Research

An Accreditation Program to Produce Native Plant Nursery Stock Free of *Phytophthora* for Use in Habitat Restoration

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Abstract

Widespread *Phytophthora* infections have been discovered in nursery stock used in California restoration plantings. In response, Nursery *Phytophthora* Best Management Practices (NPBMPs) designed to exclude *Phytophthora* from nursery plants were developed to address the need for clean planting stock in restoration projects. A pilot program to implement the systematic use of the NPBMPs, Accreditation to Improve Restoration (AIR), was developed and started in 2018. As of 2020, 13 northern California restoration nurseries have been evaluated, and five have met all the program requirements. In 564 tests conducted over 4 years with a sensitive leachate baiting protocol, no *Phytophthora* was detected from over 20,000 nursery plants produced in compliance with the NPBMPs. In comparison, *Phytophthora* was detected in 25% of tests conducted on partially compliant stock and in 71% of tests from nurseries following few or no NPBMPs. The AIR pilot program has demonstrated that container stock free of detectable *Phytophthora* can be reliably produced by adhering to an integrated program of clean nursery production practices. To obtain *Phytophthora*-free plants for habitat restoration, informed clients were willing to pay increased costs required to produce NPBMP-compliant nursery stock.

Keywords: accreditation, best management practices, *Phytophthora*, restoration, nurseries, nursery stock

Numerous studies have shown that nurseries are a major source for spread of *Phytophthora* pathogens (Bienapfl and Balci 2014; Ferguson and Jeffers 1999; Guarnaccia et al. 2021; Hardy and Sivasithamparam 1988; Hoitink and Schmitthenner 1974; Jung at al. 2016; Molnar et al. 2020; Parke et al. 2019). *Phytophthora* species cause damaging diseases in forests, wildlands, horticultural settings, and agriculture, so preventing the introduction and spread of these pathogens is critical for sustaining plant health (Erwin and Ribeiro 1996; Hansen 2015; Jung et al. 2018; Lamour 2013). In California, spread of *P. ramorum*, cause of sudden oak death and ramorum blight, from nursery stock to native forests (Croucher et al. 2013; Grünwald et al. 2012) drew renewed attention to the threat of *Phytophthora* introductions from nursery-grown plants in and near natural habitats. Concern about such spread was heightened when *P. cinnamomi* was found to be causing substantial mortality in native stands of rare *Arctostaphylos* species in California (Socorro Serrano et al. 2019; Swiecki et al. 2003, 2011).

In 2008, *P. cinnamomi* was identified as the cause of a 0.7-ha patch of dead and declining *Arbutus menziesii* and *Umbellularia californica* on watershed lands in San Mateo County, CA (Swiecki et al. 2011) that were already heavily impacted by sudden oak death. Subsequent sampling showed that *P. cactorum* and *P.* × *cambivora* were also present in the *P. cinnamomi* mortality center, which was centered along roads and trails near a landscaped historic estate with its own nursery that had a known history of Phytophthora root rot. Further sampling of symptomatic vegetation documented smaller outlying infestations of these and additional *Phytophthora* species along unpaved roads that traverse the watershed, which is managed by the San Francisco Public Utilities Commission (SFPUC).

Based on these detections, in 2011 SFPUC plant ecologists requested input on nursery production standards that might be used to prevent *Phytophthora* introductions in a planned multiyear restoration project involving installation of over 700,000 container plants. After reviewing available nursery best management practices (BMPs), we recommended that the Oregon Association of Nurseries Safe Procurement and Production Manual (Griesbach et al. 2012) be used as the basis for a nursery clean production standard. We also visited one of SFPUC's contracted nurseries to review and discuss nursery practices for preventing soilborne *Phytophthora* species. Both the nursery operator and associated restoration contractor expressed opposition to implementing additional critical clean production practices that were recommended. Nevertheless, the Griesbach et al. (2012) BMPs

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were generally followed for the stock grown under contract for SFPUC's restoration project, and a horticultural consultant was hired to assess BMP compliance and visually inspect nursery stock at intervals during production for plant health.

