

Influence of Phytophthora Root Rot on Planting Trends of Fraser Fir Christmas Trees in the Southern Appalachian Mountains

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Abstract

The Southern Appalachian Mountains are home to the attractive Fraser fir [*Abies fraseri* (Pursh) Poir.] that began to be cultivated for Christmas trees in the 1950s. Today, 5 to 6 million trees are harvested annually in this region, yielding a wholesale value of more than \$100 million. Since the 1960s, however, Phytophthora root rot has been a problem for Christmas tree production in this region. This article gives a brief history of Fraser fir cultivation and how Phytophthora root rot has influenced planting practices. It also presents the results from surveys of Christmas tree growers about planting trends and their perspectives of the Phytophthora disease problem. Even though most growers have shifted from using locally produced bareroot seedlings to out-of-State-grown planting stock, Phytophthora root rot continues to have a major impact on Fraser fir plantations, and new *Phytophthora* species have recently been found on Fraser fir.

Introduction

The Southern Appalachian Mountains are home to one of the largest Christmas tree production regions in the United States. Collectively, North Carolina, Tennessee, and Virginia account for 17 percent of the 309,363 acres (125,195 ha) of the Nation's land used for Christmas tree cultivation (USDA NASS 2014). North Carolina is the second-largest producing State, annually harvesting 5 to 6 million trees that produce a wholesale revenue of more than \$100 million (Napier and Sidebottom 2011). Fraser fir (*Abies fraseri* [Pursh] Poir.) is the main species cultivated in the region, where it naturally grows in a small number of island-like populations on high ridges, mostly above 4,250 feet (1,300 m) (Busing et al. 1993). Christmas tree production sites are generally below the natural

elevational range of Fraser fir, down to about 3,000 ft (910 m). Fraser fir has beautiful dark green foliage, a pleasant aroma, and excellent post-harvest needle retention that have made it highly desirable as a Christmas tree (Chastagner and Benson 2000).

Fraser Fir Planting Stock—The Early Years

The Fraser fir Christmas tree industry in western North Carolina and surrounding States began in the 1950s when the Toecane Ranger District of the Pisgah National Forest opened up portions of the Roan Highlands for the harvest of fir boughs and cut trees. Due to the superior quality of Fraser fir as a Christmas tree, growers became interested in planting them, which required a supply of seed and seedlings. Seed was collected primarily from Roan Mountain along the North Carolina-Tennessee border. Growers also lifted ("pulled") wild seedlings ("wildlings") or collected seed from other wilderness areas with, and sometimes without, permission. For instance, in the 1956–1957 planting season, the U.S. Department of Agriculture (USDA) Forest Service permitted the Haywood County 4-H Council to lift Fraser fir seedlings from thick natural reproduction under a virgin fir stand near Burnsville to use as planting stock. Landowners in the Mount Rogers area in Virginia also pulled Fraser fir seedlings and sold them (Sidebottom 2011).

In 1955, the North Carolina Forest Service agreed to produce Fraser fir seedlings. To hasten production, these were originally gathered as wildlings from natural stands, primarily near Mount Rogers, VA. The climate at the two nurseries used initially—Holmes State Nursery near Hendersonville and Ralph Edwards Nursery in Morganton—was too warm to produce good-quality Fraser fir. Therefore, the North Carolina

Forest Service established a seed orchard and a seedling production facility at the Linville River Nursery near Crossnore (Avery County) and began seedling production there in 1968 (Sidebottom 2011).

Fraser fir seedlings were also available from commercial nurseries in other States as early as the 1960s. Fraser fir seedlings were advertised for sale in what became the American Christmas Tree Journal (produced by the National Christmas Tree Association) from at least two nurseries in Pennsylvania and one in Maine. Even with these sources, limited seedling supply would plague the developing Fraser fir industry through the 1970s. The main limiting factor for Fraser fir Christmas tree production in western North Carolina during the 1970s was the lack of Fraser fir stock ready for field planting. Because of this insufficient supply, extension programs and North Carolina Christmas Tree Association meetings focused on teaching growers how to grow their own seed in beds and to line-out transplants. As a result, this practice became widespread in the region (figure 1). Simultaneously, in 1977 and 1978, five contractors lifted 1.5 million wildlings from Roan Mountain. The number of wildlings taken from Roan Mountain remained high through 2000, with about 500,000 seedlings pulled each year (Sidebottom 2011).

