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Root diseases in bareroot and container nurseries of the Pacific Northwest: epidemiology, management, and effects on outplanting performance

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Abstract. In forest and conservation nurseries in the Pacific Northwest USA, seedling production can be limited by root diseases caused by fungi in the genera *Fusarium* Link:Fr., *Cylindrocarpon* Wollenw., *Phytophthora* de Barry, and *Pythium* Pringsh. *Fusarium*, *Cylindrocarpon*, and *Pythium* are the most ubiquitous, whereas incidence of *Phytophthora* is mostly associated with coastal bareroot nurseries. All of these root pathogens are encouraged by water saturated soils or media. Seedlings infected with *Fusarium*, *Phytophthora*, or *Pythium* often appear chlorotic or necrotic with extensive root decay. *Cylindrocarpon* often causes serious root decay without shoot symptoms. The best approach to mitigate losses from these diseases is to use a holistic integrated pest management program. This program should combine chemical controls with cultural practices, particularly those that increase soil permeability and drainage and reduce potential sources of inoculum, especially by disinfesting seeds and containers reused for crops. In general, we found that seedlings meeting nursery specifications for outplanting on forest soil (proper height, root collar diameter, healthy shoot color, lack of disease symptoms) but having these disease organisms on their root systems perform as well as non-infected seedlings.

Introduction

In the Pacific Northwest USA, defined here as Oregon, Washington, and Idaho, about 190 million seedlings are produced annually for forest and conservation purposes. Seedlings are grown in bareroot nurseries and as container seedlings in outdoor compounds, shelterhouses, or fully-controlled greenhouses. Seedlings in bareroot and container nurseries are intensively managed. Potential for biotic disease is high in these systems because favorable environmental conditions for plant growth also favor growth of fungi capable of eliciting disease. These conditions can be exacerbated because seedlings are grown in monocultures, at high densities, at rapid growth rates that encourage succulence, and often the growth environment is initially 'sterile' (Landis et al. 1989b). In general, biotic diseases can be divided into two groups: shoot disease and root disease. We include damping-off with root disease. Management of root diseases is important because several genera of pathogenic fungi can cause severe damage.

Root diseases of bareroot conifer seedlings have been investigated since the early 1900s (Gifford 1911; Hartley and Pierce 1917) and most control options focused on using agricultural fungicides and fumigants (Hartley and Merrill 1914). Since then, researchers have investigated environmental factors associated with disease expression (Rathbun 1922; Tint 1945a, b), discerned aspects of epidemiology (Bloomberg 1971, 1973, 1976), and devised various control strategies like pre-plant soil fumigation (Bloomberg 1965; Sinclair et al. 1975; Hansen et al. 1990), soil solarization (Hildebrand 1990), fallowing (James 2000b), cover cropping (Hansen et al. 1990), inducing suppressive soils (Alabouvette et al. 1979), integrated pest management (IPM) (Mexal 1984) and incorporating biofumigants like *Brassica* spp. grown as green manure crops (Angus et al. 1994; James et al. 1996).

With the advent of container culture in the late 1970s, this process was repeated for the special conditions of container crops (James et al. 1987, 1988a, b) with a focus on IPM and sanitation (James et al. 1990; Shrimpton 1992; Dennis and Trotter 1998), biological controls (Dumroese et al. 1996, 1998; Mousseaux et al. 1998), and other techniques to reduce inoculum (James 1987; Dumroese et al. 2002).

In general, four root disease pathogens, *Fusarium* Link:Fr., *Cylindrocarpon* Wollenw., *Phytophthora* de Barry, and *Pythium* Pringsh., cause the most problems and of these, *Fusarium* is the most ubiquitous and important. Although our knowledge of root diseases and techniques for mitigating them has greatly increased in the past 100 years, we still observe losses to these organisms. The goal of this paper is to provide nursery managers with information on the biology of common root diseases, IPM techniques to mitigate losses, and data concerning growth of infected seedlings once outplanted on forest sites.

