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Rhabdocline Needle Cast of Douglas-fir

Rhabdocline needle cast is a foliage disease caused by several species of fungi in the genus *Rhabdocline* (Syd.) (fig. 1). This disease primarily affects the needles of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). *Rhabdocline* spp. are considered endemic in the natural range of Douglas-fir, i.e., Western North America (fig. 2). Most species of *Rhabdocline* are specific to Douglas-fir, however, one species, *R. laricis*, is specific to larch (*Larix* spp.) and is the cause of larch needle cast. This species was formerly known as *Meria laricis,* and unlike other *Rhabdocline* species, is only known to reproduce asexually. This publication focuses on *Rhabdocline* spp. that are specific to Douglas-fir and are

Figure 1. Foliage of Douglas-fir with severe *Rhabdocline* infection. Notice the reddish-brown fruiting bodies and mottled green, yellow, and brown appearance of infected foliage. Photo by Nicholas Wilhelmi, USDA Forest Service.

Figure 2. Natural range of Douglas-fir *(Pseudotsuga menziesii)* (Little 1971; Thompson 1999).

associated with defoliation, growth loss, and partial crown or whole tree mortality when trees are subjected to severe defoliation for 3 or more consecutive years.

Needle cast caused by *Rhabdocline* has resulted in substantial losses in many forest plantations and Christmas tree farms. For example, *Rhabdocline* needle cast is a major disease of Douglas-fir grown for Christmas trees in the upper Midwest and Northeastern United States and can cause substantial damage to trees in landscape situations. Widespread outbreaks are generally associated with prolonged periods of cool temperatures and abnormally high precipitation in spring and summer. Much of the damage associated with *Rhabdocline* has been attributed to the planting of trees that are not adapted to local climatic conditions. In general, the coastal types of Douglas-fir are much less susceptible to *Rhabdocline* than the Rocky Mountain types. The establishment of tree seed transfer zones has greatly reduced the impacts of *Rhabdocline* in planted Douglas-fir forests in the Pacific Northwest. However, *Rhabdocline* remains a chronic problem for the Christmas tree industry, particularly in the Midwest and Northeastern United States. In addition, Rhabdocline needle cast may reemerge as an issue in Douglas-fir plantations as seed zones are modified and assisted migration is considered as part of adaptive management strategies to reduce impacts of projected climate change.

Background and Distribution

Rhabdocline needle cast was first observed affecting Douglas-fir in Montana and Idaho by Weir (1917). It was subsequently reported from Douglas-fir plantations in Europe and from the Northeastern United States. All *Rhabdocline* species are believed to be endemic to the natural range of Douglas-fir (fig. 2) and have since been introduced to areas where Douglas-fir is grown as an exotic through the movement of infected planting stock. While several *Rhabdocline* species are present in Western North America, only a single species, *R. pseudotsugae,* has been reported from Europe to date. Early reports from Europe described outbreaks of epidemic proportions and led to investigation into the life cycle and management strategies for this pathogen.

Initial observations of Rhabdocline needle cast indicated that infections were predominately on Douglas-fir from seedling stage to about 30 years. Many nurseries reported heavy infestations as well. Weir (1917) also reported that the disease did not seem to prefer suppressed or stressed trees. It was observed that the severity of disease appeared to be associated with closely spaced stands of pure Douglas-fir. Researchers in Europe characterized the life cycle of the fungus and identified its dependence on live green foliage to reproduce. Management strategies were developed in Europe that were focused on removal and burning or drying of infected foliage before sporulation.

Since these initial observations, considerable variation in host susceptibility among Douglas-fir provenances has been documented. Seed sources of the coastal variety of Douglas-fir (*P. menziesii* var. *menziesii*) are much more resistant to Rhabdocline needle cast compared to the Rocky Mountain variety of Douglas-fir (*P. menziesii* var. *glauca* (Beissn.) Franco), which consistently exhibits greater defoliation in common gardens. In western Oregon and Washington, Rhabdocline needle cast is primarily associated with offsite planting (e.g., growing interior seed sources west of the Cascade Range). In the drier inland regions, the disease is associated with site conditions, such as wet draws and flats where humid air settles, as well as climatic conditions, particularly sites prone to late spring and early summer precipitation. The high variation in resistance among Douglas-fir provenances has led to the use of genetic selection as the primary management tool for Rhabdocline needle cast in Douglas-fir and use of appropriate seed sources has greatly reduced major losses in forest plantations.