Emergence and Spread of Phytophthora Root Rot

As Fraser fir planting in the region expanded during the 1960s and 1970s, growers began to recognize a number



Figure 1. Starting in the mid-1970s, extension programs focused on teaching Christmas tree growers how to sow their own Fraser fir seed in bareroot beds and to line-out transplants. (Photo courtesy of James McGraw, North Carolina State University, retired, Jackson County, NC, 1970s)

of disease and insect problems. Particularly challenging was *Phytophthora* root rot, a disease first reported on Fraser fir in 1963 on nursery seedlings in Penrose (Transylvania County, NC). *Phytophthora cinnamomi* Rands was identified as the causal agent (Kuhlman and Hendrix 1963). *Phytophthora* are fungus-like organisms belonging to the class Oomycetes (water molds). *P. cinnamomi* is exotic to the region, originating from Southeast Asia, where it was first described from cinnamon plants in Sumatra (Zentmyer 1988). It is believed to have been brought into the United States through southern ports during the 1800s or earlier on exotic plants destined for gardens of antebellum estates (Crandall et al. 1945). A map published in 1945 (Crandall et al.) showed the observed range of root rot caused by *P. cinnamomi* on American chestnut (*Castanea dentata* [Marsh.] Borkh.) and chinkapin species (*Castanea* spp.) and clearly demonstrates that this pathogen had been introduced into the Southern Appalachian region well before the start of the Fraser fir Christmas tree industry.

Phytophthora root rot affects all sizes and ages of Fraser fir. Symptoms include flagging of lower branches, stem cankers or cambial lesions with distinct borders, foliar chlorosis, reddening or browning of needles, diminished growth, and wilting of new growth, as well as darkened, sloughing, and necrotic roots (figure 2). Dying roots

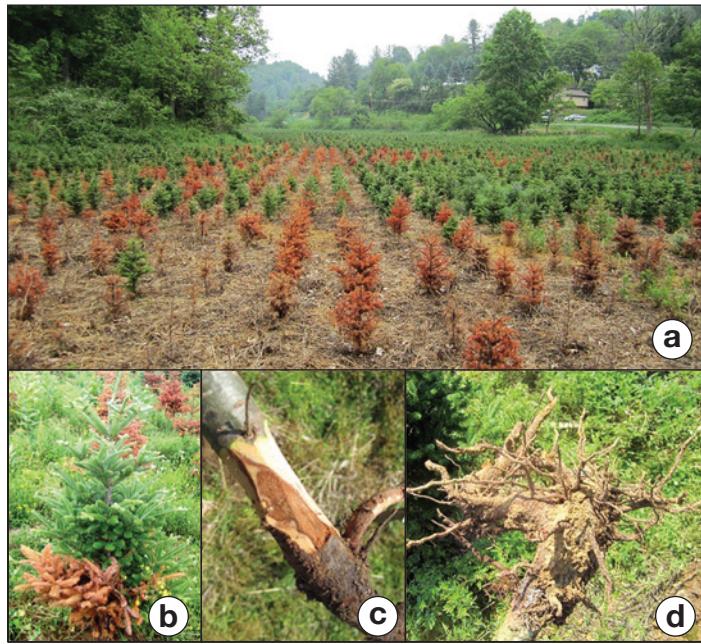


Figure 2. *Phytophthora* root rot inflicts a significant economic impact on the Fraser fir Christmas tree industry of the Southern Appalachian region. Characteristic symptoms of *Phytophthora* root rot on Fraser fir include: (a) tree mortality, (b) flagging of basal branches, (c) cambial stem lesion with distinct borders, and (d) heavily infected root systems with sloughing necrotic roots and absence of fine roots. (Photos by Martin Pettersson, 2015)

and girdling stem infections result in decreased water and nutrient translocation and often lead to a weakened tree and eventual death (Chastagner et al. 1995, Chastagner and Benson 2000).

