Chapter 19

Pest Management in Northwest Bareroot Nurseries

J. R. Sutherland

Abstract

A survey of Northwest bareroot nurseries revealed that root rots (*Macrophomina, Fusarium*, and *Phytophthora*) and *Sirococcus* blight are the ma]or diseases, that the cranberry girdler (*Chrysoteuchia topiaria*) and various aphids are the most Important insect pests, and that numerous rodents and seed-eating birds are frequent animal pests. Many site features affect both pest occurrence and successful management. However, the types of pest-management practices used depend upon factors including the availability of advice from pest-management specialists, the use of surveys, and numerous cultural practices. Nontarget effects of pesticides are also of concern. More Information is needed on many aspects of pest management so that nursery managers can grow better seedlings.

19.1 Introduction

Most of the disease, insect, and animal problems affecting bareroot seedlings in the Northwest also occur in other nurseries throughout North America. However, several pests are specific to the Northwest or to hosts grown there.

Regardless of the pest's nature, the types and severity of damage and the pest-management practices used in the Northwest are often unique. This is undoubtedly due to factors such as seedling species, cultural practices, soils, and—of utmost importance—overall effect of the area's maritime climate. Although many local problems have received cursory attention in publications on forest-nursery management [2, 3, 30, 31], forest pathology [10, 20], entomology [17], and soils [42] or in-depth coverage in bulletins devoted solely to seedling diseases [27] or diseases and insects [36], there is a continuous need to update the status of pests and pest-management practices, especially in the Northwest, where seedling production has increased dramatically in recent years.

Consequently, during the fall and winter of 1981, 21 Northwest nurseries were surveyed to determine current disease, insect, and animal problems and the techniques being employed to manage them (OSU Nursery Survey: see chapter 1, this volume). In this chapter, these survey results are summarized and trends noted so that Northwest bareroot nurseries can update their current pest-management practices.

19.2 Status of Nursery Pests in the Northwest

19.2.1 Diseases

Thirteen diseases or disease groups are present in Northwest nurseries (Table 1). Their causes, symptoms, and other pertinent information are given by Peterson and Smith [27] and Sutherland and Van Eerden [36]. Charcoal root disease [*Macrophomina phaseoli* (Maubl.) Ashby], cortical rot (*Fusarium roseum* Link), *Fusarium* (*F. oxysporum* Schlect.) and *Phytophthora* (P. spp.) root rots, and *Sirococcus* blight (*Sirococcus strobilinus* Preuss) appeared to be increasing at certain nurseries. All but the last of these are soil-borne root diseases.

Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco], spruces (*Picea* spp.), true firs (*Abies* spp.), and the two- and three-needle ("hard") pines (*Pinus* spp.) were the major seedling species affected by diseases. However, severity estimates and host data (Table 1) may be biased somewhat because Douglas-fir is the most common seedling species grown in the Northwest and because several of the diseases, such as the gall and foliage rusts and Sirococcus blight, mainly affect pines and spruces. Therefore, severity ratings may reflect host production figures as much as seriousness of a particular disease. Only four, or

In Duryea. Mary L., and Thomas D. Landis (eds.). 1984. Forest Nursery Manual: Production of Bareroot Seedlings. Martinus Nijhoff/Dr W. Junk Publishers. The Hague/Boston/Lancaster, for Forest Research Laboratory, Oregon State University. Corvallis. 386 p.

Table 1. Current status of disease, insect, and animal problems in Northwest bareroot nurseries (OSU Nursery Survey).

