PORT-ORFORD-CEDAR ROOT DISEASE IN SOUTHWESTERN OREGON AND NORTHWESTERN CALIFORNIA

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SUMMARY

Port-Orford-cedar (*Chamaecyparis lawsoniana*) is affected by an introduced pathogen *Phytophthora lateralis*, cause of Port-Orford-cedar root disease. The pathogen was first reported killing ornamental Port-Orford-cedar nursery stock around Seattle, Washington in 1923, and was detected in the host's native range in 1952. It has since spread into many areas occupied by Port-Orford-cedar in southwestern Oregon and northwestern California. Origin of the pathogen is unknown. *P. lateralis* is well adapted for active spread in water and passive, long distance transport in soil. High risk areas for infection are stream courses, drainages, or low lying areas down slope from already-present infection centers or below roads or trails where new inoculum can be introduced by earth movement in road construction, road maintenance, logging, traffic flow on forest roads, or by animals. *P. lateralis* is an extremely virulent pathogen. Once established on microsites with characteristics favorable for its spread, the pathogen kills hosts rapidly. To date, management of Port-Orford-cedar root disease has involved excluding the pathogen from areas where it does not yet occur and minimizing spread in already infested areas. Components of such programs have been road closures, timing access into stands with Port-Orford-cedar during dry weather, washing equipment that is being moved from infested to uninfested areas, roadside sanitation treatments, special care in road building and maintenance operations, and featuring Port-Orford-cedar on sites unfavorable for the pathogen (upslope situations, convex slopes, well-drained microsites, away from roads and streams). Recent discovery of Port-Orford-cedars with a degree of resistance to *P. lateralis* offers promise of another management approach for the future. Screening of Port-Orford-cedar for resistance is in progress across the range of the species, and a breeding program to enhance resistance is in the developmental phase.

PORT-ORFORD-CEDAR ROOT DISEASE

Port-Orford-cedar (*Chamaecyparis lawsoniana*) is affected by *Phytophthora lateralis*, an extremely virulent, introduced root pathogen. The pathogen was first reported killing Port-Orford-cedar stock in ornamental nurseries in Seattle, Washington in 1923 (Hunt 1959, Zobel et al. 1985); in the 1930s and 40s, it was found in the Willamette Valley of Oregon killing Port-Orford-cedar landscape trees (Tucker and Milbrath 1942, Zobel et al. 1985); and it was reported at Coos Bay, Oregon first causing tree mortality in the native range of Port-Orford-cedar in 1952 (Roth et al. 1957). Subsequently, it has spread through much of the cedar's rather small natural range in southwestern Oregon and northwestern California.

Except for *P. lateralis*, Port-Orford-cedar has few significant enemies. Cedar bark beetles (*Phloeosinus* spp., especially *P. sequoiae*) and amethyst cedar borers (*Semanotus amethystinus*), infest some trees, but usually only trees of very much reduced vigor. They rarely kill trees by themselves, but commonly administer the *coup de grace* to severely stressed cedars, especially those infected by *P. lateralis*. Black bears (*Ursus americanus*) can be locally damaging to Port-Orford-cedar when they peel bark and feed on the cambium of trees in early spring. When feeding is extensive, trees may be completely girdled and killed. Port-Orford-cedars, especially those occurring on drier sites, may succumb to drought damage during periods of protracted dry weather. Drought may also predispose cedars to attack by bark beetles or woodborers. By and large, Port-Orford-cedar is a remarkably decay resistant species. Several decay fungi, including *Phellinus pini* and *Heterobasidion annosum* have been found on Port-Orford-cedar, but are uncommon and appear to have little impact.