Phytophthora species can rapidly spread in saturated and waterlogged soils or by splashing rain, subsurface water flow, and run-off water. Heavy rains and flooding conditions accelerate the spread. In addition to water movement, *Phytophthora* species can be introduced into new fields by infected planting stock, contaminated agricultural tools, vehicle tires, field workers' shoes, and animals. In nurseries, *Phytophthora* species can infect all plants if the irrigation water is taken from contaminated streams or surface water and not sterilized or filtered prior to use. Irrigation and rain can splash contaminated soil from one infected seedling onto surrounding seedlings, which may also become infected. In the nursery, seedlings experience optimal conditions (i.e., they grow in well-drained, nutritive soils, under optimal temperature), and therefore may be less prone to display disease symptoms, especially when dormant. Furthermore, fungicides do not always kill *Phytophthora* species, so that diseased plants are often not recognized until they have been lifted and planted in the field.

Two investigations of the incidence of *Phytophthora* root rot in Fraser fir Christmas tree plantations in North Carolina suggest that this disease is common in the region. The first study was conducted in 1972 and average disease incidence due to *P. cinnamomi* in 14 Fraser fir plantations in 5 counties in western North Carolina was reported to be 9.6 percent (range = <1 to 90 percent) (Grand and Lapp 1974). In a more recent study, conducted in 1997 and 1998 (Benson and Grand 2000), the average disease incidence was similar (9 percent; range = 0 to 75 percent) in 58 Fraser fir plantations sampled in the same 5 western North Carolina counties. As in the earlier survey, all isolates from the field sites were identified as *P. cinnamomi*, except for one isolate of an unidentified *Phytophthora* species. In the more recent study, nursery transplant beds were also sampled and had a mean disease incidence of 2 percent (range = 0 to 12 percent). In addition to *P. cinnamomi*, *P. cactorum* (Leb. and Cohn) Schröeter, *P. dreschleri* Tucker, and an unidentified *Phytophthora* species were found on Fraser fir seedlings sampled in the nursery transplant beds.

In 2014, another study conducted across the Southern Appalachian region revealed that the diversity of *Phytophthora* species in Fraser fir Christmas tree plantations had increased (Pettersson et al. 2016). Six *Phytophthora* species were isolated from infected roots sampled from 82 sites in 13 counties (North Carolina, Tennessee, and Virginia). While *P. cinnamomi* remained the most prevalent species isolated (70 percent), *P. cryptogea* Pethybr. & Laff. was relatively common (23 percent). Additionally, one or two isolates of four other species were found: *P. citrophthora* (R.E. Sm. & E.H. Sm.) Leonian, *P. europaea* Hans. & Jung, *P. pini* Leonian, and *P. sansomeana* Hans. & Reeser.

Fraser Fir Planting Stock—Shift to Out-of-State Sources

As regional Christmas tree growers became more knowledgeable about the distribution and occurrence of *Phytophthora* root rot, they wanted to reduce the risk associated with contaminating clean fields with diseased planting stock. Growers gradually stopped producing their own planting stock or buying from local sources and began to import out-of-State sources of planting stock. Often seed was provided to the contracted out-of-State grower. This trend is revealed in the results of pest management surveys conducted during 1995 to 2014 by the North Carolina Cooperative Extension Service (table 1).

Table 1. Summary of responses concerning planting stock from four pest management surveys conducted by the North Carolina Cooperative Extension Service between 1995 and 2014. Respondents could select multiple choices so responses do not total 100 percent (Sidebottom, unpublished data).

Survey choices	1995	2001	2007	2014
	(percent of respondents)			
Grew seedlings in outdoor beds	23.0	24.4	32.8	17.0
Didn't set Christmas trees this year in the field	5.3	30.7	28.2	30.0
Seedlings grown out of State in outdoor bed	Not Asked	14.8	24.8	59.0
Seedlings grown by NC grower in outdoor beds	Not Asked	27.4	15.1	14.0
Seedlings grown by NC Forest Service	34.2	19.0	14.0	3.0
Seedling source was Roan Mountain wildlings	14.0	10.2	6.3	3.0

NC=North Carolina

During the period of these surveys, the USDA Forest Service began limiting the number of wildlings removed from Roan Mountain, or in some years, not allowing removal of any wildlings. The survey results reflect this trend by the decreasing proportion of growers using wildlings from Roan Mountain from 1995 to 2014 (table 1). The USDA Forest Service is currently involved in a 5-year process of developing a long-term management plan for the Roan Mountain area of the Pisgah National Forest. Because of concerns with threatened and endangered species in the spruce-fir ecosystem, wild seedlings from Roan Mountain may not be available to the Christmas tree industry in the future.