Epidemiology of common root pathogens

Fusarium *spp.*

The major soilborne pathogen in the genus *Fusarium* in bareroot nurseries is *F. oxysporum* Schlecht. (Bloomberg 1971, 1976; James et al. 1991b). Although this pathogen also occurs in greenhouse operations, *F. proliferatum* (Matsushima) Nirenberg may be more common and damaging in container seedlings (James et al. 1995, 1997). Both species are well adapted to nursery conditions and can remain viable for prolonged periods in the absence of susceptible hosts.

Fusarium oxysporum is a common inhabitant of agricultural soils, including those of most bareroot forest nurseries (Bloomberg 1976; James et al. 1991b), and commonly infests or contaminates conifer seeds used in bareroot and container nurseries (James 1987). *Fusarium proliferatum* is not an important seed contaminant, nor does it reach high populations in soil or standard

container growing media (James et al. 1995). Inoculum is likely introduced into container systems on infested organic matter and containers from previous crops (James et al. 1988c).

All conifer species are hosts of *Fusarium* (James et al. 1991b). Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco) is especially susceptible, but we have seen damage on nearly all species grown in nurseries, including trees and shrubs used for conservation. *Fusarium* causes several different types of diseases on conifer seedlings, including seed decay (pre-emergence damping-off), post-emergence damping-off, and root disease (Bloomberg 1971; James et al. 1991b). Seedling shoots may sometimes be attacked by *Fusarium*, particularly under humid conditions in both seedbeds and containers (James 2003a) but root diseases are the most economically important, manifested by extensive root decay and subsequent wilt symptoms.

In bareroot crops, most damage usually occurs during the first growing season with little damage occurring during the second season (James 2001, 2002). Container stock is affected throughout the growth cycle; however, severe root disease symptoms often become evident when seedlings are stressed to initiate bud formation and begin hardening (James et al. 1987). *Fusarium* are stimulated by high temperatures, near neutral pH conditions, and by nitrogen (especially ammonia) fertilization, particularly early in the growth cycle (James 1997a).

Infected seedlings initially turn chlorotic; needle tip dieback can be common, especially in container seedlings. Chlorotic tissues next turn necrotic and may appear either red or brown; eventually, dead seedlings turn black, rapidly decay, and may be difficult to find (James 2001, 2002). Most *Fusarium* can extensively colonize conifer seedling root systems without eliciting disease symptoms (James and Gilligan 1988a, b). From our experience, we believe it is possible that these exist as common root endophytes and only elicit disease when seedlings are stressed or if most of the isolates present are very virulent.

Symptoms caused by *Fusarium* may be similar to those elicited by other pathogenic fungi. Sometimes *Fusarium* produces definitive above-ground sporulation (sporodochia) that may help diagnosis (James 2003a). In most cases, however, confirmation of the pathogen can only be done by laboratory isolations facilitated by selective agar medium and subsequent microscopic identification (Nelson et al. 1983), a process that requires at least a couple of weeks. Recently-developed techniques using polymerase chain reaction (PCR) probes have been developed to detect some *Fusarium* pathogens (Kelly et al. 1994). Such techniques are much quicker and often more reliable than standard isolations.

Cylindrocarpon *spp*.

The anamorphic genus *Cylindrocarpon* contains several species often isolated from root systems of conifer seedlings (Booth 1966). By far the most commonly

isolated and important species is *C. destructans* (Zins.) Scholten (Bonello and Pearce 1993; James et al. 1994a; James 2004b). This species is a common rhizosphere inhabitant (Buscot et al. 1992) and is routinely isolated from both bareroot and container seedlings. It colonizes root cortical cells similarly to several *Fusarium*, but may also elicit root cell necrosis by production of toxins without actually colonizing affected cells (Dahm and Strzelczyk 1987; Beyer-Ericson et al. 1991). *Cylindrocarpon* may also be non-pathogenic root endophytes (Harney et al. 1997). Although often isolated from diseased seedling roots, *C. destructans* is generally less important than *Fusarium* in causing important seedling diseases.

Cylindrocarpon are common inhabitants of soil. Like *Fusarium*, several species produce resting structures called chlamydospores that allow the fungus to remain viable in soil for prolonged periods without susceptible host plants. Rarely isolated from conifer seeds, these fungi readily colonize inner surfaces of container walls where they can remain viable between seedling crops (James et al. 1988c). The fungus spreads within nursery environments on contaminated soil and via spores (micro- and macro-conidia) that are distributed by either irrigation or rain water (James et al. 1994a).