The origin of *P. lateralis* is unknown. Many investigators believe that it is an Asian species based on the high level of resistance to the pathogen exhibited by Asian *Chamaecyparis* species (Tucker and Milbrath 1942, Zobel et al. 1985). However, the pathogen has not actually been found in Asia. Europe has been suggested as another possible point of origin of the pathogen (Erwin and Ribeiro 1996), but evidence for an introduction from that source is not substantial. Hansen et al. (1999) confirmed the identity of *P. lateralis* isolated from container-grown Port-Orford-cedar seedlings in France but strongly believed that its presence there resulted from a recent introduction from North America rather than natural occurrence of the pathogen in Europe. Another theory concerning the source of *P. lateralis* is that the pathogen may have originated from some location in North America outside of the rather small area where Port-Orford-cedar is native. Roth (unpublished) postulated that *P. lateralis* might be an uncommon, relatively benign endemic on yellow-cedar (*C. nootkatensis*) that infected highly susceptible ornamental Port-Orford-cedars when they were planted in the range of the former species in British Columbia and then spread south in Port-Orford-cedar landscape plantings. *P. lateralis* has never been found on yellow-cedar in the wild but is capable of occasionally infecting that species when it is inoculated in the laboratory (Torgeson et al. 1954) or planted together with Port-Orford-cedars on an infested site (Hansen, Roth, and McWilliams unpublished).

P. lateralis appears to be quite host specific. Besides Port-Orford-cedar, only Pacific yew (*Taxus brevifolia*) has been found infected in the wild (DeNitto and Kliejunas 1991, Kliejunas 1994). Pacific yew is much less susceptible to the pathogen than Port-Orford-cedar, and evidence indicates that it mainly becomes infected when in close association with substantial numbers of already-infected cedars (Murray and Hansen 1997).

P. lateralis is highly adapted for spread in water. Zoospores can swim for several hours in standing water and can be carried considerable distances in flowing water. Zoospores are attracted by host root exudates and will follow an increasing gradient of chemical concentration until they contact living root tissue, encyst, germinate, penetrate the root, and initiate infection. Infection occurs primarily through the unsuberized growing tips of small rootlets that occur in the duff or at shallow depths in soil. Port-Orford-cedars produce a multitude of fine rootlets in these strata (Gordon and Roth 1976, Zobel et al. 1985). Sporangial development and zoospore production of *P. lateralis* are favored by cool, moist conditions and are optimal at temperatures between 10° and 20° C (Trione 1974). Under favorable cool, wet conditions, *P. lateralis* populations can amplify rapidly in areas where hosts are numerous because of the rapid and continuing production of flagellate zoospores.

P. lateralis is capable of surviving for considerable periods of time when conditions are unfavorable for zoospore spread and infection. When suboptimal moisture and temperature conditions develop, the pathogen forms laterally arranged chlamydospores on hyphae in infected roots. Ostrofsky et al. (1977) showed that *P. lateralis* populations detected by baiting around infected trees decreased substantially when unfavorable warm, dry conditions typical of summer months in the range of Port-Orford-cedar occurred. However, the pathogen did survive at a reduced level as chlamydospores in organic matter, especially in small roots on infected trees and fragments of roots in the surrounding soil. Hansen and Hamm (1996) demonstrated that the pathogen can survive in infected roots and fragments for at least seven years. *P. lateralis* chlamydospores are incapable of direct movement, but their structure provides protection during passive movement in infected roots or organic material in soil and mud. Oospores also can act as resting spores and may be transported from one place to another in infected root tissues. When environmental conditions become favorable, resting spores germinate, forming zoospore-containing sporangia.

Long distance spread of *P. lateralis* results from moving infected seedlings and, especially, infested soil into previously disease-free sites. Humans have been the main vectors of the pathogen. Major spread has occurred via earth movement in road construction, road maintenance, mining, logging, and traffic flow on forest roads (Roth et al. 1957, Roth et al. 1972, Kliejunas 1994). In general, the pathogen has not spread into areas where physical barriers or lack of access have prevented human activity. Movement of the pathogen in soil clinging to the feet of elk, cattle, and humans also is known to occur but on a much more localized basis than that associated with vehicles (Harvey et al. 1985, Kliejunas 1994, Kliejunas and Adams 1980, Roth et al. 1972). Spread of *P. lateralis* occurs primarily in the late fall, winter, and early spring when the cool, moist environmental conditions favorable for the pathogen prevail. Little or no spread occurs in the hot, dry summer months.