Despite these precautions, both *P. cactorum* and *P. tentaculata*, a species of regulatory concern, were detected in declining and dead *Heteromeles arbutifolia* that had recently been transplanted into a restoration project site in January 2014. In response, SFPUC discontinued planting nursery stock in project sites (Frankel et al. 2020). In subsequent sampling of container stock from four contracted nurseries, a wide variety of plants were found to be infected with these and other *Phytophthora* species. Detected levels of *Phytophthora* infection and the diversity of *Phytophthora* species present in the nursery stock were unacceptably high. Similarly, Osterbauer et al. (2014) found substantial levels of Phytophthora root rot in plants produced by nurseries complying with the USDA APHIS U.S. Nursery Certification Program, Oregon Department of Agriculture Grower Assisted Inspection Program, and Shipping Point Inspection program. Although these programs and the Griesbach et al. (2012) BMPs are intended to help reduce pest and disease levels in nurseries, they were not expressly designed to exclude soilborne *Phytophthora* from nursery plants.

Through additional sampling of restoration nurseries in both northern and southern California, a variety of *Phytophthora* taxa were identified on California native plants grown for outplanting into restoration projects (Frankel et al. 2020; Rooney-Latham et al. 2019; Sims et al. 2019; nurseries H, J, L, and M in Table 1). The incidence and diversity of root-rotting *Phytophthora* species in these restoration nurseries were similar to levels documented in other commercial nurseries (Bienapfl and Balci 2014; Junker et al. 2016; Osterbauer et al. 2014; Parke et al. 2014). Furthermore, sampling of nursery-grown plants in existing restoration plantings showed that *Phytophthora* species survived in plantings, resulting in continuing plant losses and, in some cases, spread of *Phytophthora* into nearby native vegetation (Bourret 2018; Frankel et al. 2020; Garbelotto et al. 2018).

Many habitat restoration projects in California are undertaken by public agencies as mitigation for habitat loss incurred by infrastructure improvements. These projects may involve

TABLE 1
***Phytophthora* detections from leachate baiting tests of nursery plant arrays conducted between 2016 and 2020 in nurseries or sections of nurseries that fully complied with Nursery *Phytophthora* Best Management Practices (NPBMP compliant), were partially compliant (one to several NPBMP violations conferring moderate to high contamination risk), or were generally noncompliant (few if any NPBMPs followed)**

Nursery	Year	Total tested containers	Number of tests	Detections	% positive tests	Number of *Phytophthora* spp. detected
NPBMP compliant						
A	2017	973	25	0	0	
	2018	2,978	55	0	0	
	2019	2,398	74	0	0	
	2020	1,171	39	0	0	
B	2017	973	25	0	0	
	2018	2,545	47	0	0	
	2019	582	25	0	0	
	2020	1,286	40	0	0	
C	2017	899	23	0	0	
	2018	2,471	44	0	0	
	2019	873	30	0	0	
	2020	200	6	0	0	
D	2019	1,031	21	0	0	
E	2018	198	4	0	0	
F	2020	282	8	0	0	
G[a]	2019	963	36	0	0	
	2020	812	62	0	0	
Totals		20,635	564	0	0	
Partially compliant						
C	2018	475	46	10	22	3
B	2019	351	12	2	17	1
H	2016	691	8	4	50	1
I	2018	144	6	2	33	2
J	2019	319	12	5	42	2
K	2020	150	7	0	0	
Totals		2,130	91	23	25	
Generally noncompliant						
L	2016	1,025	6	4	67	3
M	2016	53	3	3	100	3
J	2017	257	9	7	78	5
N	2019	72	6	3	50	1
Totals		1,407	24	17	71	

[a] Data supplied by San Francisco Public Utilities Commission through the Accreditation to Improve Restoration pilot program.

endangered species and sensitive habitats. Introducing *Phytophthora* species via nursery stock that can degrade restoration sites and potentially invade adjoining habitats is inconsistent with the goals of restoration and unacceptable to many land stewardship organizations. In December 2014, findings of recent restoration-related wildland *Phytophthora* introductions in northern California were shared at a meeting for individuals and organizations involved with habitat restoration in the San Francisco Bay Area. In response, staff from public agencies, restoration nurseries, conservation organizations, researchers, and other stakeholders formed the Working Group on Phytophthoras in Native Plant Habitats (PWG, www.calphytos.org). This group was formed to share information and develop strategies to minimize further spread of soilborne *Phytophthora* species into native habitats via restoration activities. The PWG was organized as a part of the California Forest Pest Council's California Oak Mortality Task Force, which was established to coordinate activities to reduce the spread of *P. ramorum*/sudden oak death (Frankel and Stanley 2006; Frankel et al. 2018).

