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Scale management in Christmas trees

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Abstract:
Foliar sprays to suppress cryptomeria and elongate hemlock scales prevent implementation of IPM in Christmas tree plantations in the northeast because they are toxic to natural enemies. Three tools will transform growers' practices: (1) chemical control: a reduced-risk insecticide applied to the trunk of the tree is directly absorbed and translocated to foliage, where it selectively kills scales, (2) biological control: several fungi found to infect armored scales will be cultured and then applied to trees, with or without whey adjuvants, to cause infections, and (3) cultural control: decreasing nitrogen fertility should reduce the intrinsic rate of growth for scales so that the existing complex of natural enemies can maintain scale populations below damaging levels. In published research trials the basal trunk spray of dinotefuran suppressed scale populations while conserving natural enemies; extension specialists in NJ, PA and RI will demonstrate this technique to growers with infested plantations. Several fungi found to infect the two targeted armored scales may provide a higher degree of selectivity than commercialized insect pathogenic fungi; if effective, these fungi could be registered through the IR-4 program. Adjustments in soil nitrogen fertility are expected to create growing conditions optimal for Christmas trees and less favorable to scales. The options being developed should readily be adopted by growers because they will be less expensive, more effective, and less toxic to the applicator and to the environment than current practices. A scale management web guide will extend the findings to growers.

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Project Description

Problem, Background and Justification

Economic importance and demonstration of stakeholder need. Christmas tree production is an important agricultural activity in the Northeast. Collectively, states in the northeast produce 15% of the total Christmas trees sold in the U.S. In CT alone, there are 495 farms with 4,833 acres in production (CT Christmas Tree Growers Association, pers. comm.) representing annual sales of approximately $18,000,000. This represents 5% of the total number of farms and 4% of the total Christmas trees sold within the northeastern U.S. (NASS, 2002 Census of Agriculture, Table 35). About as many Christmas trees are grown in Rhode Island and Massachusetts, combined, as are grown in Connecticut. As pointed out in the Christmas tree crop profile for PA (www.ipmcenters.org/cropprofiles/docs/PAchristmastrees.pdf), "The data on acres in production generated by the Census of Agriculture is grossly low. There was probably confusion among those filling out the surveys between acres in production and acres harvested. The 10,927 acres in production figure would be closer to the total number of acres harvested than the total acres in production." The estimation from the PA crop profile is that the value of Christmas tree production in PA is approximately 3× that of Connecticut, or approximately $55,000,000 per year.

NEREAP-IPM identified as an area of emphasis in May 2006 IPM strategies and tactics for ornamental crops including Christmas trees (http://northeastipm.org/nereap/priority/2006.htm), which this project squarely addresses. Additional priority concerns that are addressed in this proposal are "Development of IPM packages that improve eligibility for NRCS program funds" (Christmas trees are currently not covered by the EQIP program in CT, but are covered in some other states, like PA), "Use of web-based technologies for IPM decision making," and "Improvement and expansion of biocontrol in high value crops." Of the common pests ranked as highly important by Christmas tree growers, armored scales are the only ones that are both severely damaging and, until now, have lacked adequate control options. Presently, management practices for these armored scales affect the prospects for implementing IPM for all other Christmas tree pests. All other insect and mite pests may be managed with selective methods, and yet because injury caused by scales jeopardizes the crop, and the only tools to effectively suppress their populations have been disruptive insecticides, growers have been forced into a reliance on non-IPM compatible management practices.

Two species of armored scales, the elongate hemlock scale (EHS, *Fiorinia externa* Ferris), and the cryptomeria scale, *Aspidiotus cryptomeriae* Kuwana, both invasive exotic pests, threaten Christmas tree production in the northeastern U.S. An additional native species, *Abgrallaspis ithacae* (Ferris), the hemlock scale, has recently been found in damaging populations on spruce and in smaller populations on firs. In Connecticut, these scales were not recognized as pests 26 years ago (Merrill and Cameron 1983). However, for the past 7 – 9 years their populations and importance have rapidly increased. Infestations worsen as trees age within a planting, until trees become unsaleable as they reach marketable size. Infested trees then have to be removed and destroyed. Two problems are inherent with current management practices: (1) the IPM-compatible insecticide used (horticultural oil) is ineffective and can itself damage trees, and (2) more effective insecticides used as full foliar sprays (dimethoate in PA; bifenthrin and dinotefuran elsewhere) are inimical to the complex of parasites and predators found in Christmas tree plantations, and so their use engenders greater dependency on their continued use, which in turn risks the development of insecticide resistant scale populations. Use of dimethoate in PA constitutes reliance on a toxic organophosphate insecticide. This project is anticipated to eliminate the losses due to armored scales, for a value of over $1,080,000 per year in CT alone, and reduce the expense of chemical control by substituting an application method that is much less laborious than those that are currently used. This proposal will test and extend new approaches that are inexpensive, easy to apply on the smallest farms, use products that have low mammalian toxicity, conserve predators and parasitoids and result in excellent suppression of scale populations. If these strategies are adopted in CT, MA, NJ, NY, RI, and PA (areas influenced by our educational programs), then approximately $11M of crops will be saved per year.

The seriousness of this pest is summarized by a grower (Orrin E. Jones, pers. comm., November 2, 2006):

> "As a forester who performs Christmas tree cultural services for 18 - 22 different growers in CT and RI each year, I see the armored scales, elongate hemlock and cryptomeria, as the most serious and destructive true fir Christmas tree pests in my 25 years of growing Christmas trees. The cryptomeria scale is much more destructive than the elongate hemlock scale because it turns the tree needles yellow and they fall off. This discoloration and needle drop significantly degrades the tree to the point of being unsaleable. … I found the scale in almost every Christmas tree farm I visited. …. I have found cryptomeria scale on our farm on all my true firs and also Douglas fir. This represents 85% - 90% of my crop species ….
>
> The economic impact of this pest is huge…. I witnessed this summer a block of 1,000+ mature, very high quality Fraser fir trees with a retail value of approximately $40,000 become significantly damaged to the point where 2/3 of the trees became unsaleable. This economic loss to this small cut-your-own tree farm has the potential to close the farm permanently. On my own farm which still has a substantial mortgage, the scale problem threatens the viability of the farm. … If Christmas tree growers cannot produce a marketable product due to this pest, then the entire Christmas tree growing industry in Connecticut is at risk." (For the complete letter, see "Jones Letter.pdf" in "Other Attachments")

The economic damage described by Orrin Jones is echoed by other growers. As recently as November 9, 2009, a grower from Little Compton, RI called me for advice in managing scales. The horticultural oil applications he had been using had been inadequate, and he had started culling large trees due to scale damage, at a loss of $35 - 65 per tree (Donald Gavin, personal comm.); Christmas trees are grown at a density of 1,000 to 1,200 trees per acre. The geographical range of Christmas tree plantings suffering from EHS and cryptomeria scale infestations includes CT, MA, NJ, PA, and RI. Its range through NY to OH (Marcelino 2007) suggests that it may be a problem there in Christmas trees.

