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Comments

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Articles in all sections except the "Practical Tips" and "Little-Known Classics" are peer-reviewed by two outside, anonymous referees. Articles in the "Practical Tips" section are reviewed by a technology transfer specialist and a scientist on the advisory board. "Little-Known Classics" are chosen and adapted by members of the editorial board from regional and state newsletters and publications already in print.

Cover: Hardening the seedlings at the old Wind River Nursery, Gifford Pinchot National Forest, Washington; photograph by Rebecca Nisley, USDA Forest Service, Hamden, CT).

Computer Applications in the Nursery

Small, personal computers, compared with mainframe computers, first began entering the workplace roughly two decades ago. With this introduction came many predictions of the computers' impacts on work life. Predictions included computers replacing workers, generating shorter work weeks for those who still had jobs, and making employees more productive. In most cases in the nursery industry, only the last prognostication came to reality. I do not know anyone who is currently working less than before getting a computer. The loss of jobs, which may or may not have occurred, has likely been due to increased competition among nurseries and advances in mechanization. Most would agree that the introduction of the computer into our working lives has indeed increased both personal and nursery productivity (defined as the number of tasks per unit time).

In the early to mid-1980's, nurseries began using computers in their operations. Usually the computer was relegated to the office for administrative functions (letter writing and some accounting activities). However, over the past 10 to 15 years, computers have become integrated throughout many nurseries. Computers and computer-assisted equipment are being used to control environments in greenhouses, irrigate crops, run coolers and freezers, grade seedlings, advertise, and market—in addition to their traditional roles in administration. Nurseries vary as to their incorporation of these technologies in their operations. Failure to adopt computers and computer-driven technology in nurseries has been attributed to several factors, including lack of knowledge of the technology, failure to understand the need, and cost. The latter reason seems to be the predominate one in most nurseries. However, most nurseries do not recognize that there is a cost of not adopting these technologies.

Computers have two attributes that make them instrumental in most nurseries. First, computers can process, sort, and retrieve information quickly. The ability to process data quickly allows them to make short work of repetitive, long-drawn-out calculations, usually with fewer errors. Two examples of this type of computer application are determining fertilizer applications and sowing rates in container nurseries. Using computers to assist with these decisions allows a grower to explore the pro's and con's of various options quickly. Information generated from the computer allows the grower to compare the proposed options and, using this knowledge, to determine the ideal solution, without the distraction of having to conduct all the calculations by hand, to obtain the information. The ultimate decision of how many seeds to sow or fertilizer application rates still fall on the shoulders of the grower. The computer simply provides information to help in the decision making process.

Computers can also be programmed to execute decisions depending on the input information. This process is often called computer automation. Two examples of this in the nursery industry are the developing optic grading technology and climate control computers used in greenhouses. Both applications have been programmed to respond to certain input information by controlling some mechanical function. In climate control computers, if the temperature from the thermal sensor is too high, the computer activates a cooling system. If the temperature input is too low, the computer activates a heating system. However, the grower is still responsible for setting the temperatures at which the computer sends the signals to the mechanical devices.

The second attribute computers have is the ability to gain rapid access to information previously difficult to obtain. This ability has only been developed recently, with the advent of electronic communication, specifically the Internet and electronic mail. These abilities allow nurseries and growers access to a seemingly infinite supply of information. A person only has to look at the number of traditional format journals, electronic journals, web sites, conference proceedings, and news groups to see that the volume of information being generated is expanding at an increasing rate. However, few people in the nursery industry have taken advantage of these resources. Many of those who have are involved in research or are people who see the potential to use this technology to improve marketing.

Most nurseries I have the opportunity to work with have been "reorganizing" (for lack of a better term!) due to changes in market demands or changes in operation constraints (costs). Most of these nurseries have been asked to produce more species using the same facilities. Needless to say, the same production system used last year may not suffice this year. For example, at the New Mexico State University—Mora Research Nursery, the number of species being produced has increased over the past 4 years from 9 species of native and introduced conifers to 45 species of woody trees and shrubs, each with its own distinct cultural requirements. This, in conjunction with a doubling of the total number of seedlings produced, has resulted in many logistic challenges. Such challenges include where to find seed, propagation requirements for species, introducing new pest problems, cropping schedules, etc. However, none of these problems was insurmountable when the information necessary to make wise decisions was obtained. Using various sites on the Internet, such as university and federal libraries, we were able to obtain the appropriate information quickly.

As new information, technologies. and demands are applied to nurseries, it will become necessary for nurseries to assimilate and process this information, if they are to remain viable enterprises. The cost of personal computers capable of these activities is now less than $2,000, so cost should not be a limitation in adopting computers in the nursery. In closing, computers are just tools, it still will be up to the grower to interpret the information and make decisions, the first of which may be who to hire next.

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Note: Our concept of this editorial space is that it should be a place to publish opinions and ideas relating to the nursery, reforestation, and restoration professions. We invite you to submit ideas for commentaries. The views expressed here are solely those of the author(s) and do not necessarily reflect those of the *Tree Planters' Notes* editorial staff, the Forest Service, or the U.S. Department of Agriculture. — RN and the editorial board

Contents

Volume 48, Numbers 1 & 2 — Winter/Spring 1997

See Cover

See page 4

See page 37

Status and Management of Pales Weevil in the Eastern United States

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The pales weevil—Hylobius pales *(Herbst) is a subcortical feeding insect with a large geographic range and wide host-species range amongst conifers. It is a regeneration pest of forest and Christmas tree plantation, and nurseries, feeding on stems of seedlings and branch tips of saplings. It breeds in freshly killed stumps and slash. Across the geographic range of pales weevil, different conifer management objectives and constraints result in varying pest impacts and application of different pest management strategies. A questionnaire was sent to 32 states where pales weevil was believed to occur. Responses indicated that pales weevil is an important Christmas tree pest in the north central states, a pest of pine seedlings and Christmas trees in the northeastern states, and principally a pest of pine seedlings in the southern states. Pest management tactics used in the north central states focus on stump treatments (removal or application of insecticides). In the northeastern states, tactics include stump and seedling insecticide treatments and delayed planting of seedlings in recently harvested sites. In the South, the most popular tactic is to delay planting of seedlings. All these tactics are considered effective, yet they are also costly and those that include insecticides are not favored by land managers. Overall, there is a fair amount of dissatisfaction by foresters and landowners with currently available tactics. The need for development of more effective and less hazardous pest management tactics is discussed.* Tree Planters' Notes 48(1/2): 4-11; 1997.

The pales *weevil—Hylobius pales* (Herbst) (Coleoptera: Curculionidae)—has long been considered a pest of seedlings and sapling stage coniferous trees in central and eastern North America (Carter 1916; Peirson 1921). A complete review of the systematics, distribution, biology, and recommended pest management practices for this insect has been presented by Lynch (1984).

Pales weevil is found throughout the eastern and central United States (figure 1), as well as southeastern Canada (Lynch 1984). In general, adult weevils are attracted by the resinous volatiles produced by dead and dying trees (Fox and Hill 1973; Hertel 1970; Peirson 1921; Thomas and Hertel 1969). They then feed and oviposit in the roots, dying stumps, or boles of fallen trees, where broods develop until the onset of winter (Anderson 1980; Doggett and others 1977). Subsequently, overwintering adults emerge the following spring, or brood adults emerge the following spring and summer, and feed on tender bark and cambial tissue of seedling stems and roots, and sapling branch tips (figure 2).

Figure *1—The states in which pales weevil is known to occur are shaded.*

Pales weevil has also been implicated as the principal vector of *Leptographium procerum* (Kendr.) to eastern white pine *(Pinus strobus* L.) and Scots pine (P. *sylvestris* L). in Virginia (Lewis and Alexander 1986; Nevill and Alexander 1992a, b). Overlapping generations occur throughout the geographic range of pales weevil with the duration of the life cycle being about 1 year in southern Canada (Finnegan 1959) and northern United States (Peirson 1921) and less than 1 year in the southern

Figure *2—Adult pales weevil feeding on hark tissue of twig (photograph courtesy of Stephen Cade).*

United States (Beal and McClintick 1943; Doggett and others 1977; Speers 1974).

The abundance of pales weevil is generally dependent on host availability. Because the weevils can feed on live tissue and breed in recently killed or dead material, they can be present in different conifer management settings. This may partially explain why pales weevil is capable of becoming a pest of nursery and plantation seedlings, and Christmas trees. Another reason for its success may be that pales weevil has been reported to feed on 11 coniferous genera including 29 tree species (Lynch 1984).

Currently, the following pest management tactics are available for reducing the impact of pales weevil:

1. Determining site hazard from host species composition and site preparation activities
2. Harvesting the site before mid-summer
3. Delaying the planting of new seedlings for 1 or 2 years after harvest
4. Treating seedlings with insecticide either before or after planting (Nord and others 1982)
5. Treating stumps with insecticides (Nielsen and Balderston 1975; Thomas 1971)
6. Removing stumps of recently harvested trees (Benjamin 1963)
7. Not harvesting the bottom whorl of branches, thus keeping stumps alive (Corneil and Wilson 1984a)

Following some preliminary inquiries, I found that the perceived impact of pales weevil on conifer seedlings and Christmas tree production varied from state to state, as did the application of pest management tactics (Salom 1992). Therefore, the objectives of this paper are to more completely characterize the following information throughout the geographic range of pales weevil:

- The impact of the pest on forest, nursery, and Christmas tree management
- The pest management tactics used to combat the problem
- The research needs as expressed by state forest health officers

State forest health officers were targeted because they keep abreast of forest pest activity and are often called upon to make recommendations or develop programs for residents of their state.

Methods

I developed a questionnaire to be completed by state forest entomologists or forest health officers for all states in which pales weevil has been documented to occur (figure 1) (Lynch 1984). There were 9 questions in the questionnaire. The first 2 questions served to identify the respondent. A third question asked if pales weevil has ever been a pest of conifers in that state. If the answer was no, they were instructed not to answer any more questions. If the answer was yes, they completed the questionnaire. The remaining questions focused on situations in which pales weevil is a pest in their state. Respondents were then asked to rate the severity of pales weevil as a pest in their state. Severity classifications ranged from minor to serious relative to other pest problems within the state. The pest status of pales weevil was not based on economic data because such records are scarce. The respondents were then asked to list the host species most impacted from 1 (most impacted), 2 (second most impacted), and so on. The next question asked what management tactics are recommended. Again, respondents were asked to rank their recommendations with 1 (most frequent), 2 (second most frequent), and so on. Even though a tactic may be recommended, it may not be ideal. Therefore, the next question asked if state officials and users were satisfied with the currently used tactics. Lastly, respondents were asked to state their opinions on research needs for improving management of pales weevil.

The questionnaires were sent out to 1 state official in each of 32 states. In a few cases, more than 1 individual responded to the questionnaire, and the answers from within a state were then combined into a single response. Although some of the respondents may not have had intimate knowledge of pales weevil activity in their state, they were requested to obtain information from the person in the state best able to answer the questions or alternatively pass the questionnaire on to them. Because I considered it unlikely for each state to have more than a few individuals who could answer detailed questions about pales weevil, I focused on the most knowledgeable person in the state.

Results and Discussion

Responses were obtained from all 32 states. According to the respondents, pales weevil has never been a pest in Massachusetts and Connecticut. Therefore, the rest of the summary will not include information from these states. However, it should be noted that an important early paper on pales weevil by Peirson (1921) was based on studies carried out in Harvard Forest in Petersham, Massachusetts.

Pest status. Pales weevil was reported to cause serious damage to branches of Christmas trees in Wisconsin, Illinois, Pennsylvania, and New Jersey, and to a lesser extent in Indiana (figure 3a). Several of the midwestern states and Maine reported moderate branch damage. Serious damage to Christmas trees seedlings was reported in Illinois, New York, New Jersey, and Maine (figure 3b). In addition, 11 other states rated this problem as moderate. Pales weevil was reported to be a serious seedling pest of forest plantations in almost all of the southern states plus Maryland (a border state) and New York (figure 3c). Although the southern states have long reported this problem, it was unexpected to have Maryland and New York included in this group. Pales weevil was generally reported as a minor pest in nurseries (figure 4), although New Jersey did report serious damage to branches of nursery trees (figure 4b).

The contrast in impacts between the southern and north central states is not unexpected. Although North Carolina and Virginia have become strong Christmas-tree-producing states, the main objective of foresters for growing conifers in the South is still pulpwood and sawtimber production. Even though several of the north central states are at the top of the Christmas tree production list (National Christmas Tree Association, unpublished report), the southern states surpass the northeastern and north central states combined in volume of conifer growing stock (2:1), volume of sawtimber (4:1), harvesting of growing stock (6:1), and harvesting of sawtimber (9:1) (Anonymous 1982).

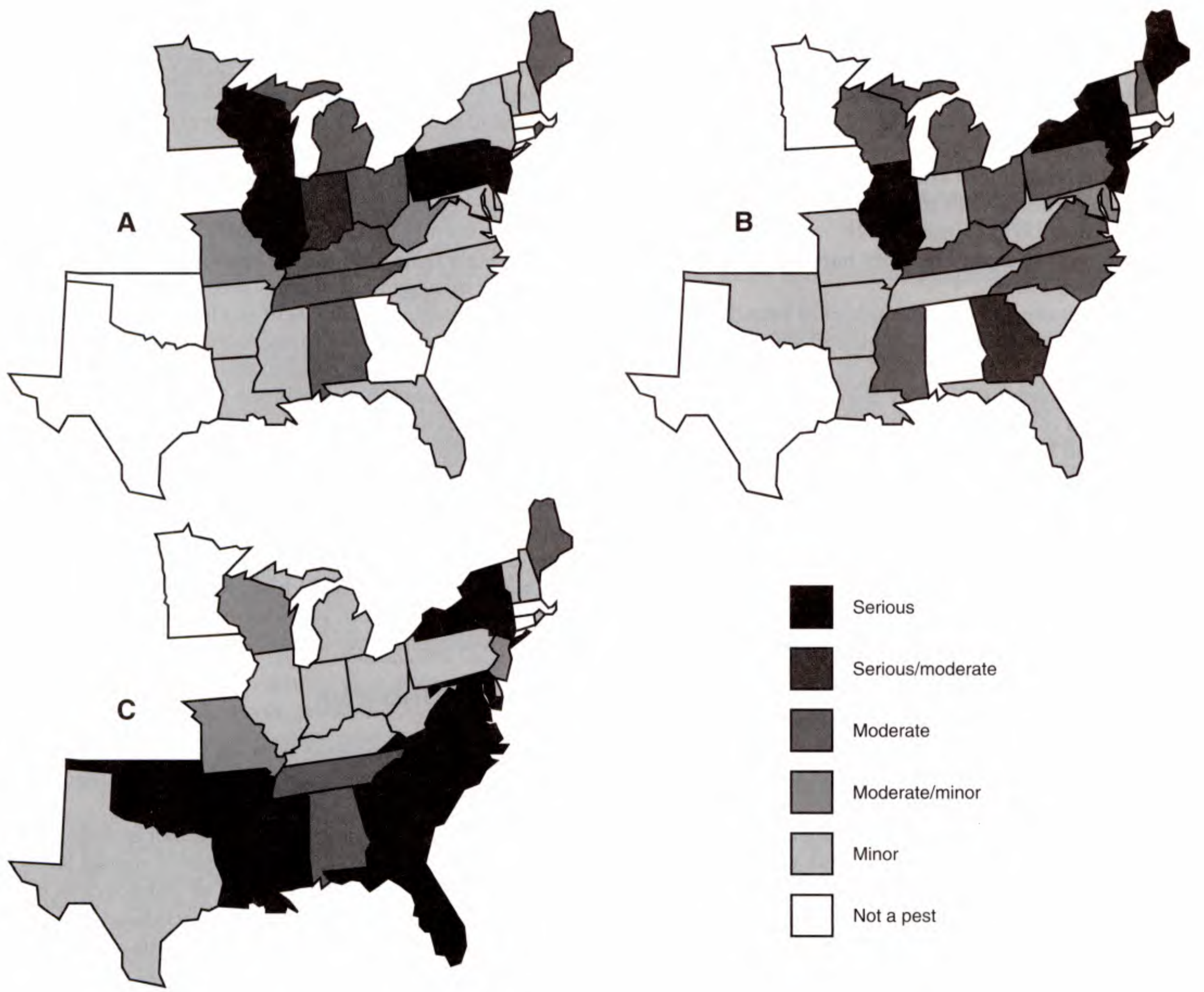

Figure 3—*Pest status of pales weevil in the eastern United States: for branches on Christmas trees (A), seedlings in Christmas tree plantations (B), and seedlings in forest plantations (C).*