Development of Nursery *Phytophthora* BMPs

A priority for the PWG and several of its participants was to develop nursery BMPs sufficient to produce nursery stock free of *Phytophthora* to the greatest practicable degree for use in restoration plantings. Alternative techniques for restoring native vegetation, such as favoring existing natural regeneration of native species or direct seeding with clean seed, pose lower risks of *Phytophthora* introduction than the use of nursery stock, and some agencies started to use these techniques more widely. However, these alternatives do not provide the same flexibility and range of species and applications that can be achieved with nursery stock. Given the continuing demand for nursery stock for restoration plantings, strict BMPs were developed that could meet the high standard needed to prevent *Phytophthora* introductions to sensitive habitats.

History. BMP development started in 2015 when the Santa Clara Valley Water District (SCVWD, also known as Valley Water) requested Nursery *Phytophthora* BMPs (NPBMPs) that could be included in contracts for production of restoration nursery stock free from soilborne *Phytophthora* species. The NPBMPs developed for SCVWD were expanded into a more comprehensive set for the California Native Plant Society (CNPS) (CNPS 2016), which adopted a policy to prevent spread of harmful pathogens via native plant nursery and plant sale stock in December 2015. About the same time, the PWG began developing similar NPBMPs, which were based on the CNPS version.

Interested parties, including nursery growers, agencies that contract for nursery stock, restoration ecologists, and plant pathologists reviewed and commented on NPBMP drafts as the versions were developed. Some nursery growers and others were reluctant to accept many of the proposed standards and practices perceived as expensive or time-consuming to implement. The most contentious standards included the minimum bench height, requirement for the use of heat-treated potting media, and prohibition of the use of systemic oomycete-suppressive chemicals. Many necessary standards and practices would not have been included in the NPBMPs without persistent efforts by plant pathologists to justify and support them. Even so, agreement on some practices, such as maintaining all stock on benches, was largely possible because most agencies used small container stock for restoration plantings.

NPBMP versions adopted by CNPS (2016) and PWG (2016) contain some differences in content and format. For instance, PWG removed most of the explanatory information found in the CNPS version to reduce total length but added details about seed collection practices. A third version (Swiecki and Bernhardt 2016) combines the two versions, retaining explanatory text but omitting comments specifically directed to CNPS nurseries. Phytosanitation standards and testing procedures referenced in the NPBMPs are maintained in linked online documents that are updated as needed.

Underlying premises. The NPBMPs are an integrated set of practices and standards designed to exclude soilborne *Phytophthora* species from nursery stock rather than only suppress their activity. Soilborne *Phytophthora* species readily reproduce and spread in nursery environments (Junker et al. 2016; Molnar et al. 2020; Redekar et al. 2020; Swiecki et al. 2018; Weiland et al. 2020) because of conditions that favor spread and infection: uniformly susceptible single species in tightly packed arrays and containers with limited soil volume and high root densities that require frequent irrigation. These favorable conditions can allow even small amounts of *Phytophthora* inoculum to initiate disease outbreaks. Exclusion of *Phytophthora* is the only viable means for producing stock free of these pathogens; as Baker (1957) advised, "Don't fight 'em, eliminate 'em".

NPBMP components. The NPBMPs use a systematic approach to disease prevention that is integrated with nursery production practices (Baker 1957; Griesbach et al. 2012; Parke and Grünwald 2012). The NPBMPs include many of the same practices described in Griesbach et al. (2012), but standards were raised as appropriate to levels capable of excluding *Phytophthora* from the production system with a high level of confidence and made mandatory.