Biology of the armored scale pests of Christmas trees

Elongate hemlock scale (EHS) and the cryptomeria scale are Asian pests of conifers in the eastern United States (Ahern et al. 2005, Gardosik 2006). Scales from both species overwinter as adults. Mated females lay eggs in the spring (EHS) or early summer (cryptomeria scale). Crawlers hatch from the eggs and settle on the underside of needles, where they first slit the cuticle of the needle, and then insert themselves under the plant's cuticle before starting to feed. Extensive feeding on the palisade mesophyll tissue, and probably injection of toxic saliva results in needle chlorosis and necrosis. Damage from cryptomeria scale can be more serious, due to the greater mobility of the crawlers and the hypersensitive response of the tree to their feeding. In a single year, a few cryptomeria scale-infested lower branches can result in the entire tree becoming spotted and unsaleable. Both scales are bivoltine, with combined crawler activity from ~mid-June until October (McClure 1979, Gardosik 2006). EHS populations increase to high population densities on conifers, especially on plant material provided nitrogen fertilizer, in which case the fecundity and survival of the scales are elevated (McClure 1980). Cryptomeria scale develops to much higher population densities than EHS in Christmas tree plantations (up to 80 vs. 10 scales per needle, Cowles, pers. obs.).

In their native Japan, the aphelinid parasitoid, *Encarsia citrina* Craw and the coccinellid beetle, *Chilocorus kuwanae* Silvestri, are effective enemies of EHS. *E. citrina* also occurs in eastern North America, but has been ineffective because its life cycle is poorly synchronized with that of EHS (McClure 1978). The coccinellid, *Chilocorus stigma* (Say) can be important in reducing populations of EHS. During the past 25 years, EHS has significantly expanded its geographical range; the climate in New England has moderated, which may allow *E. citrina* to interact more effectively with EHS (Cowles and McClure 2004). *E. citrina* was the only parasitoid species recovered from emergence cages or observed during microscopic examination of samples taken by Dr. McClure from five hemlock forests in Connecticut and one in New York during 2001.

Several other predator species are of potential importance for biological control of these armored scales. Species released in the mid-1980's for biological control of the euonymus scale (Van Driesche et al. 1998, Matadha et al. 2003) are abundant where they have not been chemically excluded and where high population densities of either or both elongate hemlock scale and cryptomeria scale occur (Cowles, pers. obs.). These species included *Cybocephalus nipponicus* Enrody-Younga (Coleoptera: Cybocephalidae) and *Chilocorus kuwanae*. Another native predator, *Microweisia* spp. (Coleoptera: Coccinellidae), is often present in mixed populations with *Cy. nipponicus*, but at much lower population densities.

Insect pathogenic fungi are other biological agents impacting scale populations. Various fungi have been isolated from EHS by McClure, Cowles and others (Cowles and McClure 2004, Marcelino 2007, Li et al. 2008, Marcelino et al. 2008, Marcelino et al. 2009). These include species such as *Lecanicillium lecanii* (Zimm.) Gams et Zare [formerly *Verticillium lecanii*], *Colletotrichum acutatum* var. *fioriniae*, and *Metarhiziopsis microspora* (Li et al. 2008). Natural epizootics among EHS populations on hemlock have been widely observed (Marcelino et al. 2009). In the last two years, both cryptomeria scale and hemlock scale were found in a Christmas tree plantations infected with *M. microspora* (Cowles and Li, unpublished data).

Review of management practices and insecticide tests

Prior to 2004, my advice to Christmas tree growers with scale problems was to apply horticultural oil during the dormant season. Oil is only toxic through suffocation and will not disrupt natural enemies after the spray has dried. However, in 2005 three observations caused me to abandon this approach: (1) Growers expending up to 15 hours of labor per acre to achieve thorough spray coverage with a hydraulic sprayer (Terry Jones, Jones Family Farm, personal comm.) were still experiencing poor control of scales, (2) Phytotoxicity occurred to even our most oil-tolerant species (Fraser fir) and (3) Damaging populations of EHS were found on Douglas-fir, a particularly oil-sensitive species (Varela et al. 1996), and on Colorado blue spruce, which loses its distinctive blue color when sprayed with oil. Overall, because of poor efficacy when applied at dormant timing and phytotoxicity when applied at other times, oil is not suitable for managing armored scales in Christmas trees.

In PA, growers spray 3 - 4 applications of dimethoate at a high labeled dosage at 3 - 4 wk intervals (Heller and Kline 2005). McClure (1977) documented dimethoate to be highly disruptive to the parasitoid *E. citrina* on sprayed hemlocks, and so its use is known to be incompatible with the natural enemies of the armored scales. The usefulness of this organophosphate product was lost to all other states following changes mandated by the US EPA; in PA this product only continues to be used under a Special Local Needs registration (Eric Schildt, PA Dept. Agric., pers. comm.). The label changes approved by the U.S. EPA only allow one spray per growing season (in states other than PA), and at a rate (1 lb [active ingredient] a.i./acre), which is less than the minimum effective dosage of 3.2 lb a.i./acre required to control armored scales (Heller and Kline 2005). We feel that PA growers will benefit by having less toxic, more selective tools available for managing scales. The need for improved management of armored scales in Christmas trees was recognized by the PA Dept. of Agriculture and that state's IPM coordinator (http://paipm.cas.psu.edu/1572.htm). PDA's new scale management program has achieved some success through better spray timing by monitoring fields, and has had growers try the non-disruptive insecticide spirotetramat (Movento) (Cathy Thomas, PA IPM Coordinator, pers. comm.). However, improvements in pest management outcome due to adoption of spirotetramat may be due to cessation of spraying broad-spectrum insecticides and recovery of natural enemies, rather than to its efficacy against scales. Trials in Christmas tree plantations over 2 years in CT have not detected activity of spirotetramat against these armored scales (RSC, unpublished data).