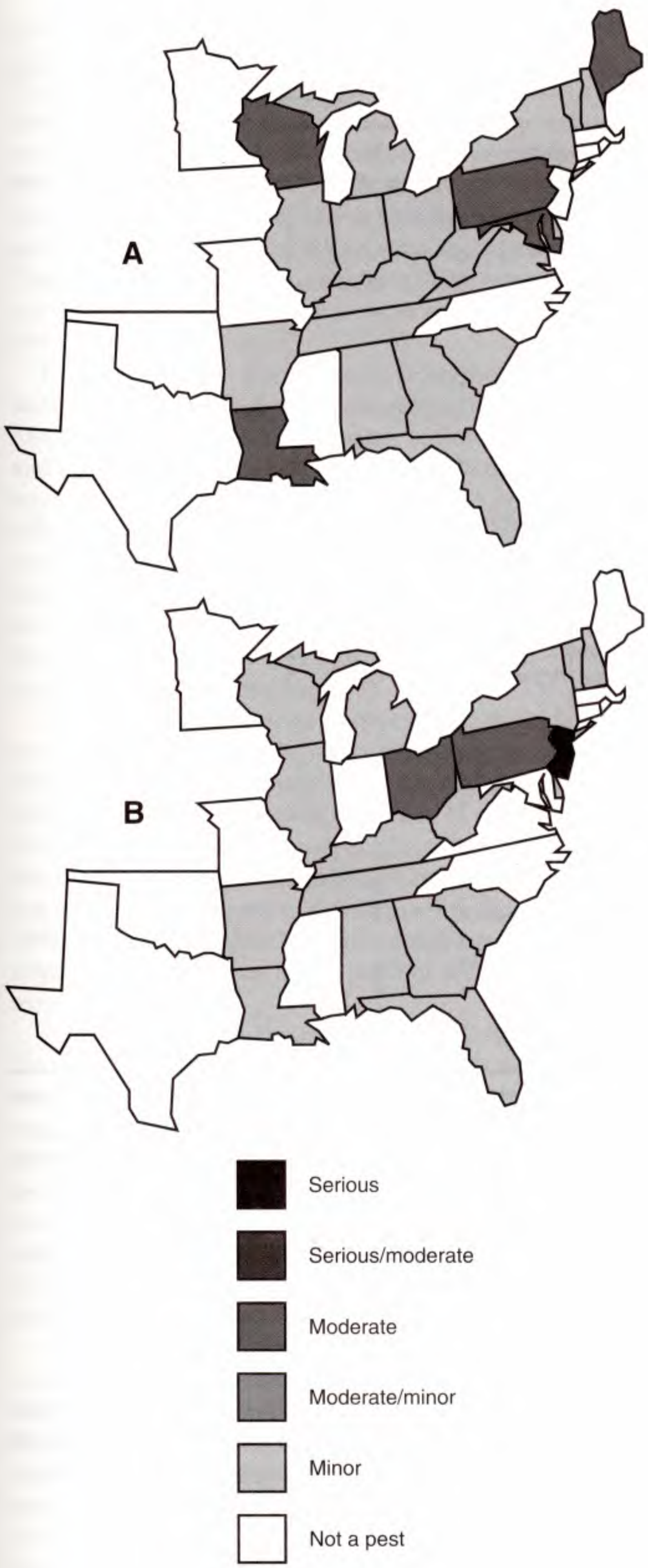

Figure 4—*Pest status of pales weevil in the eastern United States: for seedlings in nurseries (A) and branches on nursery trees (B).*

Host species. Among the surveyed states, the species of tree most frequently attacked by pales weevil is determined in part by both the geographic location and the relative importance and objectives of forest and Christmas tree managers. In the north central states of Indiana, Michigan, Minnesota, and Wisconsin, Scots pine is the most frequently attacked tree species, followed closely by eastern white and then red pine *(P. resinosa* Ait.) (table 1). Additional pine species were reported to be attacked in the northeastern states, yet both eastern white pine and Scots pines were the most highly ranked. In the South, loblolly pine *(P. taeda* L.) is reported to be the most attacked species. The second most attacked appears to be shortleaf pine *(P. echinata* Mill.). Despite being located north of Virginia, both Maryland and Delaware reported similar host species impacted as reported by most of the southern states. All species reported in this survey have been previously listed as susceptible hosts by Lynch (1984) and sources therein.

Pest management tactics, In the north central states, the treatments recommended most frequently for minimizing pales weevil damage are some form of stump treatments (table 2). Respondents were split between favoring insecticidal treatment of stumps or stump removal/slash management. Both approaches focus on reducing breeding material for pales weevil. The respondent from Wisconsin emphasized delayed planting over stump treatment, yet still ranked stump treatment with insecticides second.

Respondents in states that recommend stump removal and sanitation (table 2) are pleased with the results. In contrast, respondents in all states treating stumps with insecticides are interested in finding more "environmentally friendly" and less costly treatments. Although delaying planting 1 or 2 years is effective, it is unpopular with many growers. Even the respondent from Wisconsin, who ranked this tactic #1, is interested in finding an alternative approach.

In the northeastern states, recommendations varied (table 2). Respondents from New Jersey, Pennsylvania, Rhode Island, and West Virginia ranked insecticide treatment of stumps highest, whereas those from Maine, Maryland, and New York recommended delayed planting of seedlings the highest. Respondents from New Jersey and West Virginia gave a fairly high ranking (#2) to cutting stumps down to ground level and covering them with soil. Several of the respondents recommended treating seedlings with insecticides, yet only the Delaware respondent gave that tactic its highest rating (tied with stump removal and slash management).

Some of the respondents found treating stumps with insecticide acceptable, yet others would like an alternative to lindane, the most widely used insecticide for

Table 1— *Ranking of conifer species most affected by pales weevil (1 = most affected), as reported by surveyed states; all species are pines unless otherwise indicated*

State	Tree species ranking 1	2	3
Alabama	loblolly	longleaf	slash
Arkansas	loblolly	shortleaf	slash
Delaware	loblolly	Virginia	eastern white
Florida	slash	loblolly	
Georgia	loblolly	slash	shortleaf
Indiana	Scots	eastern white	red
Illinois	eastern white	Scots	Fraser fir
Kentucky	Scots	eastern white	loblolly
Louisiana	loblolly	shortleaf	slash
Maine	eastern white	balsam fir	
Maryland	loblolly		
Michigan	Scots	red & Jack	
Minnesota	Scots	red	
Mississippi	loblolly	shortleaf	longleaf
Missouri	Scots	eastern white	
New Hampshire	eastern white		
New Jersey	eastern white	Douglas-fir	spruce species
New York	red	Scots & eastern white	
North Carolina	loblolly	eastern white	longleaf
Ohio	eastern white	Scots	balsam fir
Oklahoma	loblolly	shortleaf	Virginia & Scots
Pennsylvania	eastern white	Scots	Douglas-fir
Rhode Island	eastern white	Scots	Fraser fir
South Carolina	loblolly	Virginia	eastern white
Tennessee	loblolly	eastern white	Virginia
Texas	loblolly	shortleaf	
Vermont	Scots	eastern white	
Virginia	loblolly	eastern white	Virginia
West Virginia	Scots	eastern white	
Wisconsin	Scots	red	eastern white

Table 2—*Pest management tactics recommended and used for managing pales weevil in the United States*

Region & state	Rank of control tactics* A	B	C	D	E	F
North Central						
Illinois			1	2		
Indiana	2		1	3		
Michigan	3	2	1			
Minnesota				1		
Missouri				1		
Ohio			2	1		
Wisconsin	1		2			
Northeast						
Delaware		1.5		1.5		
Maine	1		2.5	2.5		
Maryland	1	2				
New Hampshire						1
New Jersey			1	3	2	
New York	1	2				
Pennsylvania			1			
Rhode Island		2	1			
Vermont			2	1		
West Virginia		3	1		2	
South						
Alabama	1					
Arkansas	1					
Florida	1	2				
Georgia	1	2				
Kentucky		1				
Louisiana	1					
Mississippi	1	2				
North Carolina	2	1				
Oklahoma	1					
South Carolina	1	2				
Tennessee	1	3	2			
Texas	2					1
Virginia	2	1	3			

1 = most commonly used or recommended tactic, 2 = next most common tactic, and 3 = least common tactic; No ranking indicates tactic not even considered.

Treatment A = Delay planting 6 months to 2 years; treatment B = treat seedlings or trees with insecticides; treatment C = treat stumps with insecticides; treatment D = remove stumps, slash and /or sanitation; treatment E = cover stumps down to soil; treatment F = none.

stump spraying. Treatment of seedlings with insecticides is not a popular option with workers, as they would rather not work with hazardous materials. Covering stumps with soil is a satisfactory treatment for 2 states, New Jersey and West Virginia, but I am not aware of a published report recommending this treatment. Satisfaction with stump removal/sanitation was mixed. Some respondents stated that this tactic works, yet one respondent described sanitation as too time consuming.

In the South, all but 1 state respondent ranked delayed planting of seedlings as either the first or second most recommended treatment (table 2). This was followed by treating seedlings with insecticides. Stump treatments were rarely recommended, except in Virginia and Tennessee, which have significant Christmas tree industries. However, North Carolina and Georgia, both with strong Christmas tree industries, do not recommend stump treatments. In Texas, where pales weevil is rarely a problem, the primary recommendation is to do nothing.

Delayed planting after harvesting was considered effective by all respondents in the South. However, some do not consider this approach economical, even though the delay is from 6 months to 1 year, rather than the 1 to 2 years needed in the northern states. Insecticide treatments of seedlings were also considered effective, yet satisfaction was also mixed for this tactic for the same reasons as stated above.

The differences in treatment recommendations between the southern and north central states may be largely a reflection of their different management objectives. With the emphasis in the north central states on Christmas tree production, intensive management of plantations allows for stump treatments. Yearly harvesting and shearing practices associated with Christmas trees provide a consistent source of host volatiles and breeding material for the weevils. This makes delayed planting of seedlings less desirable and probably less effective. However in the South, where emphasis is on production of pulpwood and sawtimber, harvesting is generally intermittent on a temporal and spatial scale. Therefore, lack of continuously available breeding material makes delayed planting a more appealing and effective tactic.

Research needs, Respondents from the north central states indicated varied needs for research, including life history studies, better monitoring, biological control, and identification of pheromones. It is likely that recent research efforts and publications may not be reaching everyone equally. Much needed information on pales weevil life history (Hoffman and others 1997; Raffa and Hunt 1989; Rieske and Raffa 1990a;) and techniques for monitoring the pest (Raffa and Hunt 1988; Rieske and Raffa 1990b, 1991, 1993) is now available. Less effort has gone into the latter two areas.

Indiana reported a need to investigate the role of subcortical feeding insects in vectoring *Leptographium procerum* to trees that ultimately succumb to procerum root disease. Nevill and Alexander (1992a, b, c, d) studied this topic extensively. However, the actual timing of inoculation of the tree within the Christmas tree rotation has not been conclusively determined (Salom and Gray 1993) unpublished data). Respondents from the less impacted north central states did not feel any improvements were needed.

Respondents from the northeastern states focused on the need to develop either safer chemicals or non-chemical control tactics. One suggestion from the Maine respondent was to find a way to kill stumps. The respondent suggested that herbicide treatments might be less toxic and might solve the problem of available breeding material. Rennels and Fox (1969, 1970), however, reported little success in applying fuel oil, pentachlorophenol, or 2,4,5-T to stumps in an effort to inhibit pales weevil breeding.

In the South, the most pressing need is for the development of a method to predict weevil damage. Respondents from 6 of 12 southern states ranked this need the highest. This is not surprising. Nord and others (1982) stated that the biggest problem in managing for pales weevil is the inability to correlate number of weevils at a site with potential damage to seedlings. Sampling for field populations of pales weevil is based on three fundamental aspects of their biology:

- Adults are most active underground and are rarely active aboveground during sunny days (Corneil and Wilson 1984b)
- Adults are attracted to volatiles produced by dying conifers
- Populations are highly aggregated (Rieske and Raffa 1993)

Sampling for pales weevil is difficult and requires labor-intensive techniques, ranging from digging pits and filling them with insecticide-laced pine material (Doggett and others 1977) to using PVC drainpipe pitfall traps baited with ethanol and turpentine (Raffa and Hunt 1988). Studies have been conducted to predict weevil activity, mainly as damage to seedlings (Lawrence 1975) or pre-harvest Christmas trees (Rieske and Raffa 1993). Lawrence (1975) was unable to correlate weevil trap catches with weevil feeding on seedlings, but Rieske and Raffa (1993) did find a correlation between the number of females trapped and weevil activity in following years. However, it is unknown whether their data can be used as a reliable predictor of pales weevil activity. This may be partially due to the inherent problems associated with measuring damage to trees resulting from the complex of weevils present in the Wisconsin Christmas tree system. In Sweden, Nordlander (1987) had better success correlating trap catches of the closely related European pine weevil *(H. abietis* L.) to seedling damage.

Conclusions

There are several management options available for use against pales weevil. The differences in treatment recommendations for many of the states are partially a function of management objectives and constraints. It is apparent that recommended tactics can be effective, yet many landowners do not follow them, possibly a result of high cost or time allocation. The reasons why tactics were not often followed was not investigated in this survey.

An obvious weakness in the effective use of management tactics is an inability to correlate weevil density with damage. Such a tool would provide a relatively easy way to hazard-rate sites. Effective trapping techniques are critical for monitoring weevil densities. Such techniques became easier in the United States with the adoption of the PVC pitfall traps baited with ethanol and turpentine (Raffa and Hunt 1988). However, these traps are not effective in catching pales weevil in Virginia unless recently killed or cut host material is a component of the bouquet (Fettig 1996).

In this survey, insecticidal treatments were the least desirable, yet most often recommended tactic. The development of less hazardous and equally effective compounds was seen as a priority by most respondents. In Virginia, a nursery application of permethrin to protect outplanted seedlings has been effective without some of the negative aspects associated with use of phosmet (preplanting) and chlorpyrifos (postplanting) insecticides (Tigner 1995). Active research efforts are being made into the possible treatment of seedling stems with non-toxic, biologically based anti-feedants (Salom and others 1994, 1996) or wax (Nordlander 1995). Although this research shows some promise, more work is needed.

Progress has been made over the years in minimizing the impact of pales weevil on conifer tree production in the eastern United States. Although many of the states reported that improved pest management tactics are needed for better acceptance by growers and land managers, most are satisfied with the level of control they are able to achieve with the tactics available. We all hope that continued research will lead to even better and less hazardous control tactics for pales weevil.

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Thawing Regimes for Freezer-Stored Container Stock

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Three thawing regimes were applied over a 6-week period to frozen Douglas-fir (Pseudotsuga menziesii *(Mirb.) Franco.), western larch* (Larix occidentalis *Nutt.), and ponderosa pine* (Pinus ponderosa *Dougl. ex Laws.) container stock: (1) rapid thaw followed by cold storage, (2) slow thaw, and (3) freezer storage followed by rapid thaw. Seedlings were outplanted to 3 sites in north-central Washington. A subsample of seedlings were evaluated for root growth potential (RGP) at the time of outplanting. Seedling performance was assessed after the first and second growing seasons. Although there were significant differences among species, thawing regime did not affect seedling growth or survival after 2 growing seasons nor did it affect RGP. The results indicate that seedlings can tolerate variations in thawing practices that may occur due to weather or other circumstances beyond control. However, it is noted that it may be best to keep seedlings in freezer storage for as long as possible in order to prevent storage molds.* Tree Planters' Notes 48 (1/2): 12-17; 1997).

Freezer storage of container seedlings, although an accepted practice in the nursery industry, is still a relatively misunderstood technique in some forest nurseries and reforestation organizations. Research and experience have shown that freezer storage can be a valuable management tool to a successful reforestation program. Freezer storage gives the nursery greater flexibility by allowing for lifting during late autumn and shipping the following spring. This results in a more balanced work load at the nursery and an effective "surge buffer" between nursery and field production (Hee 1987). Colombo and Cameron (1986) found that freezer storage of container black spruce—Picea *mariana* (Mill) B.S.P.-allows managers to safely delay budset of a late-sown crop, thereby reaching minimum acceptable height, without the risk of winter damage associated with outdoor storage. Furthermore, freezer storage is more suitable for periods in excess of 2 months, because carbohydrate depletion and storage molds can be a problem with long-term cold (2 °F) storage (Ritchie 1982, 1984).