Most nursery species are susceptible to infection by *Cylindrocarpon*, although the greatest damage usually occurs on five-needle pine (*Pinus* L.) seedlings grown in containers (James 1991, 2000a, 2004a; James et al. 1994a). We found that Douglas-fir seedlings may also be routinely infected, and in British Columbia disease levels have been reported from low (Dennis and Trotter 1998) to extensive (Axelrood et al. 1998).

Cylindrocarpon prefer environmental conditions similar to *Fusarium*. Warm, wet conditions are especially conducive to buildup and spread of the fungus, particularly in container nurseries. Water-saturated growing media enhances development of *C. destructans* (James et al. 1994a; Dennis and Trotter 1998) and seedlings with infected roots usually do not display above-ground disease symptoms (James 1991, 2000a, 2004a). Unfortunately, damage often goes unnoticed until seedlings are extracted from containers for storage or outplanting, at which time roots may be extensively decayed and seedlings must be culled. In rare cases, some seedlings may exhibit typical root disease symptoms similar to those described for *Fusarium*.

Phytophthora *spp.*

Phytophthora are particularly common on bareroot conifers within nurseries near the Pacific Coast (Cooley et al. 1985; James 1997b), and are generally much less common within inland bareroot nurseries and on container stock. Many conifer species are susceptible to *Phytophthora*, although most damage has been documented on Douglas-fir (Roth 1963; Roth and Kuhlman 1963).

Phytophthora are soilborne (Hendrix and Campbell 1968) and cause problems in portions of nurseries with poorly-drained soils (Blaker and MacDonald

1981; Cooley et al. 1985). These pathogens may spread via motile zoospores that are readily disseminated in water (Hwang and Ko 1978). Most *Phytophthora* spp. are favored by fairly warm temperatures (Waterhouse 1956).

Seedling roots in water-saturated soils are infected and readily decayed (Hamm and Hansen 1982) causing typical root disease symptoms: chlorotic foliage, stunting, poor growth, and eventually death (Cooley et al. 1985). In some cases, plants are attacked on the main stem just below the groundline (James 1993). This results in stem cankers that spread around the circumference, eventually causing girdling.

Phytophthora are often more difficult to isolate from diseased seedlings than other pathogens (Waterhouse 1956). They tend to be replaced quickly by secondary plant colonizers. Although selective agar media facilitate detection of these organisms from plants and soil (Cooley et al. 1985), PCR probes are now an easier and more effective method (Cooke et al. 2000). Because the probes detect *Phytophthora*-specific DNA within infected plant tissues and from soil samples, they can also be used to identify particular species (Winton and Hansen 2001).

Pythium *spp.*

Fungi in the genus *Pythium* are important root disease organisms of many agricultural crops including forest nursery seedlings (James 1982). These organisms are similar to *Phytophthora* spp. in their requirements for high moisture (Middleton 1943). They cause problems mostly in bareroot seedlings, although damage to container seedlings can sometimes occur. In container nurseries, *Pythium* spp. can be found on reused containers (Sutherland and Dennis 1992).

Pythium spp. are common soil inhabitants that are readily isolated from nursery soils. The amount of damage they cause seems mostly related to level and persistence of soil moisture and presence of susceptible hosts (James 1982). Disease severity caused by *Pythium* spp. varies, but is often less than that caused by other root pathogens. Affected seedlings display foliar chlorosis and reduced growth. In British Columbia, *Pythium* spp. can cause disease on a variety of species, but are most damaging on spruce (*Picea* A. Dietr.) and Douglas-fir (Sutherland and Dennis 1992). Although groups of seedlings may be killed, losses are usually minor (James et al. 1991a).