From 2005 to the present, the IR-4 Program has recognized the importance of scales as a major, difficult to manage group of pests affecting ornamental crops. In 2005, my IR-4 program – sponsored trial demonstrated that several products have potential for suppressing a mixed population of scales (Palmer and Vea 2006). A follow-up trial with supposedly selective insect growth regulator insecticides buprofezin and pyriproxyfen (Grafton-Cardwell et al. 2006) proved one to not be as selective as expected (pyriproxifen) or were cost-prohibitive and ineffective (buprofezin). Based upon these results, Christmas tree growers in New England have adopted full foliar sprays of OnyxPro or Safari (active ingredients bifenthrin and dinotefuran, respectively) to control armored scales. Excellent control can be achieved when Safari or OnyxPro are applied with motorized backpack mist blower sprayers, hydraulic sprayers, or mist blower sprayers driven between every row of trees. However, these foliar applications disrupt the natural enemy complex. Furthermore, the cost of small tractor-driven mist blower sprayers (~$6,000) and the backbreaking effort required to spray a farm thoroughly with a backpack mist blower sprayer is troubling, especially considering the large number of small farms operated by elderly farmers.

The challenge addressed in this proposal is to test and extend new approaches that are inexpensive, easy to apply on the smallest farms, have low mammalian toxicity, conserve predators and parasitoids and result in excellent suppression of scale populations.

<u>Principles upon which this proposal is based</u>

Deployment of selective pesticides. We expect a selective insecticide that suppresses scale populations while not adversely affecting predator and parasitoid populations, will (1) promote integrated management, in which remnant populations of scales will be subjected to population suppression by natural enemies, (2) these dynamics will prevent or delay insecticide resistance, because scales surviving insecticide treatment will be preyed upon, and (3) scale populations on trees will be much more manageable, because "perfect" spray coverage will not be necessary. These dynamics were observed from the previous successful effort to achieve integrated management of spider mites in nursery crops (Cowles and Abbey 1999). The selective insecticides chosen for this work are dinotefuran (Safari) applied as a basal trunk spray, and specialist insect pathogenic fungi applied as a full foliar spray.

Reduction of the intrinsic rate of growth for scales. As McClure (1980) pointed out, an elevated foliar nitrogen concentration improves survival and fecundity in elongate hemlock scale. This is likely also true for most of the arthropod pests of true firs, including cryptomeria scale, spider mites, and various aphids. Growers commonly apply 10 – 150 lb actual N per acre per year in Christmas tree plantings, governed largely by the size of the trees. Firs commonly grown as Christmas trees include the balsam fir, native to northern Maine and the maritime provinces of Canada, and the Fraser fir, native to high elevations of the southern Appalachian Mountains. The native habitat of these firs suggests that they are adapted to nutrient-poor soils. Therefore, we hypothesize that these species may be grown efficiently with greatly reduced (or completely eliminated) nitrogenous fertilizers, as long as the soil has the correct pH to maintain availability of other essential minerals. One grower in CT has not applied fertilizer since 1992. The Christmas trees on that farm grow well – but more importantly, even though cryptomeria scales are present, they are found at low densities and are maintained at those low populations through the action of natural enemies (RSC, personal observations). We hypothesize that the artificially elevated foliar concentrations of nitrogen inherent with standard grower practices contributes to a greater intrinsic rate of growth in the scale populations that cannot be matched by the various predators and parasites. We conjecture that the effect of foliar nitrogen would be less direct when comparing predators and parasites to the scales on which they feed, which would lead to the observed ecological imbalance and greater difficulty in achieving biological control as plant nitrogen concentration increases.

<u>Success in finding a selective chemical insecticide</u>

Dinotefuran was registered as a reduced-risk insecticide (http://northeastipm.org/archive/insider/archive/2002/may2002.html) due to its low mammalian toxicity and potential to replace organophosphate insecticides. Although dinotefuran is intrinsically highly toxic to some beneficials when used as a foliar spray (Cloyd and Dickinson 2006), if it were presented systemically through the internal tissues of the plant we could reduce its toxicity through extrinsic factors by limiting the exposure of beneficials (Hollingworth 1976). Certain highly soluble systemic insecticides, including dinotefuran, have the unusual property of being able to penetrate through bark, be transported to the xylem, and then be distributed through the foliage of trees (Coppel and Norris 1966, Norris 1967, McCullough et al. 2007, Cowles and Lagalante 2009). I tested the concept of systemic application of dinotefuran to the bark in 2008 and 2009 with field dose-response experiments targeting mixed populations of EHS and cryptomeria scales. While soil application resulted in inefficient absorption and poor control of scales, a spray of Safari restricted to the base of the Christmas tree trunks resulted in highly effective scale suppression with all the dosages tested (Cowles 2010). A basal trunk spray can be achieved with inexpensive and simple spray equipment, including lightweight hand-pumped sprayers that any size of farm can afford.

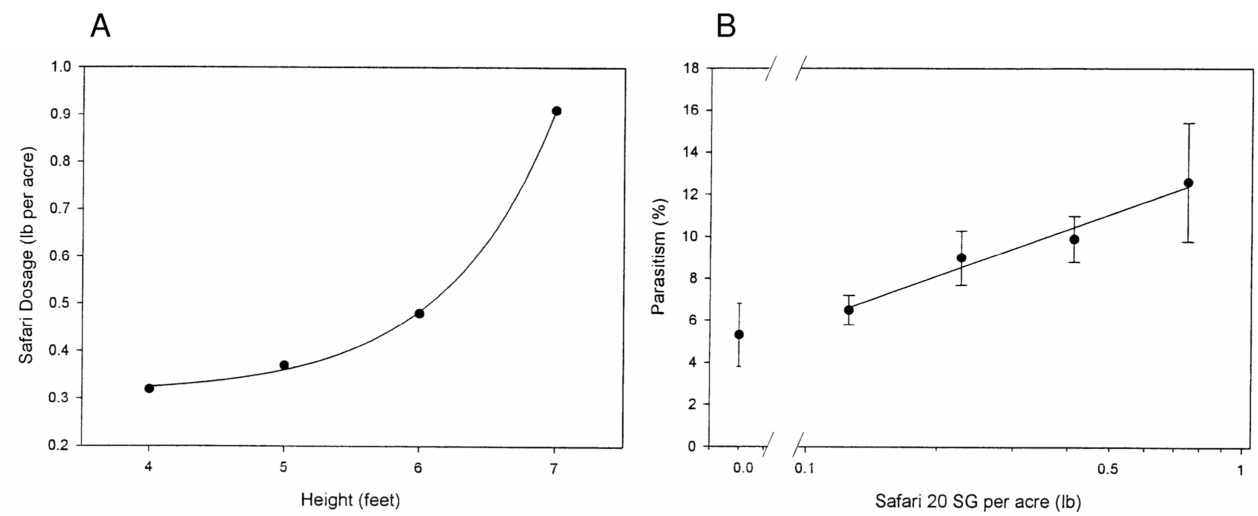

Fig. 1. (A) Quantity of Safari 20SG required to suppress scale populations by 90%, compared to untreated checks, as a function of tree height. (B) Impact of a Safari 20SG basal trunk spray on parasitism of elongate hemlock and cryptomeria scales by *Encarsia citrina*. Both results are from field trial data (Cowles 2010). Errors bars are standard errors of the means (n = 4).