The underlying concept of the NPBMPs is to "start clean, keep it clean", where clean refers to materials innately free of contamination due to source or manufacturing conditions (e.g., new containers) or treated in a way that effectively eliminates *Phytophthora* (e.g., via heat treatment). The NPBMPs include practices to ensure that all inputs (plant propagules, containers, potting media, water) are free of *Phytophthora* and that production practices eliminate the potential for contamination of plants originating from these clean inputs. Production practices, which are largely based on six basic rules of thumb (Table 2), are designed to provide overlapping layers of protection against *Phytophthora* contamination.

Unlike nurseries that produce agricultural or horticultural plants, seeds and other propagules used in restoration nurseries are typically collected from native plant populations. These populations may have varying levels of disturbance, and some may be infested with *Phytophthora* and/or other pathogens. Because different types of propagules have varying risks of contamination, the NPBMPs utilize a phytosanitary tier system (Table 3) to categorize risk level and additional practices needed when higher-risk tier propagation materials (e.g., rhizomes, root divisions) are used. The NPBMPs require separation between stock originating from higher- and lower-risk propagules to minimize potential spread of *Phytophthora* from higher-risk material that is infected or contaminated.

Visual monitoring of plant condition is of limited value for detecting Phytophthora root rot in nurseries. Especially for drought-tolerant plants, shoot symptoms may not be evident until root rot is severe (Balci et al. 2008; Standish et al. 1982; Swiecki et al. 2018), by which time the pathogen may have spread widely throughout a plant block. Testing and early detection of *Phytophthora* play critical roles in successful implementation of the

NPBMPs, which require periodic quality control testing of plant stock during production and provide guidelines for isolating, delineating, and eradicating any detected infestation. Detailed recordkeeping is also required so that the source of any *Phytophthora* detected can be traced and other plant batches potentially exposed to contamination can be identified.

The bench leachate test (Swiecki and Bernhardt 2019) was developed to provide an effective standardized method for nurseries and stock purchasers to test plant lots for the presence of *Phytophthora*. The test is conducted by irrigating arrays of container plants and baiting collected leachate for *Phytophthora* following optimized protocols (Fig. 1).

Documenting and Accrediting NPBMP Compliance

The NPBMPs and bench leachate test provided the basis for developing a program to accredit nurseries that successfully implemented the NPBMPs and were capable of routinely producing stock without detectable *Phytophthora.* In 2017, SCVWD initiated its own program for contracted nurseries based on documenting NPBMP implementation, nursery inspection, and predelivery testing of contracted stock using the bench leachate protocol. With funding provided by multiple agencies, this program was expanded into the pilot Accreditation to Improve Restoration (AIR) program, with the goal of protecting wildland vegetation by ensuring that restoration nursery stock does not serve as a source of *Phytophthora* introductions into native habitats.

FIGURE 1

Predelivery testing of container stock for *Phytophthora* using the leachate baiting protocol at an accredited restoration nursery complying with Nursery *Phytophthora* Best Management Practices.

TABLE 2
Six basic rules underlying phytosanitary practices in the Nursery *Phytophthora* Best Management Practices

No.	Rule	Comments
1.	Clean + clean = clean.	If all inputs (plant tissues, container mix, pots, water) are clean and there is no contamination during production, the plants will remain clean.
2.	Clean + contaminated = contaminated.	Clean items should never be allowed to contact contaminated materials.
3.	Contaminated plants stay contaminated.	Once contaminated, live nursery plants cannot be made clean again.
4.	If unsure, assume it is contaminated.	Any tool, surface (including benches, hands, and gloves), or input (plant materials, container mix, pots, water) should be considered contaminated unless you know or have documentation it was sanitized or treated to kill *Phytophthora* and was not subsequently contaminated.
5.	The ground is always contaminated.	The ground surface and any water in contact with it should always be considered to be contaminated.
6.	Contamination spreads with water splash.	Clean plants or other materials that receive water splash from contaminated plants or surfaces can become contaminated. Water splash from rainfall-sized droplets in still air can reach a height of about 0.6 m and can spread laterally up to about 1.5 m. Splash dispersal distances can be greater under windy conditions or with larger drops (e.g., runoff) or if generated by water under pressure (e.g., hose nozzle) or mechanical forces (e.g., splash caused by vehicle).

