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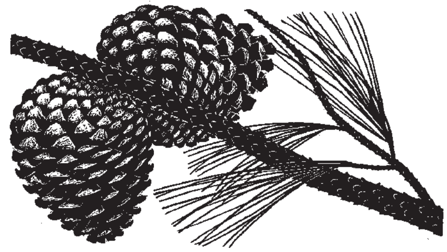

Introduction

At a 1998 workshop in Canberra, Australia to focus on *ex situ* conservation of Monterey pine (*Pinus radiata* D. Don), participants raised the question of whether the appropriate authorities in the USA would consider the *in situ* conservation of Monterey pine a responsibility (Spencer et al. 1998). Californians are the custodians of the genetic resources of a major world crop plant (K.G. Eldridge, pers. comm.). This responsibility—to protect the genetic resources upon which the wealth of other nations may depend—has been acknowledged previously (e.g., Ledig 1988), but not planned or supported adequately.

Monterey pine, native only to five small areas in California and Baja California (Figure 1), is nevertheless of great value to the international community. Internationally, it is more commonly known as radiata pine, but will be referred to as Monterey pine in this report given the focus on native populations and *in situ* conservation. Domesticated populations, varieties, and clones of this species are grown in plantations amounting to over 4 million ha worldwide. Over recent decades, domestication processes have been applied to this species in various programs worldwide to shape a more desirable tree type. These processes are similar to those used historically with food crops, and can be framed as having four elements: the original genetic variability, selection of the desired trees or genes, packaging of those genes in trees to be used, and benefit capture—converting those gene packages into growing trees that are harvested as a renewable resource (Libby 1973). Monterey pine's success as a plantation species is largely attributable to its capacity to respond to both genetic improvement and management. The planted-forest technology for Monterey pine is probably the most advanced of any tree species (Sutton 1999). The tremendous commercial value of this species is illustrated by its status in Chile, New Zealand, and Australia, in particular. In Australia, for example, Monterey pine plantations account for 75% of the total pine plantations currently established. Current value of the sawn timber produced from the total pine plantations is over $1 billion AUD per year. Furthermore, research investments have paid off handsomely, with first-generation breeding efforts for Monterey pine recently evaluated as representing a benefit/cost ratio of approximately 15 (CSIRO 1999). In New Zealand, this benefit/cost ratio has been reported to be much higher (R.D. Burdon, pers. comm.). This return on genetic research investment emphasizes the extent of genetic diversity that was inherent in the species and its value.

Indirect conservation value can be achieved through domestication of some species. For example, highly productive and concentrated forest plantations can make it possible to allocate native forests to parks and reserves, and at the same time generate positive environmental effects as plantations replace degraded marginal agricultural lands (e.g., Gladstone and Ledig 1990; Sedjo 1999). A case in point is New Zealand where forest plantations now provide 98% of that country's annual wood harvest, more than 90% of which is Monterey pine. Over half of this harvest is exported. A century ago, almost all of the wood used in New Zealand came from native forests (Sutton 1999). This shift towards plantation production has allowed New Zealand to protect most of the remaining native forests (Sutton 1995). The high productivity of Monterey pine plantations provides conservation leverage (Libby 1995).

Monterey pine is valued in California mainly for its æsthetic value and ecological roles within the restricted ecosystems that it dominates. These values, however, are frequently dwarfed by the value of this habitat for other land uses. Consequently, a considerable fraction of the Monterey pine forest has been lost to development. And valuing the ambience of the Monterey pine forest often works to the detriment of the underlying ecosystem. As more homes and recreational structures and corridors are built in the forest,

