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I would like to acknowledge my advisor John J. Brown who has patiently guided me through this process. His scope of knowledge always provided a learning moment, regardless of the situation, system, or question. My parents and wife have been an integral part of this process by providing their love, support, and encouragement on this prolonged path. I must thank my cohort of students at WSU, with special appreciation for Bob Brown, Ricardo Ramirez, Dan Skocyzlas, Sam Hapke, Cami Jones, and Adrienne Ohler. I appreciate the groundwork that both Neal Kittelson and Gene Hannon laid down prior to my arrival in the Brown Lab, and the knowledge they imparted to me regarding the Boardman Tree Farm system. I would be remiss not to mention El Jefe, Alejandro Del Pozo, who helped advance numerous concepts, experiments, and my understanding of Peruvian culture. Finally, I would like to acknowledge the members of Suspicious Package Ultimate for providing a positive outlet and supportive community.
Hybrid poplars are a short rotation woody crop grown for a variety of target markets including paper pulp, saw timber, and biofuels in the Pacific Northwest. Development of pest control strategies within hybrid poplar plantations over the last several decades has focused on controlling foliar feeding herbivores and wood boring pests, and has overlooked the epigeal arthropod community. Understanding this unstudied suite of organisms would allow pest managers to better evaluate the impact their management strategies have on the poplar agroecosystem. Qualitative surveys of the arthropod communities in hybrid poplar plantations and nearby native habitats demonstrated that a greater arthropod diversity persists in the surrounding native areas. Additionally, the poplar plantation’s epigeal arthropod community was composed of species found within sampled native areas.
Historically poplar research focused on protecting trees in the years following establishment through harvest from emerging pests while discounting cutting mortality by replanting areas of failure. Describing unrooted cutting transplant morality and distribution within newly established planting block could provide a risk assessment tool that growers could utilize to evaluate their potential crop loss. It was determined through the examination of damaged cuttings that several pests were responsible for diminishing establishment success. Identification of these risks led to the development of a management strategy to reduce mortality in newly planted areas. Soaking cuttings in imidacloprid for 48 hrs provided superior herbivore protection for unrooted cuttings until root formation allowed for uptake from chemigation treatments.

An additional study was motivated by the increased concern in growing ‘clear wood’ as poplar has migrated from pulp to saw timber. The accompanying renewed interest in reducing insect galleries in mature trees led to the exploration of deploying a mass trapping, or trap out, effort to reduce populations of *Prionoxystus robiniae* (Lepidoptera Cossidae) in specific areas of a hybrid poplar plantation. We show that a trap out effort of roughly 5 pheromone-baited traps/ha decimated *P. robiniae* populations in treated areas throughout the trap out effort and three years post application.
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Dedication

This dissertation is dedicated to my parents, Dr. Robert and Mary FL Rodstrom who always fostered my love of science, my bride Angelina Rodstrom for her patience and participation in our entomological (and non-entomological) adventures, and my dog Liliana who faithfully oversaw six field seasons in the trees.
Chapter One

Introduction

I.  Poplars in the Pacific Northwest.

Hybrid poplars have been grown as a fiber crop in the Columbia River Basin since the early 1980’s (Stanton et al. 2002).  Although hybrid poplar uses are quite varied (windbreaks, phytoremediation, carbon sequestration, wood products, chemicals and biofuels), the end use of this Pacific Northwest short-rotation woody crop has focused on fiber products (pulp and non-structural wood saw timber) and energy feedstock (hogfuel and biofuel) (Heilman 1999, Isebrands and Karnosky 2001, Stanton et al. 2002, Hibbs et al. 2003, Hannon 2006).  The largest plantations of this crop can be found west of the Cascade Mountains and in arid regions of the mid-Columbia River Basin of Washington State and Oregon.  The greatest hectarage in the western part of Washington and Oregon is located in the lower Columbia River floodplain and is generally not irrigated.  East of the Cascade Mountains, plantations are found in the mid-Columbia River basin and require regular irrigation and fertilization for optimal tree growth (Stanton et al. 2002).  A warmer and sunnier climate permits greater growth of trees in the mid-Columbia River Basin than in the west side plantations (Stanton et al. 2002, Hannon 2006).

Plantations in the mid-Columbia River Basin are located in the vicinity of Patterson and Burbank, WA and Boardman, OR.  GreenWood Resources, Inc. owns and manages plantations in the Patterson (Sandpiper Tree Farm) and Boardman (Boardman Tree Farm) areas.  Sixteen thousand hectares are located in xeric shrub-steppe and commercially produced poplar trees require inputs of water and nutrients (nitrogen, phosphorus, zinc and iron) for optimal growth (Stanton 2002, Hannon 2006).  A computerized drip-irrigation system delivers water pumped from the
Columbia River directly to planting blocks, where nutrients and pesticides can be added into mix-tanks for direct application via chemigation. GreenWood Resources, Inc. (GWR) manages these farms to produce pulp and saw timber. The desired end product of a plantation will determine the stem density within a stand of trees. Trees being grown to produce pulp can be planted at a density of up to 1,800 stems per hectare, while saw timber densities are closer to 400 stems per hectare (Stanton et al. 2002). Areas planted for nursery stock reach a density of 3,000 stems per hectare, while biofuel stands may be planted at densities exceeding 4,500 stems per hectare (L. Maynard GWR-Pacific Northwest Area Manager pers. comm.).

Hybrid poplars are propagated on GreenWood Tree Farm Fund’s (GTFF) farms by planting unrooted dormant cuttings. These cuttings are harvested from stems and branches of nursery stock. Traditionally these cuttings (‘sticks’) have been 20-30 cm long and 2 cm in diameter (Dickmann 2001), but they can be of varying length and diameter based on the nursery stock used. To decrease plantation establishment time and while production emphasis has moved towards the saw timber market, GTFF has moved to using a 3.5-5 m cutting (‘pole’) taken from 1-3 yr old nursery stock. Poles are stems (not branches) harvested from either specifically grown nursery stock or from volunteer growth (coppice) in mechanically thinned areas (M. Berk Assistant Farm Manager (East Side) pers. comm.). Pole plantings require a greater economic and time investment from growers to produce and plant than traditional planting sticks. GreenWood Tree Farm Fund has made the shift to starting most of their saw timber stands with poles instead of sticks. The shift from sticks to poles promotes better tree form and to reduces stand loss from pests during plantation establishment.
Beginning in 2001 stands on the northern half (~ 45.75 Latitude) of the Boardman Tree Farm plantation have been grown under the Forest Stewardship Council’s (FSC) management standard. In 2007, GreenWood Tree Farm Fund expanded the FSC certificate program over the entire Boardman Tree Farm. The FSC’s mission is to “promote the responsible management of the world’s forests” (Forest Stewardship Council 2011). This certification program requires that growers use management practices that promote sustainability and reduce environmental impact. Producing fiber under this certification program allows GTFF to obtain a premium price for its products. But following these guidelines severely restricts the use of many conventional insecticides and dictates that specific production practices must be followed. This limitation has forced growers and researchers to look beyond common practices and products to develop pest control tactics that adhere to the FSC’s stringent guidelines.

