



Photo: Alan Kanaskie

# PREVENTING *PHYTOPHTHORA* INFESTATIONS IN RESTORATION NURSERIES

A Key to Protecting Wildland Plant Communities



**Oregon State University**  
**Extension Service**

© 2022 Oregon State University

**Oregon State University Extension Service**

422 Kerr Administration Building

Corvallis, OR 97331

[catalog.extension.oregonstate.edu](http://catalog.extension.oregonstate.edu)

Trade-name products and services are mentioned as illustrations only. This does not mean that Oregon State University Extension Service either endorses these products and services or intends to discriminate against products and services not mentioned.

Extension work is a cooperative program of Oregon State University, the U.S. Department of Agriculture, and Oregon counties. Oregon State University Extension Service offers educational programs, activities, and materials without discrimination on the basis of race, color, national origin, religion, sex, gender identity (including gender expression), sexual orientation, disability, age, marital status, familial/parental status, income derived from a public assistance program, political beliefs, genetic information, veteran's status, reprisal or retaliation for prior civil rights activity. (Not all prohibited bases apply to all programs.) This publication will be made available in an accessible format upon request. Contact [puborders@oregonstate.edu](mailto:puborders@oregonstate.edu) or 800-561-6719.

# PREVENTING *PHYTOPHTHORA* INFESTATIONS IN RESTORATION NURSERIES

A Key to Protecting Wildland Plant Communities

**Norma Kline**

Forestry and Natural Resource Extension, assistant professor of practice  
Oregon State University

**Marianne Elliott**

Research associate, Department of Plant Pathology, Washington State University, Puyallup Research and Extension Center

**Jennifer Parke**

Professor (senior research), departments of Crop and Soil Science and Botany and Plant Pathology  
Oregon State University

**Dan Stark**

Forestry and Natural Resource Extension, assistant professor of practice  
Oregon State University

**Dave Shaw**

Forestry and Natural Resources Extension, professor, Department of Forest Engineering, Resources and Management  
Oregon State University

**Alicia Christiansen**

Forestry and Natural Resources Extension, assistant professor of practice, Oregon State University



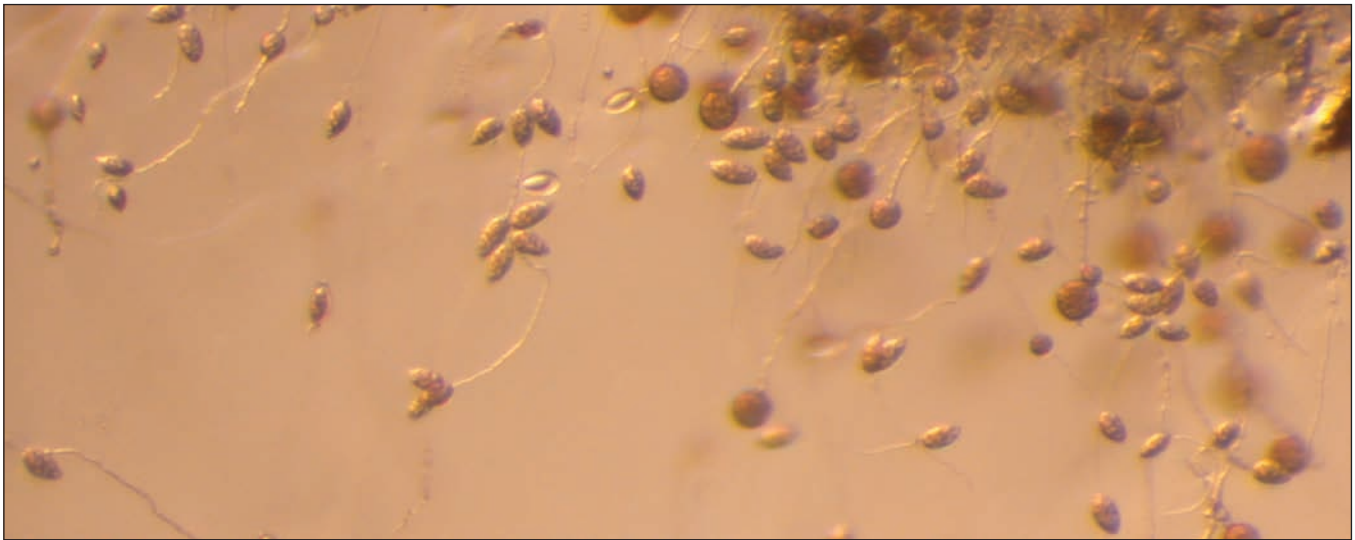


Figure 1. *Phytophthora ramorum* as seen under a microscope.

Photo: Jennifer Parke,  
© Oregon State University

## Contents

- 8 How are non-native *Phytophthora* species introduced?
- 9 Why are nurseries susceptible?
- 9 What can be done?
- 9 Prevention guidelines
- 10 Best management practices for nurseries
- 14 Disposing of unhealthy plants
- 14 Create a “gravel sandwich”
- 15 Risks of moving plants into the nursery from off site
- 15 Sanitation approaches for containers, tools, potting media and soil
- 17 Chemical disinfectants
- 19 Heat treatment
- 23 Recognizing *Phytophthora* symptoms
- 25 *Phytophthora* symptom checklist for restoration plants
- 26 What about bare-root plants?
- 26 What happens when you find plants with potential disease symptoms?
- 27 Implementing a bench testing monitoring strategy in addition to physical inspection
- 28 Diagnostic testing resources
- 29 A diagnostic test reveals that a plant is positive for *Phytophthora* — what’s next?
- 29 State and federal plant health regulatory agencies
- 29 Recommendations
- 30 *Phytophthora* species of concern in restoration nurseries
- 32 Use of chemicals and biocontrols
- 32 Nursery organization and recordkeeping
- 33 Solutions for nurseries
- 33 Nursery licensing and inspection programs
- 33 Purchasing native plants
- 33 *Phytophthora* prevention at restoration sites
- 34 What does the future hold?
- 35 Resources







Photo: U.S. Forest Service Region 5, CC-BY-NC-SA 2.0

Figure 2. Tanoak killed by *Phytophthora ramorum* in Curry County, Oregon.

**P**HYTOPHTHORA SPECIES ARE AN INVISIBLE THREAT to ecosystems in the Pacific Northwest. These plant pathogens can remain undetected in container plants, on field equipment and even footwear. They have been inadvertently introduced to wildland plant communities in the western United States and around the world (Figures 2 and 3). Once these invasive pathogens are introduced to new ecosystems, they can spread widely under the right environmental conditions, damaging and killing plants (Figure 4). Eradication is difficult or impossible. This outcome is of particular concern to restoration practitioners replanting sensitive habitats altered by past management practices and invasive species (Figures 5 and 6). Preventing *Phytophthora* infestations in nurseries and restoration sites is a critical step in the long-term success of restoration projects. This publication is designed to help nursery growers and their clients recognize and prevent *Phytophthora* infestations in nurseries and restoration sites.



Figure 3. A quarantine area in Curry County.

Photo: Alan Kanaskie



Figure 4. *Phytophthora* dieback in a Global Biodiversity Hotspot, Western Australia.

Photo: Everett Hansen, © Oregon State University

Phytophthoras are water molds, which are microscopic organisms (Figure 1) that thrive and spread in moist conditions. They cause plant diseases worldwide. Similar to fungi, they grow root-like structures called hyphae and produce spores. A unique feature of Phytophthoras are mobile spores with specialized structures that enable them to swim. There are more than 150 described species of *Phytophthora* worldwide. They are among the most destructive pathogens of agricultural and horticultural crops as well as wildland plant communities. One notable agricultural example is *P. infestans*, which caused the Irish potato famine of the 1840s. Wildland introductions include:

- **P. RAMORUM**, the pathogen responsible for the extensive mortality of tanoak in Curry County, Oregon, and central and north coastal California.
- **P. LATERALIS**, which was inadvertently introduced on infested ornamental nursery stock and spread to wildlands in southern Oregon in the 1950s and has infected and killed Port-Orford-cedar throughout its natural range.
- **P. CINNAMOMI**, which causes severe root rot problems on eucalypt forests in Western Australia, and chestnut and short-leaf pine in the eastern U.S. It is considered an increasing threat to forests of western North America as temperatures rise.





Figure 5. Restoration planting with high potential of *Phytophthora* spread due to wet riparian conditions.

Photo: Marianne Elliott, Washington State University



Figure 6. Volunteers planting bitterbrush and sagebrush to help restore native habitat.

Photo: Kirsten, CCBY 2.0

## How are non-native *Phytophthora* species introduced to natural ecosystems?

Shipment and planting of infected nursery stock (Figure 7) is considered the most common means for the introduction of new *Phytophthora* species into landscapes and habitats worldwide. Once infected nursery stock are planted, the pathogen has a number of mechanisms for spreading, including soilborne (*P. lateralis*) or wind- or rain-borne spores (*P. ramorum*). A distressing new introduction was discovered in 2012, when *P. tentaculata* was detected in several California native plant nurseries and restoration sites. This inadvertent planting of infected sticky monkey flower, *Diplacus aurantiacus*, into wild populations elevated the need to prevent further introductions through increased recognition and awareness. Since then, many native plant nurseries surveyed in California, Oregon and Washington have been found to harbor *Phytophthora* species.



Figure 7. Restoration container stock is the most common means for the introduction of new *Phytophthora* species.

Photo: Marianne Elliott, Washington State University



## Why are nurseries susceptible?

The disease triangle in Figure 8 illustrates the three factors that are necessary for a plant disease to develop. There must be a susceptible host plant, a virulent pathogen and conducive environmental conditions. Many *Phytophthora* species have a wide range of host species commonly grown by nurseries. *Phytophthora* can be inadvertently introduced into a nursery by sharing contaminated stock; using contaminated pots, soil or equipment; irrigating with contaminated water; or even carried in on employees' or visitors' footwear and vehicles. Nurseries with poor drainage or the tendency to overwater create ideal environmental conditions for these water molds. Plants grown in tightly packed arrangements and propagation from cuttings can facilitate rapid pathogen spread via soil splash or transfer on infested tools.

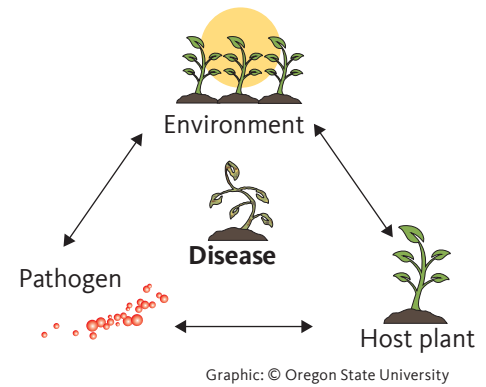


Figure 8. Plant disease triangle.