Freezer storage is often necessary to maintain crop dormancy when late-season planting is required in snowed-in units, especially for stock to be planted to high-elevation sites. Odlum (1992) noted that black spruce seedlings kept in frozen storage had greater subsequent root and shoot growth than those wintered outdoors, especially for those outplanted at a later date. Ritchie (1984, 1989) found that the rate of dormancy release in bareroot Douglas-fir—Pseudotsuga *menziesii* (Mirb.) Franco—seedlings was substantially retarded by freezer storage compared to those left in the nursery bed resulting in an expansion of the planting window and a higher, more uniform, physiological quality. Likewise, Lindström and Stattin (1994) found that freezer-stored seedlings of Norway spruce *(Picea abies* (L.) Karst.) and Scots pine *(Pin us sylvestris* L.) had a greater tolerance to freezing in the spring than those that were stored outdoors.

A concern with freezer storage is the thawing process. One thawing method commonly used is to allow the stock to thaw very slowly at temperatures just above freezing over a period of several weeks. Another method is to place seedlings in an area with ambient temperatures for several days prior to outplanting. The standard thawing practice for Weyerhaeuser nurseries is to spread seedling pallets out and allow them to thaw at ambient temperature (10 to 15 °F) for 3 to 5 days (bareroot seedlings) and for 10 to 15 days (container seedlings) (Hee 1987). Whether thawed rapidly or slowly, field foresters prefer to have the stock thawed just prior to outplanting. However, changing weather conditions or other circumstances beyond control can result in thawed stock being held for several weeks in cold storage prior to outplant. Hee (1987) noted that it is best to plant seedlings as soon as they have thawed, but also noted that they can be held in cooler storage after thawing for up to 4 weeks without detriment.

The objective of this study was to examine the effects of 3 thawing regimes on the subsequent quality of 3 species of container-grown conifer seedlings outplanted to 3 sites. The thawing regimes were designed to simulate circumstances typically encountered with frozen stock. The null hypothesis was that there would be no differences in seedling field performance for any of the species due to thawing treatment.

Materials and Methods

Douglas-fir, western larch *(Larix occidentalis* Nutt.), and ponderosa pine *(Pinus ponderosa* Dougl.) container stock (1-year-old Styro-8) were used in this study. For each species on each outplanting site, seedlings were from the same seedlot. Seedlings were grown and freezer stored under standard nursery practices.

Seedlings were shipped frozen to the Leavenworth District of the Wenatchee National Forest in late March to early April 1995, depending on the expected date of planting for each site. Three thaw schedule treatments were applied over a 6-week period as follows:

1. Seedlings were placed under a rapid thaw (5 days at 7 °C = 44.6 °F) 6 weeks before expected outplanting, then held in cold storage (1 °C = 33.8 °F) until outplanting.
2. Seedlings were placed in cold storage for a slow thaw (6 weeks) before outplanting.
3. Seedlings were kept in freezer storage (-2 °F = 28.4 °F) until 1 week before outplanting, when they were placed under a rapid thaw.

Telog temperature recorders (Model 2103, Telog Instruments Inc., Victor, NY) were placed with seedlings in each thawing treatment. Because there were a limited number of Telogs available and because Telog data cannot be examined until it is downloaded to a computer, additional digital temperature probes were placed with the seedlings and monitored weekly.

Seedlings were outplanted to 3 sites on the Wenatchee and Okanogan National Forests in north-central Washington as follows:

- Twisp District, Okanogan National Forest; high-elevation (1,372 m = 4,500 ft) dry site. The slope is 10 to 40% with a northeastern aspect, with light slash and vegetation. All 3 species were planted on June 1, 1995.
- Leavenworth District, Wenatchee National Forest; low-elevation (610 m = 2,000 ft) dry site in area burned by 1994 wildfire. Annual precipitation is 53 to 76 cm (20 to 30 in). Soil is sandy to clay loam. The slope is 60% and the burned trees (avg. dbh = 10 cm = 4 in) were left standing. Douglas-fir and ponderosa pine were planted on April 20, 1995.
- Naches District, Wenatchee National Forest; high-elevation (1,219 m = 4,000 ft) temperate site. The slope is 15% with a western aspect. Douglas-fir and western larch were planted on May 31, 1995.

Seedlings were outplanted at about the same time that the site was scheduled to be operationally planted. Because of late-winter conditions, the 6-week thawing period was extended by 7 to 10 days for seedlings planted on the Twisp and Naches Districts. For each site, all seedlings were planted on the same day. Seedlings were planted at a spacing of 1.5 x 1.5 m (= 4.9 x 4.9 ft).

Initial height and survival were measured and recorded 2 weeks after outplanting and again at the end of the first and second growing seasons (September 1995 and August 1996). In addition, a damage/vigor assessment (incidence of browse, chlorosis, etc.) was recorded for each seedling.

In addition to the outplanted seedlings, a subsample of 15 seedlings of each species/treatment from the Leavenworth and Twisp sites were sent to International Paper's Lebanon facility shortly after seedlings were outplanted (that is, after treatment) and evaluated for root growth potential. These seedlings were potted and allowed to grow in a greenhouse for 3 weeks, then evaluated for the number of seedlings with new roots.

The experimental design consisted of a split-plot design with 5 blocks, 2 or 3 species per site (whole plots), 3 thaw treatments (subplots), and 10 seedlings in each block/species/treatment for a total of 450 seedlings on the Twisp site and 300 seedlings on the Leavenworth and Naches sites. All seedlings were labeled and randomly planted within a block.

An analysis of variance (ANOVA) was performed on all data to determine if thaw treatment has a significant effect on subsequent seedling performance. Differences among mean values for species and treatment were determined using Fisher's protected least significant difference procedure. Statistical Analysis Software (SAS Institute 1989) was used for all data analyses.

Results

It took about 5 days to accomplish the rapid thaw (treatments 1 and 3) and about 3 weeks for the slow thaw (treatment 2) (figure 1).

As would be expected, there were significant differences in field performance among species on each site (figures 2 and 3). However, there did not appear to be any meaningful differences among thawing treatments. During the first season, there were significant treatment by species interactions for both height and growth on the Leavenworth and Naches sites (figure 2). However, despite the statistical significance between treatments, the differences in first-year average height and growth may not be significant from a reforestation perspective, as the differences are small (1 to 3 cm = .4 to 1.2 in) and the ranking does not follow any pattern with regard to the treatments. For example, treatment 1 Douglas-fir had the greatest height on the Leavenworth site, whereas treatment 3 Douglas-fir had the greatest height on the Naches site. Similarly, treatment 3 ponderosa pine had the most growth on the Leavenworth site whereas treatment 1 western larch had the most growth on the Naches site. During the second growing season, there were no significant differences among thawing treat-

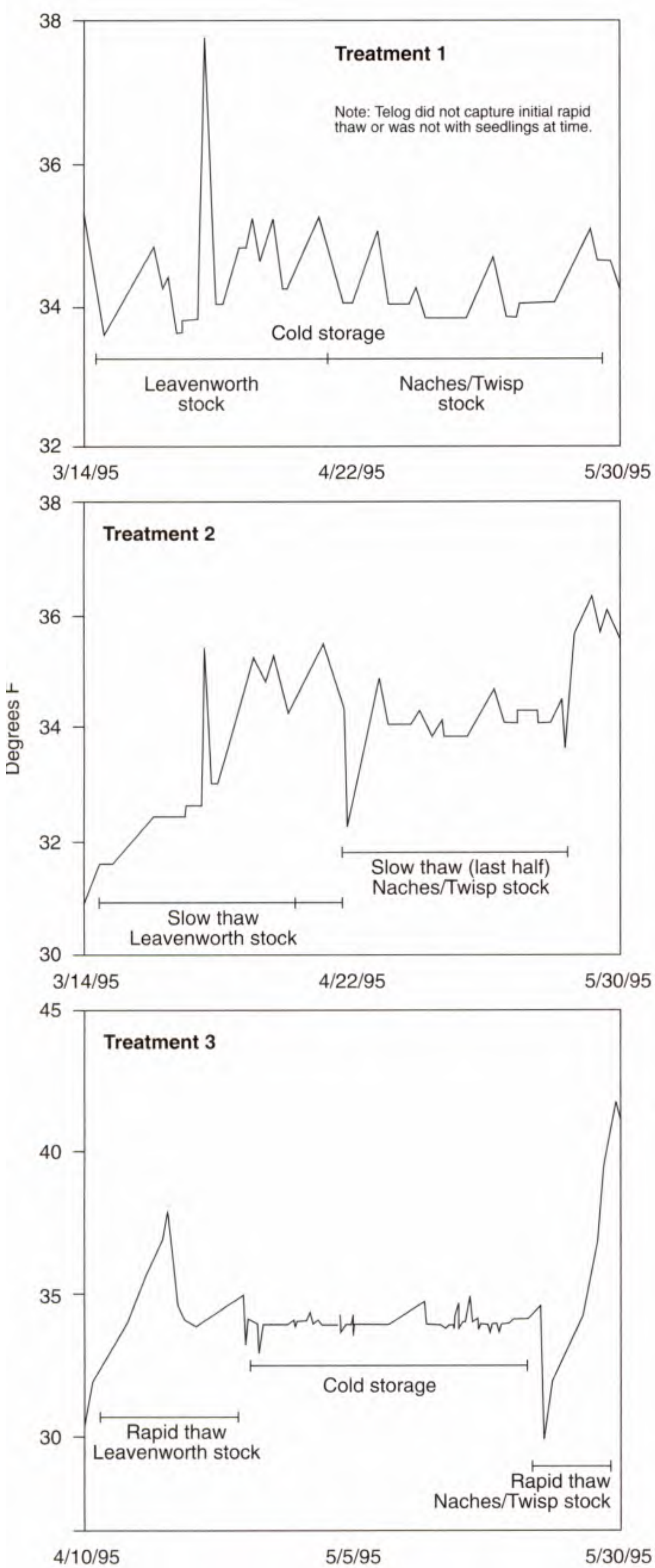

Figure 1—*Output from Telog temperature recorders showing the thawing process of each treatment.*

ments for total height, seasonal height growth, or total height growth on any of the 3 sites (figure 3).

Survival averaged 77% on the Twisp site and 96% on the Leavenworth site regardless of species or treatment. On the Naches site, survival was not influenced by treatment but was very poor for Douglas-fir (23%) compared to western larch (83%). Thaw treatment had no effect on root growth potential.

Discussion

We found that thawing regime did not affect subsequent seedling field performance. In a similar study, Camm and others (1995) reported that there were very few differences between white spruce *(Picea glauca* (Moench) Voss) and Engelmann spruce *(Picea engelmannii* Parry) seedlings planted either directly from the freezer or after 9 days of thawing. The latter broke bud 3.3 days earlier than those planted directly from the freezer but had a less uniform budbreak. Height, shoot and root mass did not differ after 3 months of growth. Camm and others (1995) suggest that a suitable on-site operational protocol for rapid thawing might be to lay frozen bundles on the ground at ambient temperature overnight. Additional possible benefits to this approach that they mention include reductions in handling costs, secondary storage facilities, and losses caused by refrigerator failure (Camm and others 1995).

The idea of a long, slow thaw has been to allow normal physiological processes to fully resume prior to planting. However, this may not be necessary because recovery of water potential after thawing spruce seedlings took hours, not days, once ice crystals left the roots (Camm and others 1995). As a result, these authors recommend against the practice of slowly thawing seedlings for up to several weeks before shipping to the plantation site because fungi *(Botrytis* spp.) often proliferate on seedlings held above freezing in the dark for extended periods. Another study showed that steady-state respiration rates increase significantly during thawing and hence have the potential to greatly deplete carbohydrate reserves, especially over time (Levesque and Guy 1994).

On the other hand, Odlum (1992) stated that rapid thawing of stock can result in damage or mortality attributable to shoots rapidly rising to ambient thaw temperature, while seedling plugs remain frozen, due to their higher water content,. Thus, foliar transpiration without water availability from the roots results in desiccation. Odlum recommended that stock be thawed slowly as described by Koistra and others (1989); seedlings are first exposed to 5 °C until completely thawed. Our findings do not suggest the need for this.

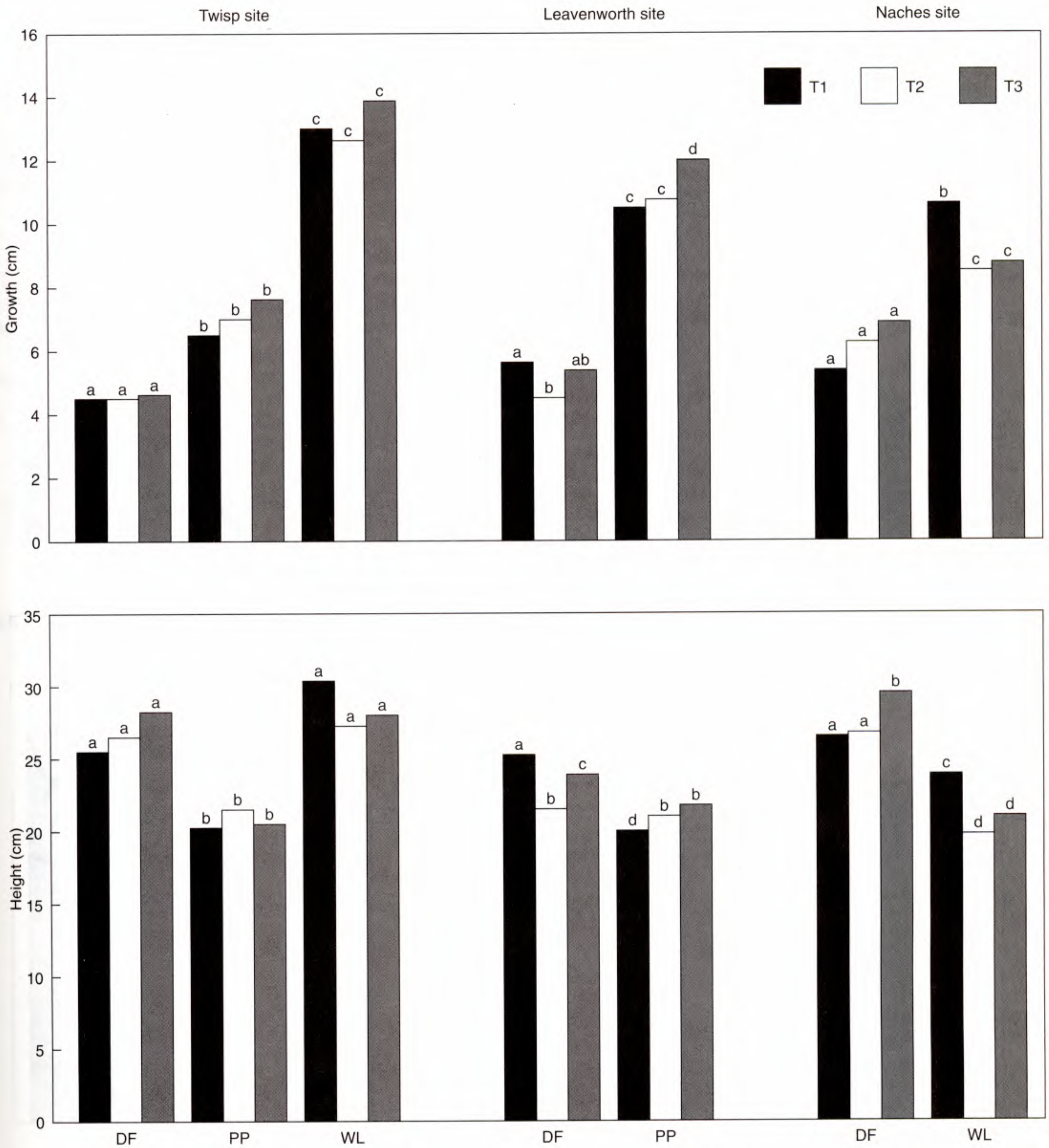

Figure 2—*Total seedling height and growth after the first growing season in the field (1995). On each site, bars with different letters are significantly different at the* $\propto \leq 0.05$ *level.*

