The Role of Genetics in Improving Forest Health

Mary F. Mahalovich[1]

Abstract.—An often ignored tool to improve forest health is the application of genetics. Tree improvement programs in the Inland West utilize genetic principles to develop seed transfer guidelines to avoid the problems associated with off-site plantings and to improve characteristics in conifers related to forest health. PC-based expert systems have been developed to aid in seed transfer in ponderosa pine and Douglas-fir. Genetic gains in adaptation, and insect and disease resistance, continue to be made in western white pine, western larch, ponderosa pine, Douglas-fir, and lodgepole pine. While progress has been made in the white pine blister rust program, restoring western white pine to Inland Northwest forests requires a continued commitment to selective breeding. Other insect and disease problems should also receive strong consideration in selective breeding programs, to prevent erosion of existing genetic resistance, and when warranted, to sustain and enhance this resistance.

INTRODUCTION

The general objectives of a tree improvement program are: (1) improving forest health, (2) conserving biodiversity, (3) ensuring an adapted seed supply for restoration and reforestation, and (4) meeting demands for wood products. These objectives are met by common garden studies (genecological studies) employed to develop seed transfer guidelines, by applying safe seed transfer, and via selective breeding. This paper highlights the role genetics and tree improvement plays in improving forest health in the Inland West.

Declining forest health conditions popularized in the media focus on improper species composition and stocking levels, insect and disease problems, and changing climatic conditions, such as sustained droughts, resulting in catastrophic wildfires. Dysgenic selection practices (high-grade logging) have also contributed to poor forest health conditions, by leaving trees with poor vigor and insect and disease problems, to become the parents of the next generation. The Western Forest Health Initiative (1994) and previous papers in this Workshop, include the common solutions of salvage logging, prescribed fire, and intermediate harvests to improve forest health conditions. Broadcast spraying of biological and chemical insecticides have also been used to control insect problems. Depending upon the condition and species involved, these treatments can be short or long-lived.

A comprehensive program for improving forest health also needs to evaluate the efficacy of including genetics as a long-lived treatment application. Genetics plays a role in improving forest health by reducing maladaptation by following seed transfer guidelines and by selective breeding for insect and disease resistance.

SEED TRANSFER GUIDELINES

Tree improvement activities begin with identifying patterns of genetic variation within a species. This information can be later utilized to develop seed transfer guidelines, identify and establish seed collection and seed production areas, and/or to develop selective breeding programs, culminating in the establishment of production seed orchards.

Common garden studies facilitate developing seed transfer guidelines based on adaptive traits.

[1]*Selective Breeding Specialist, Northern Region, U.S. Department of Agriculture, Forest Service, Moscow, ID.*

Adaptive traits include survival, cold hardiness, bud break and bud set, to name but a few. Seed transfer guidelines provide assurance that trees will be adapted to the environment in which they are planted, without significant risks to survival, growth and/or susceptibility to insect and disease problems. These guidelines set limits on the distance that seeds can be moved from their point of origin. To be effective, seed transfer guidelines must be based on genetic differences among populations that reflect adaptations to natural environments (Rehfeldt 1994).

Seed transfer in the Inland West is predominantly based on changes in elevation, then latitude and longitude (Rehfeldt 1994, 1991). Habitat types have yet to play a significant role in contributing to the patterns of genetic variation within conifer species (Rehfeldt 1981, 1979a 1979b, 1978). Seed zone map(s) and associated guidelines are found in Regional Seed Handbooks (FSH 2409.26f). These seed zone maps become obsolete once a PC rule-based system has been developed for each species. An expert system determines suitable planting sites for a target seedlot or identifies suitable collection areas for a target planting site. The hallmark of an expert system is that it combines the flexibility of both discrete and floating seed zones, i.e., recognizing that similar genotypes occur at different geographically separated localities (Rehfeldt 1991).