Natural events also contributed to the shift toward the use of out-of-State planting stock. In September 2004, remnants of Hurricanes Frances and Ivan dropped record rainfall amounts across the region resulting in excessive soil moisture and flooding. The following spring, *Phytophthora* disease was widespread in Christmas tree plantations and the Linville River had spread *Phytophthora* inoculum through some fields of

the State-run nursery. Ultimately, this nursery ceased production of bareroot Fraser fir seedlings and began producing a much smaller volume of containerized seedlings. The use of seedlings grown by the North Carolina Forest Service decreased from 34.2 percent in 1995 to 3 percent in 2014. Many growers found out-of-State contracting to be more reliable at the time when the local nurseries were in crisis.

2015 Survey of Planting Trends and Phytophthora Root Rot

In spring 2015, a survey was conducted at five different Christmas tree grower meetings in western North Carolina to determine how many growers use out-of-State Fraser fir seedlings and for how long they have done so. A total of 89 growers from 13 counties took the survey. Twenty-two of the growers had Christmas tree farms in more than one county, resulting in 123 farms from North Carolina, Tennessee, and Virginia included in the survey (figure 3). Most of the surveyed farms

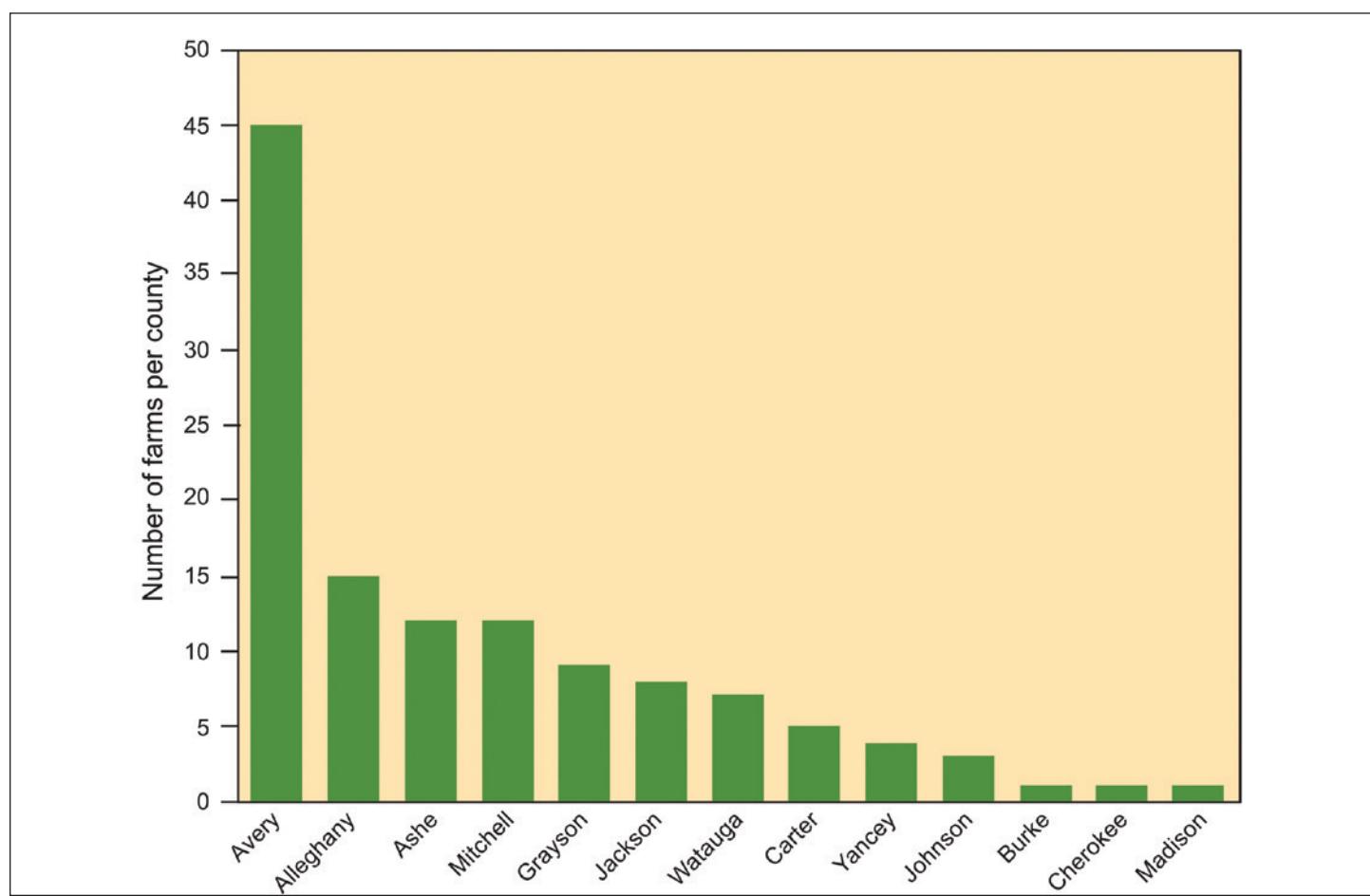


Figure 3. A total of 89 Christmas tree growers from 13 counties participated in a 2015 survey conducted in western North Carolina. Twenty-two growers included in the survey had Christmas tree farms in more than 1 county resulting in 123 farms from North Carolina, Tennessee (Carter and Johnson Counties), and Virginia (Grayson County).