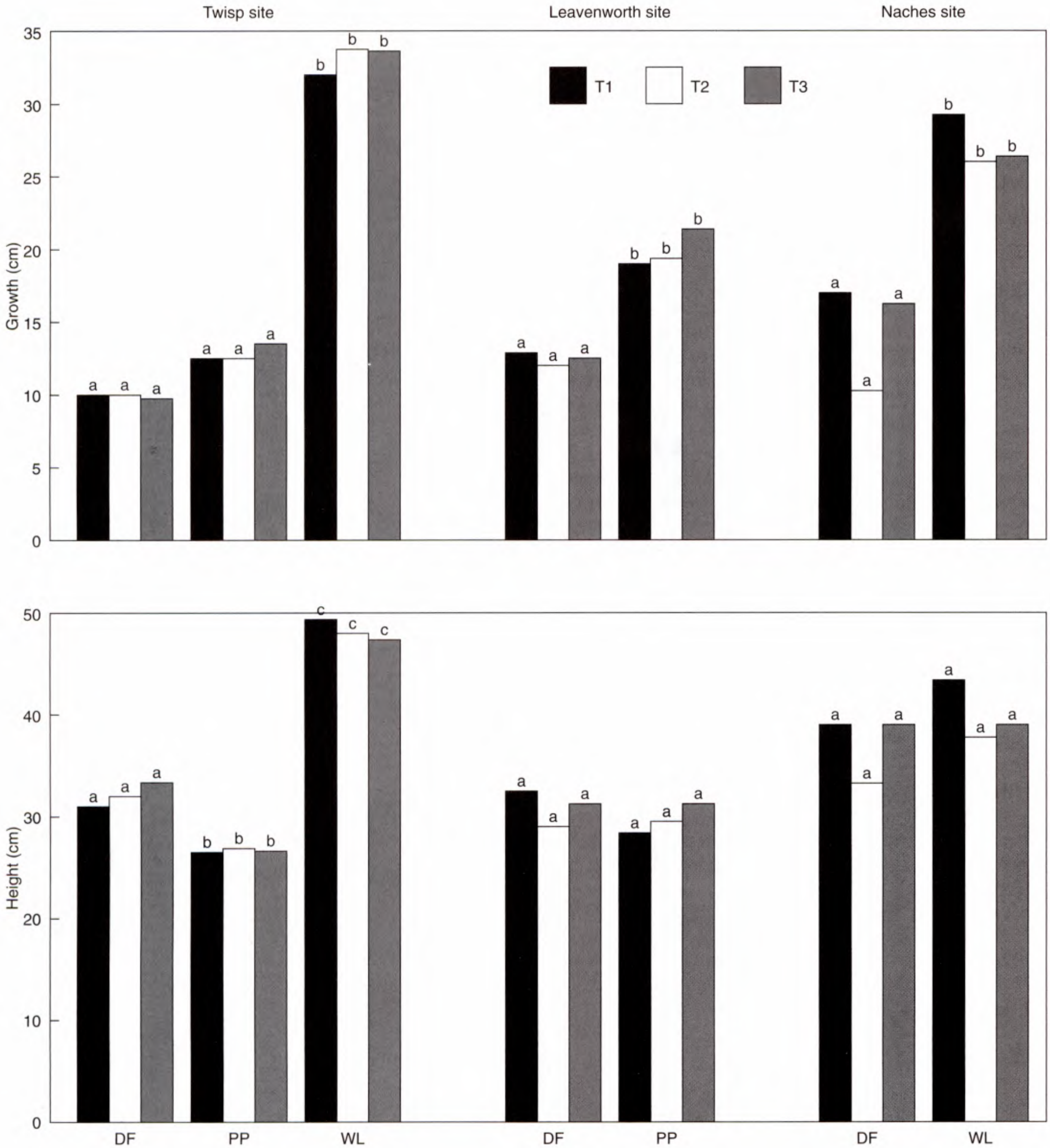

Figure 3—*Total height and growth after 2 growing seasons (1996). Although species differed significantly, there were no significant differences between thawing treatments. On each site, bars with different letters are significantly different at the* ≤ 5. 0.05 *level.*

Conclusions

Despite assertions in the literature of damage to seedlings caused by either rapid or slow thawing, the results of our study indicate that container seedlings can withstand variations in thawing regimes, as we described, without any detrimental effect to their subsequent field performance. However, managers concerned with post-storage fungal infection should consider using short thawing intervals.

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Effects of Soaking, Washing, and Warm Pretreatment on the Germination of Russian-Olive and Autumn-Olive Seeds

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There is evidence that water-soluble inhibitors in seed coats are in part responsible for seed dormancy in some Elaeagnus *species. The effects of washing, soaking, and moist warm pretreatment on germination of Russian-olive* (E. angustifolia *L.) and autumn-olive* (E. umbellata *Thunb.) seeds are reported in this paper. Autumn-olive seeds were not particularly dormant and germinated without pretreatment. However, germination of the more dormant Russian-olive seeds was improved by washing the seeds in tap water for 6 days prior to prechilling. A similar proportion of seeds also germinated during warm pretreatment in peat and sand without prechilling.* Tree Planters' Notes 48(1 /2):18-23; 1997.

Russian-olive (*Elaeagnus angustifolia* L.) and autumn-olive (*E. umbellata* Thunb.) were introduced into Europe and North America from western and eastern Asia, respectively (Bean 1973). Both species are capable of fixing nitrogen and are tolerant of salt, a wide range of soil pH, and drought (Dirr 1983). As well as being of ornamental value, both species make good windbreaks and are very useful for planting on reclamation sites and on roadsides (Gambi 1972; Vogel 1987). They also have significant conservation value, providing cover for animals and nectar for bees. Their berries are an important source of food for wildlife in winter, and they are suitable for processing into jams and syrups (Bounous 1990). However, Russian-olive can be invasive and is considered a noxious weed by a number of states in the United States (Tesky 1992).

Low and unpredictable germination of *Elaeagnus* seeds can be a problem in nurseries, possibly limiting more widespread use of these and other members of the genus in Europe (Bounous and others 1992). Seeds of *Elaeagnus* species are considered dormant and require pretreatment before sowing, usually by prechilling seeds at 1 to 5 °C (34 to 41 °F) for 10 to 90 days (Olson 1974). The need for prechilling suggests that embryo dormancy is a block to germination. The minimum effective stratification period for autumn-olive is 16 weeks (Fowler and Fowler 1987), and 9 to 12 weeks for Russian-olive (Hogue and LaCroix 1970). Fruit and seed coats are also involved in dormancy regulation because removal of the endocarp and seed coat results in rapid germination of Russian-olive (Hogue and LaCroix 1970; Zaborovskij and Varasova 1961). The effectiveness of sulfuric acid as a scarification treatment suggests that these structures may physically restrict emergence of the embryo (Heit 1967). However, Hamilton and Carpenter (1975, 1976) have shown that coumarin-like inhibitors are present in the endocarp and testa, as well as in the embryo, of both Russian-olive and autumn-olive and these compounds may be responsible for inhibition of germination. Fung (1984) found that soaking silver-olive *(E. commutata* Bernh.) seeds in water at 50 °C (122 °F) improved germination, and he suggested that inhibition was caused by a water-soluble substance that is readily leached. However, Morgenson (1990) reported that soaking silver-olive seeds at room temperature was not as effective at overcoming dormancy as moist prechilling at 4 °C (39 °F) for 30 to 90 days.

The objective of this study was to determine to what extent soaking or washing seeds of Russian-olive and autumn-olive could replace cold pretreatment as a practical method for breaking dormancy. In addition the effects of a warm moist incubation at 20 °C (68 °F) applied before chilling on dormancy release was also investigated. Moist warm pretreatment of seed before prechilling can improve germination of some species such as members of the genus *Prunus* (Gordon and Rowe 1982), and there are apparently no reports on its effects on the germination of *Elaeagnus* seeds.

Materials and Methods

Samples of seeds of both species were collected in 1992 from sites near Reggio Emilia in the Po Valley in northern Italy (44.42° N 10.37° E). The samples were combined, cleaned, and then dried to 11.5% moisture content (fresh weight basis) and stored in polythene bags at 4 °C (39 °F). Cut tests showed that 96% of Russian-olive seed and 99% of autumn-olive seed were firm and considered alive. In addition a tetrazolium test carried out on autumn-olive seed indicated that 89% of the seeds were viable.

Seed samples of each species were given 1 of 7 pretreatments, comprising 5 types of treatment, 2 of which were applied for 2 durations. These were followed by a 4-week period of chilling at 4 °C (39 °F). Treatments were replicated 4 times. The 7 pretreatments were

Control:	Seeds received no treatment
Soaking:	Samples of seed were soaked in equal volumes of distilled water at 15 °C (59 °F) for 3 or 6 days
Washing:	Seeds were washed in running tap water at about 15 °C (59 °F) for 3 or 6 days
Hot soaking:	Seeds were immersed in hot distilled water at 50 °C (122 °F) and allowed to cool in the same water for 24 hours
Warm pretreatment:	Dry seeds were mixed with moist peat and sand medium (1:1, v/v) and incubated at 20 °C (68 °F) for 4 weeks

All seeds were mixed with moist peat and sand (1:1, v/v) for the subsequent prechilling. Samples of seeds were tested for germination both before and after prechilling.

For each germination test, 100 seeds from each replicate were sown on moist filter paper in individual plastic germination boxes (Gosling 1988); the boxes of seed were then incubated at constant 15 °C (59 °F). Germination was assessed 3 times a week for 8 weeks. A seed was considered to have germinated when its radicle was at least 3 times the length of the seed coat. During the warm pretreatment, seeds of both species began germinating after 10 days, and the numbers of germinated seeds were counted at regular intervals during the remainder of this pretreatment. At the end of the warm stratification period, only ungerminated seeds were either tested or transferred to the cold prechill treatment. At the end of the germination tests, the remaining seeds were cut and categorized as being either dead, abnormal, or fresh; the latter category refers to imbibed seeds that failed to germinate under test conditions but remained clean and firm and had the potential to develop into normal seedlings (ISTA 1996). Mean germination time (MGT) (Jones and Gosling 1994) was calculated for autumn-olive only, because germination in several treatments applied to Russian-olive seed was too low. Effects of treatments on germination and MGT were tested by 2-way analysis of variance using procedures in Genstat (Payne and others 1993). An angular transformation was applied to all percentage data before analysis; MGT values were transformed to log(MGT). Reported differences between treatment means are considered significant at $P<0.05$.

Results and Discussion

More than 65% of autumn-olive seeds and 38% of Russian-olive seeds germinated during the course of the warm stratification period (figures la and 2a). A further 15% of autumn-olive, and 1% of Russian-olive germinated in a subsequent laboratory test without chilling, and there was no additional germination of warm pretreated seed after the 4-week chilling treatment.

Maximum germination of the untreated autumn-olive seed was nearly 78%, and this together with the extensive germination occurring during the 4-week warm pretreatment, suggests that this seedlot was not particularly dormant. There was no significant difference in percentage germination among the soaking, washing or hot soaking treatments before seeds were chilled. However, the average germination of these treatment groups (69%) was about 9% lower than that for untreated seed (figure la). After chilling, germination did not differ significantly among treatments (figure la). Chilling increased germination of untreated seed by about 8%, and of the washed or soaked seed by 18% to give an overall average of 86%. Only about 6% of seeds were found to be dead at the end of the germination tests (figure 1c), slightly more of the prechilled seed (8%) died compared with non-chilled seed (4%). The majority of seeds that did not germinate remained fresh and could be considered dormant (figure lb).

Prechilling significantly reduced germination time from an average of 24 days to 17 days (figure 3). Washing for either 3 or 6 days, however, caused a slight but significant reduction of about 3 days in the MGT of non-chilled seed. Generally, washing and soaking did not improve germination of autumn-olive seed and actually reduced germination of unchilled seed slightly. Chilling was the only treatment that produced significant gains in both the amount and rate of germination for this species, although the response to chilling was much less than reported by Fowler and Fowler (1987).

Seeds of Russian-olive were much more dormant than in autumn-olive. Germination of unchilled untreated and soaked seed reached only about 5% (figure 2a). Washing in running water for 3 or 6 days, or soaking in hot water, significantly increased the germination of unchilled seed to about 15%, whereas warm pretreatment increased germination to nearly 40%. Chilling did not increase germination of untreated, soaked, and hot soaked seed, nor was there any further increase in germination of warm pretreated seed. However, chilling significantly increased germination of the washed seed

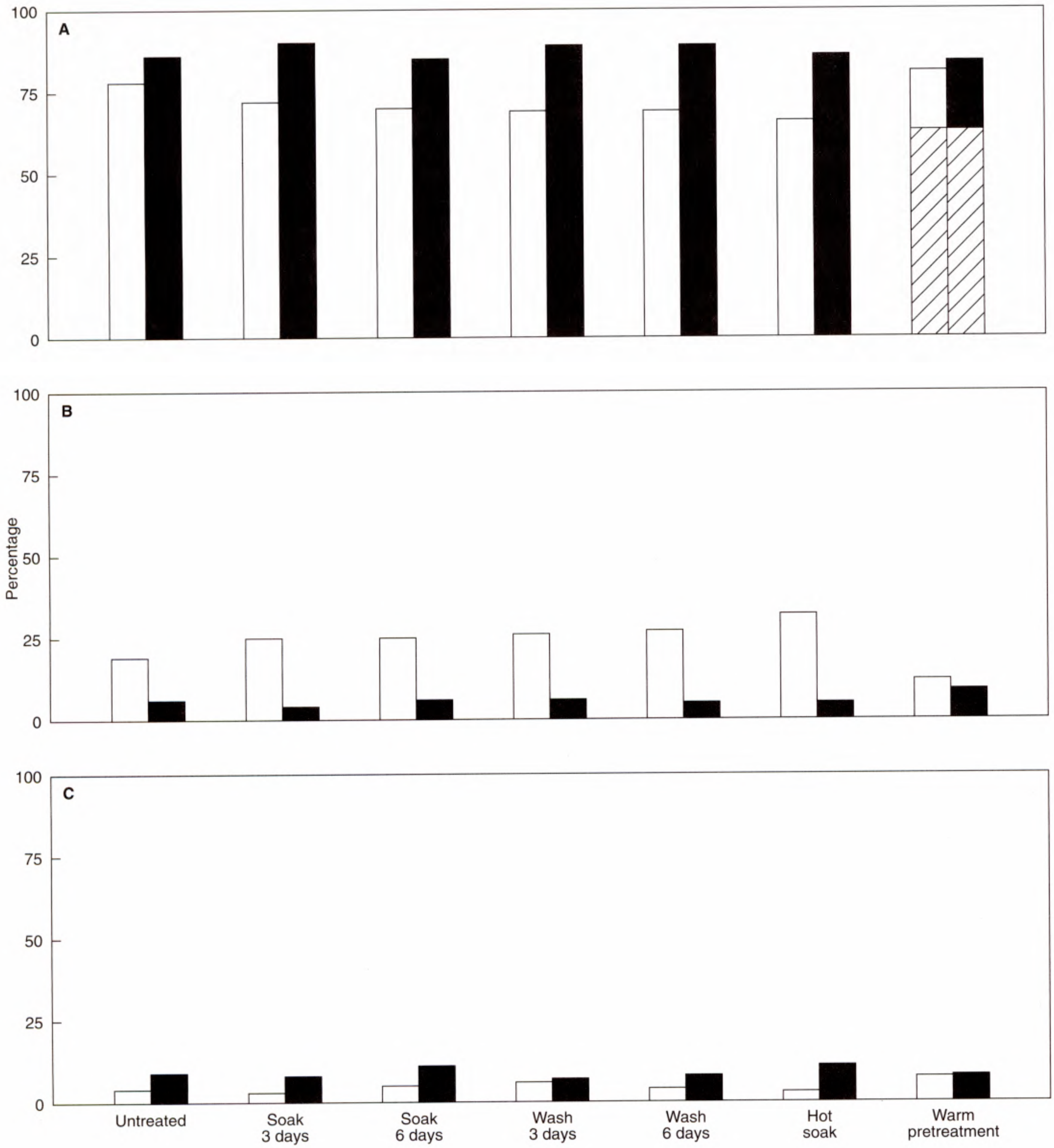

Figure 1—*Effects of soaking, washing, and warm pretreatment on (A) percentage germination, (B) percentage of ungerminated but fresh seeds, and (C) percentage of dead or abnormal autumn-olive* (Elaeagnus umbellata) *seeds. Key: germination test results determined before chilling (open columns); after chilling (solid columns) at 4 °C (39 °F) for 4 weeks; the percentage of seeds that germinated during warm pretreatment (hatched columns).*