In 2009, a large dose-response experiment, and a separate timing experiment conducted at a cooperating grower's plantation have determined how to optimize application of dinotefuran. The results from these experiments demonstrated that pre-bud break spray timing is optimal for a basal bark application, because the insecticide reaches and kills overwintering scales, leaving few crawlers to attempt settling on the foliage. Application until mid-June suppresses scale populations equivalently well, however the later spray timings results in some foliage discoloration because scale crawlers start feeding on foliage before they become intoxicated. Efficacy of Safari varied with the height of Christmas trees, suggesting that small trees can be treated effectively at dosages of 0.5 lb (formulated product per acre), whereas a 1 lb dosage will be needed to obtain acceptable results with trees over 6 feet tall (Fig. 1A). A comparison of predator and parasitoid populations in plots treated at various dosages demonstrated no adverse effects on predator populations, and a direct improvement in percent parasitization as the dosage of dinotefuran increased (Fig. 1B). This unexpected result can be attributed to reduced reproduction of scales, allowing a better match with parasitoid reproduction. These data provide information that can minimize the application of dinotefuran to the environment and so that it can replace the use of other insecticides (dimethoate in PA and bifenthrin elsewhere) that pose greater risks to non-target organisms and humans. Application of this insecticide as a directed spray to the base of the tree trunk should also mitigate the risk of this active ingredient leaching in soil, because contact of the insecticide with soil would be minimized. Indeed, NY Departmental of Environmental Conservation is approving a Special Local Needs label for basal bark spray of hemlocks to manage hemlock woolly adelgids, the first acceptance by NY of a registration of Safari, based upon the bark spray's ability to mitigate the risk of leaching (Mark Whitmore, Cornell University, personal communication). There is increasing concern about the toxicity of neonicotinoids to honey bees and other pollinators (Girolami et al. 2009, Pritchard 2009). Spot treatment of bark on Christmas trees avoids exposing pollinators that otherwise would occur from foliar sprays in plantations having diverse vegetation in ground covers. This application approach could be useful for treating trees and shrubs in nurseries.

The adoption of the Safari basal bark spray for scale management started in 2009, as growers in CT, MA and RI were eager to adopt effective management practices generated by this research program (Cowles 2009a, b, and c). Based upon direct communication with CT growers, approximately 50% of growers experiencing problems with armored scales adopted the basal bark spray method to manage scales in one year. On some farms, the results have been dramatic, with virtual elimination of scales on entire farms (Richard Geer and Pete Merrill, Voluntown, CT, pers. comm.). One grower in RI, Donald Gavin, volunteered that "Without the basal bark spray applied in 2010, he would no longer be in business" (pers. comm. to RSC, Nov. 11, 2010). These farms have reported remarkable improvement in the quality of trees, while at the same time demonstrating conservation of natural enemy populations. As with the spider mite example (Cowles and Abbey 1999), an IPM program based upon inexpensive, selective tools that satisfy a pest management need of growers is adopted quickly because it saves expense and labor, while also being safer to the growers and the environment. Management of scales using this approach is ready for demonstration as a Cooperative Extension objective, especially in NJ, PA and RI where growers have not (or have just started) adopting the basal bark spray method.

Entomopathogenic fungi for selective control of scales

The study of pathogens infecting EHS started with observations by Dr. Mark McClure from 20 trees along a 2.5-km transect through the hemlock forest at the Mianus River Gorge Preserve in Bedford, NY in 2001 (Cowles and McClure 2004). More recently, researchers at the University of Vermont reported several fungi infecting EHS, including *Lecanicillium lecanii* (Zimm.) Gams et Zare [formerly *Verticillium lecanii*], *Colletotrichum acutatum* var. *fioriniae*, and a "*Cordyceps* spp." described later as *Metarhiziopsis microspora*, described in detail below (Marcelino 2007, Marcelino et al. 2008, Marcelino et al. 2009).

While evaluating the results of chemical control tests in 2006, I discovered several elongate hemlock scales that appeared to have been infected by fungi. Dr. De-Wei Li proceeded to isolate two hyphomycete fungi from them. *L. lecanii* is a well known insect pathogen that is regularly collected from various insect hosts (Nielsen and Hajek 2005). The other species belonged to a previously undescribed species and genus, and is now named *Metarhiziopsis microspora* (Li et al. 2008). This fungus grows readily on solid media (Malt Extract Agar (MEA) and Corn Meal Agar (CMA)). It readily produces its characteristic sporodochia (asexual reproductive structures) with very small (1.5 – 1.8 μm) dry conidia on hydrated, autoclaved rye grain. Such small conidia have a significant advantage of being released and becoming airborne for dispersal. Such small spores settle in air very slowly, and are likely to settle on the undersides of foliage due to electrostatic interactions. Field studies in 2009 revealed that both EHS and cryptomeria scales in a mixed population had been infected by *M. microspora*. *A. ithacae* were found infected by *M. microspora* in 2010. Our interpretation of the joint infection with these fungi in individual scales is that *M. microspora* is probably a primary pathogen, and that *L. lecanii* is a hyperparasite. *L. lecanii* has an extremely broad host range, including nematodes, insects, and other fungi (Krauss et al. 2004). Koch's postulate demonstration of the pathogenicity of *M. microspora* was recently confirmed at the University of Vermont (J. Marcelino, pers. comm.).

Research on the use of *L. lecanii* for the management of various arthropod pests has mostly focused on the management of whiteflies and aphids, although there are also reports of it infecting various scale species (Samsinakova and Kalalova 1975, Peña and McMillian 1986) and even suggestions that it could be used for selective management of spider mites (Koike et al. 2005). Commercial products have been manufactured by Koppert Biological Systems in the Netherlands; these are marketed for control of aphids (Vertalec) and whiteflies and thrips (Mycotal) (Shah and Pell 2003). While *L. lecanii* products have been used in Europe, South America, and Asia, they have not been marketed in North America. However, Mycotal is currently being considered for release in the U.S. market (Costa, pers comm.). Limitations on the use of this fungus appear mostly to be due to its requirement for prolonged wetting or high humidity (Shah and Pell 2003, Miller et al. 2004).

A recent breakthrough in the formulation of insect pathogenic fungi is expected to enhance their efficacy, economic feasibility, and tolerance to environmental conditions. This whey-based fungal microfactory technology relies on the nutritive qualities of sweet whey, a by-product from cheese production. The whey is mixed with the fungus along with other adjuvants to enhance water retaining qualities and the competitiveness of the fungal biopesticide. When sprayed into the environment the fungi should grow on the plant and mass produce new fungal spores, thereby increasing the probability of infection. Microfactory technology allowed increases of over 100-fold on field treated hemlock foliage and led to significant reductions of hemlock woolly adelgid populations, its intended target (Costa et al. 2007, Grassano 2008, Kassa et al. 2008; Costa and Grassano, unpublished IR-4 and USDA Forest Service data).