Because Christmas tree growers in western Washington and Oregon primarily only plant coastal provenances of Douglas-fir, *Rhabdocline* is now a sporadic problem in Christmas tree plantations located in this region. However, in other regions, where intermountain provenances are better adapted to growing conditions, *Rhabdocline* remains a concern for Christmas tree growers. Several seed sources of the intermountain variety have been identified that exhibit resistance to *Rhabdocline* and should be considered for use as Christmas tree and landscape nursery stock. Seed sources from lower elevations are more resistant to *Rhabdocline* than sources from higher elevations. The use of locally adapted seed sources and the application of protectant fungicides have enabled Christmas tree growers to grow trees from these seed sources in areas prone to *Rhabdocline* infection.

Biology and Life Cycle

Rhabdocline is an ascomycete fungus that produces spores in microscopic sacs known as asci. The asci of *Rhabdocline* develop within structures called apothecia (sing. apothecium), which erupt through the epidermis of the host needle (fig. 3). Ascospores are released in

Figure 3. Apothecia of *Rhabdocline* on Douglas-fir needles. Photo by Nicholas Wilhelmi, USDA Forest Service.

late spring and early summer, generally coinciding with Douglas-fir bud burst, shoot elongation, and mild/wet environmental conditions conducive to infection.

Infections in Douglas-fir needles are initiated by the germination of mature ascospores on the needle surface. Following infection through the cuticle, the fungus grows within the needle, penetrating and killing host cells as it progresses. The physiological response of the host creates the characteristic mottled chlorosis and necrotic spots indicative of a *Rhabdocline* infection (figs. 1, 7, and 8). The fungus continues to grow and colonize the needle throughout the winter. In early spring, apothecia emerge from the large necrotic spots below the epidermis and eventually rupture through the epidermis exposing the asci (fig. 3). The apothecia are initially bright orange upon emergence and gradually darken as the season progresses. The shapes of the apothecia vary depending on the species and can range from a small, brown disc to long and narrow and can span the entire width of the needle or be limited to one side of the midrib. Apothecia can be located on the upper or lower surface of the needle, depending on the species of *Rhabdocline*. Tiny flaps of host epidermis cover the emerging apothecia when conditions are dry, and they open as the hydrated apothecium expands when sufficient moisture is available to aid the dispersal of the ascospores. In addition, one species, *R. weirii*, produces asexual spores (conidia) in masses on the upper needle surface and apothecia on the lower needle surface.

Conducive Climate Conditions

High humidity, rain, and mild temperatures are most conducive to spore release and successful infection by *Rhabdocline*. The highest concentrations of mature ascospores are generally found in April, May, and June, decreasing as the temperature warms and conditions become less conducive to spore dispersal. However, if conditions remain conducive to spore dispersal, sporulation can persist through late summer and can infect lammas growth (second flushing) in early fall. Site location can influence development of disease and may provide conducive conditions longer into the growing season, particularly sites located in wet draws or flats where humid air settles (fig. 4).

Species of *Rhabdocline*

Currently, five species of *Rhabdocline* that cause disease in Douglas-fir are recognized: *R. epiphylla, R. oblonga, R. obovata, R. pseudotsugae,* and *R. weirii.* A sixth species, *R. parkeri,* is an endophyte of Douglas-fir foliage and does not cause disease. The use of Melzer's reagent (a solution containing iodine), together with differences in apothecial size, shape, and location on needles allows for the differentiation of these species (see table 1). It is important to note that two or more species are commonly found on the same needle and may complicate identification.