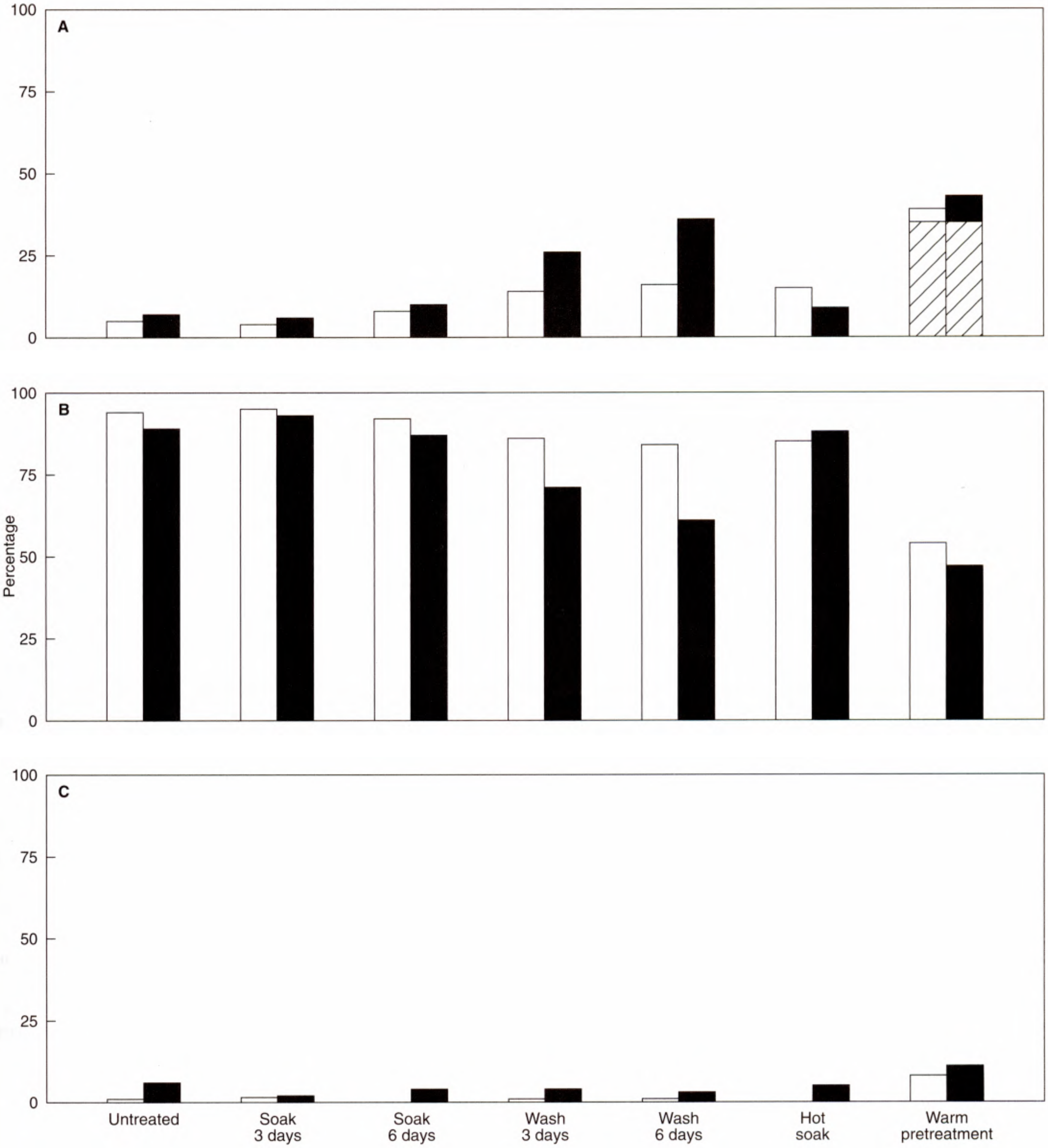

Figure 2—*Effects of soaking, washing, and warm pretreatment on (A) percentage germination, (B) percentage of ungerminated but fresh seeds, and (C) percentage of dead or abnormal Russian-olive* (Elaeagnus angustifolia) *seeds. Key: germination test results before (open columns) and after chilling (solid columns) at 4 °C (39 °F) for* 4 *weeks; the percentage of seeds that germinated during warm pretreatment (hatched columns).*

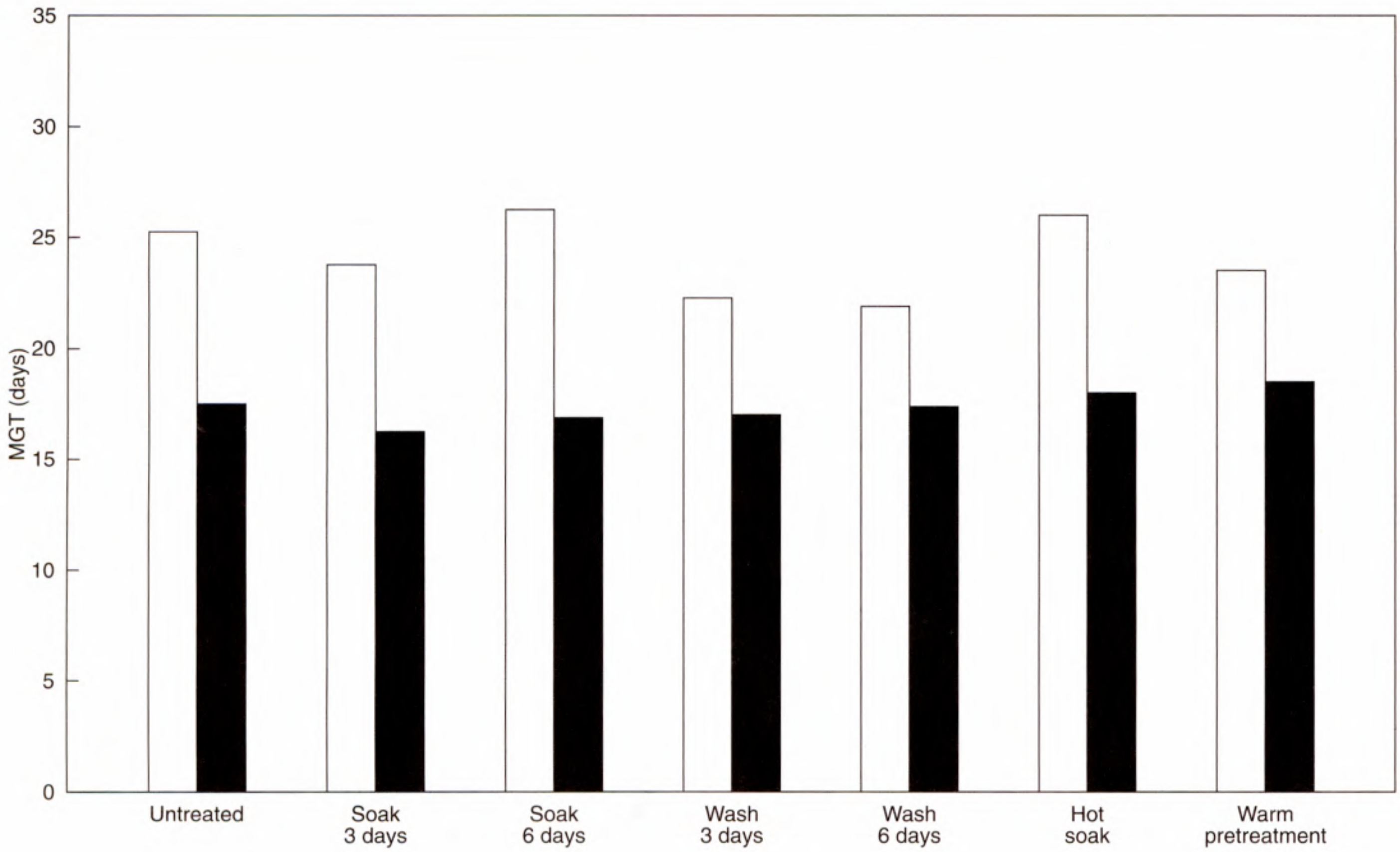

Figure 3—*Effects of soaking, washing, and warm pretreatment on the mean germination time (MGT) of autumn-olive* (Elaeagnus umbellata) *seeds. Key: MGT for seeds tested before (open columns) and after (solid columns) chilling at 4 °C (39 °F) for 4 weeks.*

from an average of 15% to 31%, and washing for 6 days produced significantly more germination (37%) than for 3 days (26%). Most of the ungerminated seeds in each treatment were still fresh and were considered to be dormant (figure 2b). The proportion of dead seeds following incubation was low (figure 2c); generally less than 1% of the unchilled seed died, but 8% died during warm pretreatment in peat and sand. Prechilling significantly increased seed death to an average of nearly 5% across all treatments (figure 2c). The results for Russian-olive show that washing seed in running water before cold pretreatment can improve germination but that moist warm pretreatment alone was just as effective. Extending the length of the chilling period to 12 weeks (Hamilton and Carpenter 1975) could increase germination further.

Overall, these 2 species of *Elaeagnus* had very different levels of seed dormancy. Autumn-olive seed was least dormant, for more than 70% of the seeds germinated without pretreatment. This particular seedlot was less dormant than previously reported for autumn-olive (Fowler and Fowler 1987). In contrast, the seedlot of Russian-olive was dormant and would probably require the recommended 9 to 12 weeks of chilling to obtain maximum germination (Hogue and LaCroix 1970). The present results suggest that this period could be significantly shortened by washing seed in running water for 6 days before incubation at chilling temperatures. A proportion of untreated seed was also capable of germinating at warm temperatures (20 °C = 68 °F) in a peat and sand mix, and this method could be used to obtain some seedlings in a shorter time than by conventional pretreatment. The medium was probably more effective at reducing the levels of inhibitory substances in seed coats than incubating seed on moist filter paper.

Conclusions

The results for autumn-olive suggest that seeds of this species may not always be particularly dormant. However, the Russian-olive seedlot was dormant, and improvements in germination by either washing seeds for 6 days and then prechilling, or by giving a warm stratification for at least 4 weeks, suggest that a water-soluble inhibitor may be an important feature of the dormancy mechanism of this species as shown by (Hamilton and Carpenter 1975).

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Osmotic Priming Hastens Germination and Improves Seedling Size of *Pinus brutia* var. *eldarica*

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Production of eldarica pine—Pinus brutia *var.* eldarica *seedlings for Christmas tree or ornamental use could be improved by more rapid germination. Seeds of this species exhibit shallow dormancy and generally do not require stratification. However, osmotic priming may speed emergence. Our objective was to examine the response of eldarica pine seeds to osmotic priming. Seeds were preconditioned at room temperature in an aerated solution of polyethylene glycol (PEG) 8000 for 2, 5, 7, 9, and 11 days, at one of the following concentrations-200, 300, and 400 g PEG /kg water. After treatment, seeds were sown in plastic trays and grown in a greenhouse for 12 weeks. PEG reduced germination 7 to 15 percentage points. However, speed of germination measured as days to 50% germination (T_{50}) was reduced 4 days by treatments of up to 9 days' duration. Because of the more rapid germination, shoot length and shoot dry weight measured 12 weeks after sowing were increased by priming. Concentrations of 200 or 300 g PEG/kg water for 9 days provided the best response. Although osmotic priming increased speed of germination and subsequent seedling size, other invigoration treatments such as stratification or controlled hydration may offer greater benefits in nursery production at lower cost.* Tree Planters' Notes 48(1/2): 24-27; 1997.

Rapid germination is desired in conifer seedling production because it increases seedling size and uniformity and improves yield. Rapid germination also can reduce to risk to soil-borne diseases during the germination process. Eldarica *pine—Pinus brutia* var. *eldarica—is* an important species for live Christmas trees, windbreaks, and ornamental use in the southwestern United States. Unfortunately, germination of eldarica pine is often variable in speed and capacity, and the cost of seed is high (>$0.02 for each pure live seed). Therefore, improvements in germination and establishment would help growers meet local seedling demands. *Pinus brutia* provenances vary in their response to stratification, with southern provenances germinating over a wide temperature range without stratification (Skordilis and Thanos 1995). Northern provenances have poor germination without stratification. Operational data from growers indicate that *Pinus brutia* var. *eldarica* behaves like the southern provenances in the aforementioned study.

Several methods have been used to precondition seeds to improve seedling establishment of vegetable and field crops. Osmotic priming is one technique offering promise for improvement in germination speed and completeness (Khan and others 1990). Priming is a controlled hydration technique that enables seed to absorb water and start pregerminative metabolic activities while maintaining seeds under mild water stress to prevent radicle emergence (Bradford 1986; Heydecker and Coolbear 1977). Water uptake is regulated with large-molecular-weight osmotic agents, such as polyethylene glycol (PEG), which are not absorbed as readily as salts.

Osmotic priming reduces days to 50% germination for shortleaf pine *(Pinus echinata* Mill.), Scots pine *(P. sylvestris* L.), and loblolly pine *(P. taeda* L.) (Hallgren 1987, 1989; Simak and others 1984). However, effects of PEG on germination percent are variable. Priming increased total germination of slash pine *(P. elliottii* Engelm.), Scots pine, and loblolly pine (Hallgren 1987; Haridi 1985; Simak and others 1984). Decreases in total germination have been reported for Norway spruce *(Picea abies* (L.) Karst.) (Simak 1985), white spruce *(P. glauca* (Moench) Voss) (Downie and others 1993), and slash pine (Hallgren 1989). This experiment measures the effect of polyethylene glycol (PEG 8000) concentrations and soaking durations on greenhouse germination and seedling growth of eldarica pine.

Materials and Methods

Seeds of eldarica *pine—Pinus brutia* var. *eldarica-* were soaked in PEG 8000 solutions (200, 300, and 400 g PEG/kg water) for 2, 5, 7, 9, or 11 days at room temperature. The osmotic potential of PEG 8000 solutions was —0.5 MPa for 200 g/kg water, —1.1 MPa for 300 g/kg, and —1.8 MPa for 400 g/kg (Michel 1983). Seeds were aerated during soaking in erlenmeyer flasks with an aquarium pump. Distilled water was added daily to maintain water level and water potential. After priming, the seeds were rinsed with tap water for about 2 minutes. The control treatment consisted of soaking seeds in distilled water for 8 hours. Unpublished work indicated that soaking seeds in aerated water for 5 or more days resulted in germination during the soaking treatment. Thus, a water duration treatment was dropped.

Seeds were sown on December 1, 1989, in a greenhouse in plastic trays measuring 52 (37 cm filled with peat moss. The seeds were covered with a thin layer of vermiculite. The temperature in the greenhouse was 25 °C (= 77 °F) with max/min variation of 5 °C (9 °F). Each treatment contained 60 seeds replicated 3 times. Emergence counts were made on alternate days until the 30th day. Emerging seedlings were tagged with colored rings to record time of emergence (Mexal and Fisher 1987). Shoot length and shoot dry weight were recorded by randomly selecting 3 seedlings from each treatment every 2 weeks from week 4 to week 12. At 12 weeks, the remaining seedlings were oven-dried at 70 °C (= 158 °F) for 3 days. The experiment was split block designed as a 3 x 6 factorial. Data were analyzed using analysis of variance technique and the least significant difference (LSD) test was applied when F-values were significant.