II. Exploring Insect Communities in Hybrid Poplars

   a. Integrated Pest Management and Epigeal Insect Communities

   GreenWood Tree Farm Fund has almost 11,000 hectares of hybrid poplars planted as a monoculture at the Boardman and Sandpiper Tree Farms. Monocultures are susceptible to pest outbreaks (Oliveria and Abrahamson 1976, Fang 1997) and insect pests have been a major constraint on GTFF’s plantations. Controlling pests in hybrid poplar plantations has been the focus of several research efforts (Morris 1960, Neel 1969, Wilson 1976, Abrahamson et al. 1977, Fang 1997, Coyle et al. 2002, Brown et al. 2006, Hannon 2006, Tenczar et al. 2007, Hannon et al. 2008, Brown et al. 2010). Hybrid poplars are fed upon by over 150 species of insects, of which roughly 60% are defoliators (Baker 1972, Wilson 1976). In 2000, hybrid poplar growers sought help from Washington State University researchers to address their pest problems. Drs. John J.
Brown and Douglas B. Walsh began investigating the pest problems and developing an integrated pest management (IPM) program for hybrid poplars grown in the inland Pacific Northwest (Brown et al. 2002-2010, Hannon 2006). A description of this IPM program and suggested strategies for these arboreal pests can be found in Brown et al. (2010) and Hannon (2006) work. These management strategies mainly revolve around the prevention of leaf loss in older trees and reducing wood-boring insect damage to saw timber, resulting in the lack of investigation directed towards the epigeal insect community.

Understanding how pest management strategies affects the entire insect community associated with poplars is important in developing a comprehensive IPM program for hybrid poplars. Decisions regarding pesticide applications in this agroecosystem are generally based solely on the presence of the target pest with little concern or understanding of the rest of the insect community. A key component to categorizing the effect on non-target organisms is determining the composition of the community. Assessment of the impacts of management practices on the insect community associated with hybrid poplar requires a characterization of that community. Chapter 1 presents results of a field study to characterize the insect communities associated with poplar stands of different age classes and, for comparison, the insect communities in habitats adjacent to poplar plantations.

b. Pests and Propagation of Hybrid Poplars

Stand establishment is one of the most vulnerable stages in the cycle of hybrid poplar production because the dormant cuttings that are planted lack a root system and have minimal leaf area. This lack of root system poses a challenge in protecting the cuttings from herbivores

A large suite of *Populus* pests has been identified within GreenWood Resources’ tree farms (Hannon 2006). Hannon’s (2006) review presents basic natural history, risk assessment, monitoring techniques, and conventional control strategies for several well-known pests of hybrid poplars. But this list of pests focuses on those insects that damage older trees and largely ignores pest issues during stand establishment. Although most of the pests described by Hannon (2006) are capable of feeding on newly planted hybrid poplars, four regularly feed upon these newly planted cuttings and can become serious problems during stand establishment. Western poplar clearwing moth (*Paranthrene robiniae* (Hy. Edwards) [Lepidoptera: Sessidae]) and poplar-and-willow borer (*Cryptorrhynchus lapathi* (L.) [Coleoptera: Curculionidae]) are two common wood borers that cause mortality in new cuttings. Cottonwood leaf beetle (*Chrysomela scripta* (F.) [Coleoptera: Chrysomelidae]) and strawberry root weevil (*Otiorhynchus ovatus* (L.) [Coleoptera: Curculionidae]) can quickly defoliate young cuttings. Cottonwood leaf beetle is commonly identified as one of the most economically important defoliation pests of poplars in North America (Harrell et al. 1981, Robinson and Raffa 1998, Coyle et al. 2005, Tenczar and
Krischik 2006). Recently, two additional defoliators have threatened establishment of hybrid poplar stands: *Gluphisia septentrionis* Walker (Lepidoptera: Notodontidae) and *Polydrusus impressifrons* Gyllenhal (Coleoptera: Curculionidae). Of these two pests, *P. impressifrons* has proven to be the most damaging to this tree stage. In 2010 over two-thirds of new plantings on the Boardman Tree Farm required insecticidal treatments for *P. impressifrons* (Brown et al. 2010). *Gluphisia septentrionis* does attack young trees, but has proven to be most destructive in older established stands of hybrid poplar (Del Pozo 2010).

Understanding the distribution of pests within hybrid poplar stands can lead to better pest management practices. The basic biology and natural history of these pests (*Paranthrene robiniae, C. lapathi, C. scripta, O. ovatus, G. septentrionis,* and *P. impressifrons*) has been documented, but their distribution within the landscape of a plantation, specifically during stand establishment has largely gone unstudied. Chapter 2 will qualitatively examine the distribution of cutting mortality in selected establishing poplar stands to provide growers with information that may assist in the development of a pest management strategy to protect their newly planted crop.

III. Crop Protection

a. Soaking unrooted cuttings prior to planting

The first flush of leaves on a hybrid poplar cutting is especially vulnerable to pests because the plant’s total leaf area is small and new cuttings lack a root system required for recovery from defoliating pests (Bingaman and Hart 1992, Reichenbacker et al. 1996, Coyle et al. 2002). Defoliation at this stage therefore can reduce stand establishment and growth potential
(Anderson and Nelson 2002, Coyle et al. 2003, Tenczar and Krischik 2006). Cuttings that suffer severe defoliation may be smaller than less severely attacked cuttings in the same (Kulman 1971, Bassman et al. 1982). In addition to defoliation, belowground herbivores by several pests (*Polyphylla decemlineata*, *O. ovatus*, Elateridae larvae) also present a challenge to successful stand establishment.