Some species of *Rhabdocline* may be distinguished based on the location of

Figure 4. Cool air drainage and humid air pooling are characteristic of mountainous terrain. Conditions for foliage diseases such as Rhabdocline needle cast may be increased in areas of humid air pooling. Red arrows indicate direction of air flow (in absence of wind) and grey wisps indicate possible fog or humid air accumulation. Illustration by Gretchen Bracher from Managing Insects and Diseases of Oregon Conifers (EM 8980), © 2018 Oregon State University.

apothecium formation on a needle. For instance, *R. epiphylla* apothecia are predominantly on the upper (adaxial) needle surface, while *R. pseudotsugae* apothecia are on the lower (abaxial) needle surface, and only rarely on the adaxial surface (table 1, fig. 5). While the apothecia of *R. weirii* and *R. oblonga* may be found on 1-year-old needles, the apothecia of *R. obovata* are only found on needles 2-years-old and older. The apothecia of *R. oblonga* generally span the entire width of the needle, traversing the midrib, while the asci of *R. weirii* are narrow and restricted to one side of the midrib. The apothecia of *R. weirii* on the abaxial needle surface are usually accompanied by asexual, reproductive structures (acervuli) that emerge from the upper surface of the needle and produce masses of asexual spores. The asexual stage of *R. weirii* was formerly

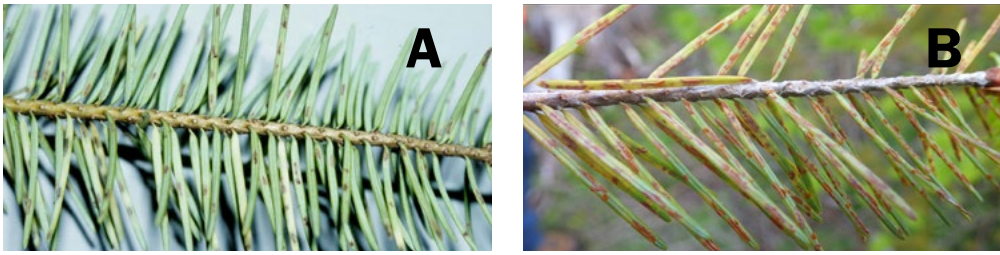

Figure 5. Apothecia of *Rhabdocline pseudotsugae* emerging from the lower needle surface (A). Apothecia of *R. epiphylla,* which may emerge from the upper or lower needle surface (B). Photo (A) by Jeff Stone (retired), Oregon State University; photo (B) by Nicholas Wilhelmi, USDA Forest Service.

Table 1. Morphological descriptions of the *Rhabdocline* species that cause disease on Douglas-fir

Rhabdocline species	Needle surface on which apothecia are formed	Extent of apothecia formation on needle surface	Age of foliage on which apothecia are formed	Spore stages produced	Ascus tip staining blue in Melzer's reagent (amyloid reaction)	Size of paraphyses	Shape of paraphyses
R. epiphylla	Mainly on upper (adaxial) surface, may also occur on lower (abaxial) surface	On one or both sides of midrib	1-year-old only	Apothecia/ ascospores only	No	> 3.5 µm	Clavate (club shaped) with enlarged apex
R. oblonga	Abaxial	Extending across midrib spanning entire width of the needle	Mostly on 1-year-old	Apothecia/ ascospores only	Yes	< 3.5 µm	Not enlarged at apex
R. obovata	Abaxial	On one or both sides of midrib	2-years-old and older	Apothecia/ ascospores only	Yes	< 3.5 µm	Not enlarged at apex
R. pseudotsugae	Abaxial, rarely adaxial	On one or both sides of midrib	1-year-old only	Apothecia/ ascospores only	No	< 3.5 µm	Not enlarged at apex
R. weirii	Abaxial	On one or both sides of midrib	1-year-old and older	Acervuli/conidia and apothecia/ ascospores	Yes	< 3.5 µm	Not enlarged at apex

designated by a separate scientific name, *Rhabdogloeum pseudotsugae,* but separate scientific names for sexual and asexual forms of the same species are no longer used.

The asci of *R. weirii, R. obovata,* and *R. oblonga* possess structures at the apex that turn blue in the presence of Melzer's reagent (fig. 6). *Rhabdocline pseudotsugae* and *R. epiphylla* do not possess this structure and therefore do not stain blue when exposed to iodine solution. Paraphyses are microscopic, sterile filaments interspersed among the asci, and the morphology of the paraphyses also aids in the identification of *Rhabdocline* species (table 1). *Rhabdocline epiphylla* possesses paraphyses that are broader (> 3.5 µm) and clavate (having inflated tips). The paraphyses of *R. pseudotsugae* are narrower, less than 3.5 µm in width, and are not enlarged at the tip.