The National Forest System and Research Branch of the Forest Service have worked jointly to develop four expert systems in the Inland West. These seed transfer programs are distinct by species and in some cases, by variety. The first three PC-based expert systems are for ponderosa pine: (1) *Pinus ponderosa* var. *ponderosa* in eastern Washington, the entire state of Idaho, and western Montana, (2) *Pinus ponderosa* var. *scopulorum* for Utah and Nevada, and (3) *Pinus ponderosa* var. *scopulorum* for Arizona and New Mexico (Rehfeldt 1991, Monserud 1990). An interior Douglas-fir (*Pseudotsuga menzeseii* var. *glauca*) expert system is available for the combined areas of eastern Washington, and all of Idaho and Montana. Development is continuing for Engelmann spruce (*Picea engelmannii*) in the Intermountain Region (southern Idaho and Utah).

Seed transfer guidelines are also closely tied to conserving biodiversity and thereby improving forest health. An often ignored aspect of conserving genetic diversity is pollen management. Once off-site plantings reach reproductive maturity, these non-native sources can contaminate native gene pools.

The use of seed transfer guidelines, be it by seed zone maps or an expert system, have increased the percentage of seedling survival, reduced the loss of growth from poorly adapted seedlings, and reduced the extreme growth variability in planted areas. Seed transfer guidelines reduce maladaptation by eliminating off-site planting, but neither improve or degrade the overall genetic quality of a species. Seed transfer guidelines also facilitate the design of selective breeding programs, particularly when there is biologically significant genetic variation at the provenance or stand level.

SELECTIVE BREEDING PROGRAMS

Selective breeding programs increase our ability to better manage adaptation and increase genetic gain. Improvements in forest health are achieved through selective breeding programs when the traits of interest focus on adaptation and insect and disease resistance. The emphasis on tree species in the Northern and Intermountain Regions include western white pine (*Pinus monticola* Dougl. ex. D. Don), western larch (*Larix occidentalis* Nutt.), ponderosa pine (*Pinus ponderosa* Dougl. ex Laws), Douglas-fir (*Pseudotsuga menziessi* var. *glauca* (Beissn.) Franco), and lodgepole pine (*Pinus contorta* Dougl. ex. Loud.). Table 1 highlights the traits of interest by species. Justifications for tree improvement programs have historically focused on increasing wood productivity per acre. The thumbnail sketch of programs for the Northern and Intermountain Regions (Table 1) place priority emphasis on those traits that contribute to improving forest health, and secondarily on growth. The ability to identify resistant families and individuals within families in our test plantings rely on opportunitistic measurements. Our ability to make progress in these resistance traits depends upon genetic variation in the host, uniform infection, and high enough infection levels to detect differences, in the absence of artificial inoculation and infection procedures.

Table 1.—Traits of interest targeted to improve forest health conditions in selective breeding programs in the Inland West.

Species	Traits of interest (priority order)
Western white pine	Blister rust resistance: adjusted bark reactions, needle lesion frequency, early stem symptoms, tolerance to cankers (horizontal resistance), no spots, needle shed, short shoot response, and bark reaction (vertical resistance). Growth.
Western larch	Cold hardiness Growth Meria needle cast resistance[a]
Ponderosa pine	Growth Western gall rust resistance[a] Tip moth resistance[a]
Douglas-fir	Cold hardiness Growth Root disease resistance[a] *Rhabdocline* and Swiss needle cast resistance[a]
Lodgepole pine	Growth Western gall rust resistance[a] Terminal weevil resistance[a]

[a]*Additional family and within-family selection criteria when data are available in test populations.*

There are several ways geneticists and land managers can incorporate additional insect and disease resistance into tree species. The process begins with generating a list of pest problems, classifying lands based on presence of a pest and risk associated with the host species, and determining the cause and effect of these pests. The next step involves reviewing effective control measures and their cost-benefit ratio.

From a genetics standpoint, one control measure may be as simple as identifying an appropriate seed source for planting. In other cases, exotic pest problems warrant selective breeding, which strives to build resistance levels in the host population. As a rule of thumb, there needs to be at least five percent of the total variation present at the family level, in one or more traits of interest, to make any progress in adaptation or insect and disease resistance. A good example of an exotic pest problem being effectively "treated" via selective breeding is the western white pine blister rust resistance program.