In addition to limiting nutrient uptake and recovery from herbivory, the lack of roots poses additional challenges for pest (Osborne 1986) because unrooted plants cannot take up systemic pesticides that are otherwise effective for protecting poplar from insect herbivores (Lawson and Dahlsten 2003, Tenczar and Krischik 2007). Insecticidal foliage sprays (indoxacarb and chlorantraniliprole) are commonly used in poplar plantations as tactics to control aboveground herbivores on all ages of trees, including newly established stands. Foliage sprays can be cost prohibitive and provide ineffective control of pests due to the small leaf area being attacked by herbivores and the rapid leaf growth. Without translaminar distribution newer leaves are not protected, and much of the topical application is lost due to runoff. In addition, belowground herbivory during the establishment of stands has also increased in some areas due to newly introduced pests including *P. impressifrons* and increased abundance of *P. decemlineata* on the Boardman Tree Farm.

Growers desire cost effective pest management tactics that minimize environmental impacts. Dipping or soaking propagules (seed, cutting, transplant) is a common pest management practice in both nursery and forestry crops as a pest control strategy (Neel 1969, Walstad et al. 1973, Osborne 1986, Watkins et al. 1996, Simms et al. 2002, Gajanana et al. 2006). This technique
introduces a systemic or non-systemic pesticide to the cutting that can reduce both above- and belowground herbivory (Neel 1969, Walstad et al. 1973, Tenczar and Krischik 2006). Tenczar and Krischik (2007) found that using this technique with imidacloprid reduced herbivore survival in container and field grown hybrid poplars. Based on that research, Chapter 3 explores the potential for this novel management technique to be deployed within poplar plantation at a commercial production scale.

b. Trapping *Prionoxystus robiniae*

*Prionoxystus robiniae* [Lepidoptera: Cossidae] is a well-known pest of Salicaceae in North America. This native moth tends to attack older stands of hybrid poplars and can dramatically reduce wood quality and the value of the grower’s end product. Although the biology of *P. robiniae* is well documented (Leppla et al., 1979; Solomon, 1973, 1988; Solomon and Hay, 1974; Solomon and Neel, 1972, Hannon 2006). Current control measures of infestations of *P. robiniae* rely on the use of broad-spectrum insecticides and selection of resistant clones (Hannon 2006). A sex pheromone for *P. robiniae* described by Doolittle et al. (1976) strongly attracts males of this species, and has been utilized for monitoring populations in hybrid poplars on the Boardman Tree Farm (Doolittle and Solomon 1985, Hannon 2006). Previous work indicates that this sex pheromone could be utilized in the hybrid poplar system to conduct attract-and-kill efforts (Hannon 2006). Hannon (2006) suggested a combination of three typical applications of sex pheromones: mass trapping, attract-and-kill, and mating disruption for control of *Prionoxystus robiniae* in hybrid poplar plantations. In Chapter 4, the use of a ‘trap out’ technique is evaluated.
IV. Integration of Findings

The work described in Chapters 2-5 augments earlier research and contributes to the development of an integrated pest management program for hybrid poplar. Previous research tended to focus on improving saw timber stands by reducing the risk from native, wood-boring Lepidoptera (Hannon 2006, Kittelson 2006). Evaluating the epigeal community, pest pressures in newly established stands, developing a better understanding of the natural history of common pests, and developing new pest management techniques would help bridge this gap and produce a greater understanding of the hybrid poplar system as a whole. Concurrent research by Del Pozo (2011) examined a complex of common defoliators and the suite of associated natural enemies.

The description of the epigeal arthropod communities associated with poplar plantations (Chapter 1) and the distribution and diversity of known pests in establishing stands (Chapter 2) will help growers and pest managers utilize more integrated control measures. Chapters 3 and 4 explore novel techniques that when applied to the hybrid poplar system may enhance the current IPM program. Chapter 3 evaluates the use of a new protection strategy for unrooted cuttings in new planting beds, while Chapter 4 further develops a type of mating disruption proposed for use in hybrid poplars by Hannon (2006). These additional management tactics could aid poplar growers producing an FSC-certified crop by promoting IPM practices.
References


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Web References:
CHAPTER TWO
Epigeal Arthropod Community in Hybrid Poplar Plantations and Adjacent Habitats

ABSTRACT
Arthropods pests of hybrid poplar in northeastern Oregon have been studied in detail since 2001, and the researchers involved have developed multiple control tactics to reduce the economic impact of established and newly introduced pests. Very little of this research has focused on describing the ground-dwelling arthropod community (hereafter the “epigeal community”). The studies detailed below examine the epigeal arthropod community and nearby habitats to develop a greater understanding of the organisms residing within and around poplar plantations. The project focused on describing the epigeal arthropod communities within newly established and mature hybrid poplar stands and that of nearby shrub-steppe and riparian habitats. Riparian habitats had the greatest arthropod diversity among the varied habitats, while the mature poplar stands exhibited the least diversity. Shrub-steppe and newly planted stands had similar abiotic conditions (temperature, wind, sun exposure, etc.) and Shannon-Weaver diversity index values. Predominant species tended to be found across all four habitats, with riparian areas and mature stands sharing the most species. These results indicate that the epigeal arthropod community within hybrid poplars is not unique, and is mostly derived of common species found in neighboring natural habitats.

INTRODUCTION
Hybrid poplars are a short rotation woody crop first planted in the lower Columbia River Basin in the early 1980’s as a reliable source of high grade wood pulp for the paper industry (Stanton et al. 2002, Hibbs et al. 2003, Hannon 2006). As pulp prices dropped in the late 1990’s
and early 2000’s, Potlatch Corporation (Spokane WA) and GreenWood Resources (Portland OR) began to explore the possibility of repurposing poplar plantations in eastern Oregon to produce non-structural saw timber. During this transitional period, Potlatch projected an increased market demand for sustainably sourced fiber products. In preparation for this new, perceived market, Potlatch began in 2001 to manage their plantation near Boardman, Oregon under Forest Stewardship Council (FSC) standards (Forest Stewardship Council 2010). FSC-certification focuses on promoting sustainability through social, environmental, and economic responsibility. This certification program requires forest managers to utilize integrated pest management techniques, reduce chemical inputs, monitor forest organisms, and promote biodiversity on their lands (Forest Stewardship Council 2010). GreenWood Resources assumed and expanded this certificate when they purchased Potlatch’s Boardman Oregon plantation in 2007.