	% nurseries rating problems as						Controls	
	Severe	Moderate	Slight	Negligible	Hosts	Damage trends	Chemical	Cultural
Diseases								
Charcoal root disease	0	0	15	85	Douglas-fir, pines	Static or increasing	Frequently, methyl bromide (MBr) soil fumigation	None specified
Cortical rot	0	10	20	70	Douglas-fir, pines	Mainly increasing	MBr soil fumigation; also benomyl drenches and sprays	Sanitation, site selection
Damping-off	0	9	81	9	Many species	Static or decreasing	Mostly MBr soil fumigation; captan or benomyl seed treatments, drenches, or sprays.	Improve drainage
Fusarium root rot	5	11	42	42	Douglas-fir, pines, spruces, true firs	Static or increasing	Mostly MBr soil fumigation; captan, benomyl, and ethri-diazola drenches; captan and benomyl sprays	Regulate seedling density and nitrogen fertilization, dry fallow
Fusarium top blight	5	19	29	48	Douglas-fir, spruces, true firs	Static or decreasing	MBr soil fumigation; captan and benomyl drenches and sprays	Regulate nitrogen fertiliza tion; irrigate to cool soil
Gray mold	0	30	45	25	Many, especially Douglas-fir	Static or decreasing	Mostly captan, benomyl, and chlorothalonil sprays	Regulate seedling density
Melampsora foliage rusts	0	0	5	95	Douglas-fir, pines	Decreasing	Unspecified fungicide sprays	None specified
Nematodes	0	15	15	70	Many, especially Douglas-fir	Decreasing	Mostly MBr soil fumigation	Bare fallow infested soils
Phytophthora root rots	5	5	26	63	Douglas-fir, true firs	Mostly increasing	Unspecified spray and MBr soil fumigation	Improve drainage, sanitation
Seed fungi	0	5	45	50	Many, including spruces, true firs, pines	Mostly decreasing	Chlorothalonil seed treatments	Running water soak (prestrati-fication?)
Sirococcus blight	5	5	29	62	Pines, sometimes spruces	Static or increasing	Chlorothalonil, captafol, and benomyl sprays	Presowing identification of in-fested seedlots; collect and destroy diseased seedlings
Storage molds	0	10	57	33	Many; least on spruces	Static or increasing	Captan and benomyl sprays	Store stock at -1 to -2°C; store dry
Western gall rust	0	0	15	85	"Hard" pines	Static or increasing	Unspecified sprays	Cull affected stock
Insects								
Aphids	0	19	52	29	Many, especially Douglas-fir	Generally increasing	Diazinon, endosulfan, carbaryl, insecticidal soap, or acephate sprays	Predaceous beetles
Cranberry girdler	0	20	45	35	Many, including Douglas-fir, true firs	Mostly increasing	MBr soil fumigation; chlorphri-fos, diazinon, or fenvolerate sprays	Encourage beneficial birds around nursery
Cutworms	0	5	43	52	Many	Static or decreasing	Mainly carbaryl sprays and insecticidal baits	None specified
European pine shoot moth	0	0	15	85	Pines	Decreasing	Carbaryl or diazinon sprays	None specified
Marsh crane fly	0	0	10	90	Many	Generally decreasing	Diazinon sprays	None specified
Root and vine weevils	0	6	17	78	Many	Generally decreasing	Acephate sprays	Bare fallow infested soils
Springtails	0	5	25	70	Many, especially spruces	Static	Diazinon and mineral oil sprays	None specified
Animals								
Birds	10	38	19	33	Many, especially pine seeds	Static or decreasing	None specified	Screening, shooting, noise; early seed sowing
Deer	0	0	6	94	No preference	None	None specified	Fencing
Miscellaneous rodents	5	5	35	55	Many	Static or increasing	Unspecified baits	Shoot
Moles	0	0	14	86	Many	Decreasing	None specified	None specified
Rabbits	0	5	0	95	Many	Static	None specified	None specified

about 30%, of the 13 diseases reported were considered severe. At most nurseries, these and the nine remaining diseases were rated moderate to nonexistent.

Northwest nursery managers use numerous chemicals and cultural procedures for seedling disease control (Table 1). Methyl bromide soil fumigation is the most extensively used control for soil-borne diseases of seeds, germinants, and roots of older seedlings. Captan, benomyl, and chlorothalonil are the major fungicides sprayed for shoot diseases; sometimes, they are applied as drenches for soil-borne pathogens. Of the numerous cultural practices employed against diseases, some (e.g., improving drainage) make the environment less conducive for pathogen survival or dissemination, whereas others (e.g., withholding nitrogen fertilizers during the early part or all of the first growing season to reduce Fusarium root rot) increase host resistance.

19.2.2 Insects

Seven insects or insect groups were reported by Northwest nurseries (Table 1). Pertinent information on their biology, life histories, hosts, and damage are given by Furniss and Carolin [17], Sutherland and Van Eerden [36], and Triebwasser and Overhulser [38]. Aphids, especially Cooley spruce gall aphid [*Adelges cooleyi* (Gillette)] and giant conifer aphids (*Cinara* spp.) as well as the cranberry girdler (*Chrysoteuchia topiaria* Zeller) caused the most damage. The latter, a relatively new (or recently recognized) problem in forest nurseries [38], is one of the few insects whose importance nursery managers feel is increasing. All insects, except the European pine shoot moth [*Rhyacionia buoliana* (Schiffermuller)] which is host specific on "hard" pines, affected many seedling species. Obviously, nursery insects have much wider host ranges than diseases do; indeed, most of these insects also damage many ornamental and agricultural crops.

Various insecticides, including carbaryl and diazinon, are sprayed to control insects on seedling shoots. Insecticidal soaps are sometimes used against aphids and probably should be tried for controlling other insects, especially springtails (order Collembola). Some nurseries use predaceous lady beetles (order Coleoptera) as a biological control for aphids whereas others encourage insectivorous birds. Bare fallowing is mentioned for root and vine weevil (order Coleoptera) control.

19.2.3 Animals

Animals, particularly rodents and seed-eating birds, are troublesome in many nurseries (Table 1). Animal damage tends to be a sporadic problem, which likely accounts for the preponderance of mechanical and disruptive control devices (e.g., fencing and noise) rather than chemicals.

19.3 Site Factors Affecting Pests

Nursery soil characteristics, climate, water quality, and general locality are the main site factors determining what disease, insect, and, to some extent, animal problems will plague a nursery. Any one or a combination of these factors will influence the kind and amount of damage caused by pests and the types, timing, and effectiveness of controls [32].

19.3.1 Soil

The ideal conifer nursery soil should have a light sandy loam texture, free drainage, and a pH of 4.5 to 6.0 and should contain 3 to 5% organic matter [41]. Northwest nursery managers rank compaction, organic matter maintenance, poor drainage, and unfavorable texture as major soil problems (Table 2). Obviously, much effort goes toward amending these conditions (Table 2). An often overlooked aspect of such soil problems is their relationship to the incidence, damage, and successful control of many pests, particularly soil-borne diseases. For example, soil compaction or heavy texture, which may be co-related, can increase preemergence damping-off losses by delaying germinant emergence, thereby increasing the period of susceptibility to the disease. Nonuniform texture within or among fields can decrease the efficacy of soil fumigants which must be applied on the basis of average soil moisture, temperature, and pest numbers. Poor drainage is one of the main factors contributing to Phytophthora root rot [19].

