterey pine evolved, there may be some valuable guidance for silvicultural, breeding, and genetic engineering efforts of those with interests in the commercial values of Monterey pine (e.g., Tewksbury et al. 1999). Without concurrent conservation of the pine forest ecological community, adult plants may be maintained for some time, but genetic diversity in future generations may be compromised. A case in point is the dawn redwood (*Metasequoia glyptostroboides*) in China, which has been protected as a species since the 1940s but without the attendant protection of its habitat. As a result, ongoing human activities have impacted regeneration such that only mature trees—perhaps the last generation—remain (Barbour 1995).

The focus of this report is on *in situ* genetic conservation. However, given that a comprehensive and effective genetic conservation program should embrace both types of conservation methods, *ex situ* conservation will also be reviewed and considered—to the extent that it enhances the goals of *in situ* genetic conservation. That latter caveat is important: given the tremendous and historical economic importance of Monterey pine, there are many genetic collections of Monterey pine worldwide, in various life forms and degrees of separation from the original collections. A comprehensive review of all of these reserves is far beyond the scope or intent of this report. Many, perhaps most, of these collections would have little or no value to *in situ* conservation goals. The treatment of *ex situ* conservation in this report will be limited to those collections that could play a supportive role in *in situ* conservation or restoration.

Ex situ genetic collections are an important parallel conservation activity to the conservation of natural populations *in situ*. *Ex situ* collections can play a variety of roles including conservation support, research, education, and commercial applications. To play a meaningful support role for

in situ conservation, however, genetic collections should represent the genetic diversity within the species or target populations, maintain the genetic diversity (e.g., seed life) over long periods of time, and be accompanied by strategies for using such collections to establish self-sustaining populations under natural conditions (e.g., Guerrant and Pavlik 1997).

Individually, *ex situ* reserves are ephemeral and vulnerable to loss. Some *ex situ* genetic resources of Monterey pine have been lost due to lack of funding (e.g., Guadalupe Island nursery, Ledig et al. 1998; Monterey pine collections at the University of California, Libby 1990). Others have been reduced or lost due to more natural disasters.

Many weaknesses in relying on *ex situ* collections for genetic conservation have been cited. A major problem is the lack of knowledge about how to sample genetic diversity appropriately—how it is distributed within the population and what alleles may be useful in future and uncertain environments. It has been suggested that there are declining increments of genetic variation collected for increasing sample size. However, under neutral theory, any allele no matter how rare may become evolutionarily significant (Hamilton 1994). Some types of rare alleles may confer large fitness advantages under conditions of frequency-dependent selection (e.g., Holsinger and Gottlieb 1991). Thus, the sampling design and intensity required to represent adequately the genetic diversity of a species have not been convincingly established.

In situ conservation is critical: it cannot be replaced with *ex situ* conservation activities. The purpose of *in situ* conservation is to maintain the evolutionary genetic adaptability of populations and species over many generations (Koski et al. 1997). This approach is the only means of achieving both genetic conservation objectives: maintaining the amount and the structure of genetic diversity. Therefore, genetic reserves are selected and managed for genetic conservation purposes, typically chosen to reflect the range and spatial structure of genetic diversity within a species (and thus, reserves are chosen to be representative of areas that are genetically differentiated). The reserves are sufficiently large to harbor effective populations of a size that would not encourage inbreeding.

Status of *in situ* reserves

Current Monterey pine protected areas have not been selected with genetic values in mind, and thus do not necessarily contain representative genetic variation, represent sufficient habitat size or effective population size, or reflect conditions that allow ongoing regeneration and adaptation. Thus, current protected areas are not necessarily *in situ* genetic reserves, but some may offer the potential for including genetic values in their management.

The protected areas described in this section are those areas that have some official status—conferred by law, agency objectives, or management policy of the landholder—that restricts direct impacts on the Monterey pine forests, such as removal of trees for any other but conservation-related purposes. However, restrictions on the type of land use do not in themselves necessarily confer protection of genetic integrity. For example, nonlocal Monterey pine trees, planted outside of but close to a reserve, can still be a source of genetic contamination to the *in situ* reserves. Some forms of recreation may also be incompatible with conservation objectives. In most reserves, the natural processes controlling the ecosystem's composition and structure may not be restorable if degradation has proceeded too far (Cropper 1993). Data from South Africa on the pressures causing extinction or threatening the survival of a species indicate that even after creating a reserve, over half of the threats are likely to continue (Hall et al. 1980). Equivalent data from Australia suggest that about half of threats are likely to continue after reserve status has been conferred (Leigh et al. 1984). Accordingly, genetic reserves must be selected with genetic diversity and structure, ecosystem health, and restoration potential in mind.

Averaged over four native populations, approximately 25% of the extant Monterey pine area has some kind of protected status. This figure excludes Guadalupe Island because of the few trees there and difficulty in converting this to area. These protected areas are not evenly distributed over the native populations. For example, the pine population on Cedros Island has no specific protection. In contrast, the California populations each have some protected area that ranges from approximately 3% to perhaps 45% of their total respective pine forest area. However, there is no standard here for 'protected area' and hence little comparability among populations for this value. Some protected areas are simply narrow greenbelt areas or small parks, or highly developed or degraded areas that conserve few genetic values. Guadalupe Island has protected status but there are grave problems there with invasive exotic species—both plant and animal. Similarly, some areas that currently do not have protection may be more suitable as genetic conservation areas than some protected areas. More information is required to ascertain which currently protected areas may also serve as genetic conservation areas. More detailed information on each of the Monterey pine populations follows.

Año Nuevo

Approximately 12 ha have some kind of protected status. Using a total pine forest area of 400 ha, this translates to three percent. In addition, a large, privately owned ranch in the area—the Swanton Pacific Ranch—was donated to California Polytechnic State University in 1993 to be managed for educational purposes. A mixture of agricultural and forested areas, much of the forest is dominated by coast redwoods and Douglas-fir. There is also a significant component of Monterey pine, but separating this from the redwood and Douglas-fir forest type is subjective. There are perhaps 50 ha that contain some natural Monterey pine forest (W.R. Mark, pers. comm.). Because harvesting is included in the management practices, and educational value is a primary determinant in property management, this property has not been included within the protected area calculation for the Año Nuevo population. Nevertheless, it is owned and managed by a public institution and may have some conservation value using different criteria.

Most of the Monterey pine forest here is privately owned. There has been some planting of nonnative trees in this population. The Big Creek Lumber Company and others have planted some trees in this area for forestry purposes—some with local origins, but others from seedlings or clones from New Zealand or other nonnative sources (Libby 1990). Approximately 4 ha of Monterey pine forest are protected within Año Nuevo State Reserve and Park, along the coast. The pine trees here, often with a prostrate phenotype, have been particularly affected by pitch canker and mortality is high (B.D. West-Bourke, pers. comm.). In the only other publicly owned Monterey pine forest here—approximately 8 ha within the Big Basin Redwoods State Park—Monterey pines grow together with knobcone pine along ridgetops towards the eastern (inland) extent of Monterey pine's natural range. Natural interspecific hybrids *(P. attenuata* × *P. radiata*), and advanced generations of these hybrids, have been observed in and close to this same area (B.D. West-Bourke, pers. comm.; Griffin and Critchfield 1972).