TABLE 3
Phytosanitary tiers for nursery production of field-collected plant propagules in California, based on potential for *Phytophthora* contamination

Phytosanitary tier	Propagule type	Soilborne *Phytophthora* risk
Tier 1A	Seed collected from plants not subject to inundation.	Least potential for contamination; very low risk if applicable NPBMPs followed.
Tier 1B	Shoot tip cuttings.	Very low risk if applicable NPBMPs followed.
Tier 2	Below-ground structures (roots, crown divisions, bulbs, rhizome, tubers, etc.) completely cleaned of soil; low stem cuttings (near ground or extending below ground); seed or cuttings collected from plant parts subject to inundation or near water line.	Moderate risk; contamination possible from established infections, which are not eliminated by surface disinfestation.
Tier 3	Below-ground structures that cannot be completely cleaned of soil and/or do not tolerate surface disinfestation.	Among field-collected material, highest likelihood of being infested from external contamination or having infections.
Tier 4	Non-NPBMP nursery plants, any propagule type.	Highest overall likelihood of being infected or infested depending on source nursery practices.

AIR utilizes a shareable online spreadsheet (using Google Sheets) to evaluate and document each participating nursery's implementation of the NPBMPs. For efficiency and completeness, the NPBMPs in the evaluation spreadsheet are organized by topic areas based on nursery production workflow and aligned with how nursery inspections are carried out. The evaluation covers all aspects of production that have a potential to introduce or spread *Phytophthora*, including nursery layout, water source, container media, plant propagules, sanitizing protocols and practices, and production practices. Many of the items addressed in the evaluation cannot be observed directly during an inspection, so information on these practices must be supplied by the nursery. The following sequence was developed for the nursery evaluation process.

1. A custom spreadsheet is provided for the nursery, with edit permission for nursery data fields assigned to specified nursery personnel.
2. Nursery staff reports on their implementation of the NPBMPs by completing nursery data input fields in the spreadsheet.
3. AIR evaluators review the spreadsheet and rate NPBMP compliance for individual items (e.g., irrigation water source, sanitation practices) to the extent possible. Items needing further information or clarification are flagged and copied to nursery inspection datasheets.
4. AIR evaluators visit the nursery. They collect data for spreadsheet sections designated for evaluator input, collect information on flagged items, discuss observations of nursery practices, provide recommendations for improved practices as needed, and photo document nursery areas.
5. If time and staffing permit and plants are at a suitable stage, leachate baiting tests may be conducted on plant material selected by AIR evaluators. Alternatively, testing may be conducted in a separate nursery visit. Biased sampling is used to include plants with the highest risk of infection in these tests.
6. AIR evaluators enter additional data from the nursery visit and assign corresponding risk ratings, providing comments and recommendations in the spreadsheet as needed. Once all risk ratings are assigned, evaluators provide an overall nursery rating or may postpone the rating pending required changes. Both the nursery and evaluators have access to the spreadsheet throughout the whole process, and all changed versions are saved automatically.

A color-coded green-yellow-orange-red rating system (Table 4) is used to evaluate every practice listed by the nursery and to provide aggregate ratings for each spreadsheet page (topic area) and for the overall nursery. Not every deviation from ideal practices carries equal risk, and the aggregate risk posed by multiple interrelated deviations from the NPBMPs needs to be considered when scoring aggregate ratings. The evaluation team is led by a plant pathologist whose experience and judgement are utilized in developing the final ratings and recommendations.

The evaluation spreadsheet includes pages where *Phytophthora* testing conducted by the nursery or third parties, such as the AIR program, can be recorded. To assist in reevaluation, the spreadsheet includes a page for the nursery to list changes made since the last evaluation that may affect ratings. Other pages include instructions and information including definitions and standards. The entire spreadsheet can be shared for viewing by nursery clients and serves as a record of compliance with the NPBMPs.