Management of root diseases

The approach to root disease management in bareroot and container nurseries depends greatly on the attitude, experience, and abilities of the nursery manager. Myopic attention on the pest and a single control measure (i.e., pesticide) often blind nursery managers from considering changes to cultural practices

that can discourage disease organisms (Sutherland 1984). For root diseases in bareroot nurseries, soil fumigation is the main pesticide control measure; in container operations, it is fungicidal drenches. As single treatments, both have short-comings. Availability of methyl bromide fumigation, the long-time standard in the industry, is precarious because of its ozone-depleting side effects and subsequent phase out of use pursuant to the Clean Air Act and international treaty (see James et al. 1994b). Even if replaced, fumigation as a sole control treatment is tenuous because any pathogenic root fungus introduced into 'sterile' seed beds through contaminated seeds, transplants, blowing soil from nontreated areas, or equipment can increase dramatically (Young 1940; Vaartaja 1967). In containers, controlling Fusarium root disease with fungicides is usually ineffective (James 1986b; James et al. 1988c; Dumroese et al. 1990a).

Further complicating root disease mitigation is the perennial problem of understanding the relationship between numbers of potentially-pathogenic fungal propagules present in nursery soil, containers, container media, and seeds and resulting potential disease expression (Hildebrand and Dinkel 1988; Kolotelo 1997; James 2003b). This relationship is difficult to discern because assays are of entire populations and not limited only to pathogenic strains. Further, ultimate disease expression depends on environmental conditions and host susceptibility. High propagule counts of, for example, *F. oxysporum*, may subsequently result in high levels of disease if the particular *F. oxysporum* is virulent, the host is susceptible, and the environment conducive for disease. Other combinations may or may not result in some disease expression.

The general rule of thumb is that propagule counts of *Pythium* >100 colony forming units (CFUs) per gram (James et al. 1996; James 2000b) and >1000 CFUs/gram of *Fusarium* (Hildebrand and Dinkel 1988) indicate a potentially serious problem, but clearly there exists a need for a more definitive answer. Recently we selected 41 *F. oxysporum* isolates collected from nurseries (soil, seeds, and healthy and diseased seedlings) for molecular characterization based on *in vitro* pathogenicity tests developed by James (1996). We are currently performing amplified fragment length polymorphism (AFLP) and DNA sequencing in an attempt to identify genetic markers related to pathogenicity. Preliminary results show that pathogenic isolates are clearly separated from non-pathogenic isolates based on AFLP markers (Figure 1). After AFLP analyses are completed, we plan to develop simple molecular probes based on AFLP markers or ribosomal DNA sequence data to differentiate pathogenic from non-pathogenic isolates of *F. oxysporum*. Such molecular probes could be used to detect, characterize, and quantify pathogen populations within nurseries, and thereby provide nursery managers with more definitive and dependable information for implementing disease management options. Such probes are used for *Phytophthora* in citrus (Goodwin et al. 1990).

Given the difficulty of mitigating root disease with conventional chemical control and uncertainties involved with differentiating pathogenic and non-pathogenic organisms, an integrated approach to root disease management is