Results

Germination. Germination percentage was decreased by duration of priming (D) but not by the concentration of PEG (table 1). Furthermore, there was a significant interaction between PEG concentration and duration. The control (water soak for 8 hours) had the best germination percentage (94.7%), but the poorest speed of germination (figure 1). Germination

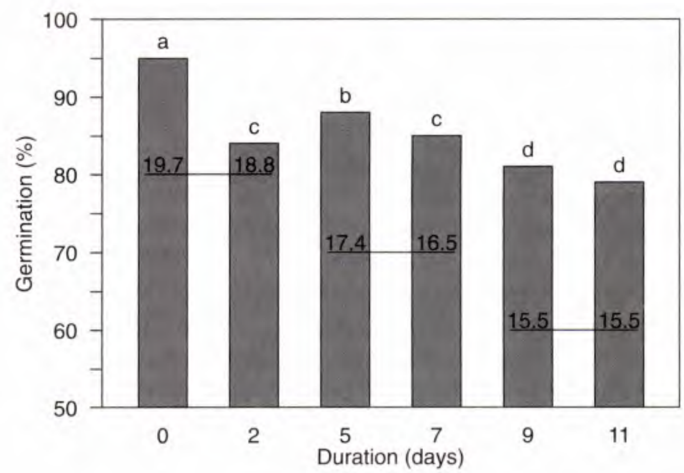

Figure 1—*Germination percent and days to 50% germination (numbers within bars) of eldarica pine seed following priming with PEG 8000 for various durations. Bars with the same letters, and numbers under the same line are not significantly different* (P = 0.05) *using least significant differences.*

decreased as seed treatment duration increased and poorest emergence was for seed soaked for 9 and 11 days. However, these 2 treatments had the fastest germination. The days to 50% germination (T_{50}) were about 4 days earlier for 9- and 11-day priming treatments compared to the control. Additionally, T_{50} was affected by PEG concentration. The lowest concentration (200 g/kg) resulted in faster emergence (T_{50} = 16.7 days) compared to the highest concentration (T_{50} = 17.9 days). The T_{50} for the intermediate concentration (T_{50} = 17.1 days) was not significantly different from the lowest concentration.

Seedling morphology. Duration of priming significantly affected shoot length and shoot dry weight, but

Table 1— *Analysis of variance of percentage germination, days to 50% germination (T_{50}), shoot length, and shoot and root dry weight of eldarica pine as affected by PEG 8000 concentration and seed priming duration.*

		Mean squares				
					Dry weight (g)	
Source	DF	Germination (%)	T_{50} (days)	Shoot length (cm)	Shoot	Root
Replication	2	12.62	12.66	0.6848	0.0037	0.0005
		—	—	—	—	—
Concentration	2	1.68	6.89	0.1631	0.0001	0.0001
		(.746)	(.003)	(.412)	(.726)	(.287)
Duration	5	103.81	27.38	0.6723	0.0010	0.0001
		(<.001)	(<.001)	(.004)	(<.001)	(.797)
C×D	10	25.62	10.00	0.2459	0.0004	0.0001
		(<.001)	(.060)	(.212)	(.138)	(.351)
Error	34	29.35	0.98	0.2868	0.0003	0.0001

Values in parenthesis are P values for mean squares values above it.

not root dry weight (table 1). Shoot length tended to increase with each increment of seed treatment duration (figure 2). The control treatment had the shortest seedlings, while the 9-day priming treatment had the tallest seedlings at the end of the study. Shoot weight tended to follow similar relationships. However, root weights were similar (figure 3), and the R/S ratio was not clearly related to treatment.

Improved growth of primed seed seemed attributable to the earlier emergence. Growth curves of all treatments fit the same linear relationship (figure 4). The only difference was that the 5- day priming treatment reached T_{50} = 2.3 days earlier than the control, and the

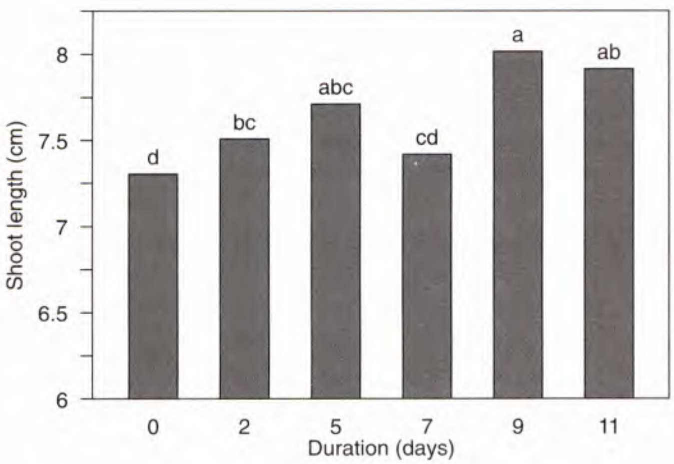

Figure 2—*Shoot length (cm) of eldarica pine seed following priming with PEG 8000 for various durations. Bars with the same letters are not significantly different* (P = 0.05) *using least significant differences.*

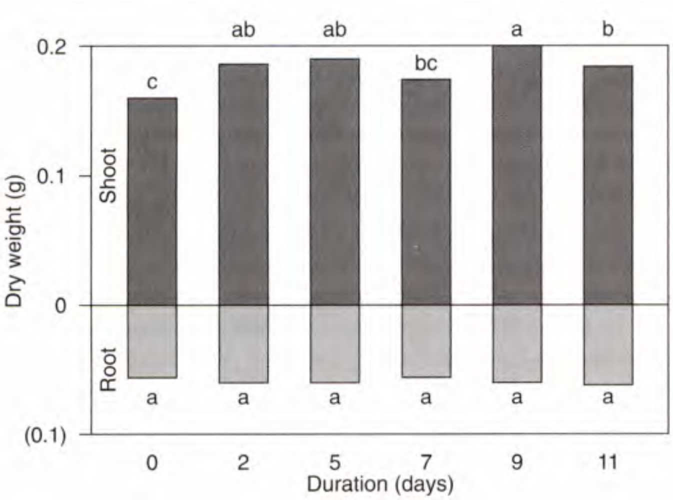

Figure 3— *Shoot and root dry weight (g) of eldarica pine seed following priming with PEG 8000 for various durations. Bars with the same letters are not significantly different* (P = 0.05) *using least significant differences.*

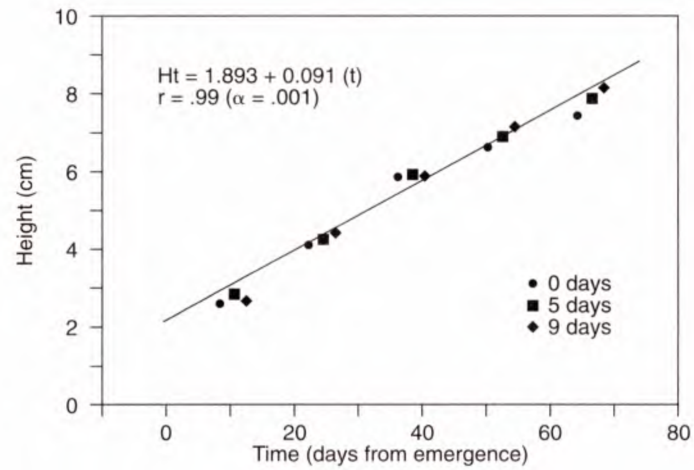

Figure 4—*Relationship between days from emergence and height (cm) for eldarica pine seed following priming with PEG 8000 for 0, 5, or 9 days.*

9-day priming treatment reached T_{50} = 4.2 days earlier. Other priming treatments were intermediate in response but not shown. The difference in time of emergence and growth over time seem to fit reasonably well on the regression line, which would explain the differences in morphology at the end of the growth period.

Furthermore, significant differences were lacking among the regression slopes of the different priming treatments. The response for shoot dry weight was similar (data not shown).

Discussion

Priming with PEG 8000 decreased total emergence of eldarica pine seed compared to seed soaked in distilled water. Similar responses of total germination were reported by Hallgren (1987, 1990) for slash and loblolly pine. Days to 50% germination (T_{50}) was reduced by priming. Maximum reduction in days to 50% emergence was observed for seed treatment duration of 9 days and a PEG concentration of 200 g/kg. Murray (1990), Lopes and Takaki (1988), Carpenter (1989), and Dearman and others (1986) also reported reduction in T_{50} when seeds were treated with PEG for different durations

Shoot length and shoot dry weight increased with each increment of seed treatment duration up to 9 days duration, but further increases in duration were of no additional benefit.

Osmotic priming hastens germination, resulting in increased seedling size of eldarica pine. However, priming also reduces overall germination. A reduction in germination is an undesirable feature that mitigates against recommending this as a promising treatment. It is possible that part of the improvement in germination speed results from the mortality of late germinants. These germinants likely would die anyway, as late emerging seedlings suffer increased mortality compared to early emerging neighbors (Mexal and Fisher 1987). In nurseries where prompt emergence is important to avoid washing from heavy rains, the tradeoff between prompt yet lower emergence may be worthwhile. Treating the seed for 9 days speeds the emergence in the nursery by about 4 days. This could reduce to risk from seedbed washing or seedling loss to soil-borne damping off, and increase the size of the crop. However, earlier sowing or possibly stratification could accomplish the same effect. This technique should be used only in emergency situations where inventory indicates a need for additional seedlings.

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Determining the Number of Seeds To Sow per Cell: An Application of the Geometric Distribution

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Using germination data, specifically total germination percentage, to determine sowing rates is necessary for effective resource allocation in container nurseries. Traditionally, binomial probability tables and, more recently, microcomputer programs are employed to determine sowing rates in container nurseries. Existing computer programs may require several iterations to deduce sowing rates, depending on test gemination percentage. When used with the binomial probability function, the geometric probability function alleviates the need to run multiple iterations of a program. We provide programming language for a spreadsheet program that combines these two probability functions to determine sowing rates. Tree Planters' Notes 48(1/2): 28-34; 1997.

Effective resource allocation in container nurseries can be improved by using germination percentage to determine sowing rates. Seed sowing and germinate thinning, both intrinsically linked to sowing strategy, are primary candidate areas for cost reduction in container nurseries (Wenny 1993). Germination percentage is a mathematical probability (Lipschultz 1968; Schwartz 1993). Initially, seed sowing guides were based on interpretations of binomial probability tables (Tinus and Mc Donald 1979). By using the factorial expansion of the binomial distribution, growers can refine their calculations using scientific calculators (Schwartz 1993). The advent of personal computers and user-friendly spreadsheet programs further simplified the use of the binomial distribution for seed sowing calculations (Wenny 1993). All these methods, when used appropriately, can improve several aspects of container production, including reducing material, labor, and greenhouse costs.

However, using approaches based on the binomial distribution function requires nursery managers to ask the question, "If X number of seeds are sown per cell, how many cells will have X number of germinates; X-1 germinates; X-2 germinates; and so on?" Depending on germination percentage, nursery managers may have to ask the question several times to achieve a satisfactory distribution. Often, the nursery managers are concerned with the question "How many seeds need to be sown per cell to achieve X number of filled cells?" This question can be answered by running several iterations of the binomial distribution. The question can also be answered with one iteration, using the geometric probability distribution. Geometric distribution is easily adaptable to user-friendly commercial spreadsheet programs that are commonly available for personal computers.

Microcomputer Application

Instructions for using the program language for the geometric probability distribution and the binomial probability distribution in concert are listed in the appendix (see page 33). Nursery managers can use this program with any commercially available spreadsheet that has natural logarithm, binomial distribution, and exponential functions. This particular formulation was developed for programs with @ FUNCTION capability. It will be necessary to format your spreadsheet program as follows:

Column A—Text format and column width of 50 characters
Column B—Fixed numeric format with 4 decimal places
Column C—Requires no special formatting
Columns D through P—Fixed numeric with 2 decimal places and column width of 7 characters

Only 2 numeric entries are necessary to run this program. First, in cell B5, seedlot germination percentage is entered as an integer. A nursery manager then enters the allowable number of empty cells per 100 cells sown into cell B9 as either an integer or a real number.

Examples of Model Applications

For our first example, let's start with a seedlot having a tested germination percentage of 95% and an acceptable empty cell rate of 1.5%. The spreadsheet program at the end of this paper provides a value for the number of seeds necessary to sow to achieve this objective (1.4 seeds/cell; cell B13). Because sowing 1.4 seeds is impractical, the program provides a floor value, the nearest whole number below the value (in this case 1 seed/cell; cell B17) and a ceiling value, the next highest whole number to the calculated value (in this case 2 seeds/cell; cell B15). On the right-hand side of the output the program generates binomial probability distributions for these 2 recommended values (figure 1).

In a second example, with a germination percentage of 75% and an acceptable empty cell rate of 1.5%, the spreadsheet recommends sowing 3.03 seeds/cell with floor and ceiling sowing rates of 3 seeds/cell and 4 seeds/cell, respectively (figure 2).

In the last example, let's use a seedlot with a germination percentage of 60% and an acceptable empty cell rate of 1.5%. The spreadsheet recommends sowing 4.58 seeds/cell with floor and ceiling sowing rates of 4 seeds/cell and 5 seeds/cell, respectively (figure 3).

These examples demonstrate microcomputer applications of the geometric probability distribution. Understanding why the geometric distribution works requires a review of some probability distributions and their inherent differences.

Technical Background on Probability Distributions

Three discrete probability distribution functions are useful in determining seed sowing rates. These are the Bernoulli distribution function, the binomial distribution function, and the geometric distribution function. The probability *(P)* of a seed from a tested seedlot germinating (success) equals the germination percentage for that seedlot. Subtracting germination percentage, expressed in decimal form, from 1 is the probability *(q)* of non-germinating (failure). Planting a single seed with these probabilities *(p* and *q)* assigned to the outcome is an expression of the simplest probability distribution function, the Bernoulli distribution, mathematically expressed as (Dudewicz and Mishra 1988):

EQUATION 1 $$P_x = p^x q^{1-x} \qquad x = 0,1$$

where: P_x = the probability of germinating
p = the germination percent in decimal form
$q = 1 - p$

For nursery managers, the utility of this discrete probability distribution is limited because germination percentage is usually already known or assumed. However,

Determining Seed/Cell Requirements			Binomial Distributions of Ceiling and Floor Number of Seeds to Sow								
From the Geometric Probability Density Function			Number of			Percentages of Number of Germinants					
			Seeds Sown		2	1	0				
Seedlot Germination %	95		2		90.25	9.50	0.25				
			1			95.00	5.00				
Acceptable Number of Empty Cells per 100	1.5										
Exact Number of Seeds to Sow per Cell	1.4019										
Ceiling Number of Seeds to Sow	2										
Floor Number of Seeds to Sow	1										
Ceiling Percentage of Empty Cells	0.2500										

Figure *1—Spreadsheet outputs, example A: seedlot with 95% germination.*

Determining Seed/Cell Requirements			Binomial Distributions of Ceiling and Floor Number of Seeds to Sow								
From the Geometric Probability Density Function			Number of			Percentages of Number of Germinants					
			Seeds Sown		4	3	2	1	0		
Seedlot Germination %	75		4		31.64	42.19	21.09	4.69	0.39		
			3			42.19	42.19	14.06	1.56		
Acceptable Number of Empty Cells per 100	1.5										
Exact Number of Seeds to Sow per Cell	3.0294										
Ceiling Number of Seeds to Sow	4										
Floor Number of Seeds to Sow	3										
Ceiling Percentage of Empty Cells	0.3906										

Figure 2—*Spreadsheet outputs, example B: seedlot with 75% germination.*

Determining Seed/Cell Requirements			Binomial Distributions of Ceiling and Floor Number of Seeds to Sow								
From the Geometric Probability Density Function			Number of			Percentages of Number of Germinants					
			Seeds Sown		5	4	3	2	1	0	
Seedlot Germination %	60		5		7.78	25.92	34.56	23.04	7.68	1.02	
			4			12.96	34.56	34.56	15.36	2.56	
Acceptable Number of Empty Cells per 100	1.5										
Exact Number of Seeds to Sow per Cell	4.5834										
Ceiling Number of Seeds to Sow	5										
Floor Number of Seeds to Sow	4										
Ceiling Percentage of Empty Cells	1.0240										

Figure 3—*Spreadsheet outputs, example C: seedlot with 60% germination.*

this probability distribution provides the foundation for 2 discrete probability distributions—binomial and geometric—applicable to developing sowing strategies.