Once introduced to a new area, *P. lateralis* spreads in water downslope from the roads and trails where it is initially established. Inoculum often builds to high levels in concentrations of hosts growing on disturbed areas close to road edges, thus increasing the likelihood of downhill spread. In virtually all cases, infection of Port-Orford-cedar by the pathogen occurs in areas where obvious avenues for water-borne zoospore dispersal exist. Infection is dependent on the presence of free water in the immediate vicinity of susceptible tree roots. High risk areas for infection include stream courses, drainages, low lying areas downslope from existing infection centers, and areas below roads and trails where new inoculum could be introduced in the future. Topography has a considerable influence on spread. Steep slopes dissected by drainages quickly channel zoospore-infested water into streams. Cross slope spread is restricted. On broad slopes or flat areas, infested water may spread out over larger areas and move more slowly. Because they are easily flooded, concave areas with Port-Orford-cedar are very vulnerable to damage. Convex slopes, on the other hand, have limited vulnerability. Port-Orford-cedar growing on sites or microsites that are unfavorable for spread of the pathogen often escape infection, even in areas where infected trees are nearby. Tree to tree spread of *P. lateralis* via mycelial growth across root contacts does occur (Gordon 1974) but is considered to be much less significant in the epidemiology of the pathogen than spread by zoospores in free water.

Port-Orford-cedar root disease is identified in the field by the rapid death of individual hosts, by the fact that only Port-Orford-cedar and rarely Pacific yew are affected, by the characteristic distribution of the disease in sites favorable for the water-borne spread of the pathogen, and by the distinctive symptoms that *P. lateralis* causes on infected cedars (Zobel et al. 1985). Crowns of infected trees first fade slightly or appear somewhat wilted. They subsequently change color from their normal green or blue green to yellowish gold, bronze, reddish brown, and finally dull brown. Symptoms manifest themselves especially rapidly and tree death occurs quickly in seedlings and saplings during periods when warm, dry weather develops after infection. With such trees, the entire progression of symptoms may occur within a few weeks. Large Port-Orford-cedars die much more slowly, declining over periods of one to four years. Signs of infection in Port-Orford-cedar roots include loss of luster of root tips, water-soaking of rootlets, and death and decay of roots. Bark on main roots may darken or turn somewhat purplish. The mycelium of the pathogen grows in the inner bark and cambium of the host, colonizing and killing much of the root system, and ultimately girdling the main stem in the lower bole. In live Port-Orford-cedar exhibiting crown symptoms, a cinnamon-colored stain that abuts abruptly against healthy, cream-colored inner bark is apparent at or above the root collar. This stain, which can be followed down into the roots, is considered diagnostic of infection by *P. lateralis*. Once a Port-Orford-cedar dies, the inner bark of the entire bole turns brown, and it is no longer possible to use presence of staining as an identification tool.

Port-Orford-cedar root disease centers consist of variable-sized groups of dead and dying trees. Port-Orford-cedar is a prolific seed producer, and new regeneration of the host often becomes established in infection centers. This regeneration usually becomes infected in turn, resulting in chronic disease expression. Because of its ability to reproduce at an early age and produce large numbers of seeds, and because many trees that occur on sites with characteristics unfavorable for spread of *P. lateralis* completely escape infection, Port-Orford-cedar has not been eliminated by *P. lateralis* in any significant portions of its range. Nonetheless, *P. lateralis* has caused very substantial amounts of mortality on individual infested sites and has greatly influenced stand structure by killing larger trees and preventing smaller trees from attaining large size. The disease can greatly influence the ecological roles of Port-Orford-cedar, particularly in streamside areas where conditions are most favorable for spread of the pathogen.

CURRENT MANAGEMENT

In the first two and a half decades after the introduction of *P. lateralis* into the native range of Port-Orford-cedar, few if any attempts were made to manage the disease it caused. The spectacular virulence of the exotic pathogen and the speed with which it spread along roads and streams as well as the obvious tie between spread and then-practiced timber harvesting techniques led to statements such as "There appears to be no hope of raising another crop of Port-Orford-cedar under existing conditions of disease and land use." and "(Production of Port-Orford-cedar) will likely decline and ultimately drop to nearly nothing as the remaining merchantable trees die or are harvested (Roth et al. 1972)." It was felt by many that with the pathogen established, active management of Port-Orford-cedar as a timber species was not worthwhile. Emphasis was placed on extensive salvage of large disease-killed cedars, and the prevailing attitude among forest managers toward Port-Orford-cedar was one of considerable pessimism.