Monterey

According to a comprehensive review of this population conducted in 1996 (Jones & Stokes Associates, Inc. 1996), approximately 22% of the current Monterey pine area had some kind of protected status. The protected area then consisted of approximately 20 properties, collectively amounting to about 849 ha, and existed as undeveloped pine forest in parks, open spaces, and scenic easements (Jones & Stokes Associates, Inc. 1996). The purchase in 2002 of a previously privately owned ranch (the 'Palo Corona Ranch'), by the Big Sur Land Trust and The Nature Conservancy, added approximately 62 ha of Monterey pine forest to the total protected area (L.W. Overtree, pers. comm.). Therefore, this new area brings the portion of forest with protected status to approximately 24% for the Monterey population. Ownership of the protected areas is diverse: state, county, and city governments; land trusts; and foundations. Management regimes and usage patterns are equally diverse. Most properties are essentially noncontiguous and many are surrounded by urban areas. None have been selected for, or managed as, genetic reserves. Again, protected status is not synonymous with natural or undisturbed condition. Many of the protected areas have been previously harvested, affected by pitch canker, planted with nonlocal Monterey pine, invaded by exotic invasive species, or affected by other management activities.

One assessment uses a combination of vegetation type, soil development, and climate to suggest a stratification system for selecting ecological reserve types for Monterey pine in the Monterey area (Jones & Stokes Associates, Inc. 1996). Of the 14 categories developed using this system (including an 'unknown' category for unclassified Monterey pine forests), it was determined that only three categories (prequaternary shale, prequaternary granitic, and other types) had sufficient reserves. Whether this classification system is an adequate proxy for within-population genetic structure has yet to be tested.

Cambria

Until recently, only approximately 35 ha within this Monterey pine population had some kind of protected status. At time of publication of this report, approximately 430 ha (48% or less of the total forest area, depending on which estimate for total forest area is used) have some form of protection. Purchases, acquisitions, and conservation easements of forest by landtrusts, environmental organizations, the University of California, and others during 1999–2000 increased the amount of protected area dramatically. Recently, The Nature Conservancy purchased a conservation easement on a 590-ha parcel, formerly known as the 'CT Ranch' and more recently referred to as the Cambria Coast Ranch. Of this area, approximately 325 ha are Monterey pine forest (K.W. Smith, pers. comm.). Another area, with approximately 28 ha of pines and known as the 'East-West Ranch', was purchased as a park. The University of California's Natural Reserve System has signed a memorandum of understanding (MOU) with the private owner of a pine forest property (approximately 162 ha of which perhaps ⅓ is pine forest) to manage the property as a reserve. The property is known as the Kenneth S. Norris Rancho Marino Reserve (D.C. Canestro, pers. comm.). Greenspace—The Cambria Land Trust recently purchased an additional 5 ha of pine forest (R.H. Hawley, pers. comm.).

The Rancho Marino Reserve, privately owned, will be managed as a University of California reserve during the agreement period—until April 2006. After this period, the reserve status is uncertain (D.C. Canestro, pers. comm.). Exact pine forest coverage is somewhat uncertain, but estimated at 46 ha. The pine forest canopy is fairly open and no recent fires (since early- to mid-1900s) have been recorded (M.R. Stromberg, pers. comm.).

Prior to these recent acquisitions and agreements, the only pine forest area in the Cambria population over 20 ha in size that had some protection was at the San Simeon State Park with ownership and management by the California Department of Parks and Recreation. The park encompasses 220 ha of which approximately 30 ha are Monterey pine forest. Two notable pine forest types occur here, differentiated by aspect, elevation, soil type, moisture regime, tree age and density, and co-dominant and understory vegetative species. Los Osos loam soils are found along the hilltop ridge, while San Simeon sandy loam is located along the north-facing slope. The elevation of the Monterey pine forest within the park ranges from 6 to 50 m. Fewer than 20 California live oak are scattered within the Monterey pines along the ridge top, while no oaks or other tree species are found with the Monterey pines on the north-facing slope. Sycamore (*Plantanus racemosa*), alder (*Alnus rubra*), black cottonwood *(Populus trichocarpa*), and willows (*Salix* spp.) are found in the riparian channel just below the pine forest. The shrub and herb layers are dominated by toyon (*Heteromeles arbutifolia*), canyon gooseberry (*Ribes menziesii*), poison oak (*Toxicodendron diversilobum*), and California blackberry (*Rubus ursinus*) (R.M. Orr, pers. comm.). Management policies include fire suppression and the most recent known fire

in this park was approximately 100 years ago (D.S. Hillyard, pers. comm.). There is no evidence of logging within this Monterey pine stand. Absence of logging history is confirmed by the Whitaker family—descendents of the Washburn family who owned this area prior to its conversion to state park status (S.A. Hamill, pers. comm.). Some planting of Monterey pine has occurred in nearby campground areas, including the Washburn (Upper) Campground and the San Simeon Creek Campground. Seedlings planted in the late 1980s were grown from seed collected in Cambria. A few Monterey pines that were planted earlier at the Washburn Campground were grown from local seed collections (H.W. Elliott, pers. comm.). Hence, there is no evidence that any planting of trees from outside of the Cambria population has occurred within or nearby this park. Some trees within this area are known overwintering sites for migrating Monarch butterflies.

Some smaller pine properties are owned and managed for conservation purposes by Greenspace—The Cambria Land Trust and the Land Conservancy of San Luis Obispo County. Collectively, these properties amount to approximately 4 to 5 ha (R.H. Hawley, pers. comm.).

Guadalupe Island

Although the island is officially under the control of the Ministry of the Interior, Mexico and is a protected area under SEMARNAT, Monterey pine has no specific protection here. Furthermore, there are no specific genetic reserves for Monterey pine. The number of mature trees has dropped dramatically since the informed estimate of 400 (±20) in 1964 (Bannister 1965b). Few seedlings were noted in the 1978 seed collection expedition and predation by goats introduced in the 19th century was continuing. The expedition in 2001 found approximately 220 (±20) trees (Rogers et al. 2002), all of them large and presumably very old. A few seedlings were seen, but are expected to be eaten by goats in the near future.

In situ conservation is challenging because of the stressful environmental conditions, continued heavy predation pressure from feral goats, and the small number of seed trees (Ledig et al. 1998). Key to the maintenance of remaining genetic diversity of the pines and the success of any natural regeneration or restoration efforts is the effective control or removal of the introduced goats. This proposal has been made at various times by different parties and may finally be making progress (Box 4). In the last two years, several thousand goats have been removed by Mexican ranchers and a binational not-for-profit organization has organized fence construction in some critical areas, including three exclosures around some of the pines.