19.3.2 Climate

Although most Northwest nurseries are located in the milder coastal zone, seedlings nonetheless are often damaged by inclement weather, particularly in winter (Table 2). This occurs because many nurseries grow several seedling species and ecotypes—e.g., seedlots whose origins are coastal ("westside") or interior ("eastside"), or high or low elevation—whose tolerances vary to harsh weather. For example, in coastal British Columbia nurseries, shoot damage from winter desiccation is normally less for interior than for coastal Douglas-fir. The important point about climate-caused damage is that it often predisposes seedlings to pathogens, including storage (numerous fungi) and gray [*Botrytis cinerea* (Fries) Persoon] molds. Although unreported by nursery managers in the OSU Survey, the cool, wet weather of spring and early summer often favors damping-off and shoot blights such as *Sirococcus*. Aphid populations frequently increase during late summer and early fall, when it is dry. Though animal damage and climate are seldom related, severe weather in interior British Columbia has caused birds to migrate to the coast, where they consume large numbers of recently sown seeds.

19.3.3 Water

Water quality was not considered a problem in Northwest nurseries, but high water tables were reported by several nurseries. Impermeable layers beneath the plow zone, either occurring naturally or created by plowing, cultivation, or unsuitable soil texture, certainly contribute to this problem. High water tables favor certain root rots [19] and the marsh crane fly (*Tipula paludosa* Meigen). Surprisingly, no nurseries reported water-borne pathogens such as Phytophthora, which may be common in irrigation ponds.

19.3.4 Locality

None of the nursery managers surveyed related nursery locality and pests. However, in retrospect, many would probably consider their nursery "off site" as far as pests are concerned because potential pest problems are seldom considered when selecting a nursery locality or even when expanding an existing nursery. Normally, indigenous pests are not severe enough to disqualify a proposed site, but they should be identified and controlled before seedling production begins.

Both the broad ecological, climatic, or elevational zone and the specific locality within a zone can dictate what the pest problems might be. The nematode *Xiphinema bakeri* Williams, cause of corky root disease [6], is a pest that occurs only in coastal nurseries from British Columbia [33] to California [11]. Sirococcus blight and the marsh crane fly also predominate in coastal Northwest nurseries. Other pests are more prevalent in specific locations adjacent to nurseries; damage from the cranberry girdler, for example, is most severe in nurseries surrounded by grassland [38]. Sometimes, forests adjacent to nurseries contain trees affected with western gall rust [*Endocronartium harknessii* (J. P. Moore) Y. Hiratsuka] or certain foliage rusts (*Melampsora* spp.), which produce inocula for nursery seedlings [36].

Table 2. Site problems, amending practices, and related pest-control difficulties in Northwest bareroot nurseries.

Problem[1]	Amending practice	Pest difficulties related to site problem
Soil		
Compaction	Subsoiling, improve drainage; add organic matter; limit vehicle access.	Preemergence damping-off increased; germinant emergence inhibited; pathogen survival enhanced; pesticide effectiveness possibly affected.
Organic matter maintenance	Add organic matter via sawdust, peat, etc.; use cover crops.	Many, including damping-off and root-rot pathogens.
Poor drainage	Subsoiling, ditching, tiling, etc.	Root rots and damping-off, especially *Pythium*- and *Phytophthora*-caused diseases; marsh crane fly; pesticide timing and effectiveness possibly affected.
Unfavorable texture (too heavy or too light)	Improve drainage, e.g., by subsoiling; add organic matter or sand; withdraw from production or change usage; use fertilizers and pesticides judiciously; compact for seeding or transplanting.	Preemergence damping-off losses increased as germinant emergence hindered; better survival of many soil-borne pathogens, e.g., *Phytophthora* and *Fusarium*; more favorable to certain nematodes, e.g., *Xiphinema*; insect larvae more prevalent.
Nonuniform quality	Carry out cultural and pest-control practices for the "average" soil; replace clay "pockets" with lighter soil; transplant into poorer areas.	Pockets or areas with nonuniform control; variation in germination and growth may affect disease incidence.
Climate		
Wind abrasion	Plant windbreaks or use snowfence windbreaks.	Winter desiccation of shoots increases storage molding.
Frost pockets	irrigate for frost protection; improve air drainage.	Frost damage of shoots increases gray and storage mold losses.
Frozen soil	Mulch, delay lifting, etc.	Possible winter desiccation of shoots can increase storage mold losses.
Water		
High water table	Improve drainage by tiling, subsoiling, or ditching.	Damping-off; many root-rot pathogens and certain insects, e.g., marsh crane fly.

[1]Major problems ranked by severity within categories (see chapter 1, this volume).

Some pests, especially soil-borne diseases and insects, are indigenous to the nursery site itself. In the mid-1960s, indigenous white grubs (order Coleoptera) damaged numerous seedlings in a new (cleared forest-grassland) nursery near Prince George, British Columbia. Nurseries established on formerly agricultural land often inherit fungus and nematode problems.

19.4 Disease and Insect Management

Nurseries should use an integrated pest-management approach comprising alternative strategies such as cultural controls and sensible use of pesticides. Which of these strategies predominates or how closely they are integrated depends upon (1) economics (not discussed here), (2) the overall philosophy of the nursery manager, (3) sources of advice and on-site expertise available to the nursery manager, (4) use of pest-detection surveys, and (5) cultural practices.