Attitudes about managing Port-Orford-cedar root disease changed dramatically in the 1980s and 90s. Forest managers on Federal Lands administered by the United States Department of Agriculture Forest Service and the United States Department of the Interior Bureau of Land Management, are now involved in an active program to minimize detrimental impacts of the root disease. There is a strong commitement to do whatever is possible to maintain and, where feasible, enhance both the ecological and economic viability of Port-Orford-cedar. Management directions for the Port-Orford-cedar program are incorporated in agency land management planning documents. The goals of the program are to integrate strategies for Port-Orford-cedar management into environmental analyses and project planning for all areas that support the species on Federal lands; to manage Port-Orford-cedar as an appropriate component of forest stands in the suitable plant associations; and to use the best practices identified from experience and research to prevent or reduce the spread of Port-Orford-cedar root disease.

Port-Orford-cedar root disease management strategies involve planned combinations of treatments that together reduce probability of disease spread and intensification as much as possible across a landscape. Treatments considered for use in a strategy are aimed at reducing the risk of introducing the pathogen into new areas or at managing a component of Port-Orford-cedar in areas that are already infested. A number of disease management techniques have been recommended and used (Betlejewski 1994, Filip et al. 1994, Hadfield et al. 1986, Hansen and Hamm 1996, Hansen and Lewis 1997, Harvey et al. 1985, Jimerson 1994, Kliejunas 1994, Kliejunas and Adams 1980, Neilsen 1997, Roth et al. 1957, Roth et al. 1972, Roth et al. 1987, Tainter and Baker 1996, Thies and Goheen 1999, USDA Forest Service 1983, Zobel 1990, Zobel et al. 1985). These include:

1) Exclusion

The exclusion approach involves protecting Port-Orford-cedar by completely preventing entry of vehicles, the main carriers of the disease organism, into areas where the disease is not yet present. Under this approach, no new roads are built into selected uninfested areas, and existing roads are permanently closed in selected areas where roads do occur but the disease has not yet been introduced. Road closures are done in such ways that vehicles cannot broach them or detour around them. "Tank traps," large berms, or rock piles are strategically located at sites where it is impossible to bypass them. Alternatively, roads are completely obliterated with their culverts removed and their beds destroyed. To be successful, exclusion must be practiced in a location that realistically can be protected. Exclusion is best used where an entire drainage or at least the upper portion of such a feature can be treated as a protection unit.

2) Temporary Road Closures

Like exclusion, the temporary road closure approach seeks to protect Port-Orford-cedar by preventing vehicles from carrying propagules of the disease organism into uninfested areas. It differs from total exclusion by allowing controlled road use in vulnerable areas during times when conditions are unfavorable for establishment and spread of the pathogen. Roads are closed during the cool, wet season of the year, typically from Oct. 1 to June 1. In addition, special closures are applied during particularly wet periods at other times of the year. Roads are closed with locked gates, guardrails, or other movable barriers, and closures are located in areas where they cannot be bypassed. Temporary closures require considerable attention to ensure that they are indeed in place when they need to be (during wet periods at any time of year) and that they are not broached. Since the roads are still present beyond the closures, uninformed, thoughtless, or uncaring people sometimes find ways around the closures at times of the year when they should not or actually force open or destroy gates or other structures to gain access. Placement and strength of barriers are important considerations in use of temporary closures, as is constant vigilance.