Planting 2 or more seeds from a seedlot (that is, possessing the same germination percentage) is a practical demonstration of the binomial probability distribution. The binomial probability distribution calculates the probability of a specific number of germinations (successes) without regard to the order of those successes (Dudewicz and Mishra 1988; Lipschultz 1968). The general form of the binomial probability distribution (Dudewicz and Mishra 1988; Lipschultz 1968) is

EQUATION 2 $$P_x = \binom{n}{x} p^x q^{n-x} \qquad x = 0, 1, 2, \ldots, n$$

where: P_x = the probability of occurrence (percentage of cells)
n = the number of independent trials (number of seed sown per cell)
x = the number of the i^{th} trial (number of germinates)
p = the probability of germinating (success)
q = the probability of not germinating (failure; $1-p$)

Each probability includes 2 components: the binomial coefficient and the Bernoulli probability raised to the power of the trial (x). The binomial coefficient can be derived using the following factorial expansion (Schwartz 1993):

EQUATION 3 $$(X + Y)^n = X^n + aX^{n-1}Y + \ldots\ldots + aXY^{n-1} + Y^n$$

where: n = the number of independent trials (seeds)
a = binomial coefficient
X = germination probability
Y = 1 – germination probability

Another way to derive the binomial coefficient is to use factorial notation. The general form for determining the binomial coefficient (Dudewicz and Mishra 1988; Lipschultz 1968) is

EQUATION 4 $$\left| \frac{n!}{x!(n-x)!} \right|$$

where: n = the number of independent trials (seeds)
x = the number of the *ith* trial (number of germinates)

Most statistics texts denote this formula using the notation $\left|\binom{n}{x}\right|$, nCx, or C(n,x). This formula is also used to determine the number of combinations from n objects (seeds) choosing x at a time (Lipschultz 1968). The exponent of the Bernoulli probability signifies the number of the trial being conducted. Therefore, when $n = 5$, the term p^3q^2 indicates that the third of 5 trials is being computed. Note that the exponents of p and q sum to n (5 in this case). Also, the probability of all successes is given by p^n and conversely the probability of all failures is q^n, because in both cases the binomial coefficient is one (Dudewicz and Mishra 1988; Lipschultz 1968).

The geometric probability distribution has the general form (Dudewicz and Mishra 1988):

EQUATION 5 $$P_x = (1-p)^x \qquad x = 1,2,3\ldots$$

where: P_x = the probability of occurrence (percentage of empty cells)
x = the number of the i^{th} trial (number of failed germinates)

This probability distribution is useful because it computes the number of trials to achieve the first success. It differs from the Bernoulli probability distribution by not restricting the number of trials to one. However, if only 1 trial is performed, the geometric probability distribution is equivalent to the Bernoulli probability distribution. The geometric probability distribution differs from the binomial probability distribution in two aspects: trials place failures before the first success and an infinite number of trials can be run.

The geometric probability distribution can be algebraically rearranged to the following form (Dudewicz and Mishra 1988; Mood and others 1974):

EQUATION 6 $$X = \frac{\ln(P_x)}{\ln(1-p)}$$

where: X = the number of the i^{th} trial (number of seed to sow)
ln = the natural logarithm
P_x = the probability of occurrence (percentage of empty cells)
p = the germination probability

This form is useful when P_x, the desired probability of occurrence (percentage of empty cells), is known, and X, the number of trials (number of seed to sow) necessary to achieve that probability, is unknown.

The geometric probability distribution can determine the number of seeds to sow per cell to achieve a specific cell occupancy. By itself, the geometric probability distribution provides no information on distribution frequency of multiple germinates per cell. Using the two probability distributions in concert can reduce the number of iterations required when using the binomial probability distribution alone, and provide the distribution of germination frequencies lacking in the geometric probability distribution.

Recommendations

The most limiting feature of production varies between container nurseries, and within nurseries based on crops and cropping schedules. Sometimes, growing space is more valuable than the labor associated with thinning. Sometimes, the converse is true. For example, at New Mexico State University's Mora Nursery, growing space is at a premium during spring and early summer months. At these times, greater emphasis is placed on sowing multiple seeds per cell (that is, using ceiling values) and lowering the acceptable empty cell rate. Later in summer, when a second crop is being sown, sufficient space is usually available to over-sow the total number of cells and sow using the floor sowing rate. Using geometric and binomial probability distributions in concert provides a tool for nursery managers to evaluate different options for producing their crops.

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Acknowledgments

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Appendix

Spreadsheet Programming Language

Establish the column width of column A as 50 characters wide.

Cell	**Entry**
AI	Determining Seed/Cell Requirements
A2	From the Geometric Probability Density Function
A5	Seedlot Germination `)/0
A9	Acceptable Number of Empty Cells per 100
A13	Exact Number of Seeds to Sow per Cell
A15	Ceiling Number of Seeds to Sow
A17	Floor Number of Seeds to Sow
A19	Ceiling Percentage of Empty Cells
A21	Floor Percentage of Empty Cells
B13	= @LN(B9/100)/@LN(1-(B5/100))
B15	= @INT(B13)+1
B17	=B15-1
B19	= (1-(B5/100))AB151 00
B21	= (1-(B5/100))AB17*1 00
D1	Binomial Distributions of Ceiling and Floor Number of Seeds to Sow
D3	Number of
D4	Seeds Sown
D5	=B15
D7	**=B17**
F4	=D5
F5	= @ IF(F4<>"b", @ BINOMDIST(F4,$D$5,$B$5/100,0)*100,"b")
G3	Percentages of Number of Germinations
G4	= @IF(F4-1>=0,F4-1,"b")
G7	= @ IF(G4<>"b",@ BINOMDIST(G4,$D$7,$B$5/100,0)*1 00,"b")

This spreadsheet formulation was developed on Corel Quattro Pro® for Windows 95 ® and has been tested on Microsoft Excel® running under Windows 95®. **The character "b" represents a blank space enclosed within double quotes.** The @BINOMDIST function may be named differently depending upon the spreadsheet you are using, possible synonyms include BINOMIAL and BINOM. Refer to the help files or user's guide for the exact syntax. The formula entries in cells F5, G4, and G7 should be copied to the right within the same row into each subsequent cell through column P. For spreadsheets operating on Windows® platforms the copying procedure should be done with the clipboard copy and paste functions.

Use the following procedure to perform the copying:

1. Select the cell you wish to copy by clicking it one time with the left mouse button.
2. Then click the copy button on the tool bar or select copy on the pull-down edit menu.
3. Then select the cell where you want to place the copy by clicking it one time with the left mouse button.
4. Then click the past button on the tool bar or select paste on the pull-down edit menu.

For applications running on other operating platforms, refer to your help files or the user's guide for copying cells. **Do not manually enter the formula into subsequent cells that you would copy the formula into, as this destroys the relative cell referencing and makes the formula invalid.**

Two entries are made into the spreadsheet:

► The seedlot germination percentage is entered into cell B5.

► The acceptable number of empty cells per 100 cells sown is entered into cell B9.

Some spreadsheets may display error messages in certain cells because of the interpretation of the formula. This is caused by not having a value available upon which to perform the operation that the formula specifies. The error messages will occur in rows 4, 5, and 7 in the columns to the right of where the binomial distribution reaches a value of zero. If error messages occur in any of these cells—B13, B15, B17, B19, B21, D5, D7, F4, F5, G4, or G7—verify that the formula is entered correctly, specifically making sure that it is not entered as text.

A New Seed Trap Design

A. David, B. Wender, P. Weis, J. Stringer, and D. Wagner

Post-doctoral scholar, forestry undergraduate, agricultural biotechnology undergraduate, and assistant and associate professors, University of Kentucky, Department of Forestry, Lexington, Kentucky

We describe a new seed trap design. Constructed of readily available materials, the trap is easy to carry into the field and assemble, retains seeds of most temperate forest tree species, and is sturdy enough to withstand several years of use. Tree Planters' Notes 48(1/2): 35-37: 1997.

Forest management activities generate a variety of reasons to collect tree seeds. For example, establishment of operational seedling plantations requires a large and reliable seed supply from which to produce planting stock. In this context, vast numbers of seeds are often collected from a single area (for example, from a seed orchard). Such seed harvesting has become relatively efficient and is sometimes mechanized. In contrast, certain other activities need only relatively small amounts of forest tree seeds. Examples include the evaluation of annual seed production and genetic quality of individuals being considered for inclusion in breeding programs, establishment of seedling seed orchards, assessment of the effects of timber harvesting on genetic diversity, and measurement of the nutritional value to wildlife of seed rain quantity and quality. Each such project may require a relatively small number of seeds from only 1 tree or just a few trees in each of several stands, but in many cases the maternal parent of each seed must be known. Because maternal parents are usually uncertain when picking up seeds from the ground, pole pruners, shotguns, and rifles are often used to harvest seeds from individual mother trees.

Unfortunately, direct collection by firearms and/or pole pruners is impractical when seeds are too high in the canopy and/or are difficult to see, as is the case in many temperate hardwoods. For such species, passive collection by traps—for example, Williams (1990); Phillips and others (1995)—can provide sufficient seed of known maternal parentage. Here we present the design of a seed trap that we have been using to investigate the effects of timber harvesting on white oak-*Quercus alba* L.— genetic diversity. This trap requires less assembly time and is easier to carry into the field than traditional traps. It also performs favorably in terms of longevity, retains a wide range of seed sizes, and is aesthetically unobtrusive.

The components of this trap are readily available at most hardware stores. One trap requires:

- 4 metal U-posts with hooks, each 4 ft (122 cm) long
- 1 section of plastic poultry fencing, with 3/4-in (1.9-cm) openings (5 x 4 ft; Tenex Corporation, Baltimore, MD)
- 1 section of fiberglass mesh window screening (5 x 4 ft)
- 1 piece of security fencing with 2-in (5-cm) openings (5 x 4 ft; Tenex Corporation) and 14 zip ties

On steep terrain the trap can be made level by substituting two 5-ft-long U-posts for the two 4-ft-long U-posts on the downhill side of the trap. The only assembly tools needed are an 8-lb (3.6-kg) sledgehammer, scissors, and a screwdriver or awl for opening the hooks on the U-posts.

Precutting the poultry fencing speeds up the installation process and decreases the amount of material that has to be carried by the field crew. Precutting begins by cutting ten 5-ft sections from a 4-ft-wide 50-foot-long (15.2-m-long) roll of plastic poultry fencing. Then an 8-in-long cut is made at each corner of the cut sections, parallel to the long ends and 8 inches from the edges, creating four 8 x 8-in flaps on each cut section (figure 1).

Field installation is rapid. A piece of precut poultry fencing is placed on the ground at the desired site. Using the precut slots as guides, 4 U-posts are pounded into the ground at the appropriate locations with the sledgehammer. Beginning at the top of the lowest U-post, 1 of the 8 x 8-in poultry fence flaps is wrapped around each U-post to form the 4 corners of an 8-in-deep "basket," so that the poultry fence engages the stakes' hooks. Each basket corner is secured to its stake with 2 zip ties, so that the top edges of the basket are level. Next, the fiberglass window mesh is laid over the basket and cut approximately 1 ft larger than the basket on all sides. A diagonal 10-in (25.4-cm) cut is made from each corner toward the center of the fiberglass mesh. The 2 resulting dog-ears at each corner of the window mesh are passed through the top sides of a corner of the poultry fencing basket, from the inside toward the outside of the basket, and tied behind the comer stake. This creates a "basket within a basket" (that is, fiber glass mesh on top of poultry fencing). Finally, a top is made from the security fencing by laying it over the basket so that the 4 stakes protrude through it. The security fencing is cut to be slightly larger than the basket on all

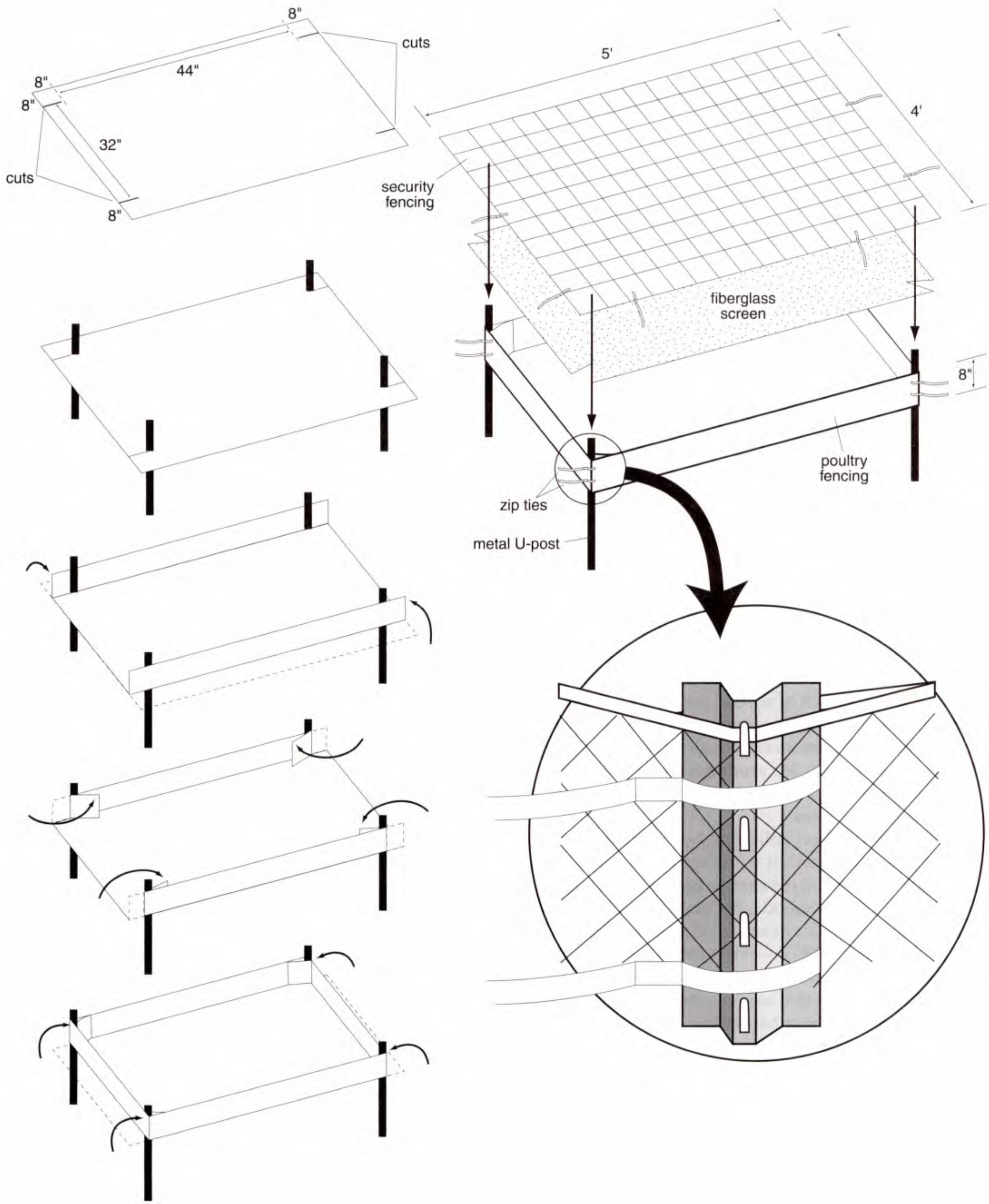

Figure 1—*Exploded diagram of seed trap.*

sides. Three edges of the security fencing are attached to the sides of the basket with 2 zip ties per edge. The overhanging fourth side of the security fencing is left unattached to allow easy access for seed removal, while still providing reasonable security from seed predators (figure 2).

Figure 2—*Fully assembled seed trap.*

Because the poultry fencing, fiber glass screen and security fence are all cut from 4-ft-wide rolls, the length of any trap (up to 50 ft) can be tailored to the specific needs of a particular project. We have found that the poultry fencing's 3/4-in openings can retain the majority of acorns of white oak, our current species of interest. A different type of fencing with a smaller mesh size may retain all acorns and make the fiberglass screen redundant, but for small-seeded species, the fiberglass screen is necessary.

A crew of 3 people can easily carry enough material to make 5 traps. Zip ties are used to bind stakes into groups for easy transport into the field, and burlap bags serve to contain the precut poultry fencing, a roll of security fencing, and a roll of fiberglass window screening. Scissors and zip ties are carried in field vests, and the sledge is carried by hand. With practice, one entire trap can be assembled by 3 people in less than 10 minutes.

At a cost of $17.71 per trap for materials the installation cost appears high compared to other designs. However, the cost per year is low when averaged over the expected life span of the trap, especially when labor and repair costs are included. The poultry and security fencing materials have a usable life span of 5 to 7 years and can withstand temperatures ranging from —23 to +49 °C (Tenex, personal communication).

In their first year following installation, 3 of our 79 traps (3.8%) required maintenance or replacement. One trap was damaged by a coyote (confirmed by tooth marks in the plastic), and the others were damaged by falling limbs. Annual estimated repair costs are $0.16/trap/year.