19.4.1 Philosophy

The philosophy of the nursery manager and staff towards various pest-management practices is of utmost importance. Sometimes, pesticides are used without considering integrated approaches or alternative strategies such as pest prevention. For example, none of the nursery managers surveyed gave any of the following as alternatives to using pesticides for preventing or controlling the following three important pest problems in Northwest nurseries (Table 1):

Damping-off: Delay seed sowing until soil temperature is high enough to promote rapid germination; sow stratified seeds for quicker germination; cover seeds with noncompacting material; maintain soil pH at 4.5 to 5.5; use areas prone to damping-off for transplants or resistant seedling species.

Storage molds: Prevent abiotic damage (e.g., frost and fertilizer burns) that predispose seedlings to storage molds; minimize the storage period; survey stored stock frequently to detect incipient molding; when possible, freeze-store stock.

Aphids: Where applicable, remove alternate or reservoir hosts from the nursery area (e.g., eliminate spruce from around Douglas-fir nurseries affected by Cooley spruce gall aphid).

Most nursery managers would insist that they do use some or most of these alternative strategies for these three and other pests, but how often does the manager relate these practices to some nonpest aspect of nursery management?

19.4.2 Sources of advice

Oftentimes, the source of advice on nursery pests will dictate the kind of pest-control procedure used. Invariably, agricultural pathologists and entomologists recommend pesticides, particularly when the tree nursery is in a vegetable- or fruit-growing area. Pesticide sales or technical representatives may be biased in their recommendations. The advice of some experts may be too academic—they may want to do a long-term research project—when in fact the nursery manager needs a quick, "best possible" answer.

To evaluate the quality of advice from outside sources and to effectively deal with pest problems, each nursery should have a pest manager on staff or on contract. This specialist should know the indigenous and potential pest problems at the nursery and the on-site factors (e.g., soil textures and drainage) that affect pest occurrence, damage, and control and should understand pest biology, pesticides (including application equipment and safety procedures), and nursery practices. The special ist should obtain up-to-date information from scientific and trade journals and by attending nursery meetings, pesticide-certification courses, and so forth. Besides the specialist, other nursery staff should attend training courses that emphasize pesticide-application equipment, toxicity, and safety.

19.4.3 Surveys

The success of any pest-management program primarily depends upon detecting problems before damage occurs—that is, usually when the pest is in an innocuous or incipient stage. This is best done by routinely surveying nursery soil, soil amendments, water, seeds, and seedlings (both growing and stored) for pathogens and insects. Pheromone or light traps, for example, can be used to detect insects. Transplants and equipment from other nurseries also should be checked for pests. Surveys pinpoint the presence, locality, developmental stage, and abundance of pathogenic fungi and insects so that preventive measures can be applied. Though field workers usually first notice impending problems, all nursery staff should be alerted to watch for initial indications of pests.

The nature and complexity of the pest problem usually determine how survey samples should be collected. Sometimes, a sampling expert must be consulted; generally, however, any system that produces a representative sample of the entire unit (e.g., field or seedlot) to be assayed will work. Soil samples may be collected according to a grid pattern, which helps nursery staff in relocating problem areas. Soil and seedling samples frequently are collected from affected and adjacent disease-free areas and then compared. Seedling samples should contain several individual seedlings, preferably in separate containers, whose symptoms vary from severe to nonexistent. Normally, samples should be kept at 10 to 15°C, protected from desiccation, and assayed soon after collection. A written account of seedlot numbers and past cultural histories should accompany samples, especially seedlings, to the diagnostic laboratory. Samples that can be used for more than one purpose are best; for example, in British Columbia, each soil sample from fallow fields is halved: one portion is assayed for soil nutrients, the remainder for pathogens and insects.

19.4.4 Cultural practices

Nearly any cultural practice may favor or deter pests. The nursery manager should avoid or modify practices that promote pests but integrate useful practices into the overall nursery-management program.

19.4.4.1 Seedling and windbreak species

The seedling species produced at a nursery profoundly affects the kinds and severity of pest-caused losses because many pests tend to be host specific. For example, a nursery growing ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) would probably have negligible losses from charcoal root disease because ponderosa pine is not severely affected by the disease [28]. Conversely, the same nursery could suffer significant losses from *Sirococcus* blight, which affects ponderosa pine.

Most nurseries contain areas that harbor or are somehow prone to certain pests. Sometimes the problem can be overcome by cropping the area with a nonhost seedling species; thus, an area known for *Fusarium* root rot, primarily a Douglas-fir disease [36], might be planted to less susceptible spruce. If possible, it is best to avoid certain pests altogether; in British Columbia, for instance, Abies seedlings are grown only in nurseries outside the zone infested by the balsam woolly aphid [*Adelges piceae* (Ratzeburg)].

Establishing windbreaks or ornamental plantings with species that promote pests is a common mistake. Nursery managers seem to particularly like Populus spp., which are alternate hosts for various conifer foliage rusts [36]. Needle distortion and chlorosis of Douglas-fir, caused by the Cooley spruce gall aphid, are most prevalent in nurseries with nearby spruces, the alternate host; a little detective work frequently reveals that the spruce were purposely planted.

19.4.4.2 Cover crops

Cover crops add organic matter to soil and retain nutrients ([15]; see chapters 9 and 10, this volume). However, the overall relationships of cover crops and pests in the Northwest are largely unknown. Davey and Krause [15] cite several examples, from elsewhere in North America, of cover crops that affect seedling diseases; for example, *Fusarium* root rot of conifers increased after a buckwheat cover crop whereas damage from charcoal root disease decreased after cover crops of rye or millet, both nonhosts.