## What can be done?

Nursery and restoration practitioners involved in planting projects play a key role in recognizing and preventing invasive pathogen introductions. Take these steps to prevent infestations in the nursery and native ecosystems:

- Follow best management practices (Table 1) to prevent pathogen introductions and conditions favorable to disease spread at every phase from the nursery to the restoration site.
- Implement a systematic monitoring plan to assess nursery plant health.
- Know what a healthy plant looks like.
- Recognize and correct problems at early stages of disease before they become widespread.
- Know when to use diagnostic tests.
- Destroy diseased plants.
- Buy plants only from nurseries that follow best management practices for disease prevention. See Table 1, page 10, and “Purchasing native plants,” page 33. Use best management practices to avoid introductions when planting in restoration sites. See “*Phytophthora* prevention at restoration sites,” page 33.

The best management practices recommended throughout this publication are intended to reduce the introduction of pathogens to nurseries and restoration sites. Adhere to monitoring, testing and sanitization to help restrict pathogen infestations. Create nursery conditions that interrupt potential paths of contamination. Take utmost care in restoring plants in sensitive habitats to prevent pathogen introductions. Ensure that each step at the nursery and during a restoration project is designed to prevent contamination. Check your state’s licensing and shipping requirements and consult with your department of agriculture to ensure compliance with state programs. (See “Nursery licensing and inspection programs,” page 33.) Additionally, a new voluntary nursery certification program, Systems Approach to Nursery Certification, or SANC, is in development; see “Resources,” page 35.

## Prevention guidelines

Preventing *Phytophthora* infestations in the nursery setting is the first step in the chain of actions that will help protect against wildland infestations and damage on a larger scale. Table 1 describes best management practices that will help reduce the conditions that foster disease and prevent pathogens from being introduced, as well as nursery practices to avoid spreading the disease. The key to disease prevention is to identify and interrupt all potential paths of contamination from potentially infested soils, plants and water, at every phase of the nursery process. These practices also aid in the production of healthy plant stock. While the focus in Table 1 is on best management practices that will help produce clean container nursery stock, many of these practices will help nurseries growing bare-root stock as well.

# Table 1. Best management practices for nurseries

Recommended practices	Poor nursery practices that can lead to <i>Phytophthora</i> infestations
-----------------------	--

## PLANT HEALTH

- Plants should appear healthy.
- Closely monitor plants for disease symptoms.
- Be careful of plants brought in from off-site. See “Risks of moving plants into the nursery from off-site,” page 15.

- Ignoring foliar, stem or root symptoms (Figure 9). See “Recognizing *Phytophthora* symptoms” (page 23).
- Improperly disposing of diseased plants. See “Disposing of unhealthy plants” (Page 14).
- Failing to monitor disease and not having and following an effective disease management plan.



Photo: Marianne Elliott, Washington State University  
 Figure 9. Don't ignore dead or dying plants, as they could be a source of disease.

## CONTAINERS AND POTTING MATERIAL



Photo: Marianne Elliott, Washington State University  
 Figure 10. Clean containers stored in marked bins off the ground.



Marianne Elliott, Washington State University  
 Figure 12. Dirty pots can be contaminated with pathogens.



Jennifer Parke, © Oregon State University  
 Figure 13. Potting soil stored in contact with the ground is at risk of infection.

- Use all new containers, if possible.
- Any containers that are reused need to be properly sanitized. See “Sanitation approaches for containers, tools, potting media and soil,” page 15. Be especially careful to sanitize used containers that are donated.
- Store clean containers off the ground in clean racks or covered bins (Figure 10).
- Use potting materials that have been heat-treated.
- Potting media, soil and compost can be baited to test for contamination. See video tutorial, *Baiting — a method for early detection of Phytophthora*, page 35.
- Store potting materials in sealed bins or bags with no direct ground contact (Figure 11).
- Ensure that tools and equipment for mixing and loading potting materials are clean.



Photo: Regina Johnson  
 Figure 11. Heat-treated commercial potting soil is low risk.

- Reusing containers that are not properly sanitized (Figure 12).
- Storing containers on the ground.
- Storing large piles of dirty containers next to clean containers.
- Using tools and equipment that have not been thoroughly cleaned.
- Placing any component of potting media in contact with the ground (Figure 13).

## Recommended practices

### WATER AND IRRIGATION

- Ensure good drainage in the nursery site.
- Confirm that all irrigation water comes from a pathogen-free water source, such as municipal water or a well. Assume that water from surface sources (rivers, ponds) is contaminated and needs treatment. If in doubt, see article Testing the waters — how to test your irrigation system for the presence of *Phytophthora* (“Resources,” page 35).
- Employ irrigation systems that minimize splash between containers, such as drip irrigation.
- Verify that irrigation systems deliver the right amount of water. There should be no pooling of water or drought-stressed plants.
- Keep hoses and wands off the ground.

## Poor nursery practices that can lead to *Phytophthora* infestations



Photo: Liz West, CC-BY-2.0

Figure 14. Untreated surface water is a source of contamination.



Jennifer Parke, © Oregon State University

Figure 15. Mud splashed onto foliage from puddles can spread disease.



Photo: Jennifer Parke, © Oregon State University

Figure 16. Standing water creates favorable conditions for spreading *Phytophthora*.

- Using irrigation practices that cause pooling. The presence of algae indicates a good environment for *Phytophthora* (Figure 16).
- Using drip irrigation for in-ground plantings with heavy soils or mulches that retain water. These moist conditions allow *Phytophthora* to survive and reproduce. If drip irrigation is used in this case, mulch should not come into contact with the plant stem.
- Storing hose wands and ends on the ground.
- Allowing rainwater runoff to accumulate into pools adjacent to plants, roadways or walkways.
- Irrigating with untreated surface water (Figure 14).
- Allowing mud to be splashed onto foliage during irrigation or by vehicles driving through puddles (Figure 15).

### WORKFLOW AND LAYOUT

- Maintain maximum separation between clean growing areas and potentially contaminated areas (holding areas for new plants, cull piles) of the nursery.
- To prevent contamination in the clean production zones, install barriers and control access by restricting movement from contaminated areas into clean production zone.
- Design workflow to move from clean areas in the nursery, such as plant propagation areas, to dirty areas, such as cull piles.
- Clearly separate the plant cull pile from clean production area to avoid cross-contamination.




Photo: Jennifer Parke, © Oregon State University

Figure 17. This cull pile poses a disease risk because it is not separated from the growing area of the nursery.

- Moving plants or materials from potentially contaminated areas into clean production areas.
- Allowing a workflow that results in potential contamination of production area.
- Placing a cull pile near a production area (Figure 17).



**Table 1.** Best management practices for nurseries (continued)

Recommended practices	Poor nursery practices that can lead to <i>Phytophthora</i> infestations
<b>PROPAGATION AND GROWING AREA</b>	
<ul style="list-style-type: none"> <li>■ Propagation area (where trays are filled and seeded, cuttings made) is kept scrupulously clean (Figure 18).</li> <li>■ Growing area kept separate from propagation area.</li> <li>■ Never place pots on bare soil.</li> <li>■ Plants are kept off the ground on benches at least 2–3 feet high (Figure 19). Pallets and overturned crates can also keep plants off the ground (Figure 20A, 20B).</li> <li>■ Surface covered by gravel, landscape fabric or “gravel sandwich” to prevent splashing from underlying soil (Figure 21). See “Create a ‘gravel sandwich,’” page 14. Landscape fabric used alone (between bare earth and pots) can become easily clogged.</li> <li>■ Ensure site has adequate drainage.</li> <li>■ Clean up leafy debris (Figure 22).</li> <li>■ Disinfect bench surfaces between crops.</li> <li>■ Prevent containers from tipping over.</li> <li>■ Dispose of sickly plants by heat treatment or in a properly located separate cull pile (Figure 23). Do not recycle diseased plants and potting media. See “Disposing of unhealthy plants,” page 14.</li> <li>■ Organize nursery with space between blocks on benches and between benches (Figure 24).</li> <li>■ In greenhouses, manage populations of fungus gnats and shore flies, which can spread <i>Phytophthora</i>.</li> </ul>	 <p data-bbox="1122 800 1481 821">Photo: Marianne Elliott, Washington State University</p> <p data-bbox="815 821 1365 846">Figure 25. Excess pooling and weeds can spread disease.</p> <ul style="list-style-type: none"> <li>■ Keeping plants in contact with native soil or in areas of poor drainage.</li> <li>■ Allowing native ground surfaces to be visible under benches and pots.</li> <li>■ Seeing signs of poor drainage (Figure 25).</li> <li>■ Having crowded benches and blocks.</li> <li>■ Failing to remove sickly and dead plants.</li> <li>■ Allowing leafy debris, weeds, moss and algae.</li> </ul>



Jeff Clark, Bureau of Land Management  
Figure 18. The propagation area should be kept clean.



Jennifer Parke, © Oregon State University  
Figure 19. Screened benches help prevent contamination.

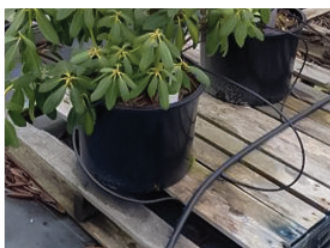


Photo: Marianne Elliott, Washington State University  
Figures 20A and 20B. Use pallets, crates and 2x4s to keep plants off the ground.



Marianne Elliott, Washington State University  
Figure 21. Landscape fabric creates a barrier between nursery plants and bare soil.



Jennifer Parke, © Oregon State University  
Figure 22. Leafy debris can be infested with pathogens and pose a risk to healthy plants.



Marianne Elliott, Washington State University  
Figure 23. Maintain separate cull pile for diseased plants.



Marianne Elliott, Washington State University  
Figure 24. Nursery organization allowing space between blocks.



## Recommended practices

## Poor nursery practices that can lead to *Phytophthora* infestations

### PHYTOSANITARY PRACTICES



Photo: Norma Kline, © Oregon State University

Figure 26. A footwear sanitation system.

- Not providing foot cleaning stations.
- Allowing workers to wear leather or cloth gloves in the growing zone.
- Using dirty tools and dirty gloves throughout nursery areas.