For aesthetic reasons, the U-posts, poultry fencing, security fencing, and zip ties can all be purchased in green to blend in with the understory. In areas of low visibility or low visitor levels, the plastic fencing can be purchased in bright orange for ease of location.

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Relating Pine Seed Coat Characteristics to Speed of Germination, Geographic Variation, and Seedling Development

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Loblolly pine—Pinus taeda *L.—evaluations indicate that speed of germination, which refects dormancy, is directly related to the ratio of the weight of the seed coat to total seed dry weight. Further evaluations with loblolly and ponderosa pine—P.* ponderosa *Dougl. ex Laws.—show significant correlations between the ratio of seed coat weight to total seed weight and ecotypic variation and seedling development. Seed dormancy was shown to vary by geographic location and to influence seedling development* if *stratification treatments are not optimized for conditions under which germination occurs. This finding may result in the maternal effects of the seed coat obscuring other genetically controlled growth processes early in seedling development. The effect of these early seed coat differences on seedling development can be minimized by extending the length of seed stratification.* Tree Planters' Notes 48(1/2): 38-42; 1997.

The influence of seed size and weight on early seedling growth of tree species has been studied for over 50 years (Baldwin 1942; Champion 1928; Gast 1937). Righter (1945) found that, in the genus *Pinus,* the positive correlation between seed weight and seedling height was temporary and disappeared after time in the field. A more recent study with loblolly pine *(Pinus taeda* L.) has shown a statistically significant positive correlation between seed weight and tree height after 15 years (Robinson and van Buijtenen 1979). Khalil (1981) reported that seed weight in white spruce *(Picea glauca* [Moech] Voss) was positively connected with annual growth of the terminal shoot at 2 and 4 years.

Several studies have evaluated the effect of size and other seed properties on germination and early seedling development. The evidence that seed size alone is a useful criterion for predicting seedling performance continues to be conflicting (Belcher and Gresham 1974; Barnett and Dunlap 1982; Wrzesniewski 1982). Other seed parameters that may be closely related to size are probably more directly related to seed and seedling performance. Dunlap and Barnett (1983) found that larger loblolly pine seeds germinated more quickly and produced larger germinants than smaller ones after 28 days. Size differences resulted from differences in the rate of germination are unique to each size class. Seedling size and possibly uniformity of growth were considered a function of germination patterns that were strongly influenced by seed size and weight. Results from a number of studies have shown that germination rates (Barnett 1979; Dunlap and Barnett 1984; McLemore 1969) and subsequent seedling growth (Barnett and McLemore 1984; Boyer and others 1985) can be manipulated in pines by means of seed stratification procedures. Seed stratification affects rates of germination of dormant seeds and, it turn, affects early seedling development. Therefore, parameters that are detrimental to or closely related to rates of germination may provide a better means of predicting early seedling performance than seed weight or size alone.

Review of Seed Coat–Germination Relationships

The relationship of the ratio of seed coat weight to total dry seed weight was evaluated in a number of southern pine species with a wide range of dormancy (Barnett 1976). This work showed that as much as 69% of the variation in speed of germination in 5 southern pine species was related to seed coat weight as a proportion of total seed dry weight. Speed of germination was expressed as days to reach peak value—the mean daily germination of the most vigorous component of the seed lot (Czabator 1962). This relationship was supported by evidence that constraint by the seed coats and megagametophytes is directly related to dormancy. Measurements of water absorption indicated that seed coats restricted water uptake by limiting how much the megagametophyte and embryo could expand. Loblolly pine seeds, the most dormant of the tested seeds, attained only about 36% moisture content (dry weight basis) until the seed coats cracked and germination began. In contrast, longleaf pine *(Pinus palustris* Mill.) seeds (the least dormant of the tested seeds) never completely stopped imbibition and attained 55% moisture content before germination began. Changes in size of the megagametophyte, with and without seed coats, support the theory that seed costs restrict imbibition by preventing swelling and limiting water absorption in the more dormant seeds.

Respiration also followed the trends of moisture imbibition (Barnett 1976), and the patterns appeared to result form imbibition levels rather than impermeability to oxygen. Germinability of de-coated seeds after different lengths of imbibition with seed coats intact and in atmospheres with various oxygen concentrations also supported the hypothesis that the seed coats slow germination by restricting megagametophytes and embryo expansion (Barnett 1972).

The total seed weight is determined by the seed coat, megagametophyte, and embryo. As the weight of the seed coat increases, the proportional weights of the embryos of total weight decreases (table 1). For 5 southern pines—longleaf, Sonderegger *(P. x sondereggeri* H. H. Chapm.), shortleaf *(P. echinata* Mill.), slash *(P. elliottii* Engelm.), and loblolly—the correlation coefficient was –0.930 (Barnett 1976). The same relationship for 5 different ecotypes of ponderosa pine *(P. ponderosa* Dougl. ex Laws.) was computed from Anantachote's data (1980) to be –0.015. Because the two parameters (weights of seed coats and embryos) are closely related, seed coats were used in the present evaluations because they were easier to measure.

The close correlation between speed of germination and the ratio of the seed coat to total seed weight provides a means of rapidly estimating relative seed dormancy. The technique may more reliably estimate innate or true dormancy than seed germination tests, particularly in lots of stored seeds. Secondary dormancy can be induced in pine seeds by unfavorable conditions during processing and storage (McLemore and Barnett 1966, 1968) and by adverse light and temperature regimes (McLemore and Hansbrough 1970; McLemore 1966), and secondary dormancy may mask the innate dormancy of seeds.

Relating Seed Coats to Ecotypic Variation

Progeny tests with many coniferous species show that 60 to 90% of the variation in seedling size is closely related to maternal factors (Perry 1976). The seed characteristics of pines and other gymnosperms are largely derived from female tissue because only the embryo contains genes from the pollen or male parent. Thus, it should be expected that seed coat properties are related to seedling performance. The early expression of these maternal traits may affect the measurement of other genetic responses.

Loblolly pine seed lots from across the range of the species were evaluated to assess the variation in seed properties. Seed weight was unrelated to either latitude or longitude of the source (table 2). However, seed coat weight—expressed as ratio of seed coat weight to total seed weight—was positively correlated to latitude and negatively correlated to longitude. If seed coat thickness is directly related to dormancy or speed of germination, the degree of dormancy in loblolly seeds should increase in the northern and eastern portion of the range and should decrease in the southern and western portion of the range. Thorbjornsen (1961) evaluated loblolly pine seed coat thickness and found thin seed coats in the western part of the range and thicker ones in the eastern part of the range.

Anantachote (1980) also evaluated ponderosa pine seedling development for a wide range of seed parameters and ecotypic selections; however, he did not attempt to relate the ratio of seed coat or embryo weight to total seed weight to geographic distribution or seedling development. A reevaluation of these ponderosa pine data shows a relationship very similar to that of loblolly pine. Percentages of the seed coat weight to total seed weight range from 39 to 53.2 and are negatively related to embryo weight (table 3). Correlations of seed coat weight as a proportion of total weight, with locations within each ecotype of ponderosa pine, provided some interesting relationships (table 4). The proportion of the seed coat was significantly related to longitude and elevation of the seed source (-0.96 and 0.89, respectively). No relationship was found with latitude of the source. However, when the product of latitude and elevation was evaluated, a positive correlation coefficient of 0.94 was obtained. Thus, seed dormancy was greater at the higher elevations in the interior portion of the range (figure 1). The coastal sources were less dormant.

Table *1—Proportions of the seed parts to total dry weight and corresponding germination data for the southern pine seeds (adapted from Barnett 1976)*

Species	Proportion of seed parts (%)			Germination data		
	Seed coat	Gametophyte	Embryo	Total germination (%)	Germination value	Peak day
Longleaf	29.2	60.2	10.6	91	44.8	6.0
Sonderegger	35.1	55.5	9.4	97	43.4	7.4
Shortleaf	35.0	55.8	9.2	92	22.0	10.0
Slash	43.5	49.9	6.6	94	25.2	9.8
Loblolly	56.4	37.4	6.2	98	24.1	12.5

Table 2—*Relation of geographic seed source of half-sib families of loblolly pine to seed weight and proportion of the seed coat to total dry weight*

Location of seed source				
County & state	Lat.	Long.	Avg. seed weight* (mg)	Proportion of seed coat to total seed weight† (%)
Cherokee, TX	31° 21'	94° 40'	32	54
Grant, AR	34° 25'	92° 20'	25	57
Lawrence, AL	34° 30'	87° 20'	36	60
Jackson, NC	35° 15'	83° 05'	30	62
Hertford, NC	36° 25'	77° 50'	26	63

* No statistically significant relationship was found between seed source and seed weight.
t Correlation coefficients between latitude and longitude and proportion of the coat to total seed weight were 0.94 and —0.96, respectively. Data are based on 3 replications of 50 seeds each.

Table 3—*Relationship of geographic seed source of half-sib ponderosa pine families to seed characteristics and seedling development (developed from Anantachote 1980)*

	Location of ecotypic source			Proportion of total weight† (%)		Seedling development‡ (cm)			
						Primary root length		Shoot length	
Ecotype*	Lat.	Long.	Elev. (m)	Seed coat	Embryo	2 mos.	9 mos.	2 mos.	9 mos.
A–California	35° 5'	120° 2'	1,524	41.5	6.5	69.8	86.0	7.8	15.5
B–No. plateau	44° 8'	118° 5'	1,348	39.0	7.5	70.0	81.8	6.6	14.2
C–So. interior	36° 0'	113° 0'	2,134	47.0	6.0	65.5	85.9	4.5	11.5
D–Cen. interior	37° 2'	105° 7'	2,165	53.2	4.0	64.7	84.0	4.8	9.0
E–No. interior	44° 5'	105° 5'	1,913	51.0	5.4	65.5	74.7	4.6	8.3

* The 5 ecotypes of ponderosa pine (Wells 1963) and the location of the sample stands:
A = California, B = Idaho and Oregon, C = Arizona, D = Colorado & New Mexico, and E = South Dakota & Wyoming.
† Seed characteristics were determined by measuring 5 randomly selected stands from each of 16 half-sib families. The number of family selections in each ecotype were A, 2; B, 2; C, 3; D, 4; and E, 5.
‡ Seedling characteristics were determined by measuring 2 plants from each family in each of 3 groups of boxes grown under greenhouse conditions.

Table 4—*Correlation coefficient relating proportion of ponderosa pine seedcoats of total seed weight, geographic location, and seedling development (from Anantachote 1980)*

Variables correlated with proportion of seed coat of total seed weight	Correlation coefficient*
Proportion of embryo of total weight	−0.915
Latitude of ecotypic sources	−0.287
Longitude of ecotypic sources	−0.959
Elevation of ecotypic sources	0.892
Latitude times elevation	0.935
Primary root length (2 months)	−0.957
Primary root length (9 months)	−0.314
Shoot length (2 months)	−0.796
Shoot length (9 months)	−0.935

* A value of ±0.878 is necessary for statistical significance at the 0.05 level.

Relating Seed Coats to Seedling Development

Anantachote (1980) provides the best data relating the ratio of the seed coat to total seed weight to seedling development. He determined the growth of the primary root system of ponderosa pine seedlings grown in glass-sided boxes in a greenhouse environment. Root elongation was measured at 2 and 9 months (table 3). At 2 months, root length was negatively related to the ratio of the seed coat weight to total weight (r = — 0.957) (table 4). However, at 9 months, no significant correlation was obtained. The same associations were determined with shoot length at 2 and 9 months. Correlation coefficients of — 0.796 and — 0.935 were found, relating shoot length at 2 and 9 months to the ratio of the seed coat of total seed weight (table 4).

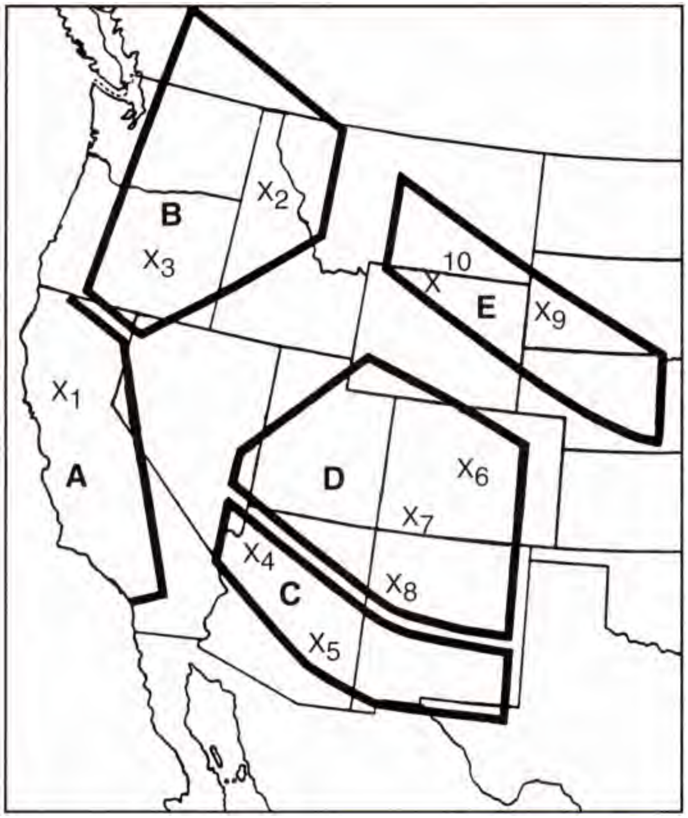

Figure *1—The 5 ecotypes of ponderosa pine (Wells 1963) and the location of the sample stands.* A = *California (sample stand 1), B = north plateau (sample stands 2 and 3), C = southern interior (sample stands 4 and 5), D = central interior (sample stands 6, 7, and 8),* E = *northern interior (sample stands 9 and 10) (adapted from Anantachote 1980).*

These data may indicate that seeds that are less dormant and germinate faster also begin root and shoot development sooner. However, the data are not sufficiently well documented to determine if speed of germination was definitely related to seedling growth.

Discussion

Although significant correlations do not necessarily reflect causal relationships, when evaluated with other biological sound data, they are important indicators of biological responses. Earlier research has established that dormancy or speed of germination in southern pines is related to embryo constraint by the seed coat and megagametophyte (Barnett 1972, 1976; Carpita and others 1983). This relationship probably holds for other pine species. Recent research has also shown that larger loblolly pine seeds produce larger seedlings primarily because they germinate more promptly (Dunlap and Barnett 1983).

Stratification of seeds usually results in faster germination, which is why stratified seeds usually produce larger plants that unstratified ones. When stratified and unstratified seeds germinate on the same date, stratification has no affect on development (Barnett and McLemore 1984). A few days difference in time of germination may significantly affect seedling development (Boyer and others 1985). Therefore, it is easy to understand how differences in seed dormancy may affect seedling development. Short periods of stratification may seem to eliminate these differences in rate of germination when evaluations are made under standard laboratory conditions. However, when germination occurs in the field or on nursery beds where conditions are less than optimum, the rate of germination is markedly reduced, and seedlings from late germinating seeds tend to produce inferior quality plants because of competition from previously established seedlings (McLemore 1969; Dunlap and Barnett 1984).

Seed dormancy in loblolly and ponderosa pine varies ecotypically with northern and eastern sources, and higher elevations have greater dormancy. This variation may also occur with other pine species. Particularly with ponderosa pine, a species that has a wide range of geographic diversity (Wright 1976), this variation in dormancy probably reflects the differences in precipitation, temperature, and day-length at the seed source. These trends probably reflect natural selection; that is, if seeds germinate too early, they may be killed by frost and, if too late, by competition for light and moisture from earlier seedlings (Campbell and Ritland 1982). The response of seeds to environmental cues during dormancy should tend to maximize fitness of optimizing the timing of germination (Levins 1969).

Maternal factors such as seed coat properties that influence the speed of germination can obscure the nature of genetic control of subsequent growth processes (Perry 1976). Less than 15% of the weight of a conifer seed is in the embryo, which is the only portion with a genetic component from the male parent. In nature, stratification is usually optimized as a result of natural conditions, but in nursery production, the genetic component from the male parent may be obscured when researchers do not optimize the stratification needs of the seed lot. Seed dormany varies by geographic location or ecotype, and stratification procedures should be designed to meet the needs of each ecotype. These stratification needs should be determined under the stress conditions that relate to nursery bed conditions where seeds are to be sown. However, the stratification period can be extended to minimize the effect of the seed coat on initial seedling development.

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