were located in Avery County, NC. Of the growers surveyed, approximately 88 percent reported that they had Phytophthora root rot causing mortality in their Christmas tree fields. That is approximately 18 percent higher than what was reported in the 2006 North Carolina Christmas Tree Pest Management Survey.

On average, 64 percent of all growers surveyed were using out-of-State material (figure 4), with larger scale growers more likely to do so (figure 5). About 83 percent of the surveyed growers with more than 50 ac (>20.2 ha) of Christmas tree production were using out-of-State Fraser fir planting stock and 46 percent of these growers were purchasing seedlings from more than one State. Seventy-one percent of growers with 10 to 50 acres (4.0 to 20.2 ha) and 29 percent of growers with less than 10 ac (<4 ha) were using out-of-State planting stock. The out-of-State Fraser fir planting stock was bought from Oregon (41.2 percent), Washington (18.6 percent), Pennsylvania (17.5 percent), Michigan (17.5

percent), and Maine (5.2 percent). Clearly, a variety of locations produce the out-of-State material being planted in the Southern Appalachian Mountains.

More than half (57 percent) of the out-of-State planting stock purchased by the surveyed growers was bareroot seedlings. About 27 percent of surveyed growers purchased bareroot transplants that had been started in containers (plug+1) while only 16 percent purchased containerized seedlings grown exclusively in a greenhouse. Twenty-one percent of the growers responding to the survey reported using more than one type of planting stock.

Of the growers using out-of-State Fraser fir planting stock, 30 percent perceived an increased incidence of Phytophthora root rot in their fields since they began using out-of-State material, 47 percent said that the incidence of Phytophthora root rot had not changed, and 18 percent said that the incidence had decreased in their plantations (5 percent did not respond to this question).