Symptoms

Initial symptoms of infection become visible in late summer or early fall as small chlorotic spots on the current year needles. These chlorotic spots represent separate infection sites and therefore can vary in abundance. As winter progresses these spots gradually enlarge and coalesce and begin darkening to brown or reddish shades. The contrast between healthy green areas and infected portions of the needle becomes much more pronounced. The appearance of the needle becomes mottled, yellow, and chlorotic. By late spring/early summer, heavily infected needles turn straw yellow to reddish light brown (fig. 7). Apothecia then begin to erupt through the needle epidermis, either on the upper or lower surface of the needle depending on the species. Needles generally abscise in early summer; however, needle abscission can occur prior to bud burst in highly susceptible trees or, in the case of light infections, needles may remain for another season. By late summer and fall, diagnosis of the cause of needle loss may be difficult, as the symptomatic foliage is gone. Infections are generally greater in the lower portion of the crown, where the microclimate is more favorable to prolonged periods of free moisture on the needles.

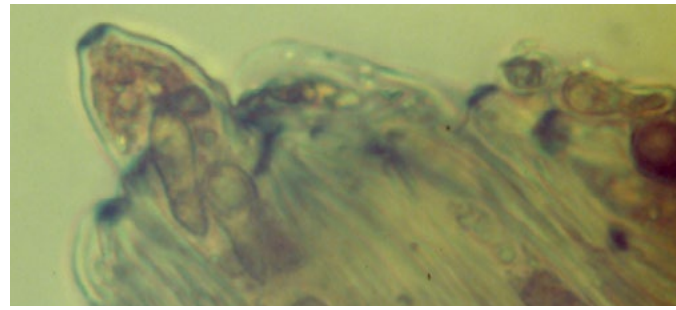

Figure 6. Asci of *Rhabdocline obovata.* Note the blue tips of the asci in reaction to Melzer's reagent. Photo by Jeff Stone (retired), Oregon State University.

Figure 7. Heavily infected, highly susceptible tree planted among trees that are tolerant or resistant to Rhabdocline needle cast. Photo by Nicholas Wilhelmi, USDA Forest Service.

Impacts

Impacts of Rhabdocline needle cast include crown discoloration, low needle retention, and growth loss. Consecutive years of severe infection may predispose trees to secondary insects and diseases and may contribute to mortality. Significant loss of foliage, particularly for consecutive years (fig. 8), will lead to reductions in diameter and height growth. Cubic volume growth loss of Douglas-fir affected by the foliar disease Swiss needle cast, which retain only a single age class of needles, is estimated to be as high as 50 percent. Radial growth of trees with moderate to severe *Rhabdocline* infection (70–90 percent of crown infected) is estimated to be 50–65 percent of that of healthy, uninfected trees. Reduction in height growth for trees with severe infection is estimated to be as high as 70 percent. Severe infections will affect the value of trees in Christmas tree markets and may render many infected trees unmarketable due to crown discoloration and reduced density associated with poor needle retention pre- and postharvest.

Figure 8. Comparison of foliage retention and color on a branch from a healthy tree (left) and branches from a tree with Rhabdocline needle cast symptoms (right). The branch on the left has greater than 2 years of foliage remaining, while the branches on the right have only 1 year of foliage. Photo by David Shaw, Oregon State University.

Forest Plantation Management

It is important to distinguish *Rhabdocline* as the causal agent of premature needle loss and disease symptoms from other potential defoliators. Needle loss can be caused by several different insects and diseases or abiotic factors. In some instances, these other causal agents may occur at the same time as *Rhabdocline*. Effective management of an insect or disease requires accurate diagnosis. The presence of apothecia on symptomatic needles is diagnostic for *Rhabdocline*. If fruiting bodies are not present, samples may need to be submitted to a diagnostic lab for positive identification of *Rhabdocline*. If *Rhabdocline* is identified, there are management practices that may help to mitigate impacts including the use of appropriate seed sources, site selection, thinning, and appropriate species selection (table 2). The use of the appropriate species and seed source for the site are the most important aspects in the management of Rhabdocline needle cast and most other Douglas-fir foliage diseases. Abiding by established tree seed transfer zones, which outline geographic zones in which seed can be transferred, aids in identifying seed sources adapted to current growing conditions and local pathogens. It also is important to establish a threshold to determine when the impacts of Rhabdocline needle

Table 2. Management options for Rhabdocline needle cast in Douglas-fir plantations and Christmas tree farms.