3) Roadside Sanitation

The roadside sanitation approach involves eliminating Port-Orford-cedar in buffer zones along either side of roads. There are two different kinds of objectives for sanitation treatments. They can either be aimed at preventing or reducing new infections along roads that cannot be closed in currently uninfested areas, or at eliminating or minimizing the amount of inoculum readily available for vehicle transport from already-infested roadsides to roadsides in uninfested areas. If a sanitation treatment that involves killing all hosts and preventing host regeneration is done along an infested road edge, *P. lateralis* inoculum available for vehicles to pick up and carry to other areas should be reduced or eliminated over time. Where a road runs through an uninfested area with Port-Orford-cedar, elimination of live cedar roots in a buffer along the roadside means that there are no live hosts close to the spots where contaminated soil is most likely to fall off of vehicles using the road. Since zoospores, the propagules of *P. lateralis* that would be involved in spread away from the road, are quite delicate, they are unlikely to be able to reach and infect hosts beyond the buffer created in a sanitation treatment. Also, inoculum will not have a chance to build up to high levels in concentrations of live trees close to roads as often happens in roadside areas where sanitation treatments have not been done. The key feature of any sanitation treatment is to create a zone along treated roads where live Port-Orford-cedar roots are absent. Cedars may be killed by girdling, cutting, pulling, or burning. Ideally all Port-Orford-cedars of any size within the sphere of influence of the road are treated. The general recommendation now given by the Forest Service is to treat all Port-Orford-cedars in a buffer zone extending 8.5m above the road or to the top of the cutbank. Below the road, recommended treatment width is 8.5m to 17m with the greater distances applied where streams or drainages cross the road or where amount of road fill is particularly substantial, resulting in especially steep slopes. Sanitation treatments need to be repeated periodically to ensure that roadside buffers are not reinvaded by Port-Orford-cedar regeneration. The preferred approach is to monitor treated areas and retreat them whenever Port-Orford-cedar seedlings 15 cm in height or greater become evident.

4) Vehicle Washing

This approach involves thoroughly cleaning vehicles and equipment to remove adhering soil or plant debris before driving them into areas where healthy Port-Orford-cedars occur or moving them from *P. lateralis* infested to uninfested areas within the forest. When vehicle washing is used as part of a Port-Orford-cedar root disease management strategy, location and design of washing stations are extremely important. Stations should be located in areas where run-off water has no chance of entering adjacent streams or drainages or of threatening nearby Port-Orford-cedars. Furthermore, stations must be designed so that vehicles that have been washed are not likely to be recontaminated by passing through wash water that contains *P. lateralis* propagules on their way out of the station.

5) Appropriate Operations Planning, Scheduling, And Execution

This technique involves separating operations in disease-free locations in both space and time from work in diseased stands. Forest management projects in stands with Port-Orford-cedars, especially in uninfested areas, are performed when conditions are unfavorable for pathogen spread and survival. Projects are preferentially scheduled and completed in the warm, dry months. Operations are usually limited to some time within the period of June 1 through October 1. Operations may be allowed outside of the normal season if especially dry conditions prevail, but such exceptions are carefully regulated. Operations are discontinued when wet conditions develop, even during the stated operating season. Repeated entries onto vulnerable microsites are avoided, and work is scheduled to proceed from healthy to infested sites, not the other way around. Equipment is not allowed to operate from a contaminated area into a clean one nor is equipment allowed to move from a clean area into a contaminated area and return. Whenever possible, access to project areas is planned along routes with the least occurrence of infested sites. Where timber harvesting operations are being done in stands with Port-Orford-cedars or where streams run into stands with Port-Orford-cedars below harvesting units, systems that minimize amount of soil movement, especially across slope movement, are preferred. Skyline systems or helicopter logging systems are used, and tractor logging systems are avoided. Where possible, all root disease prevention/management activities are coordinated with adjacent landowners (private and other agencies).

6) Integrating Disease Treatments In Road Design, Engineering, and Maintenance

Minimizing the risk of *P. lateralis* spread is an important consideration in designing and building new roads and in maintaining or improving existing roads in areas with Port-Orford-cedars. For new construction, routing decisions are made with knowledge of where Port-Orford-cedar concentrations occur. When possible, new roads or spurs are not located above concentrations of Port-Orford-cedar. Instead, they are situated below such concentrations or on the opposite sides of ridges. Culverts and waterbars are designed to direct water quickly into existing well-defined water channels away from areas where Port-Orford-cedars exist. Road beds are insloped, and, in some cases, site specific berms are used on the outside edges