Several crop management strategies had to be altered as these hybrid poplar plantations were converted to saw timber stands. Rotational length was increased from a seven-year pulp wood rotation to 12 years: syleptic (lateral branches that develop from lateral meristems without a period of dormancy) and proleptic (lateral branches that develop from lateral buds after a period of dormancy) branches (Wilson 2000) were pruned up to 10 m, and stand density was decreased from 1,500 stems per hectare for pulp to 750 stems per hectare for saw timber (Stanton et al. 2002). Pruning and wider spacing delays canopy closure leading to a potentially harsher microclimate due to increased sun exposure, higher temperatures, and decreased humidity. But increased rotation lengths may also permit resident organisms to become more abundant and may allow immigration of new fauna from adjacent habitats.
The Boardman Tree Farm is currently surrounded by several different habitats including irrigated annual crops, rangeland, riparian areas, and xeric shrub-steppe habitat (USDA Soil Conservation Service 1983). Riparian areas in this region are generally dominated by stands of cottonwoods (Populus sp. [Salicales: Salicaceae]) and Russian olive (Elaeagnus angustifolia L. [Rhamnales: Elaeagnaceae]). Shubby woody vegetation, sedges, forbs and grasses dominate the shrub-steppe. Because these two habitats may resemble different growth stages of hybrid poplar stands, they may act as sources of arthropod fauna that have established populations within nearby poplar plantations.

Regardless of their projected end-use, hybrid poplars in the Pacific Northwest are generally propagated via clonal cuttings. Cuttings are gathered from high-density nursery plantings (stool beds), cut to length (0.3-5 m) and then planted in the field using either a dibble or auger at the desired spacing. During stand establishment growers must utilize multiple field entries to conduct chemical and physical pest (weed, insect, vertebrate, etc.) control because there is not a closed canopy to shade out weeds. Mechanical application of herbicide using all-terrain vehicles (ATV’s) and tractors occur multiple times a year during the first two years of stand establishment. Management differences emerge following the second year differences in tree stand structure (canopy) and management between pulp and saw timber emerge. Dense spacing of pulp stands allows for near canopy closure by the end of the second year while more widely spaced saw timber will not approach canopy closure until the end of the fourth or fifth growing season permitting prolonged competition from weeds. Pulp stands receive very little active management other than aerial or chemigation insecticide treatments after the second year until they are harvested. Saw timber stands undergo a much more intensive management strategy
beginning in the second year. Commencing at the conclusion of the second growing season, and for the next 3-4 seasons, the syleptic and proleptic branches are pruned at increasing heights to reduce the incidence of knots and increase the amount of clear wood available in the lower section of each tree. Pruned branches are left on the stand floor to decompose promoting nutrient return, providing limited vertical habitat structure in the intermediate aged stands and reducing labor costs to move the branches to the edge of the field. After the sixth year saw timber stands do not have another normally scheduled ground disturbance until harvest. If needed, insecticide applications are made aerially or through a chemigation system. Pulp and saw timber stands are both harvested via clear cutting, which directly affects animal communities.

Harvest is a planned event within the hybrid poplar agro-ecosystem that punctuates the equilibrium of the populations of all organisms in harvested stands. After two years of periodic mechanical disturbance (ground rig-applied herbicide and mowing) during stand establishment the subsequent years of no disturbance of the poplar habitat permits the development of relatively stable arthropod communities. During and following harvest, epigeal arthropod communities are exposed to possibly a harsher environment. Harvest of mature trees disturbs the soil and eliminates the canopy cover, which markedly increases the wind and sun exposure, as well as causing higher temperatures and lower humidity levels at ground level. These abiotic changes may reduce the environmental suitability for many members of the arthropod community. Additionally, harvesting and its associated activities may extirpate less mobile or sessile organisms that are unable to escape this severe habitat destruction (Collins and Thomas 1991, Fahrig and Jonsen 1998). Determining which species reside within the hybrid poplar
arthropod community is an important step in describing how this group responds to the significant ecological disturbance that results from stand harvest.

Brown et al. (unpublished), Hannon (2006), and Kittelson (2006) conducted thorough surveys of arboreal pest species of hybrid poplars within the Boardman Tree Farm and Ice Harbor Tree Farm in the mid-Columbia River Basin. Kittelson (2006) also described the Lepidoptera community associated with this system. However, there has been little exploration into how epigeal arthropod communities within hybrid poplar plantations respond to the ecological disturbance of harvesting. This study was designed to measure the effects of poplar stand harvest on the associated ground dwelling arthropod communities. To evaluate the impacts and recolonization process, the arthropod community was assessed in mature stands, close to harvest, and young stands during establishment. Since recolonization after harvest may depend upon nearby natural habitats the study included assessments of arthropod communities in these habitats.

MATERIALS AND METHODS

Study Location. This study was conducted in Umatilla and Morrow County, OR and Benton County, WA. Hybrid poplar stands were located within GreenWood Resources, Inc. Boardman Tree Farm, near Boardman, OR. Sampling within hybrid poplar stands was focused on two main habitats: new plantings (<1 yr old) and mature stands (>10 yrs old). Mature riparian cottonwood stands were sampled southeast of Plymouth, WA and in Umatilla National Wildlife Refuge, while two shrub-steppe study areas were sited on private reserve areas adjacent to the Boardman Tree Farm. These private reserves have not been grazed in the last 20 years and
are a mix of native plants and cheat grass. One shrub-steppe reserve was located between fields 812 and 906, and the second reserve area was directly south of field 504 within the Boardman Tree Farm. Sampling was done over three time intervals during the growing season (late-April/May, July, late-August/September) between fall of 2006 and fall of 2009. Multiple poplar stands were sampled within each habitat type.

**Study Design.** Selected poplar stands between 64-110 ha were divided into four equal planting blocks with a centrally positioned manifold pump station (Figure 2.1). The same five poplar stands were sampled for the pre- and post-harvest study. Pre-harvest data collection occurred in September 2005 and the post-harvest data was collected in April and July of 2006 at the same trap locations used the prior year. Six mature (>10 yrs old) and five newly established stands (<1 yr old) were sampled in the study comparing the poplar plantation to the adjacent habitats (riparian & shrub-steppe).

Nine pitfall traps were set in one randomly selected planting block of each stand. Pitfall traps were constructed by excavating a hole in which to place a section of PVC drainage pipe (5 cm diameter x 20 cm long). This length of PVC pipe maintained the integrity of the hole and provided support for the trap. Traps were constructed of 296 ml clear Solo Cup (Solo Cup Company, Urbana, IL) filled with 100 ml of soapy water (Fig. 2.2). A liquid soap (Ivory [Proctor and Gamble, Cincinnati, OH]) was used as a surfactant to reduce arthropod escape due to individuals not breaking the surface tension. The nine traps were arranged so that they formed a diagonal transect extending through the middle of the planting block. The first trap was placed eight rows (25 m) away from the central manifold and eight trees (37 m) into the block. This
pattern of eight rows by eight trees was used to place the next eight traps (Figure 2.1). Traps in riparian and shrub-steppe habitats were installed with a similar protocol, but utilized linear distance between traps in place of tree and row counts. Transects in the 2 riparian areas and 2 shrub-steppe habitats were initiated by randomly choosing an entry point into each area. Traps were placed 45 m apart and were arranged so that they ran through the middle of each sampled natural habitat.