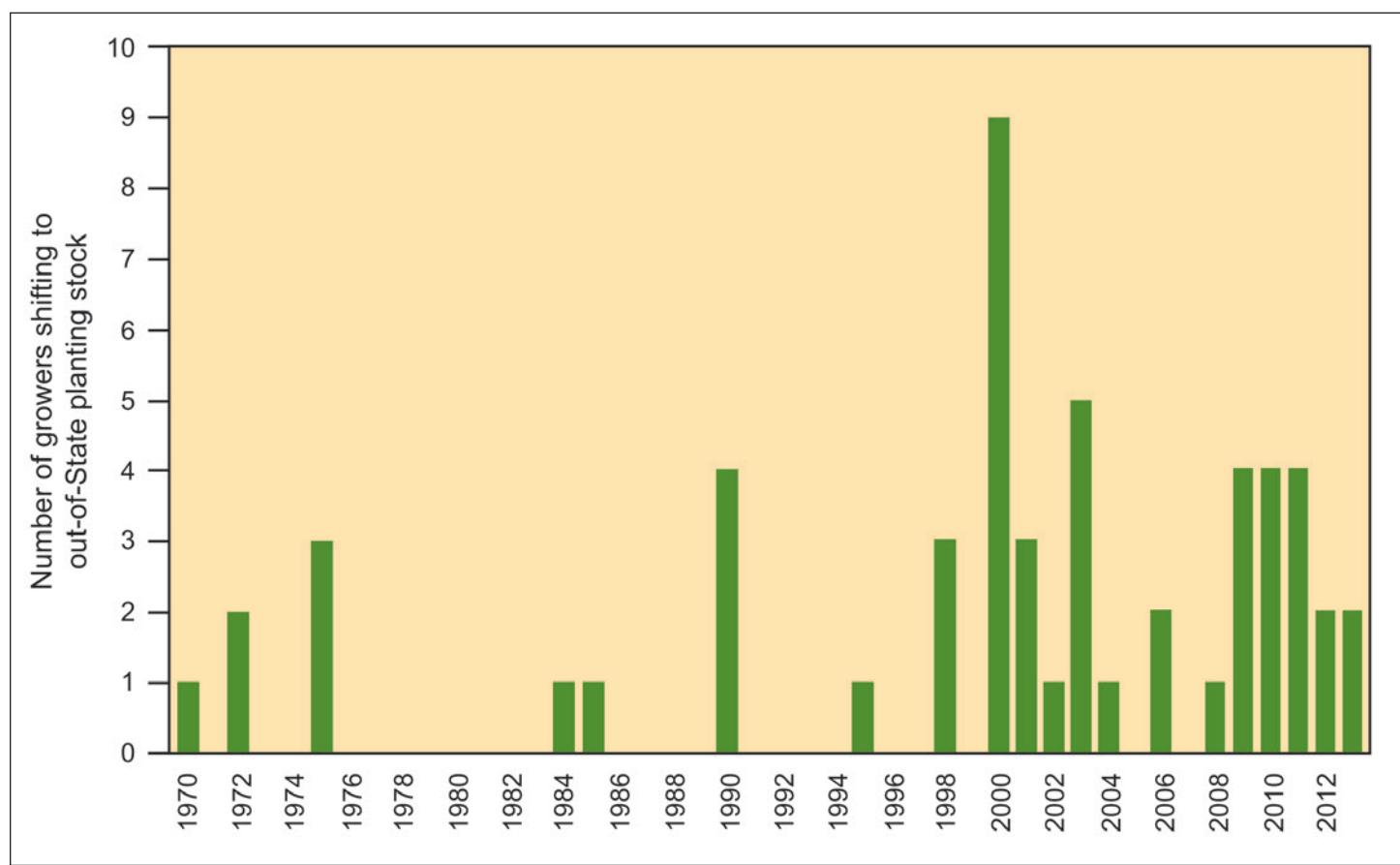


Figure 4. Christmas tree growers surveyed in western North Carolina (n=89) steadily shifted from locally produced Fraser fir planting stock to out-of-State stock starting in 1970, with the shift accelerating around 2000.