Genetic research on a portion of the seed collected in 2001 is planned. This research will provide information on the remaining amount of genetic diversity and the level of inbreeding—information critical to appropriate conservation or restoration decisions for the pines. An additional question is whether or not microenvironmental conditions remain that would support natural regeneration in the pines. Given that small seedlings were seen in May 2001 in the immediate vicinity of mature trees, at least germination and initial growth is still possible. Fog condensation on pines produces a considerable amount of moisture, so natural regeneration may still be possible within the drip zone of existing trees as long as the goats are removed or controlled before the remaining trees die.

Cedros Island

The island, under the control of the Ministry of the Interior, Mexico, has no official overall protection or specific genetic reserves for Monterey pine. Two fires have occurred on Cedros Island between 1964 and 1978. According to a 1978 visit to the island, reproduction of Monterey pine following the fires was abundant, leaving a scientist to conclude that "Cedros Island remains the least endangered of the five native radiata populations." (Libby 1978). During the 2001 expedition (Box 3), recent regeneration was noted in much of the pine-covered area, suggesting another fire within the last decade. Although the pines are largely restricted to ridge-top areas, natural regeneration seems abundant. Genetic studies that are planned for some of the seeds collected in May 2001 may provide information on differences between the extremes in the pine range and levels of inbreeding within stands. There could be some influences on the genetic diversity and integrity of the Monterey pines on Cedros Island—

Box 4. Removal and control of goats on Guadalupe Island.

Many of the islands off Baja California have experienced negative effects from introduced mammals (Oberbauer 1986; McChesney and Tershy 1998). Guadalupe Island is particularly impacted. It has been recommended at various times that the harmful introduced fauna on Guadalupe Island be removed (e.g., Moran 1996; Rico C. 1997b). Since their introduction, the goat population has fluctuated dramatically, both from climatic and associated vegetation cycles, and from their slaughter. There are reports of over 34 000 goats being removed in 1971 alone—over 20 000 of those slaughtered and the rest removed live and taken to Ensenada, Mexico (Moran 1996). However, a goat-removal effort must be large scale, comprehensive, well funded, and well coordinated if it is to be effective in terms of island conservation.

In 1980 a small temporary nursery was fenced on the island to raise Monterey pine seedlings but none were planted in the natural stands because of lack of funding. By 1994, only six young trees survived in the nursery (Ledig et al. 1998).

Two ranchers from Sonora, Mexico recently obtained permits from SEMARNAT to remove goats from the island. As of October, 2001, several thousand have been removed (J.A. Sanchez Pacheco, pers. comm.). The Island Conservation and Ecology Group (ICEG)—a binational nonprofit organization dedicated to preventing extinctions and protecting natural processes on the more than 250 islands in northwest Mexico—has long-term plans for conservation on the island. One of the first steps they took, in 2001, was the erection of fenced enclosures to keep goats out of the most sensitive areas of the island until eradication can be realized. (J.A. Sanchez Pacheco, pers. comm.).

such as tree removal or browsing by introduced animals—but these are not obvious or extreme, nor have they seriously affected regeneration.

Status of e*x situ* reserves

Ex situ collections may be held in a variety of states: planted collections, stored seeds, preserved tissues, and DNA and DNA products. Seed collections are typically distinguished from field-based plantings, but both are dynamic states and experience selection pressures. The type of collection and its management or preservation conditions affect its utility in various conservation roles.

As previously mentioned, an exhaustive review of all the *ex situ* reserves of Monterey pine, worldwide, is beyond the scope and not supportive to the objectives of this report. First, such a review would be a massive undertaking in its own right: for example, a review of the genetic reserves of Monterey pine in Australia alone was an ambitious project (Eldridge 1998a,b). Second, and more importantly, only a fraction of the *ex situ* reserves worldwide would be relevant to the goals of *in situ* conservation in the native populations. However, it is important to describe the relevant portion of those reserves—particularly those that could be used in restoration of native populations or those that predate some of the current influences on the native populations and thus could be useful for comparison purposes (e.g., collections that predate pitch canker infestations or collections from trees on Guadalupe that are now dead). Finally, some of the domestic reserves are described in some detail to make a more public and permanent record of their location and composition. *Ex situ* reserves of Monterey pine are selectively reviewed here.

Seed collections

The first European record of a specimen of Monterey pine collected from mainland California dates back to the La Pérouse Expedition of the 1780s (Lavery and Mead 1998). Collections continued, sporadically, of all populations in the 1800s and early 1900s (Fielding 1957b; Eldridge 1998b). The collections recorded in this document are those that are relatively recent—so as to have still viable seed in storage or resulting trees in cultivation—and with fairly large samples (Table 9). Most of the seed collections and other *ex situ* reserves of Monterey pine meeting those criteria originated from a seed collection trip in 1978 primarily financed and organized by Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) and trips organized and financed by the Central America and Mexico Coniferous Resources Cooperative (CAMCORE) in 1991 and 1992 (with some financial assistance from CSIRO).

CAMCORE and Carl Jackovich (with assistance from Laurie Lippitt) made a seed collection of the three mainland populations, thirty trees each, in March 1991. Seeds were distributed to Chile and South Africa and most of this material has been outplanted into the field for the purpose of genetic testing and conservation banks. Several recent seed collections (1999–2001) have been made from the mainland populations specifically for use in studies for resistance to pitch canker or for a source of possibly resistant seedlings for mitigation plantings in residential areas (R.H. Hawley, pers. comm.).

In general, Monterey pine seeds have good storage life under appropriate temperature and moisture conditions, particularly as compared with many deciduous tree species. Seed can perhaps be stored for decades without significant loss of viability (L.A. Lippitt, pers. comm.). However, a seed collection event does not provide safe, perpetual protection of genetic resources. "It is also risky to consider seed banks as 'insurance' against extinction in the wild. As with most insurance policies, you must continually pay the premiums in order to be covered. We must avoid thinking that seed banks are a one-time collecting effort if *ex situ* methods are to be useful in preserving genetic variation." (Hamilton 1994). Germination tests done in 1995 on seeds collected from the three mainland populations in 1978 and stored at CSIRO facilities (Australia) show a considerable reduction in germination from 1978 (91%) to 1995 (64%). There is also some suggestion of population variability in germination rate (or storability), with the Cambria population showing lower percentage germination in 1995 (54%) than either the Monterey (68%) or Año Nuevo (65%) populations (Eldridge 1998a). Because of notable differences in mean seed weight among the five populations, it is important to recognize these differences when estimating the number of seeds in any particular collection (Box 5).

Table 9. Major sampling events of Monterey pine populations since 1950 (adapted from Burdon 1984 and Eldridge 1997)†.