In most sampling areas DS1921G Thermochron iButton® temperature recorders (Maxim Integrated Products, Inc., Sunnyvale, CA) were placed at the fourth trap within the trapline. iButtons® were utilized to record surface temperature and were placed inside two 1 qt Ziploc® Bags (SC Johnson, Racine, WI) as a form of waterproofing, and then placed at the base of the nearest tree. This placement afforded some protection from regular farm management activities and prevented them from being in direct sunlight. Temperature records are not available for all blocks in all years, due to a limited quantity of iButtons®, several losses of the device and device failure.

Pitfall trap samples were collected weekly for three weeks in April, July and September. Trap contents were placed in Reynolds Del-Pak polyethylene pint (473 ml) deli containers (Reynolds Food Packaging, Laval, Canada) for transport to the laboratory. In the lab each sample was rinsed with slow flowing water to eliminate soap residue in a hand-held colander. Researchers removed any accumulated debris (leaves, seeds, sticks, etc.) by hand to expedite the sorting process. Samples were then placed in a 70% ethanol solution for storage until processed. Trap contents were sorted to order, family and morphospecies and either pinned or placed in labeled
vials of 70% ethanol. A Shannon-Weaver Index (H’) and evenness (J) test were calculated for each replicate within each habitat. The Shannon-Weaver Index was calculated using this equation:

\[ H' = - \sum_{i=1}^{S} p_i \ln(p_i) \]

Where S = total number of morphospecies, \( p_i \) = the proportion or frequency of species in the community. Evenness (J) represents the distribution of species within a habitat type and was calculated using:

\[ J = \frac{H'}{\ln(S)} \]

An ANOVA produced by jmp-10 was used to analyze H’ and J among habitat types, and a Tukey’s HSD test was run to determine the difference between habitats. This same program was used to conduct a paired t-test of the habitat temperatures and pre- and post-harvest communities.

**RESULTS**

**Diversity. Pre-harvest vs. Post-harvest.** Based on the harvest schedule we were able to sample five mature stands prior to their harvest, and then again once these stands were replanted the following year. There was a significant difference in the Shannon-Weaver Index (H’) between the pre- and post-harvest stands, with mature stands being more diverse than newly planted stands (paired sample t test: \( t = -7.61, \text{df} = 4, P = 0.0016 \)). Evenness was also significantly greater in pre-harvest stands (paired sample t test: \( t = -4.94, \text{df} = 4, P = 0.0078 \)). These results suggest that epigeal arthropod diversity is dependent on stand age.
**Habitat Type.** There was a significant difference in the Shannon-Weaver Index and habitat type ($F_{3,16} = 4.5844$, P-value = 0.0257). Based on Tukey’s HSD test (alpha = 0.05), H’ differed between riparian habitat and mature poplar stands, and no difference between the new stand and the shrub-steppe habitat (Table 2.1). Mature Stands are the least diverse habitat sampled, while newly planted stands and shrub-steppe habitats are intermediate in diversity between mature and riparian stands. There was no significant difference between habitat types with regards to evenness ($J$) ($F_{3,16} = 2.19$, P = 0.1468).

**Temperature:** During all sampling periods shrub-steppe was warmer than all other habitat types, followed by newly planted stands. Mature stands were cooler in April-May and August-September sampling periods than riparian stands, while riparian stands were cooler than mature stands during July (Table 2.2). These differences may be linked to irregular tree arrangement and a patchier canopy in the riparian areas. Average daily temperatures for July 2009 are shown in Figure 2.3. Trends evident in Table 2.2 and Figure 2.3 are representative of temperature data collected throughout this study.

**Community Composition.** The morphospecies of each habitat were recorded and compared across habitats. The most abundant arthropods captured in all habitats are listed in Table 2.3. It is important to note that a majority of these species are found in no less than two habitats, and approximately one-third of these species reside in three or more habitats. The two most common species captured in this study were *Calathus ruficollis* (Coleoptera: Carabidae) and *Tetramorium caespitum* (Hymenoptera: Formicidae). Although *C. ruficollis* was captured during every sampling period, abundance was greater in July and August / September.
*Tetramorium caespitum* captures seemed to be related with trap location (proximity to a colony) and not the sampling period.

**DISCUSSION**

Hybrid poplar plantations in the mid-Columbia River Basin are visibly distinct from the shrub-steppe, rangeland, and irrigated annual crops that predominate in the landscape, although poplar plantations may resemble cottonwood groves in the lowland areas near the Columbia and Umatilla Rivers at first glance. But based on the stratum of age classes present on this farm each year (0-12 yrs), younger stands may be more similar to the surrounding shrub-steppe habitat in vegetative structure than might be initially assumed. This collection of varied environments could potentially allow for immigration of fauna from nearby natural areas. However these habitats may only provide temporary habitats due to the regular catastrophic ecological disturbance of harvest every 12 years.

Stands are clear-cut at the end of a 12-year rotation, resulting in a drastically altered local environment characterized by higher temperatures, greater sun exposure, and wind gusts. Consequently the diversity of epigaeic arthropod communities of pre- and post-harvest stands differed significantly. Communities within stands prior to harvest had a higher Shannon-Weaver Index than when they were replanted the following year. This indicates that harvesting negatively affects epigaeic communities in hybrid poplars, reducing their diversity.

Building on this finding, we compared poplar stands at two stages (newly established [<1 yr] and mature [>10 yrs after establishment]) with two nearby natural habitats (shrub-steppe and riparian...
areas). We found that these natural areas were more diverse, based on H’, than either sampled poplar stands. The trend of greatest H’ in riparian areas, as compared with other habitat types could be linked to the stability and habitat heterogeneity characteristic of riparian habitats along dam controlled rivers. These habitats have a partially closed canopy of native cottonwoods and an understory of shorter wood herbaceous vegetation that together provide a more sheltered environment with greater vertical structure and plant diversity than poplar stands of either stage. These characteristics are associated with high arthropod diversity often reported for riparian habitats (Haddad et al. 2001, Herrera and Dudley 2003). Shrub-steppe areas also provide greater stability and botanical diversity than poplar plantations, but have significantly hotter temperatures (Figure 2.3) and intense sun exposure that may reduce diversity.