- Provide mandatory sanitizing foot baths (Figure 26) and instructional signage at the entrance to the growing area. See “Sanitation approaches for containers, tools, potting media and soil,” page 15.
- Have staff wear clean waterproof gloves.
- Implement a sanitizing system with clearly noted tool cleaning procedures.
- Dedicate tools, hoses, equipment for different growing areas in the nursery.

---

#### This table is adapted from these sources:

- *Buying healthy plants: What to look for at a nursery*. 2017. California Native Plant Society Ad Hoc Committee on Phytophthoras and the Phytophthoras in Native Habitats Work Group.
- *Guidelines to Minimize Phytophthora Pathogens in Restoration Nurseries*. 2020. Phytophthoras in Native Habitats Work Group, calphytos.org.



Figure 27. A “gravel sandwich” is created by placing landscape fabric below and above a layer of gravel to create a barrier between soil and plants.

Graphic: Mikayle Stole,  
© Oregon State University

## Disposing of unhealthy plants

Proper disposal of unhealthy and diseased plants is a critical step to prevent contamination in a nursery setting. Place diseased and unhealthy plants in a cull pile following these recommended practices:

- Locate the cull pile in an area separated from the growing area.
- Ensure that all water from cull pile drains away from nursery and does not drain into water used for irrigation.
- Ensure that material from cull pile is never used for compost.

For nurseries that have received a positive result for a *Phytophthora* species with a regulated status, see “A diagnostic test reveals that a plant is positive for *Phytophthora*; what’s next?” page 29.

## Create a ‘gravel sandwich’

Place plants on a gravel sandwich when it is not possible to elevate plants on benches, pallets or overturned bulb crates. Here’s how:

- Lay landscape fabric (weed cloth) over the soil to create a barrier and prevent the gravel from compacting into the soil (Figure 27).
- Next, install a layer of gravel 3 to 6 inches deep to promote drainage and prevent puddling.
- Lay landscape fabric over the gravel.
- Pin down the top and bottom edges of the landscape fabric to keep gravel in place (Figure 28).



Photo: Marianne Elliott, Washington State University

Figure 28. Pin down edges of landscape fabric to keep gravel in place.



Photo: Marianne Elliott, Washington State University

Figure 29. Leafy debris and waterlogged landscape fabric. Landscape fabric used alone can become easily clogged.

A gravel sandwich keeps out weeds and is easy to keep clean of plant debris that may harbor pathogens. While it may be tempting to use landscape fabric as a barrier between pots and the bare soil, landscape fabric alone can become easily clogged, creating drainage problems (Figure 29).

## Risks of moving plants into the nursery from off-site

Plants brought into the nursery from off-site locations pose a special risk of pathogen introduction. Off-site plants can include plants propagated at another nursery site owned or managed by the same nursery; plants shared or purchased from another nursery; or plants collected from the wild. Some restoration nurseries will not accept off-site plants due to this risk, preferring to propagate all their own plants. Plant returns are treated with the same risk as off-site plants since they were outside of the nursery's control. If you must procure plants from off-site or accept returns, follow these practices:

- Keep off-site and returned plants away from your clean areas in a segregated holding area for at least eight weeks.
- Inspect off-site or returned plants regularly. If practical, test for pathogens at the end of the holding period.
- Inform potential purchasers of plant origins. Purchasers may trust and know your nursery practices but will want to know of any plants that did not originate from your nursery or remain in your care.
- Never accept other nurseries' plants or empty containers left over from multinursery restoration projects. This transmits disease among restoration nurseries.

### Special considerations for bare-root plants from off-site locations

- Before you integrate bare-root plants obtained from off-site locations into nursery operations, segregate them as described above.
- Bare-root or plug plants obtained from off-site locations intended for transplanting in bare root beds should be purchased from nurseries with excellent practices, inspected prior to planting (Table 1, page 10) and monitored for plant health. For more information, see "Recognizing *Phytophthora* symptoms," page 23.

## Sanitation approaches for containers, tools, potting media and soil

There are several sanitation approaches available to restoration nurseries. The best methods for your nursery or restoration site depend on the scale of your operation. Materials to be sanitized, expense, labor and potential for environmental contamination are also factors.

When choosing a sanitation method, examine the tradeoff between labor costs and the cost of new materials. Packaged potting media may be the most cost-effective option for some operations. For pot sanitation, chemical disinfectants are cost-effective in terms of materials but require a number of careful steps to ensure reliable results. While sanitizing with heat treatment may be fast, it requires specialized equipment. Buying new pots can be the most expensive option for any size nursery.

Another consideration is the cost of disposing of used pots and its environmental impact. The least expensive option for a small nursery is to solarize used pots if conditions are suitable. Otherwise, consider washing and disinfecting pots, which requires more worker time but costs less in materials. Steaming is the most cost-effective choice for a larger nursery, even with higher initial costs for equipment. Labor costs for treating pots with steam are far less than for washing and disinfecting. See Table 2, page 16, for a summary of sanitation methods and their suggested uses. Refer to Tables 3 (page 18) and 4 (page 22) for safety, cost and environmental considerations of each sanitation method.

**Table 2.** Summary of sanitation methods and their suggested uses

Use	Recommended treatment
<b>Hand tools</b>	<ul style="list-style-type: none"> <li>■ Alcohol spray (70% isopropyl or ethanol), then let evaporate.</li> <li>■ Quaternary ammonium compounds, known as QAC.</li> </ul>
<b>Heavy equipment</b>	Hot water spray (82–93°C, 180–200°F).
<b>Benches — wood</b>	Hot water spray (82–93°C, 180–200°F).
<b>Benches — metal</b>	<ul style="list-style-type: none"> <li>■ Alcohol spray (70% isopropyl or ethanol), then let evaporate.</li> <li>■ QAC.</li> </ul>
<b>Floors — concrete</b>	<ul style="list-style-type: none"> <li>■ Hot water (82–93°C, 180–200°F).</li> <li>■ Bleach if soil removed first.</li> </ul>
<b>Footwear</b>	QAC, bleach (after soil is removed).
<b>Used containers</b>	<ul style="list-style-type: none"> <li>■ Chemicals (bleach, QAC, peroxides) if soil/potting media removed first.</li> <li>■ Steam (live or aerated) — regulate temperature between 60–70°C (140–160°F).</li> <li>■ Solarization — see Figure 37, page 21, illustrating solarization to disinfect used containers.</li> <li>■ Hot water dip (82–93°C, 180–200°F).</li> </ul>
<b>Potting media</b>	<ul style="list-style-type: none"> <li>■ Solarization — see Soil Solarization for Gardens &amp; Landscapes (“Resources for disease prevention,” page 35).</li> <li>■ Aerated steam.</li> </ul>
<b>In-ground planting areas and nursery substrates such as gravel beds and other production areas</b>	<ul style="list-style-type: none"> <li>■ Solarization — Large areas, during summer (long days, no clouds), full sun exposure. Does not work in shaded areas.</li> <li>■ Live steam — Maximum plot size depends on output of steam generator. Avoid saturating soil before steaming.</li> <li>■ Aerated steam — May be possible for larger plots but will take longer to reach temperatures.</li> </ul>





Photo: Marianne Elliott, Washington State University

Figure 30. Sanitizing containers in water and disinfectant bath.



Photo: Marianne Elliott, Washington State University

Figure 31. Sterilizing containers with chemical disinfectant. The amount of chlorine in the bleach bath is being measured with test strips.

## Chemical disinfectants

Container sterilization (Table 3, page 18) can be accomplished using chemical sanitizers such as bleach or quaternary ammonium compounds, or QACs. If you are using chemical sanitizers, clean the containers of any organic material first. The organic material will use up the oxidizing potential of the disinfectant. Soak the containers in water to loosen soil and media, then scrub, rinse and soak in disinfectant. Follow up by rinsing in clean water (Figures 30, 31). Chemical sanitation is not appropriate for soil, potting media or compost. Bleach and QAC solutions can be used in sanitizing footbaths.

Chlorine bleach is a strong oxidizing agent commonly used as a disinfectant in many situations. Its efficacy is affected by changes in pH, the amount of organic matter present and nitrogen contaminants such as fertilizer. Chlorine bleach is inexpensive and readily available. Test strips are available for measuring the concentration of free chlorine in water. Make a bleach bath to sanitize pots and flats by diluting bleach by a ratio of 1:10 with cold water, producing a final concentration between 525 and 800 ppm.

Quaternary ammonium compounds are ingredients in a number of common household products such as Lysol and Formula 409. They are composed of a mixture of chemicals with the active ingredient benzalkonium chloride or a similar chemical. Commercial products such as Phisan or Greenshield are available for use in nurseries. As with chlorine bleach, you can test the disinfectant bath with test strips to monitor activity. The effective range for QACs is between 781 and 1040 ppm.

Chlorine bleach, toxic on its own, is also extremely reactive and should never be mixed with ammonia, acids or other cleaning products; this can produce deadly gases. Mixing bleach with ammonia will also produce nitrogen trichloride and hydrazine, which are explosive. Do not use the same containers for mixing solutions of bleach and solutions containing ammonium compounds such as Green Shield, Phisan and others. (Check the label.)

You can sanitize metal tools and surfaces with alcohol or QACs. Use ethanol or isopropyl alcohols in the 70%–90% concentration range. Concentrations above 90% are not effective because some water is needed for disinfectant activity. Alcohols need a longer contact time than other disinfectants such as bleach, and they are inactivated in the presence of organic matter. Spray a 70%–90% solution onto the surface and allow it to dry. This shouldn't take long, as the alcohol evaporates rapidly. Don't use bleach on metal tools because it is corrosive.