AIR Program Participation

Since its start in 2018, 13 restoration nurseries in northern California have participated in the pilot program and have had nursery visits. An additional eight nurseries in southern California that enrolled in 2020 when the program expanded to that geographic area are in the second step of the evaluation process above. For some nurseries, full NPBMP compliance is limited to a specific delimited portion of the nursey, and ratings and accreditation apply only to that portion. Through the end of 2020, five nurseries completed all program requirements and received a "G" (passing) rating for the nursery or compliant portion. Final ratings for others are postponed pending recommended changes.

Some evaluated nurseries were at an early stage of implementing the NPBMPs and clearly could not meet the standards for accreditation. For these, the evaluation process provided guidance into what improvements were needed and suggestions for implementation within the nursery's specific constraints. The program emphasizes education and technical advice as well as documentation of successful NPBMP implementation. Once a nursery has been accredited, annual testing, updating of the evaluation spreadsheet to document changed conditions, and a site inspection are required to maintain accreditation.

Most of the nurseries that have participated in AIR to date include nurseries that produce NPBMP-compliant stock under contract and those that grow stock for their own organization's restoration activities. To date, participating nurseries (or their NPBMP-compliant portions) have been less than 0.5 ha in area. Requirements to grow stock on benches at least 0.76 m above the underlying surface, use new or sanitized containers, and heat treat container media are simpler to implement on a smaller scale than in an existing large nursery. When NPBMP-compliant stock is grown in only a portion of a nursery, the NPBMP-compliant portion needs to be well isolated from the noncompliant areas, which may serve as a source of contamination.

TABLE 4
Green-yellow-orange-red (GYOR) scale used in the evaluation tool for nurseries to rate risk associated with departures from best management practices and standards (NPBMPs) and corresponding corrective actions required for accreditation.

Code	Name	Description	Required actions
G	Green	No added risk: acceptable practice in compliance with NPBMPs.	None.
Y	Yellow	Low risk: minor departure from NPBMP practices or standards increases risk slightly.	Follow evaluator recommendation if possible.
O	Orange	Moderate risk: substantial departure from NPBMPs results in moderate increase in risk.	Correction required. Existing stock may be noncompliant.
R	Red	High risk: critical noncompliance with NPBMPs; unacceptably high risk.	Correction required. Existing stock is noncompliant.

Participating nurseries that built or rebuilt facilities specifically to meet AIR standards have been especially successful in implementing the NPBMPs. For example, in 2018, SFPUC completed construction of their Sunol Native Plant Nursery (SNPN), a 0.4-ha propagation facility designed to meet or exceed the NPBMPs (Frankel et al. 2020). This facility has propagated over 100,000 plants to date using only wild-collected seeds and received a passing rating from the AIR program. Based on the success of the nursery, SFPUC is considering reinstating the use of container stock in their restoration sites using SNPN material.

Assessing Effectiveness of NPBMP Implementation

Testing for *Phytophthora* by the AIR pilot program has been limited due to budget constraints. Testing has commonly served a dual purpose of training nursery staff in the leachate baiting test protocols, so six or fewer tests are typically conducted during a visit. However, since 2017, SCVWD required thorough predelivery testing of every contracted plant lot using the bench leachate protocol. This testing required one to several days per nursery, with up to 22 tests conducted per day. Some nurseries that grow stock for their own organization, including SNPN (nursery G, Table 1), also conduct extensive bench leachate testing.

Because all these tests were conducted following a standardized protocol, they can be aggregated to provide an assessment of *Phytophthora* present in stock produced in compliance with the NPBMPs. From 2017 through 2020, no detections of root-rotting *Phytophthora* species were made in 564 leachate tests in nurseries, or portions of nurseries, that were fully NPBMP compliant (Table 1).