of roads to prevent downslope flow of water. Road building and maintenance is restricted as much as possible to the dry season and only clean equipment is used. Movement of soil and debris from one place to another in construction or maintenance is minimized, and casting gravel from roads with infected trees along them into drainage ditches, streams, or over road berms during road maintenance is avoided. During construction or road upgrades, clean rock is used for road surfacing (quarry rock from certified clean rock pits is preferred over river rock). When possible, pavement or uninfested rock is added to raise roadbeds that pass through infested sites. Stream crossings on new roads are designed to keep vehicles out of contact with water and primitive roads that cannot be closed are upgraded so that fords and puddles are eliminated. Care is taken in moving soil and other material when endhauling, repairing flood damage, or removing slides, especially in or near infested areas.

7) Water Source Selection and Treatment

Under this technique, water sources on Federal lands are inventoried and those that are infested by *P. lateralis* are identified. Subsequently, when water is needed for fire fighting or dust abatement, uninfested water sources are used if possible. Where no clean water sources exist and water must be taken from a probably infested source, it is treated with Clorox before use. In areas where water sources have not been inventoried, Clorox is used as a matter of course. Adding chlorine bleach to *P. lateralis*-infested water will kill many propagules of the pathogen. Murray, McWilliams, and Hansen (unpublished) demonstrated that complete mortality of *P. lateralis* zoospores occurred after 60 minutes in 100 ppm chlorine bleach, and complete mortality of chlamydospores occurred after 30 minutes in 5000 ppm chlorine bleach. Clorox has recently been registered for use in treating water for firefighting or dust abatement to decrease probability of *P. lateralis* spread.

8) Featuring Port-Orford-cedar in Areas Unfavorable for the Pathogen

This approach involves preferentially managing Port-Orford-cedars on sites where conditions make it likely that hosts will escape infection by *P. lateralis* even if the pathogen has already been established nearby or may be introduced nearby in the future. Cedars are featured above and away from roads, uphill from creeks, on ridgetops, and on well-drained sites. Maintaining existing Port-Orford-cedars on low vulnerability sites as well as actually developing "cedar production areas" by planting and actively managing Port-Orford-cedars on sites with such characteristics are both approaches being used.

9) Special Direct Management in Currently Infested Areas

This approach involves managing some component of Port-Orford-cedar in stands occurring on already infested sites by situating or maintaining cedars in locations where they individually have a low likelihood of becoming infected and by spacing cedars widely enough that probability of root to root spread as well as spread via water is reduced. Cedars are favored in plantings and thinnings on microsites that are unfavorable for the pathogen (particularly mounds and other high places) and are not managed on microsites especially favorable for infection (close to and below roads, in or very close to streams or drainage ditches, and in lowlying wet areas). Cedars are planted or retained in thinnings in mixed species stands at wide spacing (8.5m or more between individual trees or in small groups of 10 to 20 trees 33m apart).

10) Species Manipulation

This approach involves favoring other tree species that are appropriate for local sites over Port-Orford-cedars in management. It is especially applicable on sites where *P. lateralis* is already established or in sites that are particularly favorable for future establishment of the pathogen such as wet areas, stream sides, or concave slopes below roads. Other tree species can occupy sites where Port-Orford-cedars are no longer able to and will themselves face no risk of being damaged by the root disease. However, no other species can command the same economic value as Port-Orford-cedar or consistently fulfill the same ecological roles. Some hardwoods, western red cedar (*Thuja plicata*) and yellow-cedar may be able to play similar ecological roles in riparian zones in some portions of Port-Orford-cedar's range and blister rust-resistant western white pine (*Pinus monticola*) and sugar pine (*P. lambertiana*) may ultimately provide large tree components in some stands on ultramafic soils. By and large, however, Federal managers are interested in maintaining Port-Orford-cedar itself in as many appropriate areas as possible.