Individuals residing in poplar stands during the establishment phase must withstand abiotic factors similar to those of shrub-steppe habitats, and must endure multiple mechanical and chemical disturbances. During establishment poplar stands suffer greater disturbance among the habitats sampled, with the preparation of planting beds using large farm machinery that grinds, rips, and rototills planting beds prior to planting. Combined with multiple pesticide applications during the first (and second) year, epigeal arthropods residing in this habitat are likely to be negatively impacted. Regular spacing of mature stands allows for complete canopy closure unlike the broken canopy and scattered tree arrangement of riparian areas. Mature stands also lack the vertical structure element of riparian stands as they are actively managed to reduce weed competition. Additionally, the perceived stability of this habitat may be misleading due to the potential for insecticide applications throughout the lifetime of the stand.
Historical management of the plantation may also provide clues to such a difference in diversity between nature stands and riparian areas. Liberal use of chlorpyrifos and other broad-spectrum insecticides was the industry standard on hybrid poplar tree farms (M. Berk pers. comm.). It was thought this practice created a ‘biological desert’ throughout the plantation, and may have prevented the establishment of long-term epigeal arthropod community. FSC certification required plantation manages to alter their pest control strategies through the use of ‘softer’ pesticides and the concept of integrated pest management. However, the use of insecticides persists in hybrid poplar pest management. Though FSC-approved chemicals (FSC 2007) are considered to be sustainable and less hazardous, their use still impacts non-target organisms. Del Pozo (2012) documented that beneficial arthropod populations in areas treated with an FSC-approved insecticide (indoxacarb) were reduced in the year following treatment. Although this trend may be based on host availability, it indicates that insecticide applications can directly or indirectly influence populations of non-target arthropods in the poplar agroecosystem.

Shrub-steppe and newly established stands are similar in diversity indices and habitat characteristics. Both habitats are notably warmer than either mature stands or riparian areas and have larger temperature swings throughout the sampling period (Table 2.1, Figure 2.3). These habitats also have similar physical structure characterized by an open canopy and herbaceous understory. Despite these differences, these habitats share the most abundant species with mature stands and riparian areas than they do between themselves. Overall, a third of the most abundant species were found in three of the four habitats assessed, while only two of these abundant species (Geocoris sp. and Formica sp. B) were captured in a single habitat (Table 2.3). Based on our understanding of the distribution of species across the landscape of this study, it
seems that most of these commonly captured species are generalists that utilize multiple environments. However, these generalist species may just be more active and mobile than less common species in these habitats. Pitfall trapping is recognized as a means of evaluating communities in a multitude of habitats, but their utilization results in a known bias (Luff 1975, Holland and Smith 1999, Ward et al. 2001). Pitfall trapping is a quick, cheap sampling method commonly utilized to estimate diversity of ground-dwelling arthropods, but it is limited by this technique’s preferential capture of active, abundant species (Holland and Smith 1999). This bias of capturing highly mobile organisms of a restricted species range cannot be overlooked in examining the degree of habitat breadth of the common species in this study. We recognize trap captures in all habitats reflect mostly species with large populations. Regardless of this bias, pitfall traps continue to be used to make relative comparisons among communities (Mommertz et al. 1996, Holland and Smith 1999).

The two hybrid poplar pests, *Gluphisia septentrionis* (Lepidoptera: Notodontidae) and *Otiorhynchus ovatus* (Coleoptera: Curculionidae), were captured in both hybrid poplar stands and riparian areas. The Holarctic *G. septentrionis* was captured in the largest numbers in both riparian areas and mature stands. If not controlled *G. septentrionis* larvae can quickly defoliate large areas and have been responsible for multiple defoliation events on the Boardman Tree Farm since 2007 (Brown et al. unpublished). This species defoliated over 800 ha of poplars in Mississippi (N. Schiff Research Entomologist-USDA pers. comm.). *Otiorhynchus ovatus* was commonly captured in three of the sampled areas: new and mature stands and riparian areas. Adults of this weevil species can cause significant damage to newly planted stands by feeding on new leaves directly following bud break. This pest poses much less risk to larger trees found in
mature stands and riparian areas because older trees can tolerate some short-term herbivory. The discovery of these species in riparian areas adjacent to plantations was not surprising based on the proximity of the habitats and the presence of *O. ovatus* hosts (cottonwoods and willows) in this habitat.

Hybrid poplar plantations have a lower arthropod diversity than surrounding natural habitats, but they provide habitat for species that are found within both shrub-steppe and riparian habitats. Newly established poplar stands closely resemble surrounding shrub-steppe areas in arthropod diversity and in physical structure. These environments have comparable structure and experience parallel trends in temperatures, although shrub-steppe areas tend to be warmer and drier. Growers throughout the growing season closely regulate soil moisture in poplar stands whereas shrub-steppe habitat depends on natural precipitation. Riparian areas had the highest diversity but shared many species with the community present in mature poplar stands.

Previous research focused on pest populations and how they responded to FSC-approved control strategies, largely ignoring the community of non-target organisms. That work developed a pest-centric IPM program that has been largely implemented without the thought of its effect on the whole system. This work, and that of Del Pozo (2012), has added greatly to our understanding of the poplar agroecosystem Pest managers now incorporate this knowledge of non-target organisms into their management plans, creating a fully integrated pest management plan.
REFERENCES


**Web References:**

Table 2.1. Mean Shannon-Weaver Diversity Index of each habitat type.  
(Letters indicate statistically different groups.)

<table>
<thead>
<tr>
<th>Sampled Habitat</th>
<th>$H' \pm SE$</th>
<th>$J$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riparian</td>
<td>$2.25 \pm 0.31$</td>
<td>$0.59$</td>
</tr>
<tr>
<td>Shrub-Steppe</td>
<td>$1.92 \pm 0.33$ a,b</td>
<td>$0.52$</td>
</tr>
<tr>
<td>New Stands</td>
<td>$1.79 \pm 0.22$ a,b</td>
<td>$0.52$</td>
</tr>
<tr>
<td>Mature Stands</td>
<td>$1.148 \pm 0.18$ b</td>
<td>$0.38$</td>
</tr>
</tbody>
</table>

Table 2.2. Mean average temperature during three sampling periods in 2009. These trends are similar to those between 2006-2008 (data not shown). All stands are significantly different from each other ($P < 0.0001$).