Seed source	Use local seed sources following known guidelines. If assisted migration is considered, use seed sources from climates similar to the current climate of planting location (temperature and seasonality of rainfall). Christmas tree growers may deviate from guidelines with an integrated pest management (IPM) approach strategy including the use of fungicide.
Landscape setting	Cold air drainage pockets and areas of humid air pooling, including areas adjacent to bodies of water are conducive to Rhabdocline needle cast and may need to be avoided or planted with an alternate species (fig. 4).
Vegetation management	Control of tall vegetation to reduce moisture on needles and improve airflow.
Thinning crop trees	Wider spacing of crop trees will increase airflow and reduce humidity around foliage, creating conditions less conducive to Rhabdocline needle cast.
Species composition	Changing species, either with species mixes or moving to a different species completely, may be necessary on some sites.
Fertilization	No known effects, positive or negative, for fertilization. Use only after foliage nutrient tests to determine need.
Fungicides (foliage protectants)	Fungicides can protect foliage from infection. Only recommended for Christmas tree farms particularly those that plant seeds sources susceptible to Rhabdocline needle cast. Concerns about potential environmental impacts (e.g., fish toxicity) and cost preclude utility of fungicides in forest plantations.
IPM and monitoring	In Christmas tree farms, an IPM is recommended. Monitoring is central to developing effective management strategies.

cast have become an economic threat. This will aid in management decisions regarding the disease.

Areas where cool air drainage occurs and areas where fog regularly settles also contribute to risk of foliage diseases, especially in dry, inland forests. These are the most common areas for disease development in the inland Northwest but can also play an important role in coastal forests as well (e.g., in the drier Klamath-Siskyou region). Areas with mild temperatures and high moisture, such as coastal Oregon and Washington, provide ideal conditions for foliage disease development. Local seed sources tend to be more resistant to foliage diseases. In drier forests, land managers should identify areas on the landscape where conducive conditions for disease may develop and perhaps consider an alternate species in these areas if disease continually persists. Thinning and wider spacing of trees can help to increase air flow and make conditions less conducive to disease.

Seed Source

It is generally accepted that the use of locally adapted seed sources is the most effective way to prevent Rhabdocline needle cast in forest plantations. Seed sources from outside the range of their natural habitat and climate conditions will, in general, be much more susceptible to Rhabdocline needle cast and other foliage diseases (fig. 9). Planting trees in environments similar to their native environments will help to ensure they have been exposed to and developed a tolerance and or resistance to pathogens that also prefer that environment. Utilizing established tree seed transfer zones will aid in the identification of optimal seed sources for a given site.

Figure 9. Resistant Washington coast seed source (left) planted next to a highly susceptible seed source from a drier, northern California region (right) at a low-elevation site in Oregon's southern Cascades. Photo by Nicholas Wilhelmi, USDA Forest Service.

Variation in resistance to Rhabdocline needle cast occurs in seed sources of both the coastal and the Rocky Mountain varieties of Douglas-fir. The coastal variety of Douglas-fir is generally much more tolerant/resistant to Rhabdocline needle cast than the Rocky Mountain variety. Seed sources from cool/moist climates, such as maritime coastal environments west of the Cascades are, in general, more tolerant to the disease. Resistance has also been shown to be negatively correlated with elevation; seed sources from lower elevations have consistently shown higher resistance to Rhabdocline needle cast than provenances from higher elevations. Winter temperatures are predicted to increase over the next several decades and may increasingly favor rain at higher elevations. Warmer temperatures and an increase in precipitation as rain may create conducive conditions for *Rhabdocline* infection in high-elevation settings where trees are not adapted to high-disease pressure. Therefore, natural, high-elevation Douglas-fir stands may be at increasing risk of losses from *Rhabdocline* due to climate warming. The use of lower elevation seed sources in these high-elevation plantations may help to ameliorate the impacts of Rhabdocline needle cast if damage due to this pathogen is consistently observed and exceeds acceptable thresholds. Other adaptive traits such as cold hardiness should always be considered when making these decisions.