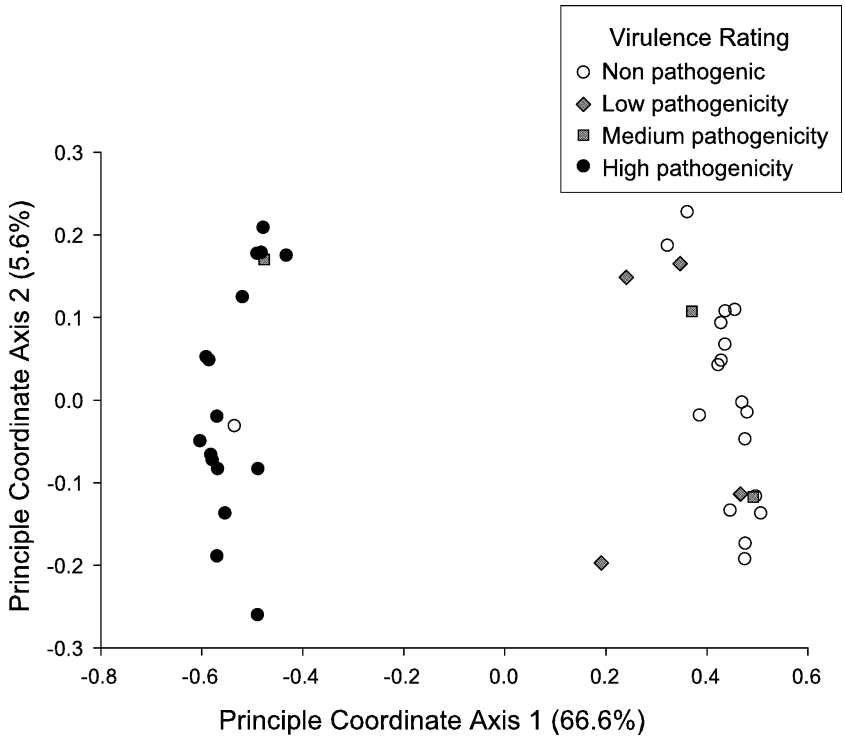

Figure 1. Principal coordinate analysis of *Fusarium Oxysporum* isolates collected from the USDA Forest Service Coeur d'Alene Nursery based on 72 amplified fragment length polymorphism (AFLP) markers. Principal Coordinate axes 1 and 2, which explained 66.6% and 5.6% of the variation among points, respectively, revealed two distinct groups corresponding to pathogenicity (non pathogenic vs. high pathogenicity).

prudent. IPM should be a holistic approach combining conventional pesticide use with other cultural treatments.

Integrated pest management

An ideal IPM plan reduces pest inoculum, mitigates environmental conditions favorable for disease expression, and enhances host resistance. In seedling culture, these three foci often interact. Effective IPM strategies reduce reliance on chemical controls while maintaining seedling production (Dumroese et al. 1990b; Shrimpton 1992). A thorough review of IPM and Fusarium root disease in container nurseries is provided in James et al. (1990).

Reducing pest inoculum

In general, using clean, vigorous seeds is a good step toward reducing root disease inoculum. *Fusarium* inoculum is readily found on cones and seeds of wildland and orchard trees (Peterson 2000). Poor cone handling and seed

extraction methods can exacerbate the pathogen problem. Although squirrel cached cones can be collected for reforestation activities and yield seedlots with acceptable viability (White and White 1986), seeds from squirrel caches usually have higher levels of inoculum of *Fusarium* and other potential pathogens than those from cones harvested directly from trees (James 1986a). Often, seedlots with historic root disease problems also have lower viability; these seedlots can be improved, and incidence of disease reduced, by removing the low vigor, and perhaps pathogen-compromised, seeds through a variety of sorting procedures (Creasy 2002).

Many chemicals (bleach, hydrogen peroxide, ethanol, fungicides) and hot water can be used to remove inoculum from seed coats; although all of these chemicals are efficacious, they can also affect seed germination, sometimes positively through reduction of inoculum and sometimes negatively by phytotoxicty (Trappe 1961; Lock et al. 1975; James and Genz 1981; Wenny and Dumroese 1987; Dumroese et al. 1988; James et al. 1988d; Axelrood et al. 1995). The appropriate chemical and treatment solution and/or duration depends on species. However, one easy and effective method for reducing inoculum before stratification and sowing is simply imbibing seeds in running water rather than water that is not changed or changed infrequently (James and Genz 1981; Axelrood et al. 1995). It is prudent to thoroughly cleanse the containers used for these soaks because *Fusarium* inoculum can remain on surfaces and potentially infest the next seedlot (Neumann et al. 1997).

Fumigation is very efficacious at killing root disease inoculum in bareroot nursery soils (Hildebrand and Dinkel 1988; Hansen et al. 1990). It is a standard treatment in most nurseries in the Pacific Northwest USA, but rarely was used in British Columbia (Sutherland 1984). As availability of methyl bromide drops and price increases, other fumigants, like dazomet, are being investigated (James et al. 1994b; Kelpsas and Campbell 1994). Inoculum levels of potential root diseases increase substantially immediately following addition of organic amendments to soil, either through cover crops or as organic additives (i.e., sawdust or compost); fumigation can be an extremely important tool in reducing or eliminating that inoculum (Hansen et al. 1990).

Bareroot nursery managers should be vigilant when accepting transplant material from other nurseries; this stock should appear healthy and lack disease symptoms. Hansen et al. (1979) found that Phytophthora root rot was spread from nursery to nursery via transplants.