**Table 3. Chemical disinfectants**

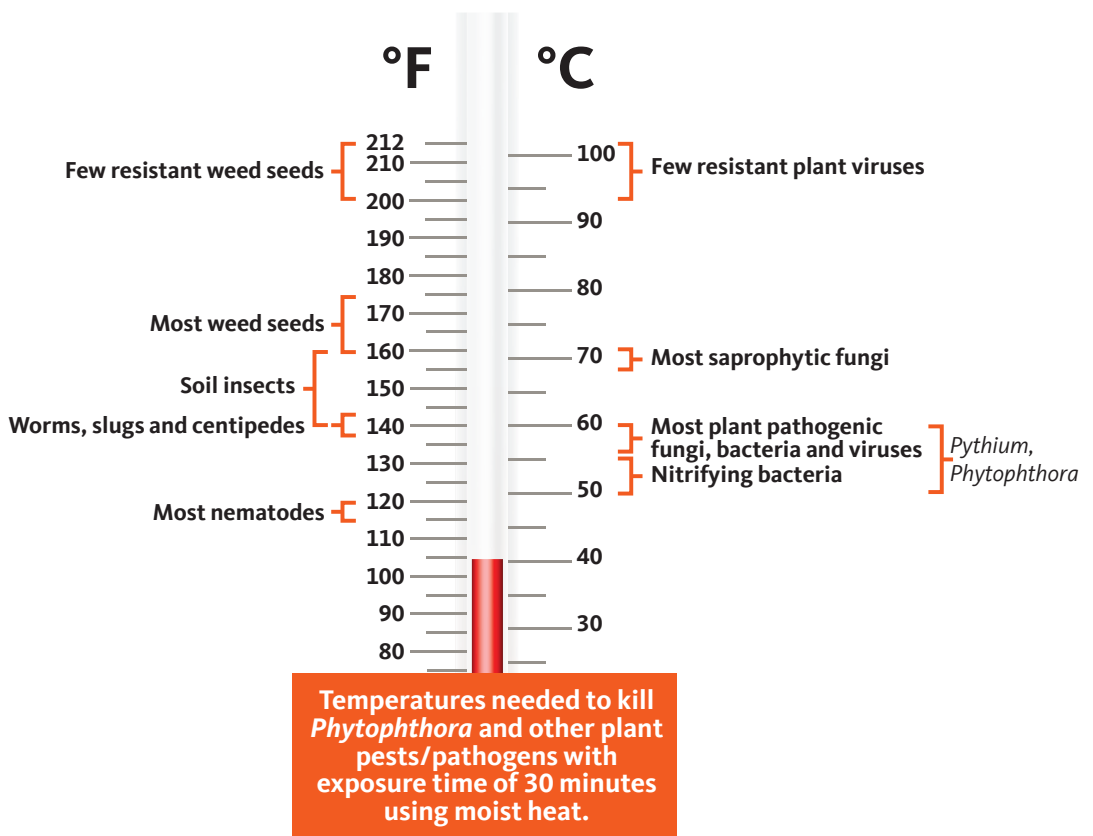
*Remove as much organic matter (soil, potting media, etc.) before treatment. This material will inactivate the chemicals.*

Suggested use	Stability	Cost	Safety and environmental impact
<b>CHLORINE BLEACH</b>			
Used containers, concrete floors if soil/organic material is removed first.	Chlorine bleach is unstable; mix diluted bleach solutions daily or more often. Chlorine is inactivated by the presence of organic matter, so items should be washed before disinfecting. Chlorine gas evaporates at a high rate after mixing when exposed to air. When you can no longer smell chlorine, the solution is used up and should be changed. You can use test strips.	Since bleach solution has to be mixed up more often, it does not save money when compared to other options, such as QACs.	Chlorine is toxic to microbes and all living things. Corrosive; do not use on metal tools. Because it is so reactive, observe safety precautions when working with chlorine. Workers should wear appropriate protective equipment when handling concentrated chemicals, and rubber gloves when working with diluted solutions.  Do not mix with QACs; toxic chemicals will form.
<b>QUATERNARY AMMONIUM COMPOUNDS, OR QACs</b>			
Footwear, used containers, hand tools, metal benches if you remove soil or organic material first.	QACs are relatively stable. Solutions can be used for up to a week if not heavily contaminated with soil or organic material. Stock solutions can be stored up to two years in a cool, dark place if unopened.	Relatively low and easily obtained.	Do not mix with bleach; toxic chemicals will form.  QACs are toxic to microbes and larger marine life.  These chemicals should be disposed of as chemical waste and not allowed to enter wastewater treatment systems or surface water bodies. While wastewater systems can process small amounts of these chemicals, large volumes (hundreds of gallons) will overwhelm the system.
<b>ALCOHOLS (70%–90% range, volume basis)</b>			
Hand tools and metal benches if soil or organic material is removed first.	Solutions are unstable as the alcohol evaporates, but they can be stored in a closed container for one week.	Most alcohols considered to be too expensive to use for disinfection on a large scale, but are more suitable for uses such as disinfecting cutting tools in a propagation house.	Flammable, so should not be used around open flames. Alcohol in high concentrations irritates tissues and can damage rubber and plastic with extended use.
<b>PEROXIDES</b>			
Used containers, concrete floors if you first remove soil or organic material.	Hydrogen peroxide is unstable, but the product ZeroTol has greater stability. Use solutions of peroxide-based disinfectants soon after mixing.	Since less ZeroTol is needed per gallon of solution, it is less expensive than food-grade hydrogen peroxide.	Hydrogen peroxide is corrosive to metals. Wear eye protection and gloves when handling. ZeroTol concentrate should be handled with the same care as peroxide, but it becomes relatively safe for use when diluted.

# Heat treatment

You can also sanitize containers, potting media, soils and substrates using heat. Temperatures of 140°F (60°C) (for specified time intervals and moisture contents) will kill *Phytophthora*. Temperatures of 140–178°F (60–81°C) will kill many other types of plant pathogens, while most weed species and certain plant viruses require even higher temperatures. See Figure 32 for temperatures necessary to kill various groups of soil organisms. Heat treatments include techniques using steam, aerated steam and solarization. See Table 4, page 22, to determine which techniques best fit your operation. Containers decontaminated using heat treatment do not require precleaning, unlike methods of chemical disinfection. However, some techniques such as steaming use specialized equipment and may not be feasible for small nurseries.

Sanitizing potting media, soil and compost with heat treatments within the range of 140–162°F (60–72°C) will avoid phytotoxicity or “chemical burn” and prevent the destruction of beneficial soil microorganisms. Excessive heat treatment between 176° and 212°F (80°–100°C) can kill beneficial soil microorganisms, resulting in a biological vacuum easily invaded by pathogens if they are reintroduced. You can use aerated steam (described below) to pasteurize potting media and soil in field plantings without eliminating most other beneficial soil microorganisms. Pasteurization heats barely moist soil to a temperature sufficient to kill *Phytophthora*, 140°F (60°C), for 30 minutes.



Graphic: Mikayle Stole, © Oregon State University

Figure 32. Diagram modified from Baker and Cook (1974) based on temperature data from Linderman and Davis (2008). See “Resources,” page 35.



Photo: Marianne Elliott, Washington State University

Figure 33A and 33B. A small steam generator (A) provides steam to treat used pots (B).



Photo: Marianne Elliott, Washington State University

Figure 34. Sanitizing containers under a tarp using steam.

### Heat treatments using steam

Containers can be heat-treated with steam inside a chamber (a wooden box or a shipping container) or piled under a tarp (Figures 33, 34). Steam can be applied directly from a boiler (live steam) or aerated with a fan (aerated steam). Monitor temperature with a solenoid and temperature sensor until the containers reach the target temperature. It is easier to control temperatures in a steam chamber than in a tarped pile. Live steam is very hot — 212°F (100°C) — and will melt some types of pots (thin-walled plastic containers or styroblocks). Heat one size of container at a time and test a small batch to ensure that steam will not destroy containers. Consider using containers made of heavier materials when heat treated under a tarp. You can steam treat a load of empty containers fairly quickly; filled containers take up to four hours, depending on the size. Steam treating containers of diseased or dead plants is an effective way to destroy *Phytophthora* before adding diseased material to a cull pile, preventing possible nursery contamination.

You can also treat contaminated soil or nursery substrates (such as a gravel bed) with steam to kill *Phytophthora* (Figure 35). This requires more steam than you need to treat used containers, so a larger boiler is usually necessary. The plot size, soil type, moisture content and compaction level will determine the amount of time required to reach the target temperatures. Heat transfer is most effective in moist soil, but steam cannot penetrate soil that is saturated with water. If you plan to steam, turn off irrigation at least 24 hours in advance. (The length of irrigation shutdown will depend on your soil type). The steaming process involves installing temperature sensors in the soil or substrate, laying out a perforated hose to deliver steam, tarping the plot, and sealing the edges of the tarp with weights to keep steam from escaping. Soil plots can take between four and 10 hours to reach the desired temperatures at 6 inches (15 cm) depth. Steam does not penetrate more than 6 inches beyond the edge of the plot due to the insulating properties of soil, so plants growing next to the area being steamed will not be damaged.

Aerated steam is used in agriculture to kill pests, pathogens and weeds in various substrates and requires an aerator fan in addition to the boiler. Using an aerator to create a mixture of steam and air lowers the temperature and is less damaging to beneficial soil microorganisms. You can use aerated steam treatment for containers and also to pasteurize potting media. Aerated steam can also be used to treat soil, gravel beds, or other substrates, but it will take longer to reach target temperatures.

### Heat treatments using solarization

Solarization can be an effective way to disinfect soil, gravel beds or containers, provided the correct environmental conditions are present. Solarization uses energy from the sun to heat the soil to temperatures lethal to *Phytophthora* species and some other plant pathogens and weed seeds.

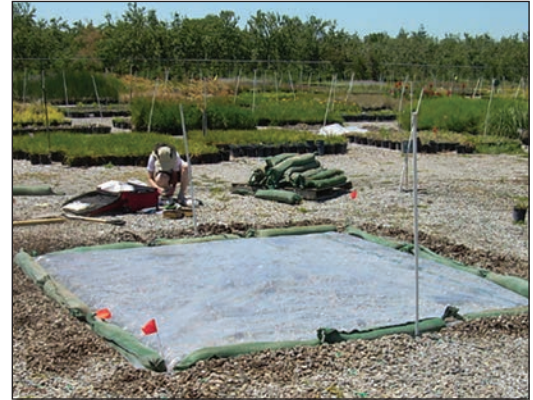
To solarize soil, lay down clear plastic over the soil or gravel and seal the edges to prevent



heat escape. Solarization works best during the warmest and most cloud-free time of the year (late June through August in the Pacific Northwest). Other requirements include full sun exposure, applying plastic close to the soil or gravel bed surface, and treating an area that is at least 8 feet x 8 feet (Figure 36). To solarize containers (Figure 37), lay black plastic on the ground and place containers horizontally on a structure, such as a pallet, to elevate them. This allows hot air to circulate. Tightly secure clear plastic directly over containers, then cover with a second layer of clear plastic supported by hoops. Seal the edges of the plastic to prevent heat escape. Solarization is unlikely to work in coastal areas where fog limits solar radiation. To estimate the amount of time needed to solarize at your location for a specific start date, see the Soil Solarization Online Model. For more information on soil solarization, see Soil Solarization for Gardens & Landscapes in “Resources for disease prevention,” page 35.