11) Regulating Non-timber Uses

A number of special use activities including Port-Orford-cedar bough collecting, mushroom picking, salal gathering, grazing, and mining are engaged in on Federal forest lands and have potential to influence spread of *P. lateralis*. Several of the activities involve extensive vehicle travel. Some, if not controlled, can involve vehicle movement from infested to uninfested areas. And some, especially bough collecting and mushroom hunting, are preferentially engaged in at times of the year when the cool, wet conditions most favorable for spread of the pathogen prevail. Port-Orford-cedar bough collecting, of course, is concentrated in areas where cedars occur, and there is considerable anecdotal evidence associating bough collecting with spread of *P. lateralis*. Concerns about vectoring of *P. lateralis* with special use activities are similar to those associated with forest management projects, but special use activities are much harder to control. Where possible, managers attempt to regulate issuance of permits, specify where activities can be done, regulate the sequence of operations, and determine the appropriate timing of activities with the objectives of limiting Port-Orford-cedar root disease spread. Efforts are also made to inform permittees about the disease and convince them of the need to cooperate with disease management recommendations. Recreationists, including hikers, mountain bike riders, horseback riders, hunters, off road vehicle users, and campers also have considerable potential to spread *P. lateralis*. They are even harder to monitor and regulate than special use permittees. Recreationists can be controlled to some degree by closures and blockades, and organized, Federally sanctioned activities can have specific, enforceable rules aimed at decreasing risk of disease spread. However, most recreationists are probably best approached through education.

12) Educational Efforts

Humans are responsible for most spread of *P. lateralis*, yet a surprising number of forest workers as well as recreationists have no idea of the significance of the pathogen and may inadvertently aid its spread due to lack of knowledge and understanding regarding the issue. Some know a little about Port-Orford-cedar root disease but do not fully appreciate the implications of their own activities in vectoring the disease organism. Federal agencies are heavily involved in efforts to disseminate information on the biology and ecology of *P. lateralis* with emphasis on how the pathogen spreads and how spread can be prevented. Presentations at training sessions, workshops, and symposia as well as newspaper articles, television interviews, pamphlets, journal articles, displays at public functions, classroom teaching materials, and information signs at BLM offices, Ranger Stations, visitor information centers, and in campgrounds, along forest roads, and at trail heads are used.

DISEASE RESISTANCE

The most intriguing potential long term Port-Orford-cedar root disease management option is the possibility of developing genetic resistance to *P. lateralis* in Port-Orford-cedar populations. Hansen et al. (1989) demonstrated that some Port-Orford-cedars exhibit a degree of resistance to *P. lateralis*. Although no immune trees have been found, some trees are less readily infected by the pathogen and some survive longer than others when infected. Mechanisms of resistance are unknown but appear to be heritable.

The Forest Service and Bureau of Land Management in cooperation with Oregon State University have embarked on a program to identify resistance mechanisms, screen a large sample of candidate trees from across the range of Port-Orford-cedar, conserve resistant families, and develop a breeding program to enhance resistance.

Over 8,000 phenotypically resistant candidate trees selected in the forest have been screened using Oregon State University's branch lesion test. Cuttings are in the process of being rooted from the 961 best performers, a conservation orchard has been started at the Bureau of Land Management's Tyrrell Seed Orchard, and a containerized seed orchard for breeding has been developed at the Dorena Genetic Resource Center. Screening and field testing is continuing and breeding work has started. Fortunately, Port-Orford-cedar is very amenable to breeding efforts. Clones are relatively easy to root from cuttings, and flowering can be induced on most trees at very early ages (as little as two years old). Outplantings of the first trees identified as exhibiting a degree of resistance show that a substantial number can survive for at least 10 years in constant presence of the pathogen on infested sites that have characteristics particularly favorable for *P. lateralis* spread and infection.

The Federal agencies believe that results of the resistance effort so far are very encouraging. However, there is no guarantee that usable resistance will result. Resistance as a disease management technique cannot be realistically evaluated until the development effort has progressed further. If Port-Orford-cedars with a usable level of resistance to *P. lateralis* are ultimately developed, careful consideration and planning to determine how they should best be deployed in the field will be required. It has been determined that *P. lateralis* is genetically quite simple (Mills et al. 1991, Winton, McWilliams, and Hansen unpublished); this is consistent with the idea that there was probably a single introduction of the pathogen. If the genetic variation of *P. lateralis* is minimal, this should increase the likelihood that if resistant cedars can be found or developed through a breeding program, the resistance should hold up over time.

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