It is important to consider potential impacts from pathogens such as *Rhabdocline* when implementing management strategies such as "assisted migration." Assisted migration may expose populations or provenances of Douglas-fir to novel environments, and possibly pathogens, to which they may be poorly adapted. Some "assisted migration" advocates have suggested the movement of populations of tree species from south to north, in anticipation of climate warming. In many instances this is movement from xeric continental areas to areas that are mesic and maritime. Such recommendations carry the risk of exposing provenances lacking disease resistance to habitats more conducive to foliage diseases, such as Rhabdocline needle cast. Such movement of seed sources may result in severe impacts from Rhabdocline needle cast, or other foliage diseases, and subsequent losses in productivity (fig. 10). Significant risk factors to consider in "assisted migration" plantings are mean winter temperature and May–July (late spring and early summer) precipitation. Moving seed sources from sites with lower to higher mean winter temperature and/or from lower to higher May through September precipitation increases risk of severe infection and losses in productivity.

Thinning

Increasing airflow through the wider spacing of trees and the control of competing vegetation will help to ameliorate conducive conditions for disease development in some regions. Lower stocking densities/wider spacing of trees will help to reduce needle wetness and allow more light and air circulation to reach the lower crowns enabling the crowns to dry more quickly while also

Figure 10. Seedling highly susceptible to Rhabdocline needle cast. Note the brown color of infected 1-year needles and bright green color of the emerging current year needles. Photo by Nicholas Wilhelmi, USDA Forest Service.

increasing the dewpoint temperature in the crown. This will help to make conditions less conducive to the dispersal of spores and infection by *Rhabdocline*. Thinning also provides an opportunity to cull visibly diseased individuals and favor the healthier, better performing trees. In areas of high-disease risk this may mean favoring alternate species as Douglas-fir is the only host for this disease.

Species Composition

Rhabdocline needle cast only affects Douglas-fir and therefore, the planting of alternate species in areas that have exhibited high-disease risk will help to reduce the impacts of the disease. Most alternate conifer species that are, or were, naturally occurring on the site are generally suitable to interplant with Douglas-fir. Economic considerations should be made when value is the main objective, a low level of disease may not warrant diversification of species. It is also important to be familiar with diseases associated with alternate species that may be preferred in order to make the appropriate decision. For example, an area that has proven to be unsuitable for Douglas-fir due to Rhabdocline needle cast may not be suitable for western larch because the larch needle cast pathogen prefers similar conditions. Similarly, ponderosa pine may be affected by foliar pathogens such as *Dothistroma* spp. or *Lophodermella* spp. Selection of an appropriate species will also be influenced by consideration of root-rot pathogens such as *Armillaria* spp., which will affect different species depending on site characteristics. Avoid planting species that are susceptible to Armillaria root disease on sites where the disease is known to occur.

Fertilization

There is no evidence that fertilization with nitrogen or phosphorus affects Rhabdocline needle cast incidence or severity. It is recommended that soil nutrient content be analyzed to determine if fertilization is needed. This will ensure an appropriate fertilizer regime for optimal growth is implemented, if deemed necessary.

Fungicides

The application of a protectant fungicide, such as chlorothalonil, at bud burst is effective in controlling Rhabdocline needle cast. Applications of fungicides are needed annually to control the disease because only current year needles are protected. Thus, because of the cost and the need for annual applications, the use of fungicides is not recommended for management of Rhabdocline needle cast in forest plantations.

Christmas Tree Plantation Management

The Pacific Northwest produces a third of the 25 to 30 million Christmas trees produced annually in the United States and around 45 percent of these trees are Douglas-fir (fig. 11). Most Christmas tree growers in western Oregon and Washington limit their production to the coastal variety of Douglas-fir because of the adaptability of this species to this region and the impacts of Rhabdocline needle cast on the more susceptible intermountain variety. However, because of characteristics, such as frost tolerance, desirable color, and post harvest needle retention, many growers in other production regions prefer to grow the Rocky Mountain variety of Douglas-fir. These characteristics make these seed sources better options for growers in the Eastern United States and other areas with similar climates.