<table>
<thead>
<tr>
<th>Habitat</th>
<th>April / May Mean Temp (F)</th>
<th>July Mean Temp (F)</th>
<th>August / September Mean Temp (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newly Planted</td>
<td>59.1</td>
<td>84.9</td>
<td>70.6</td>
</tr>
<tr>
<td>Mature</td>
<td>54.5</td>
<td>79.7</td>
<td>63.5</td>
</tr>
<tr>
<td>Riparian</td>
<td>56.2</td>
<td>78.3</td>
<td>64.3</td>
</tr>
<tr>
<td>Shrub-steppe</td>
<td>60.5</td>
<td>94.6</td>
<td>71.8</td>
</tr>
</tbody>
</table>
Table 2.3. Common species collected during this project and their associated habitats. Note how these species tend to be found in multiple habitats.

<table>
<thead>
<tr>
<th>Species</th>
<th>New Stands</th>
<th>Mature Stands</th>
<th>Riparian</th>
<th>Shrub-Steppe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trechus sp.</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Pterostichus sp.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calathus ruficollis</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Nicrophorus sp.</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Otiorbynchus ovatus</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Geocoris sp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tetramorium caespitum</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Formica sp. A</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Formica sp. B</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forficula auricularia</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Glaphisus septentrionis</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Gryllidae</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Acrididae</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Lycosidae</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Araneidae</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Opilionidae</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Armadilidiidae</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Figure 2.1. Arrangement of pitfall traps across a planting block.

One of four planting blocks was chosen at random within the sampled field. Each trap was separated from another trap by eight rows and then eight trees perpendicular to the rows.
Figure 2.2. Pitfall traps consist of a 5 cm diameter PVC drainage pipe supporting a 296 mL Solo cup. Each trap was marked with a surveyor flag.

Figure 2.3. Average daily summer temperatures of four sampled habitat types in 2009.
CHAPTER THREE

Description of Unrooted Cutting Mortality and the Associated Distribution within a Hybrid Poplar Stand

Abstract

Over 500,000 unrooted cuttings are planted each year to propagate hybrid poplars on GreenWood Tree Farm Fund’s Boardman Tree Farm. Each April cuttings are planted in rows 3-6 m apart and 5 m between cuttings within the row. Aboveground irrigation tubes with 1.1 m spacing are placed less than 0.3 m from the tree row. Producers attempt to optimize growth and desire a 3 m tree at the end of that stand’s establishment year. As hybrid poplar production has shifted from pulp fiber to saw timber and other whole-wood products, stands are being planted at loser tree densities. This results in increased value per individual cutting. Growers anticipate that some cuttings will fail, but research has been required to determine the cause of cutting failure. Cuttings in newly established saw timber stands were evaluated over the course of 3 years to determine the cause of mortality (failure) of unrooted cuttings and to describe the distribution of these failures within stands. It was confirmed that Polyphylla decemlineata (Say) [Coleoptera: Scarabaeidae] is the primary belowground herbivore in this system, and that defoliators that attack a cutting’s initial arboreal shoot pose the greatest risk of cutting mortality. In addition, the distribution of mortality and the causal agent has been documented. This work has provided poplar producers with a better understanding of the risks of establishing hybrid poplar stands.

Introduction

GreenWood Tree Farm Fund has approximately 10,000 ha of hybrid poplars in the Columbia River Basin being grown to partially meet today’s fiber needs. These needs include a
wide range of end products and uses, including high-grade wood fiber for the paper and pulp industry, non-structural saw timber, engineered wood products, hog fuel residuals, and biofuel (Stanton et al. 2002, Hibbs et al. 2003, Hannon et al. 2008). In the Columbia River Basin, hybrid poplars are propagated by planting dormant, unrooted cuttings. The quick growth of adventitious roots makes this planting stock an inexpensive method of stand establishment (Stanton et al. 2002). The spacing of the cuttings is dependent on the desired product or goal for that planting block. Hybrid poplars are commonly planted at a rate of 500 (saw timber) to 2,200 (stool bed) trees per hectare (Stanton et al. 2002). Cuttings to be planted generally range from 0.23-4.5 m in length. Shorter cuttings are planted by hand, often with the assistance of a dibble stick, while holes for larger cuttings are generally drilled with an auger. Planting crews consist of up to fifteen laborers that traverse the planting blocks on foot.

Cuttings represent one of the most vulnerable life stages of growing hybrid poplar and establishment in the first year is essential. The failure of a cutting to establish represents an economic loss that will persist throughout the rotation (7-14 yrs) of the stand. In addition, areas of failed cuttings are hard to replant after the first year due to the rapid growth of the surrounding surviving trees. Approximately six and twelve weeks after the initial planting, the crews return to the fields to replace any cuttings that may have failed to break bud. This is done to prevent the presence of gaps in a stand that lead to an economic loss. Replanting is costly because planters need to evaluate every cutting within a planting block. Laborers are trained to recognize a failed cutting, but there is little understanding of the cause of each failure.
Although there are numerous causes of cutting failure, the factors that contribute to mortality remain poorly understood. Several studies recognize that both the reduced leaf area and the favorable Leaf Plastochnron Index (LPI) make cuttings susceptible to several common *Populus* defoliators (Bingaman and Hart 1992, Reichenbacker et al. 1996, Coyle et al. 2002, Tenczaz and Krischik 2006). Herbivory can severely lower the economic value of the stand during the establishment period by causing mortality, subsequently reducing biomass (Kulman 1971, Bassman et al. 1982, Coyle et al. 2003, Anderson and Nelson 2002, Tenzcar and Krischik 2006). Insect and deer herbivory poses a major risk to the establishment of saw timber stands in the Pacific Northwest due to both tree mortality and deformity. Root feeding by herbivores also endangers newly planted cuttings. Larval Coleoptera are known to feed on the roots and buried stems of the cuttings of several forestry crops (Abrahamson et al. 1977, Van Steenwyk and Rough 1989, Sidebottom 2004). Root damage is observed above ground through rapidly yellowing leaves and leaf drop, while belowground damage can be described by the loss of fibrous roots and the stripping of bark from cutting and larger roots (Schwardt 1942). Damage of this sort often results in a weakened or dead hybrid poplar sapling.

Failed cuttings may also be the result of improper handling and planting or a cutting that was not viable when planted. For example, during handling buds can break off as the cuttings are moved from storage to planting satchels. Sometimes when the buds are small or through planter error cuttings may be planted upside down leading to failure if the cutting does not have enough energy reserves for the shoot to reach the surface. Despite its common occurrence and cost to production, the causes of cutting failure are poorly understood in this system.
An objective of our studies was to provide hybrid poplar growers with a greater understanding of what causes cutting mortality and its distribution within poplar stands. The cause of mortality was addressed with two types of sampling techniques (intensive and inspection) to identify what damage a potential root-feeder or defoliator inflicts on a cutting. We utilized SADA (Spatial Analysis and Decision Assistance; The Institute for Environmental Modeling, University of Tennessee, Knoxville, TN)) to describe the distribution of cutting mortality within a newly established stand.