Blister Rust Resistance in Western White Pine

There are approximately 90 known rust diseases on North American conifers, with two being most serious (Kinloch 1982, Hepting 1971). Fusiform rust (*Cronartium quercum f. sp. fusiforme*) is a native pest of southern pines, while white pine blister rust (*C. ribicola* Fisch.) is an exotic pest of white pines. Diversity of resistance genes is the most effective means of stabilizing pathogen populations, which is why tree improvement programs shouldn't focus on single-gene resistance mechanisms or breeding for immunity.

Land managers and academicians are questioning the utility of continued selective breeding for blister rust resistance in western white pine. Much progress has been made in the Phase I program, with production seed orchards exhibiting resistance levels of 35–65% over standard woodsrun collections (Howe and Smith 1994, Bingham et al. 1971). The Phase I program is certainly a success story, but should carry a "warning label", in that the continued success of the Phase I program rests on no new virulent genes of blister rust getting a foothold in plantings or remnant populations of western white pine. Single-gene resistance in western white pine (McDonald et al. 1984) and sugar pine (Kinloch and Dupper 1987) has already failed in geographically limited areas. Moreover, agricultural crop failures are well documented in the literature, when breeders have relied on single-gene resistance mechanisms to combat native or exotic pest problems (Vanderplank 1984, 1975).

What role does the Phase II program and advanced generation breeding play in restoring western white pine in Interior Cedar/Hemlock/White Pine ecosystems? Restoring western white pine to a significant forest type in the Inland Northwest requires a consistent reforestation program on a large scale. It will also require a continued commitment to research and development to assure that adequate rust resistance is maintained over time in western white pine. Phase I seed orchard donors share a limited genetic base, with resistance based on three, putative single-gene resistance mechansims. Since western white pine has not shared several generations of coevolution with this exotic pest, it is impractical to assume that the existing resistance levels are permanent.

As knowledge of the resistance mechanisms developed, and the focus of the Phase II program embraced both horizontal and vertical resistance mechanisms, as well as growth, additional plus tree selections were needed to broaden the genetic base to meet the new program goals (Howe and Smith 1994). These 3,098 new selections were completed in 1976. Inoculated seedlines are presently screened for eight resistance traits, four of which suggest polygenic inheritance (Table 1). Scoring these Phase II selections is anticipated to be completed by 2003.

The top Phase II families are selected on the four resistance mechanisms that suggest polygenic inheritance. This selection strategy is like an insurance program. In the event that a new race of rust neutralized a single-gene resistance mechanism, it is highly unlikely it would also contain the appropriate mutations at multiple loci to neutralize the polygenic resistance mechanisms. Packaging this horizontal resistance among families provides resistance levels in the range of 30–35% over woodsrun material. But like an insurance policy, development of stable rust resistance requires that the "insurance premium" be paid, by maintaining a selective breeding program. The selection strategy also chooses individuals within the top families which possess one of the four single-gene traits. When the number of resistant individuals exceeds the selection target, individuals are also selected for superior height-growth performance. This family and within-family selection strategy, coupled with a blocked seed orchard design, should increase resistance levels to 100%, with modest improvements in growth (Mahalovich and Eramian in prep.).

Advanced generation breeding began in 1995 among the Phase II elite families that have been identified to date. The selection strategy continues to develop horizontal and vertical resistance traits and growth, whereas the breeding strategy incorporates small replicate populations (sublines) to manage inbreeding and to maintain the genetic base. These strategies for advanced generations are an extension of the original breeding program (Bingham et al. 1971) in an effort to: (1) stablize the balance between host and pathogen, (2) meet biodiversity objectives, (3) sustain long-term improvements, and (4) provide flexibility for changes in program direction as knowledge increases and/or product demands change.