The management strategies outlined for operational forest plantations, other than the unfeasibility of the use of fungicides, also apply to Christmas tree growers (table 2). An integrated pest management (IPM) strategy is best used, and fungicides can be targeted for the final 3 years of growing to enhance crown fullness. It is important to establish a threshold to determine when Rhabdocline needle cast has become an economic threat. This will aid in management decisions regarding *Rhabdocline*. Contact your regional pathologist or extension agent for additional information and recommendations relating to fungicides.

Figure 11. Douglas-fir trees growing on a tree farm in the Willamette Valley, Oregon. Licensed photo by Jacquie Klose/Adobe Stock.

Seed Sources

Many Pacific Northwest Christmas tree growers have transitioned to using seed sources of the coastal variety of Douglas-fir because of the susceptibility of the more desirable Rocky Mountain variety to Rhabdocline needle cast. The use of coastal variety seed sources greatly reduces the risk of losses caused by Rhabdocline needle cast, and the use of these seed sources will also reduce the need to apply fungicides to control disease, thus, requiring less economic investment in the management of Rhabdocline needle cast.

For growers who prefer to grow the Rocky Mountain variety, highly disease-resistant seed sources have been identified. Research has shown that northern interior seed sources, such as those from Montana and Idaho, generally have a higher resistance to Rhabdocline needle cast than sources from the Southwest. However, certain seed sources from New Mexico also have shown a high resistance to Rhabdocline needle cast. Due to various characteristics, these seed sources are very desirable in the Christmas tree industry. Research has also shown that, in general, seed sources from lower elevations are more resistant to Rhabdocline needle cast than seed sources from higher elevations. However, it is important to know that resistance to Rhabdocline needle cast can be variable, even within families that are, on average, resistant. Therefore, unless the trees planted are rooted cuttings or clones of a known resistant genotype, the level of true resistance will be unknown. Sourcing seed from regions known to have a high level of resistance will help to ameliorate the impacts of disease and is recommended in areas that are prone to this disease.

Site Establishment

When choosing a site for the establishment of a Christmas tree plantation, be sure that it has good air circulation, sufficient water drainage, and is not located in an area of cool air drainage or an area where fog tends to settle (fig. 4). Control competing vegetation and space trees to promote air flow and the drying of the lower crowns where disease tends to be most severe. Wider spacing of trees can help to increase air flow and make conditions less conducive to disease.

Monitoring and Adaptive Management

Monitoring is a critical aspect of a successful IPM regime. Start monitoring for disease in the late winter to identify susceptible trees showing the characteristic *Rhabdocline* symptoms, paying close attention to the lower crown where disease tends to be the worst. Continue monitoring throughout the early spring until bud burst. Early identification and removal of heavily infected, highly susceptible genotypes will help to reduce losses and will also help to reduce the inoculum levels on the site. This will also enable the establishment of a different, possibly more resistant, genotype in the place of culled individuals. Remove susceptible trees prior to bud burst. When monitoring, pay close attention to areas

of poor air circulation, areas that tend to hold fog, and those that have exhibited disease in the past. Regular monitoring will provide valuable information as to whether the use of fungicides is appropriate.

Fungicides

The use of fungicides can be very practical and effective in controlling Rhabdocline needle cast in Christmas tree plantations and is very important if growing highly susceptible Rocky Mountain variety seed sources. Chlorothalonil is the most commonly used protectant fungicide and is sold under various product names. Azoxystrobin has also been labeled for use for Rhabdocline needle cast under the trade name Quadris®. Tests have proven this product to be less cost effective and less effective in the control of Rhabdocline needle cast.

Most fungicides are protectants and cannot control disease development once infection has taken place. Thus, it is generally recommended to apply a chlorothalonil-based product when trees begin to show signs of bud burst. Because there is often tremendous tree-to-tree variation in bud burst, it is recommended to wait until there is 1 to 2 inches of new growth on 50 percent of the trees in a plantation before the first application. Given that needles are susceptible as soon as they emerge, it is better to make the initial application early than late. Depending on disease pressure, an additional application may need to be applied 2 to 3 weeks after the initial application is applied.

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Assistance

Private landowners can get more information from State forest health specialists, State agricultural departments, or university agricultural extension agents. Federal resource managers should contact the USDA Forest Service, Forest Health Protection (https://www.fs.fed.us/foresthealth/).

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