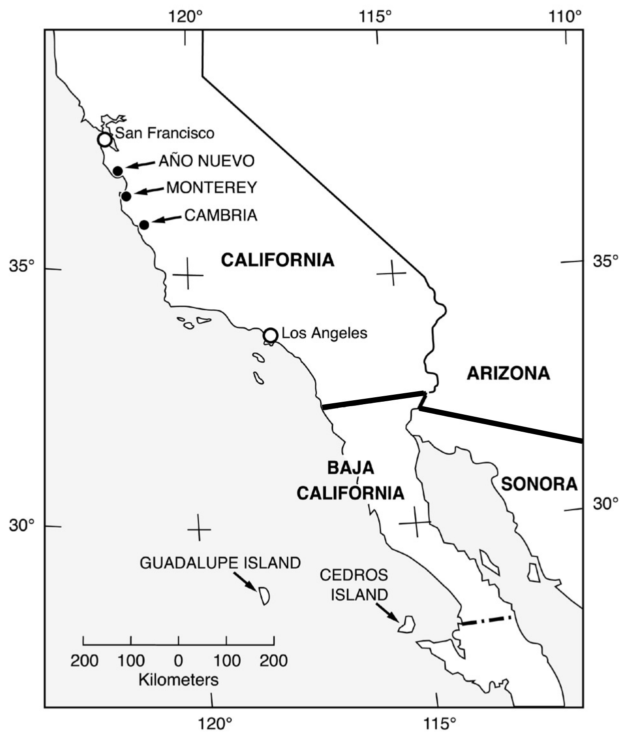

Figure 1. Locations of current natural populations of Monterey pine: Año Nuevo, Monterey, and Cambria in California and Guadalupe Island and Cedros Island in Mexico. (Figure modified from Ledig et al. 1998, p. 36 with permission of the publisher, Society of American Foresters, 5400 Grosvenor Lane, Bethesda MD 20814-2198.)

the landscape is further fragmented and natural ecosystem processes are interrupted.

Its æsthetic value in horticultural use may also have worked to the detriment of the species—both in ecosystem health and public sentiment. Symmetrical when young, dramatic when mature, often with vigorous, dense, deep green foliage, this species has much horticultural potential. However, it has been overplanted and inappropriately matched to site in many cases, undermining its reputation and underrepresenting its potential value (Sigg 1987).

Pitch canker, an introduced disease caused by the fungus *Fusarium circinatum*, which was first noted in Monterey pines in California in 1986, has spread to 18 counties throughout coastal and near-coastal California and may potentially cause high mortality in native Monterey pine populations (Owen and Adams 1999). This disease has heightened interest in conserving remaining native gene pools as they are the context within which disease-resistant trees may emerge for regenerating the native areas. Concern was sufficient to produce California State Senate Bill 1712 for disease mitigation. Disease-influenced mortality—together with habitat losses from urban development; possible genetic contamination from planted, nonlocal trees; habitat fragmentation; changes in natural disturbance regimes and age structure; and other pressures—prompted the organization of a 1996 conference entitled 'Monterey pine forest: A forest at risk' (Smith and Ferlito 1997). Continuing and mounting conservation concerns prompted the 1999 submission of a petition by the California Native Plant Society to list the species as threatened under the California Endangered Species Act (CNPS 1999).

Role of genetic diversity

Maintaining the natural levels and structure of Monterey pine's genetic diversity is important because of the potential consequences for both the species and its associated ecosystems. At the population level, genetic diversity may provide opportunities for adaptation to local conditions. This is increasingly important in situations where environmental conditions manifest considerable change over time and where there is little potential for direct migration. The adaptational system may be thought of as having two types of environmental conditions: those conditions that cause modifications of the individual (e.g., leaf shedding) and those that cause selection and hence adaptation. Given the limited ability to control these environments and the lack of understanding about their interconnections, maintenance of genetic diversity and evolutionary flexibility are very important. For example, detrimental effects of human activities on the stability of forest ecosystems could be due to the disruption of existing natural connections between these two (modifying and adaptive) environments (Gregorius and Kleinschmit 1999).

At the ecosystem level, disturbances to genetic diversity or structure of a population can have cascading effects throughout the system. Any genetic changes that alter a given species' ecological properties are likely to be felt and magnified in the community, as much as if the species were removed or a new species were added (Endler et al. 2000).

Need for *in situ* genetic conservation

An international workshop on conservation of forest genetic resources of the North American temperate zone was held in Berkeley, California in 1995. At least three of the workshop's 12 consensus recommendations are directly related to this endeavor (Rogers and Ledig 1996). Workshop participants recommended:

1. The development of national programs to address issues in the conservation of forest genetic resources.
2. That conservation of forest genetic resources should be addressed by multiple approaches and that, whenever possible, they should include ecosystem reserves.
3. Recognizing that many North American temperate forest tree species are important plantation species on this and other continents, and that it may be necessary to draw upon these forest genetic resources in the future, Canada, Mexico, and the United States should conserve these resources *in situ*.