Population	1958	1961	1964	1978	1991	1992	2001
	—— (Number of trees sampled per year) ——						
Año Nuevo	–	100	–	179	30	–	–
Monterey	–	100	–	244	30	–	–
Cambria	–	100	–	99	30	–	–
Guadalupe Island	51	–	77	48	–	76	80
Cedros Island	–	–	100	51	–	–	101
Reference‡	1	2	3	4	5	6	7

†In addition, there have been several expeditions by Mexicans to Guadalupe Island and Cedros Island with the objective of collecting seeds for both potential restoration of the natural populations and *ex situ* conservation. During the period of 1975–1982, at least four expeditions to Guadalupe and Cedros Islands were made by faculty and students from the Universidad Autónoma Chapingo to collect seed from Monterey pine (Ravest Santos 1983). However, only a few seeds remain in storage (most probably with a very low germination percentage) from those collections (J.J. Vargas H., pers. comm.).

‡*Key:* 1 Moran (Bannister 1958); 2 Forde (Forde 1964); 3 Libby, Bannister, and Linhart (Libby et al. 1968); 4 Eldridge and others (Eldridge 1978a,b; Libby 1978); 5 CAMCORE (Dvorak 1991); 6 CAMCORE (Dvorak 1993); 7 Rogers, Matheson, Vargas Hernández, and Guerra Santos (Rogers et al. 2002)

Some seeds from the 1978 and 1990 seed collections remain in storage in various locations in California (Table 10). Late in 2000, individuals involved in maintenance, conservation, and research (e.g., USDA Forest Service, California Department of Forestry and Fire Protection (CDF), and University of California) met to discuss appropriate care and use policy for these remaining genetic collections in California. One outcome from this assembly was consolidation of some seed collections: the collection previously held at the Pacific Southwest Research Station of the USDA Forest Service (Albany, California) was transferred to the CDF seed storage facility at Davis, California.

Existing collections from Cedros and Guadalupe Islands are of particular interest because of the protected status of Guadalupe Island, the real or potential decline of the populations since previous collections, and the considerable expense involved in making new collections in these remote locations. The existing seed collections from Guadalupe Island, in particular, are in part irreplaceable because of the serious decline in parent trees and apparent genetic erosion since the 1978 collection. The fate of seeds from these islands that were taken to Australia and New Zealand is described in Box 6.

Seed collections can play a supportive role, but do not in themselves constitute a long-term genetic conservation strategy. "For sustained genetic conservation through stored seed, old seed would have to be grown out in plantations before it loses its viability (to prevent the seed store from becoming a seed morgue) and replaced with pure seed of equal genetic variability without loss of rare genes." (Eldridge 1998b).

Concern over introducing diseases either from or into the native populations of Monterey pine puts another constraint on the transfer of seed for *ex situ* conservation or restoration purposes. For example, the apparent nonexistence of pitch canker disease on Guadalupe and Cedros Islands suggests caution in moving seeds stored in California to those islands for any restoration activities. Risks are too high, currently, to allow seeds from California to be transferred to Australia or New Zealand.

CSIRO (Australia) has approximately 30 kg of Monterey pine seed in storage, with an average germination of 64% when last tested in 1995. A detailed description of the Monterey pine seed in storage in Australia (mainly from the 1978 seed collection event for the five native populations) is contained in a 1998 report (Eldridge 1998a). This collection contains more than 600 seedlots from the five populations. The report, commissioned by the CSIRO Australian Tree Seed Centre, contains recommendations on the best conservation strategy for this seed resource. A major recommendation is that the seed in storage be outplanted (with the exception of some seed in special long-term storage at Black Mountain, Canberra) within the next two to three years in well-designed genetic conservation plantings. It is suggested that, based on previous germination tests, germination may be low for many of the seedlots within as little as ten years. The seed in storage is considered irreplaceable—with the uncertainty of safe quarantine procedures for new seed collections from the native populations and the uncertainty of the current and future integrity of the genetic diversity in the native populations. Therefore, restoration of the current pure seed supplies may only be possible through expensive controlled pollinations of the outplanted seed reserves (Eldridge 1998a). A recent update of this report shows that seed germination percentage has declined dramatically—to about 37% (average of California populations) in 2001 (Eldridge 2002).

Box 5. Differences in mean seed weight among the five Monterey pine populations.

Differences in cone characteristics were one of the first differences noted among Monterey pine populations in native conditions. Later, controlled studies confirmed a genetic basis for such characteristics as cone dimensions, number of scales, and mean seed weight (e.g., Burdon and Low 1973). However, the relative (mean) seed weight among populations will vary according to the protocol for the sampling procedure (number of trees sampled per population and number of seeds weighed in total and per tree), moisture content (and so, maturity of the seed, fresh or stored, amount of time in storage, and storage conditions), environmental conditions, and other factors. Two reports on mean seed weight per population show almost a twofold difference in mean seed weight between the lightest and heaviest seed weights, but differ in the ranking of the (lower three) populations. Because both sets of weight estimates are based on seeds taken directly from the native populations, these ranking differences reflect differences in the composition of the samples (e.g., number of trees sampled per population and number of seeds weighed per tree) and possibly other factors such as those described above.

To convert *ex situ* seed collections from a weight basis to numbers of seeds per population (i.e., when numbers of seeds are large), these conversion estimates may be useful. However, in making such conversions to number of seed in storage, to inform conservation policies or seed management decisions, it is important to consider how the estimates were derived and whether the population differences have been reflected in these estimates.

	Mean seed weight (mg) per population	
Population	Burdon 2001b†	K.G. Eldridge pers. comm.‡
Año Nuevo	42	34.5
Monterey	23	24.5
Cambria	48	36.4
Guadalupe Island	29	32.4
Cedros Island	29	20.0

†Based on weighing approximately 600 seeds per population, except for Cedros Island for which 850 seeds were weighed (R.D. Burdon, pers. comm.).

‡Based on weighing one hundred seeds per tree for each of the trees collected from the source populations in 1978.

Planted domestic reserves

Most of the genetic conservation plantings for Monterey pine in California were planted on University of California (UC) property as a result of the initiative of W.J. Libby. During the 1960s and 1970s, Libby and colleagues made collections from native populations, conducted controlled pollinations, and established seed and hedge orchards and other research and conservation plantings at several central and northern California sites. Some of these plantings have already been removed; many others are at risk for removal for other land uses. For example, two hedge orchards on University of California property containing clones from all five native populations were removed in 1987 and 1988

Table 10. Monterey pine seed in storage in California in 2000.