We anticipate that at least one of the fungi isolated from scales could have practical use for selective biological control of armored scales in Christmas trees. By comparing available fungi isolated from these scales with commercially available mycoinsecticides, we hope to discover whether pathogens can be used as a selective practical tool in conjunction with naturally occurring predators and parasitoids. The investigation of insect pathogenic fungi as an effective biological control tool fits within the general IPM priorities for the Northeast Regional IPM program http://northeastipm.org/priority/2006/generalpriorities.htm. "Biocontrol - Research on biological control of … arthropods…; extension of this research into production systems of horticultural crops - Research/extension demonstrations of biocontrol methods for growers and private pest control operators."

The importance of the work and the consequences if it is not done. The implications of not finding adequate control methods for these armored scales are (1) continued reliance on disruptive, broad-spectrum insecticides that will lead to exclusion of natural enemies of all other Christmas tree pests and insecticide resistance, essentially blocking implementation of IPM for this crop, and (2) severe economic losses to growers due to unsaleable large trees. The continued reliance on dimethoate in PA involves extensive application of a hazardous organophosphate insecticide. We are now poised to deliver a method for managing armored scales that will serve as the key for unlocking the potential for Christmas tree IPM in the Northeast. By adopting a selective insecticide for managing scales, growers will be better able to integrate management of spider mites and aphids because their natural enemies can be conserved, too.

Objectives and Anticipated Impacts:

(1) Demonstrate compatibility of an optimized systemic insecticide application method with naturally occurring predators and parasites (Extension Objective)

(2) Test commercially available and field-collected insect pathogenic fungi against armored scales (Research Objective)

(3) Measure the influence of nitrogen fertilization on scale population, scale natural enemy population, and Christmas tree growth (Research Objective)

(4) Publish a web-based guide to the biology and management of armored scales (Extension Objective)

Economic analysis and anticipated impacts. The economic damage caused by armored scales can be estimated by these pests' prevalence multiplied by the average direct losses due to unsaleable trees, and the combined chemical and labor costs for managing this pest. We can estimate the value of lost trees as follows: True firs experience ~90% of the losses due to scales. True firs are approximately 50% of the total acreage of trees planted to Christmas trees in CT, which amounts to 4,833 acres (total acres of Christmas trees) × 50%, or ~2,400 acres. Of these acres, about 1/8 are harvested in any year, equivalent to 300 acres of fir trees. At 1,200 trees per acre and a retail value of $30 per tree, this amounts to $10,800,000 per year. Losses have ranged from insubstantial (for uninfested plantings) to 2/3 of the trees becoming unsaleable. An estimate is about 10% of fir trees, on average, being unsaleable due to armored scales, for an annual loss in Connecticut of $1,080,000. When extrapolated to include losses in RI (where a higher level of infestation is common) and PA, where about 9× as many trees are grown, a conservative estimate of the economic loss would be about $11M per year.

Training growers began in February 10, 2010, at the PA state growers' meeting; May 1, 2010 for RI growers; and for NJ growers on January 29, 2011. Training in these states will continue through the demonstration trials described below. We anticipate a rapid adoption of Safari to replace dimethoate, which is a positive impact relative to conservation of natural enemies and reduced applicator exposure to organophosphates.

At the end of this project, growers will know precisely how to apply a systemic insecticide to provide the most cost-effective control of armored scales. Success will be measured by a reduction in the number of farms in which armored scales are rated as a serious threat (a quick before-and-after survey of growers will take place at growers' meetings), by a reduction in the number of trees culled because of scale infestation, reduced labor costs associated with scale control management, and demonstrated conservation of armored scales' natural enemies. Conservation of these natural enemies will be beneficial to growers due to the value of their ecological services. More involvement of natural enemies will contribute to the overall sustainability of the Christmas cropping system, including resistance management.
If the insect pathogenic fungi are found to infect and suppress armored scales in field trials, then a partnership will be pursued with a company having a strong program in developing and marketing biocontrol fungi. Developing these fungi for registration and commercial use would employ the IR-4 Program for Registration of Biopesticides.

If reduction in nitrogen fertilization is found to reduce pest management problems while preserving good growth and color of Christmas trees, then growers will save by having to apply less fertilizer. Reduced fertilizer inputs would also use less energy-intensive natural resources, reduce the labor costs for fertilizer application, and would reduce nutrient loading in the environment.

Approach and Procedures

This project combines the general field and laboratory testing capabilities of Richard Cowles (lead investigator) with the expertise of extension specialists (Tim Abbey, Steven Alm, and Mark Vodak) for conducting demonstrations of the basal bark spray method for the chemical control component, expertise in plant nutrition with horticulturist Ricky Bates, and mycological expertise of DeWei Li and Scott Costa.

Objective 1. Demonstrate compatibility of an optimized systemic insecticide application method with naturally occurring predators and parasites (Extension Objective)

Cooperating growers will be chosen for a 3 replicate, 3 treatment completely randomized design demonstration trial repeated in PA, NJ, and RI, where the experiment is replicated by farm. Farms will be chosen for their abundance of armored scales and willingness of the grower to participate in this two-year demonstration. A two-year demonstration may be necessary to permit natural colonization of fields by generalist scale predators, and to show the long-term trends in tree quality and scale populations. Infested sites are already being selected for these tests. Dr. Steven Alm, University of Rhode Island, and The York County Extension Advisor (PA), Mr. Timothy Abbey, will apply Safari 20 SG approximately 2 – 3 weeks prior to bud break, using a Solo backpack sprayer equipped with a 21 p.s.i. control flow valve pressure regulator and 6502E flat fan nozzle oriented vertically to direct a calibrated basal bark spray. The sprayer will be calibrated to deliver 0.75 - 1 lb of Safari 20SG per acre, with the per acre dosage determined by the average height of trees in the treatment area. The dosage for each tree will be adjusted based upon its size, with small trees receiving approximately 15 ml total, and trees over 6 feet in height receiving up to 60 ml. The treated trees will be compared with adjacent untreated control trees within the planting, and with other plantings of trees that the grower will manage according to standard procedures (most likely foliar dimethoate sprays in PA; horticultural oil or OnyxPro in NJ and RI).