In situ genetic conservation activities for Monterey pine are called for because genetic integrity is at risk, genetic information in its entirety is not being considered by other present actions and planning efforts, genetic values affect and are affected by current and possible management activities, and only a dedicated focus on genetic conservation will provide an effective and comprehensive framework for considering genetic information in relation to the broader ecology of the species and related conservation options. In 1981, the Guadalupe Island population of Monterey pine was declared 'endangered' by the FAO Panel of Experts on Forest Gene Resources due largely to grazing pressure from introduced goats (FAO 1986). Concurrently, the panel found the genetic integrity of the Monterey and Cambria populations endangered due to the highly urbanized environment in which much of the remaining forest occurs and the genetic contamination from planted trees. A report by this expert committee in 1993 again identified Monterey pine as a species with high global, regional, and national priority for genetic conservation (FAO 1994). The species is on the World List of Threatened Trees and the five populations have been classified according to the International Union of Conservation of Nature and Natural Resources' (IUCN) Red List Categories. In the IUCN system, the Guadalupe and Cedros Island populations are listed as endangered and the three mainland populations as conservation-dependent (i.e., in which the cessation of conservation activities would result in the populations qualifying for one of the IUCN threatened categories within a period of five years) (Hilton-Taylor 2000).

The IUCN categories of threat are widely used and have become an important tool in conservation activities at international levels and at national and lower scales. However, their utility and comparability could be improved with more objectivity in the assignment of threat categories. One reassessment of this system suggests, for example, that an assignment of *vulnerable* status might be appropriate for species estimated to have at least a 10% probability of extinction within 100 years (Mace and Lande 1991).

There is theoretical as well as empirical evidence that genetic conservation attention is necessary for Monterey pine. Generally, the species that need special attention (and hence, here, a species-based plan) are those with the largest area requirements, specialized habitat needs, functional importance in the community, or greatest sensitivity to human activities (Noss et al. 1997). This concept encompasses both areas that are naturally fragile because of large, natural and internal successional changes and those that change as a result of external disturbances (Nilsson and Grelsson 1995). Sensitivity to climate change and the loss of natural fire regimes may be particular areas of vulnerability for Monterey pine.

In fact, the genetic integrity and long-term viability of native Monterey pine populations were at sufficient risk even in the early 1980s to inspire the drafting of a conservation proposal that focused on their *in situ* and *ex situ* genetic resources (Kafton 1985). That proposal highlighted such issues as genetic contamination in the native stands and poor storage conditions and lack of funding for the seed collections that resided within the State. It is apparent that the proposal was not implemented.

Report attributes

My procedure in compiling relevant information and developing recommendations for genetic conservation for this species:

- was based on scientific information;
- included all five populations although my emphasis was on the USA mainland populations;
- employed expert opinion in the absence of complete information;
- considered both *in situ* and *ex situ* genetic resources, with an emphasis on *in situ* conservation; and
- was embedded within the broader goal of conservation of ecosystem function and processes.

This report is an information document, not an implementation instrument. It therefore lacks authority for direct implementation but serves to inform management decisions. The information provided should be considered within the context of broader values, economic considerations, and public will. The advice of Noss et al. (1997)—that conservation plans should be "biologically conservative, scientifically defensible, politically realistic, and able to provide a high probability of meeting widely accepted conservation goals"—is well applied here.

Genetic conservation efforts are ideally conducted in a proactive manner, before the genetic resource is so depleted as to leave few options for recovery and before it has lost significant current and potential adaptations. It is difficult to sense the urgency of such action, however, because the loss of locally adapted gene complexes is cryptic, hence called 'secret extinctions' (Ledig 1991). In some cases, the loss of genetic diversity may be apparent—as may happen if there are rapid and extreme losses in the number of trees (e.g., on Guadalupe Island). In other cases, the genetic resource may be severely degraded without an immediate loss in census number. For example, mahogany *(Swietenia mahogani*) has been so seriously exploited in the Caribbean that it is no longer found in its tree form (Ledig 1991), but has been reduced to a multi-stemmed shrub (Styles 1972). The alleles specifying the tree form in this species have certainly been reduced in frequency and may have been lost, even though the species itself is still widespread (Ledig 1991).