Photo: Marianne Elliott, Washington State University  
Figure 35. Sanitizing soil with steam.



Jennifer Parke, © Oregon State University  
Figure 36. Solarizing ground with a sheet of clear plastic film.

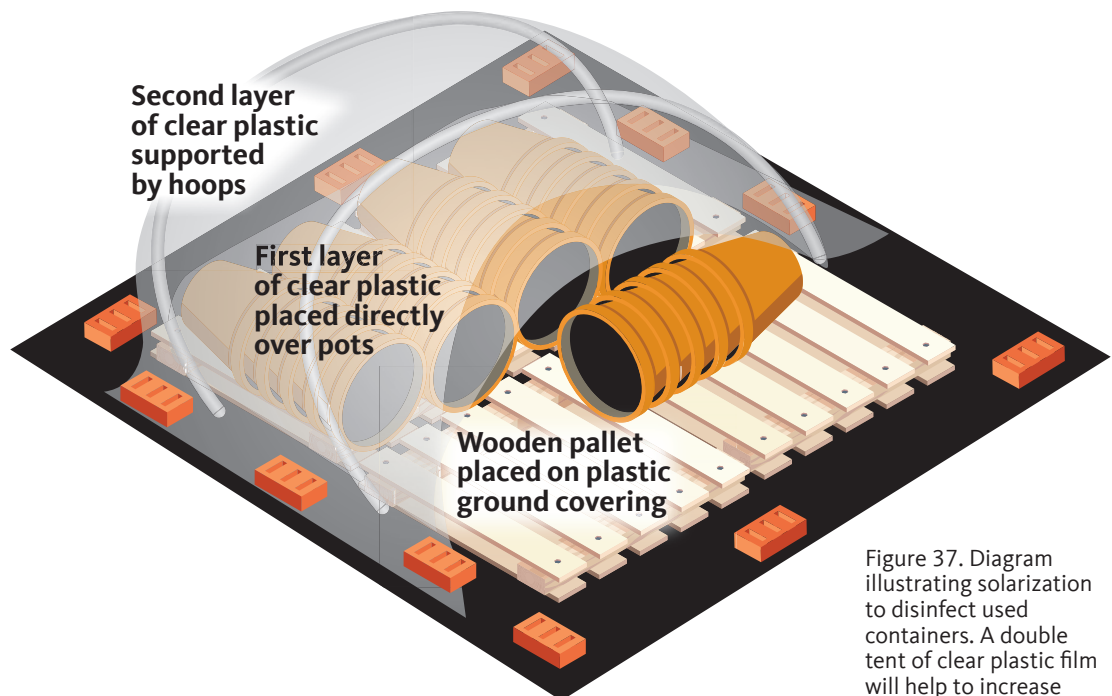


Figure 37. Diagram illustrating solarization to disinfect used containers. A double tent of clear plastic film will help to increase heating.

Graphic: Mikayle Stole,  
© Oregon State University

**Table 4.** Heat sanitation methods

Suggested use	Cost	Safety and environmental impact
<b>SOLARIZATION</b>		
<p>Used containers and potting media. See Soil Solarization for Gardens &amp; Landscapes (“Resources for disease prevention,” page 35). Can be used for in-ground planting areas and nursery substrates. The technique requires long days with no clouds and does not work in shaded areas. See Soil Solarization Online Model (“Resources for disease prevention,” page 35) to determine suitability.</p>	<p>Relatively low. Costs include plastic sheeting, labor.</p>	<p>Safe and low impact. Disposal of used plastic is the main concern; it often can be used again or recycled.</p>
<b>HOT WATER (82–93°C, 180–200°F)</b>		
<p>Used containers, floors and wooden benches.</p>	<p>Can be high if you need a large volume of hot water.</p>	<p>Avoid burns from contact with boiling water and steam.</p>
<b>LIVE STEAM (80–100°C, 176–212 °F)</b>		
<p>Used containers and potting media if temperature is regulated between 60 and 70°C (140–160°F). Can be used in in-ground planting areas and nursery substrates, depending on boiler capacity. Avoid saturating soil at least 24 hours before treatment.</p>	<p>High initial equipment costs for steam generator and equipment. Operating costs for fuel and labor.</p>	<p>Steam is a relatively safe technique, as there are no toxic chemicals or noxious fumes. Hot surfaces should be avoided. Wait several hours after the steamer is shut off and take care when removing tarps after steaming. Environmental Impact: low.</p>
<b>AERATED STEAM (60–70°C, 140–160°F)</b>		
<p>Used containers and potting media. In-ground planting areas and nursery substrates. May be possible for larger plots but will take longer to reach temperatures. Avoid saturating soil at least 24 hours before treatment.</p>	<p>See live steam.</p>	<p>See live steam.</p>

## Recognizing *Phytophthora* symptoms

Nursery and restoration practitioners should carefully inspect nursery plants for signs of disease weekly during the growing season and conduct diagnostic testing when needed. Nurseries that have developed a systematic monitoring plan will be in good position to catch plant health issues early. Restoration practitioners need to assess each purchase for signs and symptoms of disease prior to transporting and planting. Start your visual plant assessment by understanding what a healthy plant looks like for each species that you grow or purchase. Figure 38 shows an example of a healthy red huckleberry, compared to a specimen that is in decline. What do you do when you see a plant that might be sick? Inspect the plant further by looking for both above-ground and below-ground symptoms described in Table 5, page 24; some *Phytophthora* species tend to infect the foliage while other species typically infect the roots. Note that unlike many fungal infections, *Phytophthora* structures are not visible to the naked eye (Figure 39).

Use the Table 5 checklist as part of a systematic monitoring plan or upon observation of a declining plant in the nursery or recent purchase. Note that plants may be asymptomatic and still be infected.



Figure 38. Red huckleberry showing symptoms of shoot blight (left) compared to healthy plant (right).

Photo: Marianne Elliott, Washington State University



Figures 39A and 39B. Foliar symptoms of (A) fungal infection and (B) *Phytophthora*. Leaf spots caused by fungi can have tiny pinhead-like fruiting bodies. *Phytophthora* has no fruiting bodies and often infects where water accumulates at the edges or tips of leaves.

Photos: Marianne Elliott, Washington State University



## Table 5. *Phytophthora* symptom checklist for restoration plants

Place a checkmark if condition is observed.

### DISTRIBUTION OF PLANT SYMPTOMS IN THE NURSERY

**Non-uniform distribution of plant damage in the nursery**

Might be an indication of disease. Look for symptoms of disease.

Note: Uniform distribution of plant damage is often caused by nutritional problems affecting an entire block of plants, or environmental factors such as temperature, light or water (too much or too little).



Photo: Jennifer Parke, © Oregon State University

Figure 40. Non-uniform distribution of plant damage in containers.

### STEM, BRANCH AND FOLIAR SYMPTOMS

**Wilting**

Wilting of the above-ground parts is often the first visible above-ground symptom of root damage by pathogens. By the time a plant wilts, it is typically heavily infested. It can also indicate insufficient water. Examine the roots to determine the cause. Consider using a bench testing monitoring strategy in addition to physical inspection to help detect infestations early (page 27).



Photo: Jennifer Parke, © Oregon State University

Figure 41. Above-ground wilting can indicate root disease. The juniper plant at left was killed by root infecting *Phytophthora*, the middle plant shows wilting associated with initial stages of root infection, and the plant at right is healthy.

**Foliar blight**

This might look like dark areas (lesions) on stems or on the leaf blade, leaf edge, midrib, or petiole.

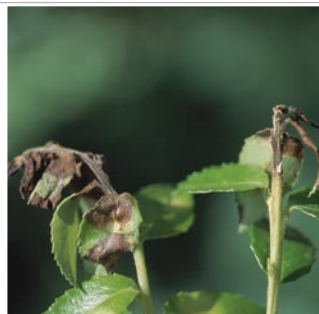


Photo: Alan Kanaskie

Figure 42. *P. ramorum* shoot blight on evergreen huckleberry.



Photo: Norma Kline, © Oregon State University

Figure 43. *P. ramorum* leaf symptoms on evergreen huckleberry.



Photo: Ebba Peterson, © Oregon State University

Figure 44. Shoot blight on tanoak.

**Shoot dieback**

The tips of shoots and branches are killed.



Photo: Gary Chastagner, Washington State University

Figure 45. Shoot dieback on grand fir caused by *P. ramorum*.

**Stem lesions or cankers**

Sometimes the symptoms are hidden beneath the bark. Take a knife and peel back bark at the base of plant near the root crown. Look for discolored plant tissue under the bark.



Photo: Ebba Peterson, © Oregon State University

Figure 46. Stem lesions on (A) *Juniperus communis* and (B) *Microbiota decussata* caused by *Phytophthora lateralis*.



## ROOT SYSTEMS

Take the plant out of the pot or bed and inspect the root system. Root inspections can damage newly established seedlings. To prevent damage, consider the bench testing approach described in “Implementing a bench testing monitoring strategy in addition to physical inspection,” page 27.

### Absence of fine roots

Note the absence of fine roots on the plant on the right, compared to a healthy root system on the plant at left.



Figure 47. Phytophthora root rot on lavender caused by *P. pseudocryptogea* on the right compared to healthy plant on the left.

Photos: Marianne Elliott, Washington State University

### Discolored or decayed roots



Photos: Jennifer Parke, © Oregon State University

Figure 48. Examples of discolored and decayed roots.

### Blackened root collar



Figure 49. Root and collar rot on tanoak caused by *P. cinnamomi*.

Photo: Ebba Peterson, © Oregon State University

## What about bare-root plants?

Not all restoration plants are grown in containers. Some trees and shrubs are grown in the ground, lifted, then carefully stored and transported without soil for immediate planting at the restoration site. Nurseries and buyers should inspect bare-root plants for the same symptoms as described in the Plant Health checklist (Table 3).

## What happens when you find plants with potential disease symptoms?

Because the *Phytophthora* organism is microscopic, symptoms always require testing to confirm infection (Figure 50). *Phytophthoras* do not have characteristic reproductive structures (fruiting bodies) visible to the eye, like many fungi. If you find any of the foliar, stem or root symptoms listed in Table 5, follow up with diagnostic testing. Early detection and prevention can save additional nursery plants from being infected and prevent pathogens from being inadvertently introduced into the natural ecosystem.