The OSU Nursery Survey revealed that many of the U.S. Northwest nurseries sow lupines and other leguminous cover crops. The terminal crook fungus (*Colletotrichum acutatum* Simmonds f. sp. *pinea* Dingley & Gilmour) on Monterey pine (*Pinus radiata* D. Don) in New Zealand supposedly originated from lupine cover crops [16]. In the Northwest, gramineous cover crops might lead to buildup of and seedling damage by the cranberry girdler.

19.4.4.3 Irrigation

Besides satisfying the seedlings' water needs, irrigation can alter the nursery environment for pest control (see chapters 11 and 12, this volume). judicious use of irrigation water can reduce preemergence damping-off by speeding seed germination and germinant emergence. Irrigation can also be employed to cool seedbeds and thereby diminish certain fusaria-caused root rots, though withholding water helps check gray mold outbreaks. Irrigation can prevent high moisture stress, which predisposes Douglas-fir seedlings to *Phomopsis* canker (*Diaporthe lokoyae* Funk) [29]. Using irrigation water to prevent frost damage controls disease indirectly because frost-damaged seedlings are prone to storage molds [21].

19.4.4.4 Crop rotation

Many nongovernment and (particularly) transplant nurseries rotate various agricultural or ornamental crops with forest-nursery seedlings. However, pest populations can build up on these other crops and subsequently damage tree seedlings. Seedling damage from root-feeding larvae of vine weevils, following a crop of strawberries, would not be unusual. Constant monoculture of tree seedlings also can lead to pest buildup. Conditions permitting, seedling species should be rotated in such nurseries.

19.4.4.5 Mulches, seed coverings, and soil amendments

Pests can be brought into nurseries on mulches and seed covers. *Meria laricis* Vuill. can be introduced on larch needles, S. strobilinus on pine needles, and the seed pathogen *Caloscypha fulgens* (Persoon) Boudier in forest duff. Seed coverings such as sand, grit, or peat mulches can contain pathogenic *Pythium* and *Fusarium*. New sources of these materials should be assayed for such fungi.

Mulches can also improve pathogen survival. Bloomberg [7] showed decomposing sawdust (from mulch) readily yielded the *Fusarium* root-rot pathogen of Douglas-fir seedlings. Cutworms (species of *Euxoa* and *Peridroma*) often hide in sawdust mulches. Besides pest problems, decomposing sawdust or other organic materials may produce phytotoxic compounds or tie up nutrients, resulting in seedling nutrient deficiencies [15].

Pests also enter nurseries in soil amendments. In British Columbia, Xiphinema bakeri nematodes were brought into the

Duncan Nursery in infested sand used to lighten a clay soil. Peat is another good source of pest fungi and insects. All soil amendments, especially those from new sources or suppliers, should be assayed for pests before being used.

19.4.4.6 Equipment and transplants

Pests can be introduced both within and among nurseries via equipment or transplants. To prevent the spread of pathogens and insects among nurseries, all used equipment should be steam cleaned or otherwise sanitized before moving it to another site. Preventing within-nursery spread of pests on equipment is nearly impossible.

Pests are commonly introduced in nurseries by transplants. A classic example in the Northwest is *Phytophthora* root rot [19]. Transplants should not be moved among nurseries, and pest-infested trees should not be transplanted to "clean" areas within a nursery.

19.4.5 Pesticides

All Northwest nurseries use pesticides, mainly (in order of importance) herbicides, fungicides, and insecticides. Use at a particular nursery depends upon the economic importance of pests and the general philosophy of the manager and staff towards pesticides. Pesticides are applied as seed dressings, sprays, and drenches or as soil fumigants. The major pesticides used in the Northwest, application methods and timing, rates, safety, storage, and other pertinent information are contained in publications by Berg [4], Capizzi et al. [12], Hamel [18], and MacSwan and Koepsell [23] for U.S. nurseries and by Miller and Craig [25] for those in British Columbia. The last-mentioned publication has good sections on safety, handling, formulations, and application equipment as well as a pesticide-terms glossary.

19.4.5.1 Seed treatments

Fungicides may be dusted or stuck onto seeds with methyl cellulose, for example, to protect them from damping-off both before and after germinants emerge. Captan, thiram, and benomyl are the fungicides most often used on seeds in the Northwest. The main drawback to fungicide seed treatment is that fungicide phytotoxicity often outweighs the beneficial effects of disease control, particularly when damping-off losses are static [22]. The difficulty of finding the ideal fungicide—one high in fungi toxicity but low in phytotoxicity—is illustrated in studies by Carlson [13] and Vaartaja [39], who tested 326 fungicides in total and found only six new materials suitable for use on tree seeds. Interestingly, four of these contained the two old standbys, captan and thiram.

Fungicide seed treatments have other disadvantages: (1) they often cause sticking or clumping of seeds and impede sowing; (2) because their fungicidal spectrum is too narrow, they are ineffective when several pathogens are present (a common situation); (3) they are too short-lived to protect seeds and germinants throughout the entire preemergence-through-postemergence susceptibility period; and (4) they may lose their effectiveness by killing susceptible strains of the pathogen, leaving only resistant ones. This is evident when the effectiveness of a newly used fungicide gradually declines over a few years. Such a problem might be overcome by changing fungicides every few years or by using a mixture of materials each year.