One of the best techniques for reducing root disease in container nurseries is disinfesting containers between seedling crops. Because containers are made of Styrofoam^{TM} or hard plastic, they can often be reused for several seedling crops. Pathogen inoculum commonly occurrs in containers (James et al. 1988c; Sturrock and Dennis 1988); as the number of crops grown increases in a given container, mortality increases and seedling growth decreases (Dumroese et al. 2002). A myriad of chemical treatments were tested to disinfest containers (Sturrock and Dennis 1988; Peterson 1990; Dumroese et al. 1993b), but we feel the best treatment seems to be immersing containers in hot water. Different

reports have recommended different efficacious temperatures and durations (Table 1), not surprising considering the variety of container types, Styrofoam™ densities, crop species, container ages, and inoculum loads. In general, a soaking temperature of 75–85 °C for 30–90 s should be sufficient to remove most inoculum from Styrofoam™ containers, whereas 15–30 s is probably sufficient for hard plastic containers. Soaking Styrofoam™ for longer durations at 85 °C or at temperatures >85 °C can cause them to distort.

Finally, sanitation is an important tool in reducing inoculum. Other sanitation techniques not discussed above include removing dead and diseased seedlings which can infect healthy seedlings (Landis et al. 1989b; James et al. 1990), eliminating weeds in and around production areas that harbor and allow build-up of potential pathogens (Landis et al. 1989b; James et al. 1990), treating cull piles that serve as sources of disease inoculum (Sutherland and Dennis 1992), cleaning equipment used to handle seeds (Neumann et al. 1997), and in container nurseries, vigorous cleaning of benches, walls, and floors to remove inoculum (James et al. 1990).

Mitigating favorable environmental conditions and enhancing host resistance

In general, root diseases are favored when soils or media are water-saturated, therefore, any cultural techniques to improve drainage reduces incidence. Because high soil water tables favor *Phytophthora* (Hansen et al. 1979) and *Pythium*, bareroot nurseries should ideally be located on well-drained soils. Regularly using deep tillage to disrupt soil pans; adding organic matter to improve soil tilth, aeration, and water penetration; avoiding overwatering; and refraining from operating equipment on wet soils to avoid compaction all promote improved drainage. Not only do these treatments reduce conditions favorable to the diseases (Juzwik et al. 1997), but they also improve host resistance by reducing or avoiding seedling stress associated with anaerobic conditions (Sutherland 1984). In container nurseries, using a well-drained artificial growth medium is essential (Phipps 1974; Sutherland and Dennis 1992) and monitoring medium moisture content to avoid overwatering is essential. In bareroot and container nurseries, irrigation frequency and duration should be based on seedling need rather than on the habits of nursery personnel. Simple techniques like using container weights in container nurseries (Landis et al. 1989a) and pressure chambers, tensiometers, or gravimetric methods in bareroot nurseries (McDonald 1984) can help nursery managers quantify when irrigation is necessary.

In bareroot nurseries, it may be possible to rotate crops or allow prolonged fallow periods (James 2000b) to mitigate inoculum build-up. Planting more resistant species in areas known to be problematic may also be useful. In bareroot and container nurseries, inoculating seedlings with beneficial organisms like mycorrhizal fungi or biological controls (for example, *Trichoderma*) may provide some benefit (Sinclair et al. 1975, 1982; Dumroese et al. 1996; Mousseaux et al. 1998). These biological controls may be efficacious through colonization of root niches that subsequently deny pathogens access to the root

Table 1. Hot water temperatures and durations, and post-treatment colonies of *Fusarium*, *Cylindrocarpon*, and *Pythium*.

Source	Container material	Water temperature (°C)	Soak duration (s)	Resulting colonies per sample (%)		
				Fusarium	*Cylindrocarpon*	*Pythium*
Sturrock and Dennis (1988)	Styrofoam™	80	180	0	0	0
	Styrofoam™	100	60	10	0	5
James and Woollen (1989)	Styrofoam™	68	600	3	3	–
James (1992)	Styrofoam™	75	60	0	0	–
James and Eggleston (1997)	Styrofoam™	79	30	0	0	–
	polystyrene	66	15	0	0	–
Dumroese et al. (2002)	Styrofoam™	77–82	90	0	3	–

(Axelrood 1991), competition with pathogens for nutrients, water, oxygen, light, and space (Baker and Cook 1974), or parasitism on the pathogen (Papavizas 1985).