Do-it-yourself diagnostic kits are available to detect the presence of *Phytophthora* in plant tissue (Figure 51). These tests are rapid and relatively inexpensive (approximately \$10 each) and are useful for confirmation of symptoms. However, a negative result does not indicate the absence of *Phytophthora*. See “Resources for testing and baiting techniques,” page 35, for more information on where to purchase rapid test kits and a video tutorial on how to use them.

Alternatively, you may send disease samples to a lab for diagnostic testing. Lab testing is fee-based and may include additional information such as identification of *Phytophthora* species present. Use Table 6 to find a diagnostic lab near you and to learn how to submit a sample.



Photo: Norma Kline, © Oregon State University

Figure 50. A plant pathologist examines a plant sample under a microscope for signs of *Phytophthora*.



Photos: Jennifer Parke, © Oregon State University

Figure 51. Using a do-it-yourself diagnostic test. The test on the left indicates a positive result for *Phytophthora*. The test on the right indicates a negative test.

## Implementing a bench testing monitoring strategy in addition to physical inspection

Bench testing is a nondestructive approach using simple tools and techniques to test for the presence of *Phytophthora* by “baiting” the organism out of the soil without sacrificing plants. Bench testing, when used in addition to inspection of visible symptoms, can help increase the chance of early detection.

To perform a bench test, select the worst-looking plants within a growing block that show symptoms described in Table 5. Test these as a group to determine if the pathogen is present in the block. Place the selected plants on a cart or bench and irrigate to produce leachate (water drainage) from the soil. Capture the leachate with a simple collection system beneath the bench. Add a “bait” of unripe pears or rhododendron leaves that have not been recently sprayed with fungicides; the baits should not have spots or lesions. Place the mixture in gallon-sized plastic bags for a specified incubation period. Baits infected with *Phytophthora* will develop lesions (Figure 52). You can send the baits to a diagnostic lab for testing, or test them with a do-it-yourself rapid diagnostic kit as described above. Diagnostic testing from baits can be more successful than diagnostic tests using symptomatic plant material. If a bait tests positive during bench testing, conduct further testing within the block to determine the source of the infection. For more detail on a bench testing approach, see “Resources for testing and baiting techniques,” page 35.

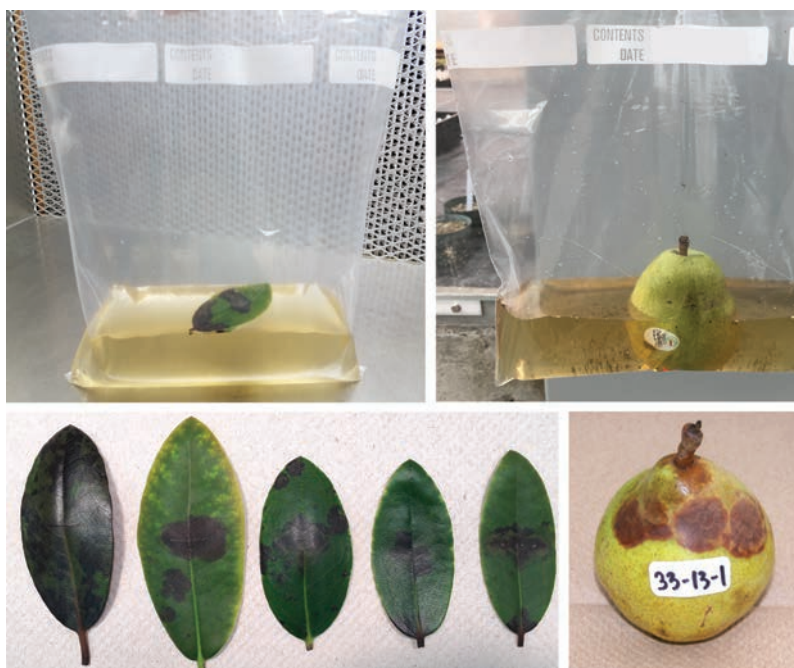


Figure 52. Hard green pears and rhododendron leaves can be used to bait *Phytophthora* from soil, water or container leachate.

Photos: Jennifer Parke,  
© Oregon State University

## Table 6. Diagnostic testing resources

### Oregon Department of Agriculture

**Plant Health Program:** Testing resources for landowners, restoration groups

503-986-4620 • [PlantHealth@oda.state.or.us](mailto:PlantHealth@oda.state.or.us)

<https://www.oregon.gov/ODA/programs/PlantHealth/DiagnosticServices/Pages/PlantPestsDiseases.aspx>

**Nursery Program (licensed nurseries):** <https://www.oregon.gov/oda/programs/NurseryChristmasTree/Pages/AboutNursery.aspx>

### Oregon State University Plant Clinic

541-737-3472 • <https://bpp.oregonstate.edu/plant-clinic>

How to submit samples: <https://bpp.oregonstate.edu/plant-clinic/submit-sample/how-submit-plant-materials>

### *Analytical Laboratories Serving Oregon, EM 8677*

OSU Extension guide to laboratories serving Oregon and other states, along with specific information about their laboratory services.

<https://catalog.extension.oregonstate.edu/em8677>

### Idaho State Department of Agriculture Plant Pathology Lab

208-332-8500 • <https://agri.idaho.gov/main/laboratories/plant-pathology-laboratory/info@isda.idaho.gov>

### University of Idaho Plant Diagnostic Services

208-722-6701 • <https://www.uidaho.edu/cals/plant-diagnostics>  
[plantdiagnostics@uidaho.edu](mailto:plantdiagnostics@uidaho.edu)

### Washington State University Plant & Insect Diagnostic Laboratory

253-445-4582 • <https://puyallup.wsu.edu/plantclinic/>

### National Plant Diagnostic Network

Diagnostic tips and resources, including information on invasive species and a list of laboratory contacts by state.

<https://www.npdn.org>

### Western Plant Diagnostic Network

<https://www.npdn.org/wpdn>

### Commercial diagnostic labs

[https://mtvernon.wsu.edu/path\\_team/diagnosticLabs.htm](https://mtvernon.wsu.edu/path_team/diagnosticLabs.htm)



# A diagnostic test reveals that a plant is positive for *Phytophthora* — what next?

A nursery that receives a positive result for a *Phytophthora* species with a regulated status should contact their state's department of agriculture program immediately.

## Oregon Department of Agriculture

### Nursery & Christmas Tree Program

503-986-4644 • [Nursery@oda.state.or.us](mailto:Nursery@oda.state.or.us)

<https://www.oregon.gov/oda/programs/NurseryChristmasTree/Pages/AboutNursery.aspx>

## Idaho State Department of Agriculture

### Plants & Insects Program

208-332-8650 • <https://agri.idaho.gov/main/plants/nurseries-florists-and-landscaping/>

## Washington State Department of Agriculture

### Plant Services Program

360-902-1874 • [nursery@agr.wa.gov](mailto:nursery@agr.wa.gov)

<https://agr.wa.gov/departments/plant-health>

## U.S. Department of Agriculture Animal and Plant Health Inspection Service

**Plant Pests and Diseases Programs**, <https://www.aphis.usda.gov/aphis/ourfocus/planthealth/plant-pest-and-disease-programs/pests-and-diseases>

To view species under federal quarantine for each state, select a state or region in the search function: <https://www.aphis.usda.gov/aphis/resources/pests-diseases/hungry-pests/pest-tracker/states/oregon>

## Recommendations

A nursery that receives a positive result for a nonregulated *Phytophthora* species of concern listed in “*Phytophthora* species of concern” (page 30) should use the following recommendations to control and monitor the infestation:

- Quarantine or destroy all host plants within 3 feet of infected plants.
- Quarantine adjacent blocks in place and test those plants.
- Test other blocks that have the same plant batch.

A nursery that receives a positive result for a *Phytophthora* species not listed in “*Phytophthora* species of concern” should review nursery practices; conditions or practices that favor the establishment of one *Phytophthora* may be similar to other species. Consult your state's nursery specialist or plant clinic for recommended actions for species not listed. It is important to plant clean nursery plants in restoration sites.

See “*Phytophthora* species of particular concern in restoration nurseries,” page 30, for a list of the most harmful *Phytophthora* species and their regulatory status as of this publication date. For an updated regulatory status for *Phytophthora* species, check with your state's department of agriculture program or the U.S. Department of Agriculture, Animal and Plant Health Inspection Service (USDA-APHIS).

**Table 7. *Phytophthora* species of concern in restoration nurseries<sup>1</sup>**

Species	Plant diseases	Hosts	Notes
<i>Phytophthora</i> species found in U.S. nurseries or wildland communities that are considered high risk for causing disease on Pacific Northwest native plants. Species in bold are federally regulated.			
<i>P. cactorum</i>	Damping off of seedlings, fruit rot, leaf and stem rot, collar and crown rot, stem canker, root rot	At least 154 genera of vascular plants, including trees, shrubs and herbaceous plants	Found in native plant and ornamental nurseries, landscapes, forests, agricultural crops. Cosmopolitan.
<i>P. cambivora</i>	Root and crown rot, canker, often in conjunction with other <i>Phytophthora</i> species	30 genera including <i>Abies</i> , <i>Acer</i> , <i>Alnus</i> , <i>Arctostaphylos</i> , <i>Castanea</i> , <i>Chrysolepis</i> , <i>Fagus</i> , <i>Juglans</i> , <i>Lupinus</i> , <i>Notholithocarpus</i> , <i>Platanus</i> , <i>Prunus</i> and <i>Quercus</i>	Present in forests, Christmas tree farms. Causes disease of chinquapin in the Pacific Northwest. In Europe, causes ink disease of chestnut and mortality on European beech. Also a pathogen of fruit trees. Cosmopolitan.
<i>P. cinnamomi</i>	Root rot, wilt	266 genera, commonly hardwood trees. Includes <i>Abies</i> , <i>Arbutus</i> , <i>Arctostaphylos</i> , <i>Castanea</i> , <i>Pinus</i> , <i>Quercus</i> .	Aggressive species favored by warm soil conditions as in greenhouses. Causes mortality of native manzanitas in California. Predicted to cause increased damage in the Pacific Northwest as a result of climate change. Responsible for jarrah dieback in Australia, ink disease in Europe.
<i>P. citricola</i> complex ( <i>P. multivora</i> , <i>P. pini</i> , <i>plurivora</i> ). Note: <b><i>P. citricola</i></b> is federally regulated.	Crown rot, blight, canker, root rot, wilt, shoot blight, leaf blight, decline, collar rot	75 plant genera including many trees, shrubs and herbaceous plants	Found in ornamental nurseries, landscapes, agricultural crops. The complex is associated with declining woody hosts in Australia, North America and Europe.
<i>P. cryptogea</i> complex ( <i>P. cryptogea</i> , <i>P. drechsleri</i> , <i>P. pseudocryptogea</i> )	Damping-off, foot rot, stem rot, leaf blight, wilt	141 genera including many trees, shrubs and herbaceous plants	Found in ornamental nurseries, landscapes, agricultural crops. Cosmopolitan.
<i>P. lateralis</i>	Root and crown rot, girdling, death. On <i>Chamaecyparis</i> , foliar infections have also been reported rarely.	Limited to a few genera: <i>Chamaecyparis</i> , <i>Juniperus</i> , <i>Microbiota</i> , <i>Taxus</i> , <i>Thuja</i>	Causes root rot of Port-Orford cedar in its native range in northern California and southern Oregon forests. Present in ornamental nurseries and ornamental plantings. Also found in France and the United Kingdom. Widespread.
<i>P. nicotianae</i>	Damping-off, crown rot, leaf blight, fruit rot	255 genera including many trees, shrubs and herbaceous plants	Found in ornamental nurseries in the Pacific Northwest. Aggressive in warm soil conditions such as greenhouses. Cosmopolitan.
<i>P. occultans</i>	Wilting, stem lesions, root rot	<i>Arctostaphylos</i> , <i>Ceanothus</i> , <i>Gaultheria</i> , <i>Mahonia</i> , <i>Rhododendron</i>	A recently described species found in Oregon native plant and ornamental nurseries. Also found in Europe.
<b><i>P. quercina</i></b>	Decline	<i>Quercus</i>	Implicated in oak decline in Europe, Turkey. Recently reported from soil under declining oak in Missouri.