Whether it is breeding for adaptation and/or pest resistance, a typical selective breeding program culminates in seed orchard establishment. There must also be an active reforestation program to deploy these seeds, to capture the payoff of improved insect and disease resistance, cold hardiness, and growth. The Western Forest Health Initiative (1994) identifies a series of recommended actions that the Forest Service can take over the next two years. Meeting the annual seed needs to produce 3–4 million rust-resistant seedlings will involve a sustained, long-term commitment in selective breeding to restore Inland Northwest forests.

With little additional effort, inoculation and screening techniques employed to develop blister rust resistance in western white pine can also be extended to improve blister rust resistance in populations of whitebark pine (*Pinus albicaulis* Engelm.) (Hoff and Hagle 1990). Basic research is still needed to unravel patterns of genetic variation in unstudied species to better understand host-pest interactions, and to assist in conserving genetic diversity through seed transfer guidelines and pollen management.

Tree Improvement and Other Insect and Disease Problems

Table 2 and Table 3 list some of the native insect and disease problems in the Inland West where progress could be made in low (cone collections from resistant trees) or high level (selective breeding) programs to build resistance in the parent population. When resistance was observed among individuals, but statistical significance among provenances or families was not explicityly reported, columns report a dash (—). Severity or impact of the pathogen/pest was gleaned from several sources, and lends itself to debate among managers and researchers (Byler et al. 1994, Hagel et al. 1990).

Disease Resistance

Genetic-based resistance to infection resulting from coevolution of forest trees and their patho-

Table 2.—Inland Northwest disease problems with a genetic component in host conifer species.

Disease of Concern	Impact	Species[a]	Genetic Differences: Provenance	Family	Citation
Dwarf Mistletoe					
Arceuthobium sp.	High	PP	**[b]		Scharpf and Roth 1992, Roth 1974
Foliar Diseases[c]					
Lecanosticta sp.	Low	WP		**	Hoff and McDonald 1978
Lophodermella concolor	Low	LP	**	**	Hunt et al 1987, Hoff 1985, Rehfeldt 1987, 1985, Hunt 1981
Lophodermium sp.	Low	PP	**	**	Hoff 1988b
Meria laricis	Mod	WL	*	*	Rehfeldt 1992
				**	Mahalovich unpublished data
Rhabdocline sp.	Mod	DF	**	*	Hoff 1987, Stephan 1973
Root Disease					
Armillaria ostoyae	Low	WL	NS	*	Hoff and McDonald 1994
	Low	WP	NS	NS	
Western Gall Rust *Endocronartium harknessii*	Low	LP	**	**	Hoff 1992, van der Kamp 1988, Martinson 1980
	Mod	PP	**	**	Hoff 1991a, 1991b, 1990, 1986
White Pine Blister Rust *Cronartium ribicola*	High	WP	NS	**	Hoff and McDonald 1972, McDonald and Hoff 1975, Kinloch 1982
	High	WBP		—	Hoff and Hagle 1990

Source (Hoff and McDonald 1994)

[a]*LP=lodgepole, PP=ponderosa, WP=white, WBP=whitebark pines, WL=western larch, and DF=Douglas-fir.*

[b]*** Denotes a significant difference at the 1% level (p=0.01)*

** Denotes a significant difference at the 5–10% level (p=0.05–10)*

NS = No statistically significant difference.

— Resistance observed, needs further testing.

[c]*Impact of needle diseases may be moderately damaging on young trees, but overall impact on growth is generally small.*

gens has been the chief means of disease control in natural ecosystems (Vanderplank 1984). There are a large number of native insects and pathogens that are in a dynamic genetic equilibrium with their host species (Byler et al. 1994). Understanding this resistance, maintaining it and applying seed transfer guidelines, guard against an imbalance that could lead to large-scale problems such as bark beetles, western spruce budworm, root disease, dwarf mistletoe, and western gall rust.