Past research on fungicide treatment has overlooked the fact that conifer seeds, unlike many agricultural seeds, vary greatly in both germination capacity and speed, even within seedlots. Consequently, some seedlots, which germinate well and rapidly, may need little or no fungicide or may simply require a different fungicide than a seedlot that germinates poorly and slowly. Fungicide prescriptions are needed for seedlots, based on seedlot characteristics such as seedcoat damage, germination speed, and capacity [9, 35]. The problem here is that because slower germinating seeds require longer protection, they are also subjected to prolonged fungicide phytotoxicity.

In sum, to date, no one has been able to find the magic chemical to protect conifer seeds from damping-off. Moreover, "bad" seeds cannot be made better by treating them with some chemical. At present, the best solution for most Northwest nurseries seems to be to collect high-quality seeds, which probably do not need a presowing fungicide treatment.

19.4.5.2 Sprays

In most Northwest nurseries, fungicides and insecticides are applied as sprays. Generally, fungicide sprays are for shoot diseases such as gray mold on Douglas-fir, and insecticide sprays are for aboveground feeding insects. Sprays usually give satisfactory results provided the prerequisites (e.g., formulation, timing, application method) are correct; otherwise, pests may not be controlled, phytotoxicity may result, or both.

Phytotoxicity commonly arises when materials are applied to seedling species or age classes for which phytotoxicity data are lacking. Changing formulations can cause problems too, especially for emulsifiable formulations where the emulsifier, rather than the active ingredient, may be phytotoxic. When phytotoxicity risk is unknown, apply the material to a few seedlings for one to several days before operational spraying. Compared to other application methods, sprays are the most likely to contaminate nearby crops or nursery workers. Precautions should be taken to prevent pesticide drift from sprays.

19.4.5.3 Drenches

Fungicides, insecticides, and nematicides are often applied as drenches to the soil. Regardless of the pest, drenches are generally used only in desperation and are frequently unsatisfactory for large-scale applications.

In the Northwest, fungicide drenches have varied from being totally ineffective—for controlling spruce damping-off [34]—to being somewhat promising—at very high dosages for Fusarium root rot of Douglas-fir [8]. The inconsistencies are probably due to the short soil life of drenches resulting from chemical or microbial decomposition and dilution or from chemical binding. Inherently, all pesticide drenches pose the risk of phytotoxicity, which is especially serious for postplanting applications but also can occur with preplanting applications unless soil conditions are suitable and sufficient time is allowed for drenches to disappear before sowing or planting.

19.4.5.4 Soil fumigation

Soil fumigation with 67% methyl bromide/33% chloropicrin is the most widely practiced pest-control procedure in U.S. Northwest nurseries (Table 1). In contrast, soil fumigation is seldom used in British Columbia nurseries, except to initially eradicate pests (including weeds) in nurseries being established on formerly agricultural land. This difference may occur (1) because the methyl bromide formulation registered in Canada—only 2% chloropicrin—provides inadequate control, (2) because conventional herbicide practices may be better established, thereby eliminating the need to fumigate soil, or (3) because fumigation is expensive. Soil fumigation costs $1,000 per acre ($2,500 per ha) and controls (usually) weeds, diseases, and insects. Weed control alone (with herbicides) costs $200 per acre, leaving a theoretical $800 per acre for controlling diseases and insects. Sites requiring this level of maintenance might best be abandoned or paved for a container nursery! Less drastic courses include using the $800 per acre "savings" to buy or clear an additional acre of land that is pest free-the enlarged nursery might better lend itself to implementation of alternative pest-management strategies—or to correct condi-ions such as poor drainage that favor pests.

Proponents of fumigation argue, on the other hand, that it is a valuable insurance measure (an extremely difficult position to refute), that the high value of seedlings warrants (equals or exceeds) the fumigation costs, and that the nature of certain pests (e.g., sclerotia-forming pathogens) makes fumigation the only practical control. The cost competitiveness of soil fumiga-ion might be improved with fumigants other than methyl bromide [5, 40] that require less expensive application pro-edures. Solar pasteurization [14, 26] also could be useful for controlling soil-borne pests in Northwest nurseries.

19.4.5.5 Nontarget effects

Though primarily used to control pests, pesticides also affect other organisms, including seedlings [1].

Methyl bromide is the most commonly used biocide in U.S. Northwest nurseries (Table 1), but this and other soil fumigants are seldom used in British Columbia. Soil fumigation has the undesirable effect of eliminating (at least temporarily) ectotrophic mycorrhizal fungi; this can lead to stunted, phosphorus-deficient seedlings. Cool, wet soils can retain fumigants, which can then damage seedlings. Research is needed to determine how re-peated long-term fumigation of soil affects soil microbe populations, including soil-borne pathogens.

Pesticide phytotoxicity to seedlings is not uncommon and may vary depending upon many factors including seedling development stage (37]. Under certain circumstances, such as low incidence of disease, pesticide phytotoxicity may outweigh the beneficial effects df the pesticide. For example, in British Columbia, seeds are not treated with fungicides because the chemicals kill as many seeds and germinants as they protect from damping-off [22]. Pesticide damage, even though not visible, may predispose seedlings to pathogens—for example, the apparently increased susceptibility of Douglas-fir to *Fusarium* top blight following herbicide applications [36]. Not all second-ary effects are undesirable, however; herbicides that can re-duce Collembola populations eliminate the need for insecticide spraying [24].