	USDA Forest Service Albany, CA†		L.A. Moran Reforestation Center Davis, CA‡		USDA Forest Service Placerville, CA	
	Seedlot§	Seedlot size	Seedlot§	Seedlot size	Seedlot§	Seedlot size
	(count)	(seeds/seedlot)	(count)	(kg)	(count)	(seeds/seedlot)
Año Nuevo (AN)	21	10–700	1	2.7 IT	174	40–100
Monterey	21	40–1000	1	1.7	237	40–100
			1	2.4 IT		
Cambria	22	60–1000	3	2.6	96	40–100
			1	3.4 IT		
Guadelupe Island (GI)	16	10–60			47	100
Cedros Island (CI)	41	5–90			50	100–400
Date of collection	1978#		1990 & 1991¶		1978#	
Within-population crosses††						
AN × AN	88	0–300				
Monterey × Monterey	69	0–200				
Cambria × Cambria	54	0–200				
GI × GI	101	0–200				
CI × CI	70	0–200				
Among-population crosses‡‡						
Assorted crosses	60	0–200				
Unknown or mixed	1	2000				
	1	5000				

†Germination tests conducted in 1999 show germination for open-pollinated seedlots (i.e., seeds collected from native stands) of 80 to 100% and for control-pollinated seedlots of approximately 50% (D.L. Delany, pers. comm.). In 2001, these collections were moved from the facilities at USDA Forest Service, Albany, CA to the California Dept. of Forestry and Fire Protection's L.A. Moran Reforestation Center, Davis, CA.

‡A unit of the California Dept. of Forestry and Fire Protection (CDF).

§The term 'seedlot' as used here stands for 'unit of stored seed'. How such units are defined, measured, stored, and inventoried varies with the institution. A seedlot could mean in one case a bulked collection of seed from many individual trees and in another case a collection of seed from individual trees, the seed from each tree packaged and kept separate from the others, but regarded altogether as one unit. The latter case, when known, is denoted by the letters IT (for individual tree) in the seedlot size field.

#Seedlots are from the 1978 seed collection trips (D.R. Johnson, pers. comm.) by Eldridge and others (Eldridge 1978a,b; Libby 1978).

¶Individual tree collections (IT) are from 1991 CAMCORE collections, while all others are from 1990. There are also small amounts of seed in cold storage at North Carolina State University from the 1991 CAMCORE collections. There are also small quantities of seeds in storage from six individual trees at Año Nuevo, collected by Dave Adams (CDF). Four of the trees appeared resistant, at time of collection, to pitch canker; the other two appeared susceptible (L.A. Lippitt, pers. comm.).

††Within-population crosses were made in 1978 through 1980 by W.J. Libby.

‡‡No further information is available for this material.

Box 6. Fate of Australia and New Zealand collections from native Monterey pine populations from Guadalupe and Cedros Islands.

Australia: "In long-term -18°C secure storage at CSIRO Plant Introduction Laboratory, Black Mountain, Canberra there are about 30 seeds of each of about 515 mainland families, 50 Cedros, 48 Guadalupe, and also 30 of each of 76 Guadalupe families from the 1992 collection. We expect all this old seed will germinate well, after stratification, as it was extracted under relatively benign conditions and has not had the quarantine treatments of sodium hypochlorite dip and methyl bromide fumigation.

"In the cold room at CSIRO Forestry and Forest Products Laboratory at Yarralumla, Canberra there is more than 20 kg of the 1978 seed which probably has low germination due to inappropriate quarantine treatment in 1978 and imperfect storage since. Within this collection, there is plenty of Monterey and Año Nuevo, very little Cambria, no Guadalupe, and a little of Cedros." (K.G. Eldridge, pers. comm.; more details in Eldridge 1998a)

New Zealand: "We received 42 Guadalupe families (from the 1978 collection trip) which went out into a pedigreed planting in Kaingaroa Forest. From a combination of this planting, and earlier plantings ('Genetic Survey', i.e., provenance-progeny trial) from 50 families collected by Reid Moran (in 1958) and five by Libby et al. (in 1964), about 80 good phenotypes have been selected and are being intercrossed (in archives) to maintain pure Guadalupe material. There is also controlled crossing being done to produce F_1 hybrids with our local, mainland origin, stock as a pilot commercial operation.

"In addition, we have a small block of pure but unpedigreed Guadalupe material, which produces a mix of purebred and hybrid seed, the purebred component being at least free of most of the inbreeding of *in situ* seed.

"Regarding the Cedros material from the 1978 collection, of which Ken Eldridge sent some to New Zealand, we have a tale of total loss, in which the final, decisive chapters stemmed indirectly from our institutional changes. However, we do have some material, representing less than 15 families, plus some unpedigreed trees, left from the Libby et al. collection in early 1964. Ten or so clones have been archived and are being used for some crossing.

"No seeds from the 1978 trip remain: we have sown everything and planted out what resulted." (R.D. Burdon, pers. comm.).

(Libby 1990). In addition to pressures from competing land uses and uncertain funding provisions, the UC collections remain at risk from western gall rust, pitch canker, and, at some locations, fire.

At the University of California's Russell Reservation, near Berkeley, California, several Monterey pine plantings are maintained. Three breeding orchards were established here in 1963–1965. One orchard was planted in 1965 with open-pollinated seedlings from 98 trees on Cedros Island (from a 1964 seed collection trip). Another was planted with seedlings from 73 trees sampled from Guadalupe Island. A third was planted with close to 270 clones from trees in the three mainland populations (90 from each). These trees originated from a 1962 collection of eight trees within ten selected stands of each of the three mainland populations. These orchards are not sufficiently distant from one another for genetic isolation and controlled crosses would be required to be assured of pure-population progeny. A hedge orchard was established here, originally with 940 clones. It was repropagated in 1974, but an informal UC 1984 report says it was then dying of western gall rust. Various other plantings occur at this site, including an exhibit with representatives of all five native populations plus some interpopulation hybrids. A series of field studies were installed here in the early 1980s to determine family and population differences in resistance to western gall rust (e.g., Old et al. 1986).

Another set of field trials at the Russell Reservation, planted in 1988, contains material from all five native populations, mainland × island crosses, and selected families from Australia and New Zealand. A total of 32 clones are replicated on four sites. The four field trials, established with rooted cuttings, were intended to test for differences in resistance to western gall rust. The difference in response is dramatic after 12 years. The field trials are expected to be continued for perhaps three more years. As the original hedge orchard from which these cuttings were derived has been destroyed, the principal investigator for this experiment, Detlev R. Vogler, plans to 'reconstitute' the hedges by taking cuttings from the ramets in the field. If successful, this source of germplasm may be perpetuated (D.R. Vogler, pers. comm.).

At another UC property in Albany, California (Gill Tract), part of the mainland population breeding orchard was replicated. In 1988, approximately 90 clones were removed to install a sewer line. A 940-clone hedge orchard was also established here that occupies approximately 0.1 ha. Neither planting is well maintained and the future of the material here is uncertain (M.A. Diegan, pers. comm.).

Ramets from half of the 270 clones in the mainland population breeding orchard at the UC Russell Reservation were planted in northern California. The property, near Korbel, California, is owned by the Simpson Timber Company.

International *ex situ* reserves and interest in the native populations

For well over a century, there has been much international interest in Monterey pine, particularly from the southern hemisphere (Box 7). Monterey pine is grown as a plantation species in Chile, New Zealand, Australia, and to a lesser extent in Argentina, South Africa, Spain, and several other countries. Combined, the countries that have commercial plantations of Monterey pine have more than 4 million ha in production (Table 11). This is over six times the plantation area recorded in the mid-1950s (Scott 1960). Current trends suggest that the Pacific Rim countries are increasing their dominance in Monterey pine plantations (Lavery and Mead 1998).