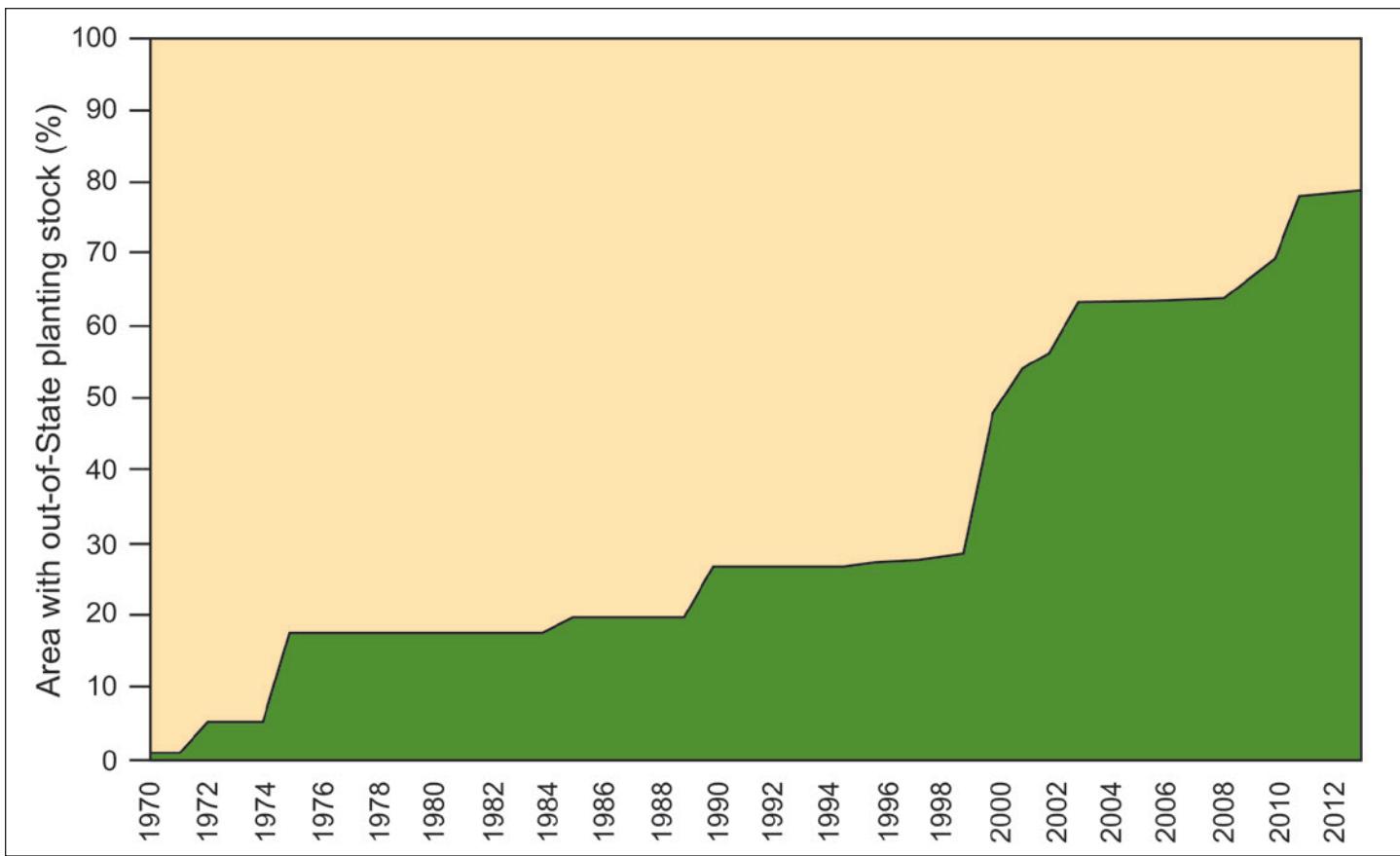


Figure 5. Over a 43-year period (1970 to 2013), 64 percent of Christmas tree growers surveyed in western North Carolina shifted from using locally produced to out-of-State planting stock. Because growers with more land were more likely to shift, about 80 percent of the land base managed by the surveyed growers was planted with out-of-State planting stock by 2013.

Perspective

Almost since its inception, the Fraser fir Christmas tree industry of the Southern Appalachian region has been afflicted by *Phytophthora* root rot. Although there is evidence that this exotic pathogen had previously been introduced into the region, undoubtedly the industry has contributed to its spread, especially through the movement of infested plant material. Once infested, land remains unsuitable for Fraser fir cultivation indefinitely. As Christmas tree growers understood the problem, they shifted toward importing out-of-State material to reduce the risk of contaminating sites with *Phytophthora* species, so that today only a small portion of Christmas tree plantations is regenerated with locally produced planting stock. Despite pursuing this strategy, *Phytophthora* root rot remains a menace to the regional Fraser fir industry. Most growers switching to out-of-State material perceive that their *Phytophthora* root rot problems have either stayed the same or increased since switching.