The comparison between these groups of trees will include scale, parasite, and predator populations (evaluated in October of each year). The scale and percent parasitism will be evaluated with sample branches cut from trees and examined under a dissecting microscope by R. Cowles and/or T. Abbey. Predator populations will be determined from beating samples, using a standard beating sheet to collect predators from half of a tree, to be sorted later in the lab (Cowles 2010). Not all predators will be characterized; only *Chilocorus* spp., *Cybocephalus nipponicus*, and *Microweizia* spp. are likely to be important and abundant. Counts of scales, their predators, and percent parasitization will be subjected to analysis of variance to assess treatment differences.

Objective 2. Test commercially available and field-collected insect pathogenic fungi against armored scales (Research Objective)

This objective will make use of an interdisciplinary team identified as having expertise suited to conduct this work. Dr. DeWei Li is a mycologist experienced in isolation and identification of fungi; Dr. Scott Costa is experienced in growing insect pathogenic fungi and formulating them with adjuvants that permit additional spore production on the leaf surfaces; Dr. Richard Cowles has experience in conducting trials for managing scales.

Commercially available (BotaniGard - *Beauveria bassiana* and Mycotal – *Lecanicillium muscarium,* U.S. and foreign registered, respectively) and field-collected insect pathogenic fungi (*Metarhiziopsis microspora*, *Colletotrichum acutatum* var. *fioriniae*, *Lecanicillium lecanii*, and *Cladosporium* spp.) will be compared and tested in the laboratory and field to determine their efficacy against armored scales, as measured by percent infection rates and the scales' population growth. These fungi will be grown on appropriate media (agar-based and various grains) in CT and in VT (laboratories of Li and Costa, respectively) and spores harvested to form sprayable suspensions with 0.2% Tween 80 or 0.05% Silwet L-77. Logical steps in progression toward field testing are as follows:

Year 1. Determine the effective concentration of spores to use, and compare the virulence of the fungi. This will be accomplished with dose-response methodology using naturally infested hemlock seedlings, artificially infested Fraser fir transplants, or excised naturally infested branches provided water. Infection challenge tests will take place in controlled growth chamber conditions (Marcelino 2007) and the data will be subjected to probit analysis of proportion infected scales vs. dosage of spores. Additionally, the growth response of these fungi to microfactory technology (propagation on the leaf surface by provision of sweet whey) will be evaluated to optimize an 'Operational Formulation' for field testing in Year 2; an optimized formulation for Mycotal is already available. These tests will serve as the basis for deciding which fungi, and at what application dosages, the fungal spores will be tested in the field.

Year 2. The field test will be conducted in cooperating growers' fields in CT and/or RI. Spores will be applied to 6 single-tree replicates, separated by several buffer trees, with a Stihl backpack mist blower sprayer at a volume of 30 gallons per acre to ensure adequate deposition of spray droplets to the undersides of needles. Fungal spores will be applied in a factorial design with and without sweet whey adjuvants to determine the benefit of the microfactory concept. Scales per needle, percent parasitization, and population measurements of predators will also be performed for this objective in the same manner as for Objective 1, except that percent infection of scales will be measured in late June for the first generation, and again in September or October for the second generation.

Demonstrating suppression of scales with these fungi could lead to an ideal biological control agent for commercial development, because most literature on the subject suggests that mycoparasites can be integrated with predator or parasitoid based biocontrol agents (reviewed in Shah and Pell 2003). Furthermore, the microclimate in Christmas tree plantations, especially the hard-to-spray areas, should have slow drying conditions that are suitable for insect-killing fungi. This is evident from their having been collected from a commercial Christmas tree plantation, and from the presence of *L. lecanii* in this microhabitat. Commercial use of fungal products will require EPA registration, which is currently possible with dramatically reduced fees for biopesticides, particularly from smaller businesses. However, development of the registration package for novel fungi with no commercial history can be costly. The USDA IR-4 program supports research that leads to biopesticide registration for minor crops. Most of the true firs do not require application of fungicides for control of needle cast diseases, which could interfere with entomopathogenic fungal efficacy. Spruce, Douglas-fir, and concolor fir are susceptible to foliar diseases, and so the fungal pathogens for biocontrol of scales may not be useful for managing scales affecting these tree species.

Objective 3. Measure the influence of nitrogen fertilization on scale population, scale natural enemy population, and Christmas tree growth

This objective has the potential to reduce reliance on pesticides, and may have an added benefit of decreasing the quantity of inputs (fertilizers) used to produce Christmas trees. Baseline information on the levels of minerals in Christmas trees are available in PSU's database from laboratory tests of tens of thousands of samples, for which Ricky Bates provides interpretive expertise. Modifications to standard nitrogen fertilization practices will be measured by manipulating the nitrogen fertility for Christmas trees grown at the Pinchbeck Farm in Guilford, CT. Growth effects from reductions in fertilizer application can take several years to manifest themselves, because of nutrients stored within the soil (Tom Rathier, CAES, pers. comm.). Therefore, using a conventional Christmas tree plantation and reducing the fertility may not show multitrophic effects for several years. Christmas trees at the Pinchbeck Farm provide a unique opportunity to investigate the effects of nitrogen fertility. Their fields have not been fertilized since 1992; both cryptomeria scale and *E. citrina* are present, and the scales are currently maintained at low population density via biological control (RSC, personal observation). Plots containing ~50 trees will be established as a randomized complete block design (6 replicates), with replication across fields. Trees will either not be fertilized, be provided normal fertilization (1×), 2×, or 4× the normal N fertilization, where "normal fertilization" is defined as 50 lb/Ac of actual N applied for 6 year old trees. The 1× fertility practice is commonly exceeded by many of the growers in the state, but is a recommended fertility program (Tom Rathier, CAES, pers. comm.). Fertilizer will be applied during spring of 2010 by R. Cowles. Foliar nitrogen and mineral nutrition will be determined through foliar analyses prior to fertilization and in July for each of the two years of the study post fertilization, after terminal elongation. R. Cowles will sample trees and send them to R. Bates for processing and analysis. Samples will be compared to each other within the experiment and to the Penn State database for Fraser firs, which includes historical data from tens of thousands of samples submitted over decades. The scale populations' intrinsic rate of growth, parasitization rate, and assessment of predator population densities will be determined as described for Objective 1. Measurements of terminal growth and color ratings in the various plots will determine whether and to what degree the nitrogen fertilization affects the growth rate of Christmas trees, which in turn will be used to model the economic benefit of fertilization.

Objective 4. Publish a high-quality guide to the biology and management of armored scales (Extension Objective)

A high-quality color web publication on the biology and management of armored scales in Christmas trees will be developed for publication on the Penn State/PA Department of Agriculture web site (http://ento.psu.edu/extension/christmas-trees/insect-fact-sheets). The IPM guide will include photos showing the life cycle of these two scale species, photos of their predators and parasitoid, photos of other arthropods commonly encountered while conducting beating samples, and illustration of a crawler trap for monitoring purposes. Details for optimizing a sprayer for applying a basal trunk spray, a video demonstrating the basal trunk spray method, and horticultural best management practices and photographs demonstrating basal pruning will be included in the web site. The core information will be written and added to the web site in 2010, and updated as new information and photos become available in 2011.