Species	Plant diseases	Hosts	Notes
<i>P. ramorum</i>	Sudden oak death (stem canker, crown death) and ramorum leaf blight (foliar blight, dieback, leaf necrosis)	At least 26 genera. Stem canker hosts include <i>Fagus</i> , some <i>Quercus</i> ; foliar and shoot blight hosts include <i>Rhododendron</i> , <i>Gaultheria</i> , <i>Mahonia</i> , <i>Umbellularia</i> , many others. Some species show both foliar symptoms and stem cankers including <i>Notholithocarpus</i> and in Europe, <i>Larix</i> .	Regulated status. See department of agriculture websites for Oregon, Washington, Idaho for information and contacts, Table 5. The pathogen has killed over 50 million trees in 16 California coastal counties and in part of Curry County, Oregon. Nursery stock with well over 100 plant species is regulated. See <a href="http://www.suddenoakdeath.org">www.suddenoakdeath.org</a> for more information.
<i>P. siskiyouensis</i>	Root disease, canker	<i>Alnus</i> , <i>Notholithocarpus</i> , <i>Umbellularia</i>	Found on riparian alder in Oregon forests and likely on alder nursery stock. In California, found on ornamental plantings. Also found in Australia and England.
<i>P. syringae</i>	Twig blight, fruit rot, root rot, leaf blight, shoot blight and stem cankers	29 genera including <i>Fraxinus</i> , <i>Kalmia</i> , <i>Malus</i> , <i>Pyrus</i> , <i>Rhododendron</i>	Cool season <i>Phytophthora</i> species common on woody hosts in nurseries. Widely distributed around the world.
<i>P. tentaculata</i>	Root rot, stem rot	Several herbaceous and shrub species including <i>Diplacus</i> .	Found in native plant nursery trade and restoration sites in California. Also found in China and Europe.
<i>P. uniformis</i>	Root and collar rot	<i>Alnus</i>	Riparian alders, nursery stock. Found in Europe, Alaska, and Oregon.
<b><i>Phytophthora</i> species not currently found in the U.S. as of 2021 (Range of hosts indicates potential risk to Pacific Northwest native species.)</b>			
<i>P. xalni</i> <sup>3</sup>	Root and collar rot	<i>Alnus</i>	A hybrid of <i>P. uniformis</i> and <i>P. multiformis</i> . In Europe, causes extensive dieback in riparian alders and is present in forest nurseries.
<i>P. austrocedri</i> <sup>3</sup>	Necrotic lesions on roots extending to stems; dieback, mortality	<i>Austrocedrus</i> , <i>Chamaecyparis</i> , <i>Juniperus</i>	Causes “mal del cipres” disease in South American <i>Austrocedrus chilensis</i> forests. Additional hosts confirmed in the UK in 2011.
<i>P. kernoviae</i> <sup>3</sup>	Bark necrosis and stem canker, foliar blight, shoot dieback, foliar necrosis, wilting	<i>Fagus</i> , <i>Liriodendron</i> , <i>Pinus</i> , <i>Quercus</i> , <i>Rhododendron</i> , <i>Vaccinium</i> , others	Present in UK, New Zealand and Chile.

1. Additional *Phytophthora* species may be found to cause plant disease.
2. Listed on the U.S. Regulated Plant Pest Table (modified June 2, 2020), <https://www.aphis.usda.gov/aphis/ourfocus/planthealth/import-information/rppl/rppl-table> [Accessed May 14, 2021]
3. Listed as an “Additional Pest of Concern” by the National Cooperative Agricultural Pest Survey (CAPS) FY2020 Priority Pest List, <http://caps.ceris.purdue.edu/pest-surveillance-guidelines/2020> [Accessed May 14, 2021]
4. Disease and host information from the U.S. National Fungus Collections Nomenclature Database, <https://nt.ars-grin.gov/fungal-databases/Nomen/Nomenclature.cfm> and IDphy: Molecular and morphological identification of *Phytophthora* based on the types, <https://idtools.org/id/phytophthora/index.php> [Accessed May 3, 2021]

## Use of chemicals and biocontrols

We recommend that restoration nurseries use cultural controls as an effective disease management program. In certain situations, (for example, to protect rare endangered plants), fungicides might be an option of last resort. But there is the danger of developing resistance to certain fungicides. Most chemical fungicides will not cure *Phytophthora* infestations and may mask symptoms. Buyers of nursery plants need to be aware of the potential suppression or masking of *Phytophthora* symptoms by some chemical control agents; ask the nursery for the treatment history. Investigation into approaches using surfactants and film-forming polymers (anti-transpirants) show promise to help prevent foliar infection without masking symptom expression. Some biocontrol products containing the fungus *Trichoderma* can be used as a seed treatment or soil drench to protect seedlings in a nursery (Figure 53). *Trichodermas* are naturally found in acidic substrates like bark mulch and compost. Effective biocontrol species or strains generally proliferate in the root zone. Trials using the fungus *Trichoderma* indicate that it is most effective at low pathogen inoculum levels. Similar to chemical fungicides, it will not cure an advanced infection. If chemical fungicides are being used to control *Phytophthora*, check for compatibility with biocontrol fungi. Broad-spectrum fungicides will kill both pathogens and beneficial fungi. For more information on biocontrol see *Rhododendron-Phytophthora Root Rot*, in the *Pacific Northwest Pest Management Handbook*, in “Resources for Additional Technical Information,” Page 36.



Photo: Marianne Elliott, Washington State University

Figure 53. A selection of biocontrol products.

## Nursery organization and recordkeeping

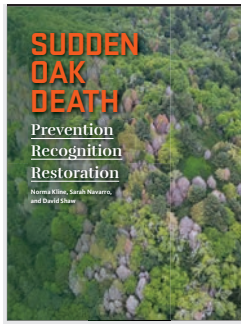
Organize nursery plants in blocks with a systematic plant labeling and recordkeeping system to improve monitoring and disease eradication efforts. Many nurseries grow individual species or cultivars in blocks as a practical way to provide appropriate growing conditions for a given species. This block organization also makes it easier to monitor, sample and focus infestation control measures to specific areas of concern and prevents unnecessary plant destruction. Use a systematic plant labeling and record keeping system to document plant origin, movement within the nursery, monitoring information and sale information (Figure 54). More information regarding recordkeeping can be found in the *Safe Procurement and Production Manual: A systems approach for the production of healthy nursery stock* and *Nursery Industry Best Management Practices for Phytophthora ramorum — to prevent the introduction or establishment in California nursery operations*. see “Resources for disease prevention” (page 35).



Photo: Norma Kline, © Oregon State University

Figure 54. Clearly labeled flats in a nursery. Yellow insect traps are used to monitor insect populations.





A GUIDE FOR HOMEOWNERS • SMALL WOODLAND OWNERS  
RESOURCE MANAGERS • CONSERVATION GROUPS  
Oregon State University  
EM 9216  
September 2016

## Recognition and restoration resource

If you are in an area infested with *Phytophthora ramorum*, see *Sudden Oak Death: Prevention, Recognition, Restoration*, EM 9216. This booklet offers planting suggestions and other helpful tips.

## Solutions for nurseries

Restoration nurseries often work on a shoestring budget with a dedicated but small staff, making it difficult to adopt intensive monitoring programs. Utilizing volunteers to conduct monitoring as part of a citizen science project may be a feasible way to establish a monitoring program while providing community outreach and involvement.

Restoration nurseries could benefit from contracting for monitoring and diagnostic services either individually or as part of a group of nurseries. As restoration practitioners become more aware of the damaging consequences of *Phytophthora* introductions, phytosanitary nursery practices and monitoring programs will become more widely adopted and higher associated costs accepted.

## Nursery licensing and inspection programs

Oregon, Washington and Idaho have nursery licensing programs administered through each state's department of agriculture. Nurseries that ship plants out of state must comply with regulatory and certification requirements of their destination state or country. Check your state's licensing and shipping requirements and consult with your department of agriculture to ensure compliance. Nursery inspection programs are often focused on certain regulated pathogens and on shipments coming in and out of the state. State inspection programs aim to inspect all nurseries annually. Nurseries that are frequent shippers are inspected more frequently as the import of nursery stock from out of state or offshore locations is considered to be a high risk pathway for the introduction of unwanted pests.

## Purchasing native plants

Restoration practitioners purchasing plants of any stock type (container or bare root) for restoration projects will want to procure plants from nurseries that follow the nursery best management practices described in Table 1. Prior to purchasing plants, ask for a nursery tour during the growing season to assess their practices and plant health. Make sure your shoes have been disinfected before visiting a nursery.