19.5 Animal Management

Management of animals is largely by exclusion or eradica-tion [18, 25, 30]. Large animals such as deer can be excluded by animal-proof fencing around the nursery. Though trying to keep small animals and birds out of the nursery is impractical, some physical methods, such as covering seedbeds with window screening, may be used to protect recently sown seeds and germinants from birds, mice, and squirrels. The habitat of windbreaks and areas around the nursery should not favor rodents, but encouraging predatory birds might be worthwhile. In extreme situations, traps, shooting, or poisoning might be used to eliminate such pests. However, many poisons may no longer be considered environmentally acceptable or safe.

19.6 Recommendations for Future Research

To improve pest management in Northwest bareroot nurseries, we now need to:

- Determine effects of various cover crops on pest enhancement
- Assess long-term effects of soil fumigation on beneficial and harmful soil microorganisms
- Investigate possible use of solar pasteurization of soil for pest control
- Treat seeds with fungicides for disease control on the basis of prescriptions for specific seedlots
- Use more biological control agents
- Reduce pesticide usage with better application techniques
- Determine effects of diseases such as damping-off on seed-ing distribution and, in turn, on seedling quality
- Use auditory and olfactory repellents for protecting seeds and seedlings from animals
- Design better survey and predictive techniques
- Coordinate efforts to identify and manage pests and dissemi-ate information about them to nurseries

References

1. Abrahamson, L. P. 1980. Pesticides in forest tree nurseries—primary and secondary effects. Pages 191-204 in Proc., North American forest tree nursery soils workshop (L. P. Abrahamson and D.H. Bickelhaupt, eds.). State Univ. New York, Coll. Environ. Sci. and Forestry, Syracuse.
2. Aldhous, J. R. 1972. Nursery practice. Her Majesty's Stationery Office. London. Forestry Commun. Bull. 43. 184 p.
3. Armson, K. A., and V. Sadreika. 1979. Forest tree nursery soil management and related practices. Ontario Ministry of Natural Resources, Toronto. 179 p.
4. Berg, G. L. (ed.). 1982. Farm chemicals handbook. Meister Publ. Co., Willoughby, Ohio. (Published annually.)
5. Bloomberg, W. J. 1965. The effect of chemical sterilization on the fungus population of soil in relation to root disease of Douglas-fir seedlings. Forestry Chronicle 41:182-187.
6. Bloomberg, W. J. 1968. Corky root of Douglas-fir seedlings. Can. Dep. of Forestry and Rural Dev. Bi-Monthly Res. Notes 24(1):8.
7. Bloomberg, W. J. 1976. Distribution and pathogenicity of *Fusarium oxysporum* in a forest nursery soil. Phytopathology 66:1090-1092.
8. Bloomberg, W. J., and W. Lock. 1974. Importance of treatment timing in the control of Fusarium root rot of Douglas-fir seedlings. Phytopathology 64: 1153-1154.
9. Bloomberg, W. J., and J. Trelawny. 1970. Effect of thiram on germination of Douglas-fir seed. Phytopathology 60: 1111-1116.
10. Boyce, J. S. 1948. Forest pathology. McGraw-Hill, New York. 550 p.
11. California Forest Pest Control Action Council. 1971. Forest pest conditions in California—1970. California Dep. of Forestry, Sacramento. 25 p.
12. Capizzi, J., G. Fisher, H. Homan, C. Baird, A. Retan, and A. Antonelli. 1982. Pacific Northwest insect control handbook. Ext. Services of Oregon State Univ., Corvallis; Washington State Univ., Pullman; and Univ. of Idaho, Moscow. (Published annually.)
13. Carlson, L. W. 1972. Forest tree nursery disease control. Pages 111-114 in Proc., Joint meeting, Western Forest Nursery Council and Intermountain Forest Nurserymen's Assoc., Olympia, Wash-ington.
14. Cooley, S. 1981. Progress report: solar pasteurization of nur-sery soil. Forest Pest Management, U.S.D.A. Forest Serv., Portland, Oregon. 17 p.
15. Davey, C. B., and H. H. Krause. 1980. Functions and mainte-nance of organic matter in forest nursery soils. Pages 130-165 *in* Proc., North American forest tree nursery soils workshop (L. P. Abrahamson and D. H. Bickelhaupt, eds.). State Univ. New York, Coll. Environ. Sci. and Forestry, Syracuse.
16. Dingley, J. M., and J. W. Gilmour. 1972. *Colletotrichum acutatum* Simmds. f. sp. pinea associated with terminal crook disease of Pinus spp. New Zealand J. Forestry Sci. 2:192-201.
17. Furniss, R. L., and V. M. Carolin. 1977. Western forest insects. U.S.D.A. Forest Serv., Washington, D.C. Misc. Publ. 1339. 654 p.
18. Hamel, D. R. 1981. Forest management chemicals. U.S.D.A. Forest Serv., Washington, D.C. Agric. Handb. 585. 512 p.
19. Hansen, E. M., P. B. Hamm, A. J. lulis, and L. F. Roth. 1979. Isolation, incidence and management of *Phytophthora* in forest tree nurseries in the Pacific Northwest. Plant Disease Reporter 63:607-611. p