Timeline

January 2011, teach NJ Christmas tree growers about scale management
March 2011, Abbey, Alm, and Vodak will find cooperator's fields in NJ, PA and RI
April 2011, 1st year basal sprays applied in demonstration plots: Abbey, Alm, Vodak
    Initiate propagation of entomopathogenic fungi, Li and Costa
May 2011, Cowles applies fertilizer to Pinchbeck farm plots, Guilford, CT
June 2011, Growth chamber tests of entomopathogenic fungi, Cowles and Li
    Costa conducts lab tests for whey effect on sporulation
July 2011, Cowles samples foliage at Pinchbeck farm to submit to Bates
August 2011, Cowles, Li, Costa: Additional lab and initial field tests of entomopathogenic fungi
September – November 2011, Abbey, Alm, Vodak: Collect foliage samples to analyze efficacy, predator populations, and parasitization rates from demonstration plots vs. conventional treatments. Rate growth and color at Pinchbeck farm.
December 2011, Cowles: Draft Fact Sheet for PSU/PA Dept. of Agriculture web site
February 2012, Conduct PA Christmas tree growers' short course, survey growers again
April 2012, 2nd year basal sprays applied in demonstration plots, Abbey, Alm, Vodak
    Li and Costa ramp propagation of best entomopathogenic fungi
May 2012, Cowles applies fertilizer to Pinchbeck farm plots, Guilford, CT
June 2012, Cowles: Field tests of insect pathogenic fungi in CT
July 2012, Cowles: Sample foliage at Pinchbeck farm to submit to Bates

August 2012, Cowles: Additional field tests of entomopathogenic fungi
September – November 2012, Abbey, Alm, Vodak: Collect foliage samples to analyze efficacy, predator populations, and parasitization rates from demonstration plots vs. conventional treatments. Cowles: Growth and color ratings at Pinchbeck farm.
December 2012 – March 2013, Complete analysis of field data, update web site for growers

Evaluation Plans

Success in this research project will be measured for each objective.

Objective 1. Success will be measured by (a) the adoption by growers of the trunk spray method for selective control of armored scales in Christmas tree plantations, (b) the declining number of farms in which armored scales are considered to be a major problem, and (c) the continued presence or reestablishment of important natural enemies in Christmas tree plantations.

Success for Objective 1 will be measured by surveying growers attending state Christmas tree grower educational meetings. Based upon the extraordinarily rapid adoption of this method in CT, I expect that we should be able to record a change in grower practices within the duration of this project. Five-minute surveys, given at the beginning and end of the project will ask growers about their losses due to armored scales, which insecticide they use for managing scales (if they have a scale problem), the numbers of sprays applied per field to manage scale, whether they scout for predators, and whether they use crawler traps to monitor scale activity. This survey has already been used with PA growers, to measure baseline data.

The impact of the basal bark spray, relative to conventional treatments, on activity and abundance of predators and parasitoids will be quantified as a result of the replicated demonstration plots and populations assessments from the research/extension team.

I anticipate that the trunk spray application method studied in this objective should readily be adopted by growers because it is reliably effective and the application can be made with the least expensive spray equipment and with reduced labor (compared to the backpack mistblower method).

Objective 2. Success will be measured by having found one or more fungi that will cause significant mortality of scales when applied to trees in a cooperating grower's field.

Objective 3. Success will be measured by determining whether minimal nitrogen application results in lower intrinsic growth of scale populations while maintaining good growth of Christmas trees. This objective probably also would be readily adopted by growers, but probably not within the time scale of this project.

Objective 4. Success will be measured by publishing on-line a scale management fact sheet for Christmas tree growers. The impact of this web site will be measured by automated counting of the number of "visits" to the web page.

SITUATION: Effective insecticides that Christmas tree growers use for managing scale insects are damaging to predators and parasitoids. Their use will result in insecticide dependence and resistance, and requires expensive equipment and laborious application.

PRIORITIES: Demonstrate selective and cost-effective chemical and biological tools and cultural practices for scale management

PROGRAM ACTION- LOGIC MODEL

Inputs	Outputs		Outcomes		
	Activities	Participation	Short	Medium	Long
Research base (expertise)	Field demo of optimized systemic insecticide	Cooperating growers	Guidelines for chemical control of scales	Reduced selection for insecticide resistance	IPM methods for all other pests
Time			Reduced chemical expense; exposure		Ecological balance between scales and their enemies
Field resources (infested sites)	Greenhouse and field tests of insect pathogenic fungi	Cooperative extension	Improved survival of beneficials	Reduction in N fertilizer use	
University web space	Test of plant nutrient vs. scale outbreak concept	State Christmas tree associations	Identification of most useful fungi	IR-4 project to pursue fungal registration	Optimum growth of trees; increased profitability
	Design of scale management guide		Adoption of basal trunk spray		
	Field day teaching				
	Workshops				

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Title: Scale management in Christmas trees

Joint Research-Extension

Project Summary

Sprays for armored scales (cryptomeria, hemlock and elongate hemlock scales) prevent implementation of IPM practices in Christmas tree plantations in the northeast. Three important tools will improve upon current practices: (1) chemical control: a reduced-risk insecticide applied to the trunk of the tree is directly absorbed and translocated to foliage, where it selectively kills scales, (2) biological control, in which several fungi found to infect armored scales will be cultured and then applied to trees, with or without whey adjuvants, to cause infections, and (3) cultural control, by decreasing nitrogen fertility to reduce the intrinsic rate of growth for scales, the existing complex of predators (three species) and parasitoids (one species) may maintain scale populations below damaging levels. In published research trials a basal trunk spray of dinotefuran suppressed scale populations while conserving natural enemies; this technique will be demonstrated to growers with infested plantations in NJ, PA and RI. Several fungi found to infect the two targeted armored scales may provide a higher degree of selectivity than commercialized insect pathogenic fungi; if effective, these fungi could be registered through the IR-4 biopesticides program. Adjustments in soil nitrogen fertility are expected to create growing conditions less favorable to scales and closer to those for which these Christmas trees are adapted. The options being developed should readily be adopted by growers because they will be less expensive, more effective, and less toxic to the applicator and to the environment than current practices. A scale management web guide will extend the findings to growers.