Of particular concern is the increased risk of introducing new *Phytophthora* species via importation of seedlings from bareroot nurseries and nurseries where containerized plants have been transplanted into outdoor beds. Most *Phytophthora* species are harmful plant pathogens that can cause serious and unpredictable, ecological and economic damage when they are introduced to a new environment. The Southern Appalachian climate, with its relatively warm soil temperatures and plentiful rainfall throughout the year, enhances the chance of survival and dissemination of many *Phytophthora* species. Further, the coexistence of multiple *Phytophthora* species in overlapping geographic areas increases the risk of another bleaker problem—a hybridization event from which a more virulent race could evolve (Érsek and Nagy 2008).

The number of *Phytophthora* species isolated from Fraser fir in the Southern Appalachian region has recently increased and *P. cryptogea*, in particular, appears to have rapidly spread (Pettersson et al. 2016). Regions from which Fraser fir planting stock is imported (the Pacific Northwest, Great Lakes,

and Northeast) are known to have different *Phytophthora* species afflicting fir, including *P. cryptogea* (McKeever and Chastagner 2016). For example, much of the planting stock (approximately 60 percent) used in the Southern Appalachians is produced in the Pacific Northwest where at least eight *Phytophthora* species have been reported to cause mortality in fir Christmas tree fields (Chastagner et al. 1990, 1995; Chastagner and Benson 2000). While most of these *Phytophthora* species have not yet been found in the Southern Appalachian region and there is no direct evidence that species have been introduced from other regions, vigilance is warranted because the nursery trade is known to contribute to the introduction and dispersal of plant pathogens (Jones and Baker 2007, Brasier 2008, McKeever and Chastagner 2016). Once introduced and dispersed in a new region, *Phytophthora* species have proven to be nearly impossible to control.

Christmas tree growers must be watchful to detect symptomatic plant material prior to and after planting. Symptomatic seedlings should be discarded; the cost of planting stock is inconsequential compared to the cost of losing Fraser fir production on a site due to the introduction of *Phytophthora* species. Today, suspect plant material can be evaluated with easy-to-use kits designed for rapid field-diagnosis of *Phytophthora* species. The North Carolina State University Cooperative Extension Service has been training regional Christmas tree growers on how to use these kits. Symptomatic seedlings may also be sent to a plant disease clinic for further verification and possible *Phytophthora* species identification. Growers must also employ good sanitation practices to prevent *Phytophthora* species spread from infested areas via equipment, vehicles, boots, water drainage, and other means.

Recently, a number of regional Christmas tree growers have begun greenhouse production of containerized Fraser fir seedlings. This movement is in its infancy and involves much experimentation with cultural aspects such as media, containers, lights, irrigation, etc. The results have been variable but some attempts are clearly on the path to achieve economically viable production systems. These efforts are encouraging and may provide a route to minimize the introduction of additional *Phytophthora* species to the region while also providing local income and reducing the cost of planting stock.

Although the use of genetically resistant material could offer a reasonable solution to this intractable problem, Fraser fir is generally highly susceptible to Phytophthora root rot and no useful level of resistance has been identified to the most prevalent species in the region, *P. cinnamomi* (Frampton and Benson 2012). Growers in the region commonly plant known infested areas with other species that have greater tolerance or resistance: eastern white pine (*Pinus strobus* L.), Canaan fir (*A. balsamea* var. *phanerolepsis* Fern.), Nordmann fir (*A. nordmanniana* (Steven) Spach.), and Turkish fir (*A. bornmuelleriana* Mattf.). Compared with Fraser fir, however, these species are generally less valuable as Christmas trees, and they sometimes succumb to Phytophthora root rot—especially on infested sites with poor drainage. Some growers in the region are piloting a more costly but effective strategy: the deployment of Fraser fir grafted onto rootstock of momi fir (*A. firma* Sieb. and Zucc.), the most Phytophthora-resistant fir species (Hibbert-Frey et al. 2010, Frampton et al. 2012). There is a need to evaluate the resistance of alternative Christmas tree species to the newly found *Phytophthora* species in the region, as well as to develop Phytophthora-resistant Fraser fir, either via genetic engineering (faster development but controversial) or a hybridization and backcross program (long-term development).

Phytophthora species will no doubt continue to plague the Fraser fir Christmas tree industry of the Southern Appalachian Mountains. Nonetheless, vigilance and the pursuit of a variety of amelioration strategies may help to reduce its future impact.

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