Root disease and effects on outplanting performance

Nursery managers and foresters are concerned about outplanting seedlings infected with these root pathogenic fungi. The primary concern is whether the pathogen will reduce survival and growth. It is difficult to determine the potential impact when root diseases bring seedling quality to the threshold of acceptance and vagaries of the planting site, particularly climatic, interact. Moreover, studies to elucidate the factors are difficult to establish because of problems in achieving a gradient of disease incidence across a particular seedling crop. A few studies, however, provide some insight.

Smith (1967) outplanted bareroot sugar pine (*Pinus lambertiana* Dougl.) seedlings infected with *Fusarium oxysporum* on a forest site. Levels of infection decreased annually and after 4 years the pathogen could no longer be detected on seedling roots. Similarly, on a crop of container Douglas-fir seedlings, of which 60% had about 10% of their root systems infected, *Fusarium* could not be detected on seedling roots 4 years after outplanting (Dumroese et al. 1993a). Infected seedlings grew and survived as well as non-infected seedlings. The two main fusaria, *F. oxysporum* and *F. proliferatum*, were found on the plug roots that originated in the nursery and seldom on egressed roots, probably because *Fusarium* competes poorly with, and is antagonized by, forest soil microorganisms (Baker and Cook 1974). Axelrood et al. (1998) also concluded that *Fusarium* had little influence on outplanted Douglas-fir seedling mortality on reforestation sites in British Columbia.

On a crop of container western white pine (*Pinus monticola* ex D. Don) with healthy-looking shoots, we found that 50% of the seedlings were infected with *Cylindrocarpon* (mostly *C. destructans*) and average root colonization was 63%, resulting in seedlings with insufficient root plugs for outplanting (Dumroese et al. 2002). With this crop, however, we failed to correlate new root production in a greenhouse study with either infection or colonization and for most seedlings new root production was class 4 or higher on Burdett's (1979) scale (5 is maximum). Of the 12% of the crop with poor root growth potential, 70% were infected with the pathogen, but these infected seedlings produced more new roots than the 30% without *Cylindrocarpon*. Another subsample of seedlings meeting all morphological standards for outplanting (firm root plug, minimum root collar diameter and height) grew well on a forest site; height growth was similar between infected and non-infected seedlings. Although we still isolated *Cylindrocarpon* at very low levels 5 years after planting, only 25% of the seedlings killed by something other than herbivory were positive for the fungus (Dumroese et al. 2000). In British Columbia, Axelrood et al. (1998) found that *Cylindrocarpon* on outplanted Douglas-fir seedlings decreased linearly from the original root plug, indicating

poor competitiveness on forest sites, but seedlings showing severe root rot symptoms in the nursery had higher mortality on the outplanting site.

On a forest site, mortality of bareroot Douglas-fir seedlings was correlated with intensity of symptoms caused by Phytophthora root disease (Hansen et al. 1980). Seedlings with severe symptoms at outplanting had the highest mortality and poorest growth 18 months later. Seedlings with 'inconspicuous symptoms' fared as well as healthy, control seedlings. The pathogen persisted on outplanted seedling roots but failed to colonize new roots and did not infect healthy seedlings when diseased and healthy seedlings were outplanted in the same hole (Hansen et al. 1980).

It appears that, despite the pathogen persisting on roots formed in the nursery, organisms pathogenic to seedlings in nurseries compete poorly in the rhizosphere of new roots penetrating into forest soil. Further, seedlings meeting nursery standards for quality (morphological and physiological) should do well on most outplanting sites. Dennis and Trotter (1998) recommend that seedlings with root rot symptoms be given critical attention and that healthy-looking seedlings from diseased seedlots may need a root growth potential test to ensure outplanting performance. Ideally, mitigating disease expression through IPM circumvents concerns about sending to the field seedlings compromised by pathogens.

Summary

Root diseases caused by species of *Fusarium*, *Cylindrocarpon*, *Phytophthora*, and *Pythium* can cause serious losses in bareroot and container forest and conservation nurseries in the Pacific Northwest USA. Generally, all of these pathogens are favored by saturated soils or media. Incorporating an IPM system into seedling production is the best method to mitigate disease impacts. Diseased seedlings meeting nursery criteria for outplanting (including healthy-appearing shoots) perform satisfactorily and similarly to non-diseased seedlings.

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