Project Description

Problem, Background and Justification

Two bivoltine armored scale pests of Christmas trees from Japan, elongate hemlock and cryptomeria scales, have increased in importance and are now the most seriously damaging pests of Christmas trees in the Northeast. The economic losses due to armored scales in Christmas trees can be extreme, because salable sized trees become unmarketable: they turn yellow and experience excessive needle loss. With 1,200 trees planted per acre, the reported 67% loss in some fields would amount to a gross loss of $20,000 to $50,000 per acre, calculated from values of $25 – 65 per tree. Christmas tree production is an important agricultural activity in the Northeast. Collectively, states in the northeast produce 15% of the total Christmas trees sold in the U.S. In CT alone, there are 495 farms with 4,833 acres in production representing annual sales of approximately $18,000,000. This represents 5% of the total number of farms and 4% of the total Christmas trees sold within the northeastern U.S. Production in RI and MA, combined, is similar to CT; these states, NJ and NY are also affected by the scale pests targeted by this project. PA estimates its crop value to be approximately 3× that of CT, or ~$55,000,000 per year (www.ipmcenters.org/cropprofiles/docs/PAchristmastrees.pdf). Improved management of armored scales in Christmas trees is a need recognized by the PA Dept. of Agriculture and that state's IPM coordinator (http://paipm.cas.psu.edu/1572.htm).

NEREAP-IPM identified as an area of emphasis in May 2006 IPM strategies and tactics for ornamental crops including Christmas trees (http://northeastipm.org/nereap/priority/2006.htm), which this project squarely addresses. Additional priority concerns that we address in this proposal are "Development of IPM packages that improve eligibility for NRCS program funds" (Christmas trees are currently not covered by the EQIP program in CT, but are covered in some other states, like PA), "Use of web-based technologies for IPM decision making," and "Improvement and expansion of biocontrol in high value crops." Of the common pests ranked as highly important by Christmas tree growers, armored scales are the only ones that are both severely damaging and, until now, have lacked adequate control options. Presently, management practices for these armored scales involves full foliar sprays of disruptive insecticides (dimethoate and bifenthrin) that stymie efforts to implement IPM for all other Christmas tree pests. Continued reliance on dimethoate in PA is troubling, as it is a toxic organophosphate.

This project combines the general field and laboratory testing capabilities of Richard Cowles (lead investigator) with the expertise of extension specialists (Tim Abbey, Steven Alm and Mark Vodak) for conducting demonstrations of the basal bark spray method for the chemical control component, extension expertise in plant nutrition with horticulturist Ricky Bates, and mycological expertise of DeWei Li and Scott Costa. This mixture of expertise is required to fully exploit two complementary avenues for achieving integrated management of armored scales: selective tools for suppressing scale populations without adversely impacting their natural enemy complex (through targeted use of the reduced risk insecticide dinotefuran, and by deploying specialist insect pathogenic fungi), and cultural practices (management of soil fertility) to reduce the intrinsic rate of growth for scales so that the biological potential of natural enemies can better match that of their prey.

Objectives and Anticipated Outcomes:

1. Demonstrate compatibility of an optimized systemic insecticide application method with naturally occurring predators and parasites (Extension Objective). Research trials have already proven effectiveness and selectivity. Growers in CT are rapidly adopting this method, so we know that growers will adopt these practices quickly once they are informed. We expect that growers observing the effectiveness of this application method in their fields will quickly substitute this method for their current use of broad-spectrum foliar sprays of dimethoate (PA) and bifenthrin (NJ and RI). These growers will act as bellwethers for the other growers, and the field results will be shared with other growers at educational meetings. The replacement of dimethoate, an organophosphate no longer permitted for this use in states other than PA, with dinotefuran, a reduced risk insecticide, will reduce applicator exposure to toxic compounds. Replacement of dimethoate and bifenthrin with a basal trunk spray of dinotefuran has already been demonstrated in field trials to be compatible with scale predators and parasites, so biocontrol will increase in importance relative to current practices. The basal trunk spray application method will minimize environmental risks to pollinators and groundwater. Finally, this application technique uses inexpensive spray equipment already owned by small producers. Many Christmas tree growers are retirees that grow trees for supplemental retirement income. This application method uses inexpensive equipment available to small farms and matches the physical capabilities of these older farmers.

2. Test commercially available and field-collected insect pathogenic fungi against armored scales (Research Objective). Several species of fungi have been found to naturally infect either or both elongate hemlock and cryptomeria scales. These fungi can be cultured in the laboratory to test their effectiveness as a foliar spray against scale populations. If they are effective, and are not deleterious to the scales' natural enemies, then registration will be pursued through the IR-4 Biopesticides Program.

3. Measure the influence of nitrogen fertilization on scale population, scale natural enemy population, and Christmas tree growth (Research Objective). Growers may be applying excessive nitrogenous fertilizers, believing that this will ensure an attractive green color at the time of harvest. However, true firs are adapted to nitrogen-poor conditions in their natural habitat, and much of the applied N may be wasted (relative to improvement of plant growth) or be deleterious, through promotion of greater survivorship and fecundity of the various arthropod pests. If we find that reduced N conditions lead to satisfactory tree growth and color, and reduced scale populations, then growers will rapidly adopt lower N practices. Fertilizers have dramatically increased in cost, and growers adopt practices quickly that are economically advantageous.

4. Publish a high-quality guide to the biology and management of armored scales (Extension Objective). We anticipate that a module within an existing web site that provides practical management guidelines (http://ento.psu.edu/extension/christmas-trees/insect-fact-sheets) for managing armored scales will influence growers' behaviors. The impact can and will be measured by querying growers at their annual meetings. Specific questions we will ask growers are whether they use the PA Christmas tree web site, and whether they have changed their practices for managing scales as a result of this project.

SITUATION: Effective insecticides that Christmas tree growers use for managing scale insects are damaging to predators and parasitoids. Their use will result in insecticide dependence and resistance, and requires expensive equipment and laborious application.

PRIORITIES: Demonstrate selective and cost-effective chemical and biological tools and cultural practices for scale management

PROGRAM ACTION- LOGIC MODEL

Inputs	Outputs: Activities	Outputs: Participation	Outcomes: Short	Outcomes: Medium	Outcomes: Long
Research base (expertise)	Field demo of optimized systemic insecticide	Cooperating growers	Guidelines for chemical control of scales	Reduced selection for insecticide resistance	IPM methods for all other pests
Time	Greenhouse and field tests of insect pathogenic fungi	Cooperative extension	Reduced chemical expense; exposure	Reduction in N fertilizer use	Ecological balance between scales and their enemies
Field resources (infested sites)	Test of plant nutrient vs. scale outbreak concept	State Christmas tree associations	Improved survival of beneficials	IR-4 project to pursue fungal registration	Optimum growth of trees; increased profitability
University web space	Design of scale management guide		Identification of most useful fungi		
	Field day teaching		Adoption of basal trunk spray		
	Workshops				