CONSERVATION AND BREEDING OF FOREST TREES

Namkoong, Gene
North Carolina State University and the University of British Columbia, and Principal, International Forestry Genetics Research Associates, USA

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1. Species in Different Ecosystems

There is a wealth of genetic variation extant in the world today, distributed among and within the many tree species that stretch around the globe, and it is necessary for the production of forest products and for maintaining forest environmental services. However, the resource is not a static resource, as are metal ores that once extracted, cannot be recovered, but it is a dynamically changing and complex entity. There has also been much variation that evolved in the past that may have been used and lost, or may have never been of value for long term survival. Now that we are changing our global forest environment and using more of its more limited resources, we are beholden to consider what we need to do to protect the fundamental genetic resource on which the ecology and material welfare of the world relies.

The conservation and use of the genetic resources of forest trees may require benign neglect in some cases, or varying intensities of managed intervention to ensure its continuing availability, and the knowledge of when and how to choose between them. Yet while we know that the health of the genetic resource is necessary for the continuing evolution of tree species, and the forest ecosystems in which the vast majority of plant and animal diversity lies, we also fear that we are losing irreplaceable parts of the system. We know that about one third of the land area that was occupied by forests only 2 millennia ago has disappeared and that some of the most species diverse forests remaining in the world are under immediate threat.

In the face of such threat we do have tools at our disposal for conserving the resource in perpetuity. Much is known in general about how to genetically manage and breed forest trees and the technology would seem to be at least theoretically available to attack problems in maintaining and developing the genetic resources of any tree species. But since we can actually work intensively with only a few species at a time, and most of our experience so far is limited to pioneer and temperate zone species and their ecological conditions, the practical difficulties of working with many trees in the time and space required are formidable. Thus, for most of the 25,000 or so species of woody plants that exist in the world today, little is known about their actual status with respect to extinction threat and few are so well utilized that much data is available on how to manage their survival and reproduction. A triage approach to choosing genetic management strategies might therefore be appropriate in which we consider an evaluation of the threats to what may be judged to be valuable species, which species may be susceptible to those threats andwhat management tactics may be appropriate for assuaging either threat or susceptibility. Then methods for constructing a program may be considered and the appropriate use of breeding and intensive genetic interventions evaluated.

2. Status with Respect to Use and Value

Conservation goals are often assumed rather than stated, but this leads to ambiguous objectives and poor evaluation of alternatives for achieving specific end criteria of success or failure. There are also different assumptions made about whether evolutionary processes are to be conserved or if a particular set of species and genetic structures and conditions are to be met. It some ways it is trivially easy to describe a goal as achieving a particular state of the genetic resource. This is akin to describing a forest that existed some years ago, or before European invasion of North America, or before any human migrations, etc. as an aboriginal or primeval ideal, and often assumes a maximum diversity and stability. To effectively use this to guide specific objectives would require describing the conditions of population sizes, their distributions, the allocation of variation among populations, the inter-species competition and arrangement, the ecological conditions, etc. that are to remain as they were. This requires very strong biological as well as moral assumptions about an ideal state, in addition to massive amounts of data that are not available, and therefore is not a feasible goal.

Rather, a goal of enabling continued evolution may be more difficult to state, but may give clearer objectives. Continuing evolutionary processes require that many different allelic forms of many genes exist in some population structure and are available for future use. The genetic processes that we can control to ensure evolution involve control of population size, mating patterns, the structure of populations, and selection. Since all species vary in these factors at one time or place or another, there may be no fixed condition for these parameters, but rather some minimum benchmarks that portend danger. Since management effects also vary in their effectiveness, exact prescriptions may be impossible to design, but rather a system of early warnings and extreme actions may be useful as guidelines.

3. Status with Respect to Threat

The commercially important tree species are primarily the pioneer or rapidly growing species that can be managed in plantations on relatively short cycles of planting and harvesting. Most experience has been with temperate zone species since those are the ones that have been developed in areas of intensive forest management, but in the globalized economies of the 20th and 21st centuries, species adapted to the tropical zones are included. A few widely planted boreal conifer species are also included in breeding programs, but industrial forestry concentrates on some *Eucalyptus*, Poplar, and Pine species, including less than 50 species worldwide. These can be said to have large population sizes, to be well known for their biological habits and how they can be utilized, and to have low susceptibility to range wide threats. Any problems that exist with the genetic health of these species are more in the realm of optimum development and use rather than immediate extinction.

At a slightly lower scale of recognized economic significance, are a few hundred species that have been economically useful for wood or non-timber forest products which may have been nurtured in the field but have not been cultivated as a crop. Many of these species may have a high potential for development into a commercial crop but have not been developed because of a lack of information on their biology or cultivation, or for market reasons, have not been brought into development. These may be nearly as well known for their distribution as are the commercial species, but have less experience in management.

At the other end of the extreme, there are around 500 species listed by the FAO that are substantially threatened in all or significant part, and require some effort to ensure their survival. For many, they are not known to serve in any especially significant ecological function, but they may and if threatened, have value if only for their unique existence. While many of these species lie in the tropical zone, many lie in areas that have been over-utilized by humans and in areas where their original sites of occupation have been destroyed. These species represent a very mixed bag of life histories, reproduction mechanics, threats to existence, and therefore management effects on each can have highly variable effects.