The prevailing management philosophy for native disease problems is that damage can be effectively controlled by silvicultural methods. For example, dwarf mistletoe tends to be host specific so manipulation of tree species composition can reduce infection levels. This philosophy discounts the availability of resistant stock to enhance silvicultural control programs or fails to acknowledge that investments being made in improving other traits would already bear some of the costs for

Table 3.—Inland Northwest insect problems with a genetic component in the host conifer species.

Insect of Concern	Impact	Species[a]	Genetic Differences Provenance	Family	Citation
Gouty Pitch Midge *Cecidomyia piniinopis*	Mod	PP	*b	**	Hoff 1989, 1988
Mountain Pine Beetle *Dendroctonus ponderosae*	Low	LP	—	—	Raffa and Berryman 1987
Western Spruce Budworm *Choristoneura occidentalis*	Mod	DF	*	*	McDonald 1985, 1982
Terminal Weevil *Pissodes terminalis*		LP	**	**	Hoff unpublished data
Tip Moth *Rhyacionia* sp.		PP	—	*	Kegley et al. 1994, Mahalovich unpublished data

Source (Hoff and McDonald 1994)

[a]*LP=lodgepole, PP=ponderosa, WP=white, WBP=whitebark pines, WL=western larch, and DF=Douglas-fir.*

[b]*** Denotes a significant difference at the 1% level (p=0.01)*

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NS = No statistically significant difference.

— Resistance observed, needs further testing.

building genetic resistance to native diseases (Martinson 1980, Roth 1974). When dwarf mistletoe occurs in pure stands, planting other species or clearcutting to remove the infected stand may not be feasible or silviculturally desirable (Scharpf and Roth 1992). So in some cases, an active selective breeding program may be warranted.

Insect Resistance

McDonald (1982) pointed out that foresters are attracted to resistance because it generally does not require repeated attention and is easily incorporated into integrated pest management plans. Resistance.to insects has been found in forest trees (Hoff and McDonald 1994, Hanover 1976, Gerhold 1966). Genetic variation present in hosts to various insects in the Inland Northwest is partially summarized in Table 3.

Building resistance relies on "attraction" elevated to "need", and the ability to develop reliable (repeatable) progeny test screening procedures. For the time being, screening of families and individuals for insect resistance will be handled opportunistically in genetic tests. This approach has proven effective in identifying families resistant to tip moth (*Rhyacionia* sp.) on ponderosa pine (Mahalovich, unpublished data) and terminal weevil (*Pissodes terminalis*) on lodgepole pine progeny tests (Hoff, unpublished data).

Tip moth infestation in an early selection trial for low-elevation ponderosa pine in Idaho was reported by Kegley et al. 1994. Collaborative efforts with Kegley et al. (1994) made it possible to detect family differences in tip moth damage (Mahalovich, unpublished data). These data were used to incorporate resistance to tip moth damage in production seed and breeding orchards, without reducing gains in height-growth or quality, by adding this additional trait to the selection index.

Recommendations for Building Insect and Disease Resistance

Efforts to build resistance levels can be as simple as identifying resistant parent trees for operational cone collections, for propagating in seed orchards, or for placing these parent trees in selective breeding programs. Selection of resistant parent trees should be avoided in low infection areas or from infected trees in general. Desirable candidates are those that are in high infection areas but are free of infection or are free of symptoms in spite of being infected. For selective breeding to be a viable option there needs to be: (1) a "market" for resistant planting stock, (2) a good return on the investment (plus tree selections, testing, and seed orchard establishment), and (3) development of reliable inoculation/infection test procedures.

SUMMARY

Forest health means balancing the detrimental effects of endemic insects, pathogens, and other agents on resource values over the short-term, against their beneficial ecological functions over the long-term (Byler et al. 1994). This paper serves to briefly outline the efficacy of applied genetics as one of the tools available to improve forest health. Genetic resistance is essential for restoring our forests, and progress can be maintained with a continued commitment to the western white pine selective breeding program and application of seed transfer guidelines, and further development of expert systems for western larch and lodgepole pine. Moreover, maintaining existing tree improvement programs provides the opportunity to assess and monitor genetic resistance to insects and diseases.

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