More detail on the history and nature of Monterey pine plantations worldwide is available elsewhere (e.g., Lavery and Mead 1998). The focus here is on providing a brief description of the commercial context of Monterey pine, to the extent that there are genetic resources internationally that could be considered *ex situ* reserves with relevance to genetic conservation of the native populations. Summaries and comparisons among countries are complicated because breeding and conservation programs in these countries differ considerably in the extent of documentation of the original collections that form the basis of their programs, the degree of recording the breeding histories of existing material, and the units and variables by which the plantings are described. Much of the information provided here is derived from responses to a 1998 questionnaire (a list of respondents is provided in Appendix B), supplemented by several specific reports on the Australian and New Zealand reserves and information offered through recent personal communications.

Genetically pure reserves—having not been shaped by artificial or natural selection in the host (nonnative) country—are not only in the minority among germplasm reserves in these countries, but are the most valuable towards conservation or restoration of native forests. There is an important distinction here between germplasm that can serve as an *ex situ* genetic reserve for the native populations versus that for plantation purposes. Substantial genetic reserves for Monterey pine exist internationally, but pure-population reserves are a small proportion (i.e., perhaps a few hundred ha of provenance trials and stored seeds) and are at risk from a variety of threats. At some point, the stored seeds must be grown out and, in so doing, are subject to selection pressures different from those in the native populations and, in some cases, genetic contamination. "The option of maintaining pure native-population stocks as gene resources in New Zealand is threatened by ubiquitous pollen contamination from plantations, unless massive controlled-crossing operations are practiced." (Burdon et al. 1997b). Planted reserves are vulnerable to a variety of risks and are difficult and expensive to maintain in the long term. "[In Australia] it is clear that, in a time scale of several rotations, the present *ex situ* radiata pine genetic conservation plantings must be regarded as EPHEMERAL [*sic*]. There will be a considerable challenge to continue to have such uncontaminated 'wild' material still available in 100 years, and it seems likely that most of it would disappear in the next 20–30 years unless determined action is taken now to recognize its value, preserve the best of the present plantings beyond the normal rotation age, and plan for their replacement." (Eldridge 1998b).

Argentina. The area of Monterey pine plantations is approximately 15 000 ha and has not changed significantly in the last decade or so. One of the main limitations is finding appropriate sites with sufficient moisture, especially during the summer months. Some plantations, established 50 to 60 years ago in areas with annual precipitation of over 2000 mm, now lie within the boundaries of national parks. These plantations show very good growth. The other plantations in Argentina are mainly in Cordoba province and along some Altantic coastal areas in Buenos Aires province (L.A. Gallo, pers. comm.).

Australia. Sources of information on the Australian breeding program for Monterey pine include Matheson and Brown (1983), Cotterill (1984), Eldridge (1985), Boomsma (1997), Matheson et al. (1997), and many others. The description here will focus on the genetically pure *ex situ* reserves. The major organization with research and conservation interests and historically and currently making large investments in these activities is the Division of Forestry and Forest Products, CSIRO.

An excellent summary of much of the outplanted Australian germplasm is provided in an annotated catalogue of Australian provenance trials and genetic conservation plantings (Eldridge 1998b). There are 67 such trials in Australia, the earliest planted in 1933. Of these, 12 no longer exist (i.e., harvested, burned, abandoned, or lost). The total area of the remaining plantings, as of 1998, is approximately 237 ha. There is good representation, among the remaining trials, of all five native populations.

Forty-five of the remaining trials contain trees derived from the 1978 seed collection effort organized by CSIRO, most having been planted between 1979 and 1981. A recent field inspection of six of these plantings revealed both conservation opportunities and problems (two in Gippsland, Victoria on Australian Paper Plantations land and four near Tumut on State Forests New South Wales (NSW) land) (K.G. Eldridge, pers. comm.). Because these field plantings are now approximately 20 years old, and were planted at a spacing that required some selective thinning, they are not well designed for long-term growth comparisons. The tests were planned not only for genetic conservation but also for shorter-term genetic testing. Thus, some trees have been, or will be soon, removed. Natural mortality is not random within the plantings. For example, the Cedros and Guadalupe Island trees, at two of the NSW areas, have suffered heavy mortality and thus some plantings do not have the same conservation value as they did when planted for all five populations. Active management and thoughtful consid-

Box 7. Early observations on the commercial significance of Monterey pine.

"This is probably the most important conifer from the view point of commercial afforestation that has been introduced to countries of the southern hemisphere, Australia, New Zealand and South Africa. Planting of the species has now been going on for 40 to 50 years and a very considerable amount of capital, both State and private, has been invested in these operations. Quite insignificant in its native habitat, on the coast of California, its rapidity of growth and adaptability to a wide range of conditions in many countries of the southern hemisphere, render it an invaluable species in providing softwood supplies to meet the shortage in that region." (Lindsay 1932).

eration of these plantings will be required to maintain some of their genetic conservation potential in the long term. Most of the plantings from the 1978 seed collection—in both Australia and New Zealand—are due for clear-cutting within the next 20 years (K.G. Eldridge, pers. comm.). A report that provides an update of the status of both CSIRO field plantings and seed reserves of Monterey pine and recommendations for their management has been recently published (Eldridge 2002).

There is continued strong interest in the conservation of the native gene pools *in situ*. Because of the many problems associated with *ex situ* conservation of pure-population genetic resources, Australian plantation managers and owners value the native populations as a source of new genes. It is acknowledged that technologies and biosafety protocols would be required to prevent introduction of disease (such as pitch canker) into Australia if new collections were made. Also, there is concern about genetic contamination of the Monterey and Cambria stands due to the planting of trees raised from New Zealand seed (thought to be largely of Año Nuevo origin), the uncertainty of property owners allowing future seed collections, and the serious decline of the Guadalupe Island population (Eldridge 1997).

Australia's interest in and commitment to the conservation of the native gene pools in Monterey pine has been expressed for decades in such activities as sponsoring expensive seed collection expeditions (e.g., 1978), provision of funds to the University of California for genetic conservation (e.g., Libby 1990), establishing numerous provenance trials, conducting considerable genetic research, and organizing workshops and meetings to discuss the importance of genetic conservation and appropriate policies and procedures for *ex situ* genetic conservation collections.

Chile. Monterey pine was introduced to Chile in the late 1800s. Later, there was interest in using this species to help stop erosion problems that threatened the Coastal Range. The first commercial plantations were planted in the early 1940s and today Monterey pine constitutes the basis of the Chilean forest economy. Exports from these plantations contributed over $1.5 billion USD in 1994 to the national economy (Toro and Gessel 1999). Little is known about the source of the seed used for early plantations (Jayawickrama and Balocchi 1993). Because the cone sizes and seed weight from the plantations are similar to those found in New Zealand landraces, it has been suggested that the seed source of the Chilean Monterey pine is the same as that for New Zealand, namely the Año Nuevo and Monterey populations (R.D. Burdon, pers. comm.).