## *Phytophthora* prevention at restoration sites

Careful sanitation measures do not stop after restoration plants have been purchased; there is still the risk that plants can be infested in intermediate holding sites or that pathogens are carried into the restoration site on dirty vehicles or equipment. Follow these guidelines during initial restoration work and conduct follow-up monitoring to help reduce those risks in restoration plantings:

- Ensure that intermediate holding areas are clean and dry, and that plants are not placed directly on the soil.
- Provide clean transport that is clear of plant debris and sanitized before loading.
- Use clean tools for restoration work. Do not lend or share tools.
- Clean tires and the underside of vehicles prior to accessing restoration sites.
- Ensure that field staff sanitize boots prior to entering restoration sites (Figure 55).



Photo: Shawna Horner, © Oregon State University

Figure 55. Sanitizing boots with brush and disinfectant.



Photo: Marianne Elliott, Washington State University

Figure 56. Western redcedar heartwood chips applied to a trail in Curry County to help prevent the spread of *P. ramorum*.



Photo: Marianne Elliott, Washington State University

Figure 57. The risk of transferring *Phytophthora* into a restoration site can be reduced by direct seeding. Emerging seedlings in this photo are protected from damage inside the tube.

- Provide boot and tool sanitization supplies and clear procedures for using them.
- Adding western redcedar chips to well-used trails may help prevent pathogen spread. Wood chips provide a barrier between soil and foot travel. Western redcedar chips have been shown to be toxic to *Phytophthora ramorum* in trials (Figure 56).

Do you see evidence of dying or unhealthy plants in sites planned for restoration? Some restoration sites may already be infested with *Phytophthora* species. Consider testing symptomatic plants for *Phytophthora* species; if positive, select resistant or low-risk host species to prevent new plantings from succumbing to disease already at the restoration site. High-risk host species include plants in the genera *Alnus* and *Lupinus* and plants in the families Rosaceae and Ericaceae. Low-risk species include grasses. Direct seeding in sensitive restoration sites is an option to help prevent the introduction of pathogens (Figure 57). For more information see Guidelines to Minimize *Phytophthora* Contamination in Restoration Projects, “Resources for Disease Prevention,” page 35.

## What does the future hold?

For the Pacific Northwest, climate models indicate warmer temperatures and a variable precipitation trend. A warming trend associated with increased precipitation would create favorable conditions for *Phytophthora* infestation in areas currently considered to be at low risk of infestation. Land managers and restoration practitioners east of the Cascades (the “dry side”) will be well served to maintain vigilance about nursery practices along with their counterparts on the wetter “west side.” All nurseries, no matter where they are located, may harbor *Phytophthora* pathogens. Following the best management practices listed here and in the Resources section below will improve plant health and help prevent *Phytophthora* introductions into wildland plant communities.

# Resources

## Disease prevention

- Buying healthy plants: What to look for at a nursery.* 2017. California Native Plant Society Ad Hoc Committee on Phytophthoras and the Phytophthoras in Native Habitats Work Group. <http://www.suddenoakdeath.org/wp-content/uploads/2018/01/Buy-in-Guide-December-2017.pdf>
- Disease Risk Model. 2019. J. Majsztrik, J. L. Parke, C. Swett, B. Pitton, S. Kumar. <https://occviz.com/CW3/pathogen/pathogen.html>
- Forest Phytophthoras of the World. <http://forestphytophthoras.org/>
- Guidelines to Minimize Phytophthora Pathogens in Restoration Nurseries.* 2020. Working Group for Phytophthoras in Native Habitats. [https://www.suddenoakdeath.org/wp-content/uploads/2020/08/Restoration.Nsy\\_Guidelines.final\\_092216\\_rv\\_8.20.20.pdf](https://www.suddenoakdeath.org/wp-content/uploads/2020/08/Restoration.Nsy_Guidelines.final_092216_rv_8.20.20.pdf)
- Guidelines to Minimize Phytophthora Contamination in Restoration Projects,* Working Group for Phytophthoras in Native Habitats. [https://www.suddenoakdeath.org/wp-content/uploads/2016/04/Restoration\\_guidance\\_FINAL-111716.pdf](https://www.suddenoakdeath.org/wp-content/uploads/2016/04/Restoration_guidance_FINAL-111716.pdf)
- Nursery Industry Best Management Practices for Phytophthora ramorum — to prevent the introduction or establishment in California nursery operations,* California Association of Nurseries and Garden Centers. [https://ccuh.ucdavis.edu/sites/g/files/dgvnsk1376/files/inline-files/cangc\\_bpm\\_Phytophthora%20Eng\\_1.pdf](https://ccuh.ucdavis.edu/sites/g/files/dgvnsk1376/files/inline-files/cangc_bpm_Phytophthora%20Eng_1.pdf)
- Phytophthora Online Course: Training for Nursery Growers,* Oregon State University. <https://horticulture.oregonstate.edu/osu-nursery-greenhouse-and-christmas-trees/phytophthora-online-course-training-nursery-growers>
- Plant Health and Disease Diagnosis for Nursery Crops. Oregon State University website. <https://workspace.oregonstate.edu/course/plant-health-and-disease-diagnosis>
- Safe Procurement and Production Manual: A systems approach for the production of healthy nursery stock.* 2011. J. A. Griesbach, J. L. Parke, J. L., G. A. Chastagner, N. J. Grunwald, J. Aguirre. Oregon Association of Nurseries. <https://www.oan.org/general/custom.asp?page=861>
- Soil solarization for Gardens & Landscapes. University of California Statewide Integrated Pest Management Program website: <http://ipm.ucanr.edu/PMG/PESTNOTES/pn74145.html>
- Soil Solarization Online Model. Oregon State University website. <https://uspest.org/soil/solarizeV2beta1>

## Testing and baiting techniques (including video tutorials)

- Baiting: a method for early detection of *Phytophthora* from water or soil. Video tutorial. Oregon State University. <https://www.youtube.com/watch?v=SJx7gzXyXoM>
- Bench testing leachate from batches of container nursery plants. 2019. T. Swiecki, E. Bernhardt, *Phytosphere Research*. [http://phytosphere.com/BMPsnursery/test3\\_4bench.htm](http://phytosphere.com/BMPsnursery/test3_4bench.htm)
- Do-it-yourself diagnostic kits for purchase (at the time of this publication there are limited vendors in the United States). <https://www.potadahocom/test-kits>
- How to use rapid test kits to detect *Phytophthora* in plant samples. Video tutorial. Oregon State University. <https://www.youtube.com/watch?v=5BoqfIldNwg>
- Leachate Baiting Technique for Phytophthora Screening.* Video tutorial. 2019. Phytosphere Research and COMTF. <https://www.youtube.com/watch?v=1OZGxRwuSxc&feature=youtu.be>
- Systems Approach to Nursery Certification. <https://sanc.nationalplantboard.org/>
- Testing Procedures for BMPs for Producing Clean Nursery Stock. 2019. *Phytosphere Research*. <http://phytosphere.com/BMPsnursery/Index.htm>
- Testing the Waters — how to test your irrigation system for the presence of *Phytophthora*. 2019. N. R. Redekar, J. L. Parke. *Digger Magazine*. <http://www.diggermagazine.com/testing-the-waters/>



Three new *Phytophthora* detection methods, including training dogs to sniff out the pathogen, prove reliable. 2018. T. Swiecki, M. Quinn, L. Sims, E. Bernhardt, L. Oliver, T. Popenuck, M. Garbelotto. *California Agriculture* 72(4):217–225. <https://doi.org/10.3733/ca.2018a0026>.

### Additional technical information

Antimicrobial activity of extracts and select compounds in the heartwood of seven western conifers toward *Phytophthora ramorum*. 2008. D. K. Manter, R. G. Kelsey, J. J. Karchesy. In: S. J. Frankel, J. T. Kliejunas, K. M. Palmieri, technical coordinators, Proceedings of the sudden oak death third science symposium. General Technical Report PSW-GTR-214. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. pp. 375–378. <https://www.fs.usda.gov/treearch/pubs/29958>

Control of *Phytophthora* species in plant stock for habitat restoration through best management practices. 2019. L. Sims, S. Tjosvold, D. Chambers and M. Garbelotto. 2019. *Plant Pathology* 68: 196–204. <https://doi.org/10.1111/ppa.12933>. | PDF: [https://www.researchgate.net/publication/327165019\\_Phytophthora\\_species\\_in\\_plant\\_stock\\_for\\_habitat\\_restoration\\_can\\_be\\_controlled\\_through\\_best\\_management\\_practices](https://www.researchgate.net/publication/327165019_Phytophthora_species_in_plant_stock_for_habitat_restoration_can_be_controlled_through_best_management_practices)

Film-forming polymers and surfactants reduce infection and sporulation of *Phytophthora ramorum* on rhododendron. 2019. E. K. Peterson, E. R. Larson and J. L. Parke. *Plant Disease* 103: 1148–55. <https://doi.org/10.1094/PDIS-05-18-0802-RE>.

*Phytophthora* introductions in restoration areas: responding to protect California native flora from human-assisted pathogen spread. 2020. S. J. Frankel, C. Conforti, J. Hillman, M. Ingolia, A. Shor, D. Benner, J. M. Alexander, E. Bernhardt and T. J. Swiecki. *Forests* 11: 1291. <https://doi.org/10.3390/f11121291>.

*Phytophthora* species repeatedly introduced in Northern California through restoration projects can spread into adjacent sites. 2021. L. L. Sims, M. Garbelotto. *Biological Invasions* 1–18. <https://doi.org/10.1007/s10530-021-02496-6>

*Phytophthora* spp. associated with nursery-grown native plants in the Pacific Northwest. 2017. J. L. Parke, M. Elliott, J. Eberhart and G. Chastagner. Eighth meeting of the IUFRO Working Party 7.02.09, Sapa, Vietnam. March 19–25, 2017. Poster presentation. Page 78 in <http://forestphytophthoras.org/sites/default/files/proceedings/IUFRO-WP-7-02-09-Sapa-2017-abstracts-V2.pdf>

Rhododendron-*Phytophthora* Root Rot. *Pacific Northwest Pest Management Handbooks*. <https://pnwhandbooks.org/plantdisease/host-disease/rhododendron-phytophthora-root-rot>







*This publication was made possible through a grant from Bureau of Land Management Secure Rural Schools and Community Self Determination Act Title II funds and support from the Bonneville Environmental Foundation through a Coordination and Collaboration grant from the Climate Resilience Fund.*



**Oregon State University**  
Extension Service