This report is rather unusual—in the domain of conservation plans—in its focus on genetic attributes and processes, its inclusion of the entire range of a species, its consideration of both *in situ* and *ex situ* genetic resources, and its proactive nature (i.e., as compared with a species recovery plan). No perfect models for such a report are known. Perhaps the most germane is the conservation plan for black poplar (*Populus nigra*) (Heinz et al. 2001), a diœcious European forest tree species with riparian habitat. Black poplar is not endangered in the sense of few remaining individuals. Rather, concern is based on the facts that the number of poplar populations is decreasing, that remaining populations are more and more fragmented, that natural regeneration has been impacted by floodplain alteration and regulation, and that there is a potential threat of introgression from cultivated poplar clones that have been planted extensively across continental Europe (de Vries and Turok 2001; Heinze and Lefèvre 2001).

Although there are yet more complex challenges in crossing the political border to include the two Mexican populations, this inclusion is considered essential to assess appropriately the genetic resources and the most effective conservation activities. These island populations have some genetic attributes that not only deserve conservation in their own right, but may have broader significance. For example, the Guadalupe Island Monterey pines have shown some resistance to red band needle blight (caused by *Scirrhia pini*) and western gall rust (caused by *Endocronartium harknessii*)—diseases that could be of great concern to countries where Monterey pine is grown as a commercial plantation species (Cobb and Libby 1968; Old et al. 1986; Ledig 1991). Trees from both island populations have shown significantly greater resistance to wind-induced toppling than those from the mainland populations (Burdon et al. 1992a). More generally, Mexico is a major center of diversity for the genus *Pinus*, and home to almost half of all pine species known worldwide (Styles 1993).

Objectives

Effective conservation strategies demand clear definition of objectives, adequate knowledge, and appropriate conservation methods (Eriksson et al. 1993). The overall objective of *in situ* genetic conservation of Monterey pine is *to provide the best opportunity, given current information and understanding of the species biology, to maintain adaptive potential and patterns and levels of genetic diversity that are within the normal range for the species*. Under ideal conditions and for a species with numerous populations, the normal sequence of activities in genetic conservation of forest tree species is as follows (Graudal et al. 1997):

1. Assessment of genetic variation (i.e., amount and pattern) within the species;
2. Assessment of the conservation status of the species;
3. Identification of populations to be conserved; and
4. Identification of possible conservation measures.

Due to time constraints imposed by a sense of urgency and because there are only five populations to consider, these sequential steps can be somewhat condensed for Monterey pine. No new research was performed specifically for this report during its preparation. Specific objectives of this report—containing both relevant information and recommendations for *in situ* genetic conservation entire planning—were to:

- Determine the status of the genetic resources of Monterey pine;
- Identify key genetic issues;
- Recommend actions related to genetic conservation for various management contexts, including management of the species in parks, reserves, and at the interface with development or situations in which there may be genetic impacts such as roadside or median strip planting;
- Identify needs associated with increasing public appreciation for long-term genetic conservation;
- Determine and discuss theoretical and empirical issues related to establishing *in situ* genetic reserves to conserve adaptive potential, appropriate levels of genetic diversity, and meaningful aspects of genetic structure;
- Inform discussions about other conservation plans for Monterey pine;
- Identify missing information on the genetic diversity, genetic structure, and related natural processes of Monterey pine in its native habitat;
- Address both the more immediate (e.g., genetic contamination, reduction in gene pool due to tree removal and disease) and longer-term (e.g., genetic bottleneck, inbreeding effects, regeneration success) genetic issues; and
- Formulate tentative functional genetic relationships among the natural populations of Monterey pine and the *ex situ* reserves of seeds and trees in California and worldwide.

Riggs (1990) suggests that, in view of our incomplete knowledge about genetic materials, environmental relationships, and our own future needs, we should strive to achieve three goals in the pursuit of genetic conservation:

- Improve access to existing knowledge;
- Maintain genetic continuity and integrity wherever possible; and
- Integrate and coordinate a diversity of conservation activities to the best possible effect.

This report clearly attempts to satisfy the first goal and contributes to the other two.