In nurseries or portions thereof with partial NPBMP compliance (one to several moderate to high-risk BMP violations), *Phytophthora* was detected in 25% of tests (Table 1). This percentage was significantly greater ($P < 0.0001$) than the 0% detection rate in fully compliant nurseries based on Boschloo's unconditional exact test for proportions in 2 × 2 tables (R package Exact, version 2.1). The overall amount of *Phytophthora* infestation in this partially compliant stock was unsuitably high for plants used in habitat restoration. However, the overall *Phytophthora* detection rate in partially compliant nurseries was significantly lower ($P < 0.0001$, Boschloo's test) than the 71% detection rate in tests from nurseries that implemented few if any of the NPBMPs (Table 1). Similar results were reported from a 21-month study of five nurseries by other researchers participating in the PWG (Sims et al. 2019) using a less detailed version of the NPBMPs.

At two nurseries with NPBMP compliant areas (nurseries B and C), *Phytophthora* was detected in plant lots grown in portions that had substantial NPBMP violations (listed as partially compliant in Table 1) but not in the fully compliant areas. NPBMP violations included plants that were not started in heat-treated media, inadequate sanitization of reused containers, and insufficient separation between plants in different phytosanitary tiers. Both nurseries made initial detections in the problem areas through their own testing. In accordance with the NPBMPs, the infestations were delimited through testing, and all infected and suspect plant batches were destroyed.

Pythium (sensu lato) was sometimes detected in leachate tests conducted in NPBMP-compliant nurseries. *Pythium* species vary widely with respect to potential pathogenicity. If detected *Pythium* species are especially aggressive or present at unusually high levels in leachate baits, isolations are made to identify species and determine whether planting stock should be rejected. Decisions to reject planting material based on *Pythium* presence are based partly on the sensitivity and disturbance level of the planting site and published information on the distribution and pathogenicity of the detected species. Because *Pythium* and *Phytophthora* are introduced via many of the same risk pathways targeted by the NPBMPs, *Pythium* detections may indicate weaknesses in phytosanitary practices that should be addressed.

Conclusions and Significance

The overall objective for the AIR program is to sustain wildland plant health by preventing *Phytophthora* introductions from restoration plantings. Accredited nurseries must be able to consistently produce plants free of soilborne *Phytophthora.* Results from extensive testing support the conclusion that this standard has been met for several years in nurseries that are in full compliance with the NPBMPs.

Consistent nursery compliance with the NPBMPs is the best indicator that stock will be free of *Phytophthora*. Because the AIR program's nursery testing is limited, more extensive predelivery testing of contracted stock by the client is recommended to provide greater confidence that *Phytophthora* is below detectable levels. Although testing during production and predelivery serves as a check on the system, testing limitations, especially the possibility of false negative results from a single test, need to be recognized by both nurseries and clients. The reporting of all testing conducted by the nursery and outside parties on the nursery evaluation spreadsheet provides a more complete record of nursery performance than what is seen in limited annual testing by the AIR program, providing greater transparency and confidence in accreditation.

The successful implementation of the NPBMPs and the AIR program has been due in large part to a high commitment to environmental stewardship by both the restoration nurseries and their clients. Most participating nurseries incurred substantial one-time fixed costs to upgrade facilities and purchase equipment such as steam generators. They also have ongoing increased operational costs related to phytosanitary practices, testing, and employee training. Nurseries were able to implement the NPBMPs in stock grown under contract because clients were willing to pay additional costs required to produce *Phytophthora*-free stock. Expanding this clean production model to other nursery industry segments would require an informed customer base that is willing to pay more for *Phytophthora*-free plants as well as growers philosophically committed to the value of producing such stock.

The AIR program provides a model alternative to a traditional regulatory approach that would require regulation of many *Phytophthora* species on hundreds of host plant species. Regulatory programs, such as the program of inspection, compliance agreements, and treatment used to minimize interstate spread of *P. ramorum* in the nursery trade (U.S. Federal Regulations, 7 CFR 301.92 to 301.92-12) would be extremely difficult to design and enforce for California native plant and restoration nurseries. Although the AIR program is a voluntary system, compliance can be enforced by including NPBMP compliance (or AIR certification) and adequate testing in specifications for stock grown under contract or purchased from existing inventory. To effectively prevent pathogen introductions into wildlands, this approach would need to be widely adopted by agencies and organizations conducting restoration projects and other plantings near native plant habitat.

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