Several provenance trials, comparing the growth of Monterey pines from the five natural populations and several foreign and domestic seed orchards, may be considered *ex situ* reserves. Measurements show differences in volume among the various source populations. The good growth rates of some of the subpopulations, and the desirable straight stems shown by the material from Guadalupe Island, suggested to researchers that it may be desirable to incorporate material from the natural populations directly (rather than just continuing with domesticated material) into Chilean tree improvement programs (Jayawickrama and Balocchi 1993).

Table 11. Estimate of plantation area of Monterey pine internationally.

Country	Area in plantations	Reference
	(ha)	
Argentina	15 000	Rogers and Ledig 1996
Australia	745 000	From 1998 survey (unpublished data)
Chile	1 500 000	Rogers and Ledig 1996
Great Britain	270	C.J.A. Samuel, pers. comm.
Ireland	300	D.G. Thompson, pers. comm.
New Zealand	1 540 000	From 1998 survey (unpublished data)
South Africa	71 840	DWAF 1996
Spain	237 400	From 1998 survey (unpublished data)
Turkey	2 800	B.N. Cengel, pers. comm.
Total	**4 112 610**	

Breeding and selection has contributed to shaping a genetic resource that is more appropriate for the plantation conditions and market needs in Chile. These localized genetic resources are important for commercial conservation purposes, but less valuable in relation to conservation of the native Monterey pine forests. A breeding program that began in 1976 has resulted in more than 200 ha of seed orchards, more than 1000 full-sib families in progeny trials, as well as clone banks and hedge orchards. The response to a 1995 survey suggested that the genetic reserves were considered adequate for the future of the breeding program in Chile. However, long-term genetic conservation is not institutionalized here because the plantation property and reserves are all privately owned: forest industries own approximately 70% of the Monterey pine plantation area and smaller private landowners the rest (Rogers and Ledig 1996).

Great Britain. There are currently almost 300 ha of Monterey pine plantations in Great Britain, approximately evenly divided between public (Forest Enterprise) and private ownership. Most of the publicly owned Monterey pine plantations are located in Wales or the southwest England peninsula. Monterey pine is also used as an ornamental tree, particularly common along the south coast of England.

Species and provenance trials of Monterey pine have been planted, particularly in the Bournemouth area. One of these field trials, planted in 1980, contains trees from seeds collected from planted Monterey pines in southern England as well as samples from the three California native populations and some Australian-source material from Guadalupe Island (i.e., Guadalupe *ex* Canberra). The California mainland and Guadalupe material was obtained from CSIRO. Thirteen-year results show that the best height growth and survival are found among the home-collected seed sources, showing that a single generation within Britain can have a

beneficial effect. This observation has also been made for other exotic conifers in which a comparison is possible between directly imported germplasm and first-generation domestic seed collections (C.J.A. Samuel, pers. comm.). The Guadalupe material also showed good survival and growth. Among the three mainland populations, the Año Nuevo material generally had the best survival. (C.J.A. Samuel and R.L. Jinks, pers. comm.)

Greece. The first recorded introduction of Monterey pine to Greece was in 1913 as a addition to the Arboretum of Vytina. Monterey pine is currently a minor plantation species here and is limited to particular sites that have sufficient moisture and microclimate (Varelides 1996).

Ireland. Monterey pine is a minor but important plantation species in Ireland, currently growing in plantations of total area of approximately 300 ha. It adds to species diversity, has among the highest wood production rates of forest plantation species there, and grows on less fertile sites than Sitka spruce (*Picea sitchensis*)—another favored plantation species with similar yields. Guadalupe Island is the seed source of most interest for the plantations, primarily due to its lower (relative to other populations) severity of symptoms from *Cyclaneusma* disease (D.G. Thompson, pers. comm.). Plantation area of Monterey pine—Guadalupe source in particular—may increase, particularly in the south near Cork, as some of the practical and technical limitations are overcome (Box 8).

New Zealand. Although records have not been exhaustively searched, it appears that Monterey pine—as germplasm rather than a wood product—was introduced in the late 1850s (R.D. Burdon, pers. comm.). As with Australia, there is a sophisticated and long-established breeding, genetic research, and germplasm conservation program here for Monterey pine, much of it provided by the New Zealand Forest Research Institute, based in Rotorua, New Zealand. Some sources of information on the breeding programs include Shelbourne (1970), Shelbourne et al. (1986), Jayawickrama et al. (1997), Shelbourne (1997), Shelbourne et al. (1997), Sorensson et al. (1997), and many others. As with Australia, the description of genetic reserves will focus on those that are the most genetically pure derivatives from the native populations.

Box 8. Commercial significance of Monterey pine in Ireland.

"Forestry in Ireland is divided between Coillte Teoranta—the Irish Forestry Board (i.e., forests established under state forestry 1905–1989)—and privately planted, owned, and managed forests. For Coillte, we have 261 ha of Monterey pine in our inventory out of a total of 325 000 ha or about 0.08% of our forests. No current details of Monterey pine in the private sector exist, but a survey done in 1973 found only 21 ha.

"The genetic base is rather unclear because although there is a register of all seed imports for the period 1930 to 1980, there was little attention paid to the exact origin of imported seed until perhaps the 1960s or 1970s. Therefore, the seed source is generally recorded as 'western North America' or 'California'.

"The average yield class (i.e., volume of wood produced per ha per year) of Monterey pine in Ireland is 16.5 cubic meters which is among the highest species production rates recorded here. Nevertheless, Sitka spruce (*Picea sitchensis*)—which has about the same yield class—grows on a much wider range of sites than Monterey pine and therefore is the major commercial species.

"There has always been an interest in Monterey pine in Ireland because of its productive potential. One of my colleagues says: 'Every generation of foresters rediscovers Monterey pine'. The main problems with Monterey pine in Ireland have been: 1) determining the site requirements; 2) determining the right seed origin; and 3) development of quality nursery stock.

"We now know on what sites it performs well and they are typically nutrient-poor soils where sitka spruce requires large amounts of repeated fertilization. It also provides variety to forest plantations, both visually and perhaps ecologically, providing unique habitats for different plants and animals. Provenance trials established in the early 1980s identified Guadalupe Island as the most productive seed source, mainly because we have found much lower levels of *Cyclaneusma* disease in this seed source. The *Cyclaneusma* infection greatly reduces needle area which results in greatly reduced wood production. We have tested some of the 'Guadalupe *ex* Canberra' material from Australia and unfortunately find that it has considerable yellowing due to hybridization with local Monterey pine. This is the reason why we are interested in obtaining a source of pure Guadalupe island material. We also had a programme of collecting seed and scions from local individuals of unknown origin that did not exhibit the yellowing problems, but they also are not as productive as the pure Guadalupe Island material.