This leaves the vast majority of species, about which some hope exists, potentially able to be prevented from descending into a status of threat, that might be sustained and might maintain a potential for further evolution. The genetic management of these is the major problem for conservation and use.

The effectiveness of genetic management in forestry is highly dependent on how the forests themselves are managed and, since there is a wide range in the style and intensity of field forestry, each of the methods of genetic management will have a different effect on conservation or use. We discuss the genetic management tactics first under conditions of managed forests, then of unmanaged forests, and finally of semi-managed conditions.

4. Management Tactics

The genetic forces in populations that can be managed are traditionally classified into selection, migration, and population size, with mutation usually considered unmanageable. It is possible to engineer genes now to certain specifications, and to insert them in genomes to obtain individual effects, but these still require that they be managed within sets of individuals, or populations, in order for them to be useful. We consider here only the population level forces and the management of those forces to retain evolutionary capacity for their continued development.

Selection under human direction usually involves preferentially choosing individuals for reproducing the next generation and often excluding certain individuals entirely from reproducing at all. This obviously changes the average phenotype of the parental class and, for inherited characteristics, also changes the genotypic composition of the population. For many traits that seem to be affected by many genes, the process seems to work with fair predictability and in accord with common plant breeding experience. For commercial purposes, there have been large changes in the growth, vigor, stem form, and disease resistance of trees in breeding programs due to this selective process. One of the reasons for the rapid progress achieved has been the addition of strict regulations on the mating process that limits breeding to a few highly selected parents and unlike natural selection, separates the breeding population from intermating with unselected individuals.

Under conditions of natural regeneration, selection also occurs, but under a very different reproductive system. First, selection occurs for a general "fitness" in which many traits that affect growth, survival, and reproduction simultaneously define which parents are to be preferred. Second, the contribution of individuals to the progeny generation usually varies widely, with many more individuals participating, though often with a heavily skewed distribution toward relatively few. In other words, mating with parents that may be undesirable from many perspectives can still occur and would tend to draw the next generation mean back to the mean of the last generation.

Third, wild populations of forest trees also tend to be very large and changes due to selection must usually be expected to be very slow. In addition to the "drag effect" of large populations, the fact that a tree species often grows over a wide range of environments makes the selection for specific growth conditions less effective than if confined to cultivated sites. Selection for a wide range of conditions forces a selection for the average condition that tends to stabilize an average environmental response. Fourth, some tree species have evolved over a wide range of geographic locations that may have been isolated at some time in the past. Then, inter-mating between populations that have adapted to different conditions can generate a greater range of phenotypic responses to selection than a single population could if selected for uniform goals.

All of the effects of natural regeneration on selection, population size, and migration can be recreated in breeding populations by changing those factors in some design. By varying the parental contributions, by changing the numbers of parents and their mating design, by segregating populations and managing their rates and design of inter-mating, any condition can be reconstructed. Thus, the same forces of evolution operate in breeding populations as in those that are naturally regenerated, but they are managed differently, can have very different effects, and of course, carry different costs of operation.

Obviously, prevention of a conservation problem is cheaper than restoration of an ecosystem, but judging how much of the various types of management to apply is difficult. In some cases, for example of "rescue breeding" for a species or population, only highly artificial means of parental management may be effective for a species - even in its "natural state" if it is in a depauperate state. In other cases, only benign neglect may be likely to save a species by any means, because known interventions create higher risks than they assuage. Nevertheless, breeding and genetic management can create options that natural processes cannot, such as by intercrossing among threatened and isolated populations or by preventing uncontrollable and dysgenic selection or undesired hybridization.

4.1. Managed Forests

In managed forests, such as those including plans for planting programs, many can be brought under direct and designed genetic management though the use of planted breeding materials, such as seeds, seedlings, or clones. This most intensive form of genetic management includes many stages of plant development as outlined elsewhere and for commercially important species, can be a richly rewarded investment if applied on a scale that allows for the investments to pay off. Even for those managed forests that rely on natural regeneration, and that must endure interventions by harvesting, controlled burning, grazing, or other human effects, the genetic resource can be monitored and partially managed.

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Biographical Sketch

Gene Namkoong, was Professor of Forestry, Genetics and Biomathematics, North Carolina State University, from 1963 to 1992, as well as being a research scientist with the United States Department of

Agriculture, Forest Service. In 1972, he was promoted to the prestigious status of Pioneer Research Scientist, USDA, Forest Service. In 1993 he moved to the University of British Columbia to become Department Head, Forest Sciences Program and Professor of Forest Genetics. Dr. Namkoong has published many leading scientific papers and books in the area of forest tree breeding, population and quantitative genetics and in forest genetic resource management. He has for many decades been considered one of the world's leading authorities in forest genetics, and in 1994 was awarded the Wallenberg prize for his theoretical and applied contributions in the field. He retired from the University of British Columbia in 2000, moved back to his mountain home near Asheville, North Carolina, where he actively continued his consulting and writing Professor Namkoong passed away on March 3rd, 2002, after a long and courageous battle with cancer.