20. Hepting, G. H. 1971. Diseases of forest and shade trees of the United States. U.S.D.A. Forest Serv., Washington, D.C. Agric. Handb. 306. 658 p.
21. Hopkins, J. C. 1975. A review of moulding of forest nursery seedlings in cold storage. Can. Forestry Serv., Pacific Forest Res. Centre, Victoria, B.C. Rep. BC-X-128. 16 p.
22. Lock, W., J. R. Sutherland, and L. J. Sluggett. 1975. Fungicide treatment of seeds for damping-off control in British Columbia forest nurseries: Tree Planters' Notes 26(3):16-18, 28.
23. MacSwan, I. C., and P. A. Koepsell. 1982. Pacific Northwest plant disease handbook. Ext. Services of Oregon State Univ., Corvallis; Washington State Univ., Pullman; and Univ. of Idaho, Moscow. (Published annually.)
24. Marshall, V. G., and S. Ilnytzky. 1976. Evaluation of chemically controlling the collembolan *Bourletiella hortensis* on germinating Sitka spruce and western hemlock in the nursery. Can. J. Forest Res. 6:467-474.
25. Miller, A. V., and S. M. Craig. 1979. Handbook for pesticide applicators and pesticide dispensers. Province of British Columbia, Ministry of Environ., Victoria. 233 p.
26. Old, K. M. 1981. Solar heating of soil for the control of nursery pathogens of Pinus radiata. Australian Forest Res. 11:141-147.
27. Peterson, G. W., and R. S. Smith, Jr. 1975. Forest nursery diseases in the United States. U.S.D.A. Forest Serv., Washington, D.C. Agric. Handb. 470. 125 p.
28. Smith, R. S., Jr. 1975. Charcoal root disease. Pages 11-13 *in* Forest nursery diseases in the United States (G. W. Peterson and R. S. Smith, Jr., tech. coordinators). U.S.D.A. Forest Serv., Washington, D.C. Agric. Handb. 470.
29. Smith, R. S., Jr. 1975. *Phomopsis* canker of Douglas-fir. Pages 42-44 in Forest nursery diseases in the United States (G. W. Peterson and R. S. Smith, Jr., tech. coordinators). U.S.D.A. Forest Serv., Washington, D.C. Agric. Handb. 470.
30. Stoeckeler, J. H., and G. W. Jones. 1957. Forest nursery practice in the Lake States. U.S.D.A. Forest Serv., Washington, D.C. Agric. Handb. 110. 124 p.
31. Stoeckeler, J. H., and P. E. Slabaugh. 1965. Conifer nursery practice in the Prairie-Plains. U.S.D.A. Forest Serv., Washington, D.C. Agric. Handb. 279. 93 p.
32. Sutherland, J. R., and R. L. Anderson. 1980. Seedling disease and insect problems related to nursery soil conditions in North America. Pages 182-190 in Proc., North American forest tree nursery soils workshop (L. P. Abrahamson and D. H. Bickelhaupt, eds.). State Univ. New York, Coll. Environ. Sci. and Forestry, Syracuse.
33. Sutherland, J. R., and T. G. Dunn. 1970. Nematodes in coastal British Columbia forest nurseries and association of *Xiphinenw bakeri* with a root disease of Douglas-fir seedlings. Plant Disease Reporter 54:165-168.
34. Sutherland, J. R., and W. Lock. 1977. Fungicide-drenches ineffective against damping-off of Sitka and white spruces. Can. Forestry Serv., Dep. of Environ. Bi-Monthly Res. Notes 33(1):6-7.
35. Sutherland, J. R., W. Lock, and L. J. Sluggett. 1975. Damping-off in British Columbia forest nurseries: control trials with fungicides applied to different quality seeds. Can. Forestry Serv., Pacific Forest Res. Centre. Victoria, B.C. Rep. BC-X-125. 20 p.
36. Sutherland, J. R., and E. Van Eerden. 1980. Diseases and insect pests in British Columbia forest nurseries. B.C. Ministry of Forests/Can. Forestry Serv., Victoria. Joint Rep. 12. 55 p.
37. Sutherland, J. R., T. A. D. Woods, and S. Ilnytzky. 1977. Pesticide phytotoxicity studies with seeds, germinants and seedlings of British Columbia conifers. Can. Forestry Serv., Pacific Forest Res. Centre, Victoria, B.C. Rep. BC-X-165.7 p.
38. Triebwasser, M.E., and D. C. Overhulser. 1981. The cranberry girdler in conifer nurseries of western Washington and Oregon. Pages 80-83 in Proc., Intermountain Forest Nurserymen's Assoc. and Western Forest Nursery Assoc. combined meeting, Boise, Idaho, Aug. 12-14, 1980. U.S.D.A. Forest Serv., Intermountain Forest and Range Exp. Sta., Ogden, Utah. Gen. Tech. Rep. INT-109.
39. Vaartaja, O. 1956. Screening fungicides for controlling damping-off of tree seedlings. Phytopathology 46:387-390.
40. van den Driessche, R. 1963. Partial sterilization of Douglas-fir seedbeds with formalin and chloropicrin. Forest Sci. 9:330-334.
41. van den Driessche, R. 1980. Health, vigour and quality of conifer seedlings in relation to nursery soil fertility. Pages 100-120 in Proc., North American forest tree nursery soils workshop (L. P. Abrahamson and D. H. Bickelhaupt, eds.). State Univ. New York, Coll. Environ. Sci. and Forestry, Syracuse.
42. Wilde, S. A. 1958. Forest soils. The Ronald Press, New York. 537 p.