"Given that we have identified appropriate sites, and assuming that we can develop a reliable source of Guadalupe seed, the question of producing high-quality planting stock is the remaining limiting factor. Instability or 'toppling' of young, container-grown plants is the major problem at present. It appears that there is an inappropriate allocation of photosynthate to shoot growth relative to root growth. Monterey pine has the reputation of being difficult to transplant so containerized planting stock seems to make sense. Cultural practices such as sowing date, fertilizer rates, and other nursery practices are probably critical in the production of high-quality planting stock. I do not think that the production of bare-root plants will overcome these problems.

"We plan to increase planting of Monterey pine in the southern part of the country around the Cork area because of the warmer temperatures and the availability of sites where Monterey pine does well with only modest fertilization (i.e., nutrient-poor, old, red, sandstone-derived soils). If we can overcome the toppling problem and have a verified seed source, I expect that planting of Monterey pine will increase. It will never become our major commercial species, but in light of the current emphasis on biodiversity, it could play an important role in certain parts of the country." (D.G. Thompson, pers. comm.).

Seed collections from 1958, 1961, and 1978 (Table 9) are represented in breeding-population parents from field plantings for Año Nuevo, Cambria, Monterey, and Guadalupe populations. However, there are now some dramatic differences between the original collections and the remaining trees. Some field plantings have been felled or thinned. Also, natural selection for New Zealand conditions (disease and general local adaptation) has removed some of the trees, and thus, truncated genetic diversity. Approximately 50 to 75% of these original collections of the three mainland populations have been lost in the field from a combination of thinning and natural selection. Representatives from up to 92 parent trees from Guadalupe Island have been installed in field plantings. One-third to one-half of these trees has been lost either from planned harvesting or disease or other natural selection. Approximately one hundred parent trees from Cedros Island were represented, via seeds collected, in field plantings. Probably the majority of these have been lost. In general, material collected from the 1961 seed collection trip (from mainland populations) has been partially harvested and the remainder will be removed in the foreseeable future. Plantings from the Cedros Island population, in particular, have largely vanished owing to a combination of suppression by trees of faster-growing material and low interest in the genetic resources from this source for the breeding program (R.D. Burdon, pers. comm.). In addition to these pure population collections, some breeding-population selections have been made from these collections and planted in new field sites.

Risks of low to moderate levels include fire, climate change, and ash eruptions from active volcanoes. Pollen contamination is potentially a major (if poorly quantified) risk in connection with any attempt to maintain reasonably large native-population entities in New Zealand without controlled pollination. New diseases or pests, whose behavior in New Zealand conditions is unpredictable, present additional risks. Perhaps the most pressing and most certain risk comes from institutional and political conditions: despite policy protection for these reserves, institutional upheavals may generate both human error and a lack of funding which undermines effective, long-term conservation strategies (R.D. Burdon, pers. comm.).

Although there is a sophisticated tree improvement program here with advanced domesticated generations and local landraces, native gene pools are still considered valuable. For example, Monterey germplasm may improve edaphic tolerances and Guadalupe germplasm may be useful in improving stem form and wood quality and possibly snow resistance (Burdon et al. 1997b). Currently, there is strong commitment to maintaining the New Zealand plantings of Guadalupe as a pure population that can be used to produce F_1 crosses with local, improved stock for commercial plantings (R.D. Burdon, pers. comm.). Conservation and introgressive use of the Cedros Island and Cambria populations may also be of real value because of unpredictable benefits of completely new gene combinations and to help meet unforeseen selection criteria that might emerge in the future (Burdon 1992). Monterey gene pools are also of interest as they are underrepresented in landrace stocks in New Zealand (as compared with Año Nuevo) and because of the general adaptedness of trees from this population, particularly in the north of the country. Año Nuevo is well represented in the landrace stocks, tending to reduce interest in the native population. However, its general adaptedness to New Zealand conditions, particularly in the south, could refocus interest on the native germplasm if landrace stocks and the breeding population could not meet some need that arose. These native genetic resources are difficult to maintain *ex situ*. Perhaps the greatest concern is that the native populations remain in a condition that enables them to continue to regenerate, maintain diversity, and give rise to trees that are resistant to pitch canker or any other pest that might reach California before eventually reaching New Zealand (R.D. Burdon, pers. comm.).

South Africa. Monterey pine is very important for the Cape region, particularly the Monterey population. Provenance trials, containing material from the three mainland populations and some Canberra-collected seed of Guadalupe origin, have been replicated on six sites. Assessments have shown that there are not significant differences among provenances within populations (of the traits assessed), but the superior population varies by trait and by trial site (Falkenhagen 1991).

Aside from the provenance trials, much of the germplasm has been shaped in some way towards local conditions, and is less valuable as an *ex situ* genetic reserve relative to the native populations. A Monterey pine breeding program initiated in 1962 by the South Africa Department of Forestry has been taken over by the South African Forestry Company Ltd. (SAFCOL). The basis for this program was a selection of 562 superior trees from close to 16 000 ha of Monterey pine plantations in the Cape Province. These plantations contained a mixture of trees from some of the native populations. Of these, 466 were approved for use in the breeding program, and were supplemented with some trees from Australia and New Zealand. Open-pollinated seed orchards were established with the best of these selections. Seventeen progeny trials were established with representation as follows: 484 selections from open-pollinated progeny from the seed orchards, 108 open-pollinated and 24 full-sib families from Australia, 30 open-pollinated families from New Zealand, and 86 full-sib families from local breeding efforts. Selections were then made from these progeny trials to form the basis of a breeding population. Two second-generation progeny trials (210 selections) and a second-generation seed orchard (100 selections) were established (D.J. Steyn and H. Rossouw, pers. comm.). There is a high degree of risk to germplasm from fire and a moderate risk from disease (C. Bester, pers. comm.).

Spain. There are three seed orchards established with material from the Año Nuevo population, each with approximately 100 trees. There are also three progeny tests with seedlings from the plus trees (i.e., trees selected, based on phenotype, for desirable traits) from these seed orchards. For each of

the Cambria and Monterey populations there is one seed orchard, each with approximately 250 trees. There is also one small seed orchard with trees of unknown origin.

Monterey pine is a very important species in the north of Spain. It grows in over 162 000 ha in the Basque country (Espinel et al. 1995). The Monterey population, in particular, is of great importance in the Basque country because this population shows growth performance superior to the other three mainland populations in field tests here.

Turkey. The Monterey pine plantation area is approximately 2800 ha. The genetic source for these plantations is known in some, but not most, situations. The only genetic reserve is a plantation in northwestern Turkey, near Adapazari, that is growing well and protected as a seed production area. Interest in Monterey pine as an exotic plantation species is not increasing. In 1984, many plantations suffered damage from *Evetria buoliana* and interest was lost in Monterey pine as a result. However, some trees have almost totally recovered (B.N. Cengel and Z. Kaya, pers. comm.).