**Material and Methods**

**Study Sites.** The planting blocks used in these studies were located in GreenWood Resources’ two tree farms in the middle Columbia River Basin: Boardman Tree Farm (Boardman, Oregon) and Sandpiper Tree Farm (Patterson, Washington). Units on both farms in the first year of establishment to be sampled were chosen randomly. Each unit consists of multiple planting blocks, and the size of these planting blocks (12-26 ha) depended on the size and division of the unit. The planting blocks are transected by irrigation driplines spaced approximately 3 m apart across the width of the field. Depending on the end product, *Populus* cuttings are planted 1-7 m apart at an emitter. For most of the planting blocks sampled in this study, cuttings were planted at a 4.5 m spacing. The length of each dripline serving each row is roughly 400 m.

Within the growing seasons of 2006-2009, sampling was initiated one month post-planting (early June) to ensure that cuttings had flushed their leaves, and was continued to the middle of August of that year. If a cutting was collected, it was replaced with another cutting in the same location.
In planting blocks where replanting crews returned to fields before sampling occurred, the crews marked the location of the failed cutting with a wire surveyor flag and placed the removed cutting perpendicular to the dripline next the flag. The location, type of damage and state (alive or dead) of each cutting was recorded on a gridded map of the planting block. In this way, every cutting was accounted for within the sampled area.

**Characterizing Cutting Damage Study.** *Intensive Sampling.* All cuttings within two newly established stands were closely examined for damage to the leaves, buds, subterranean stem, and roots. The location of the damaged cutting was then recorded on a gridded map of the stand. Damaged cuttings were then closely observed for aboveground damage prior to their collection using a modified clam digger (0.61 m steel tube [0.15 diameter] attached to a 1.1 m steel beam). Individual cuttings were examined for the presence of pests and any sign of insect feeding (scalloped leaf margins, holes without necrotic edges, missing leaves, etc.). Insects observed feeding on the cuttings were collected in labeled 3-dram glass vials and photos were taken of the associated damage to the cutting. At the conclusion of the aboveground inspection the contents of the modified clam digger (the damaged cutting and all the soil in a 0.13 m area centered on the cutting to a depth of 0.45 m) were placed in a labeled 7.5 L plastic bag. Before sealing the collection bag with a 0.05 m cable tie, the belowground portion of the cutting was closely evaluated for any signs of herbivory and/or damage. Observations of both above- and belowground damaged helped researchers determine if there was a link between the two types of damage. Soil samples were taken to the Washington State University’s Entomology Integrated Pest Management laboratory at the Boardman Tree Farm and sieved to determine the presence and identity of insects in the vicinity of the damaged cutting. The sieving process consisted of
passing the soil sample through wire screens ranging from coarse to fine. After each screening, the material was examined for the presence of adult or immature insects and insect parts.

_Sampling by Inspection._ This sampling method followed the protocol provided in the above _Intensive Sampling_ section, but no soil was sampled. In lieu of soil collection, damaged cuttings were removed from the ground and closely examined for belowground damage. Damage cuttings were recorded on a gridded map of the newly established stand. Beginning in the 2007 growing season, sampling by inspection was the only methodology utilized.

_Damage Description._ From the description of cutting damage from both the intensive sampling and sampling by inspection studies researchers to identify several types of mortality. The cause of mortality was broken into two categories: insect and non-insect. Insect mortality consisted of two classes: defoliation and belowground herbivory. Non-insect mortality was caused by the improper handling of the cuttings, feeding by deer (Artiodactyla: Cervidae), or planting of non-viable cuttings.

**Distribution of Cutting Mortality Study.** This study was conducted concurrently with Study 1 during 2006, but the sampling by inspection technique was adopted to examine the distribution of cutting mortality in the sampled planting blocks. For each planting block that was sampled, a gridded map was used to show the location of individual cuttings. This gridded map was then condensed into groups of nine trees (3 trees x 3 rows). GreenWood Resources determined that a grouping of this size represents the smallest area of mortality (if all nine trees were dead) that results in an economic loss. Areas smaller than a group of nine trees can most
likely recoup the economic loss of missing trees through increased growth resulting from less
competition (D. Rice pers. comm.). These groups of nine trees were then transposed into
columns to be entered into SADA to create visual representations of cutting mortality within
planting blocks. Mortality was displayed both as total mortality and as individual damage types
and presented to the growers.

Results

Characterizing Cutting Damage Study. Cutting Damage. Insect defoliation is commonly
caused by several documented Populus pests: cottonwood leaf beetle (Chrysomela scripta F.
[Coleoptera: Chrysomelidae]), strawberry root weevil (Otiorynchus ovatus (L.) [Coleoptera:
Curculionidae]), and Polydrusus impressifrons Gyll. [Coleoptera: Curculionidae]). Adult C.
scripta damage to leaves is recognizable by consumption across secondary leaf veins and the
presence of smeared frass across the leaf blade. Damage caused by larval C. scripta is readily
apparent from the presence of larvae on a cutting’s leaves, as well as feeding across leaf veins.
Curculionidae damage is characterized by a distinct scalloping of the leaf margins, giving the
leaf a toothed appearance (Figure 3.1: SRW). Without discovering individual adults on the
cutting, it is difficult to differentiate between O. ovatus and P. impressifrons feeding damage.
Obliquebanded leafroller (Choristoneura rosaceana (Harris) [Lepidoptera: Tortricidae])
defoliates hybrid poplar cuttings, but accounts for limited mortality. The presence of a C.
rosaceana larva is easily determined by the characteristic rolling of a leaf into a tubular shelter.
Poplar-and-willow borer (Cryptorrhynchus lapathi (L.) [Coleoptera: Curculionidae]) probes
young shoots and petioles of the cuttings, resulting in the destruction of vascular tissue going to
those leaves (Figure 3.1: PWB).
Belowground damage is most often caused by the tenlined June beetle (*Polyphylla decemlineata* (Say) [Coleoptera: Scarabaeidae]). This damage is characterized by the stripping of the bark down to the woody part of the stem up to the cutting’s soil crown (Figure 3.1: TLJB). This damage is also visible aboveground with shriveled shoots and yellowing leaves (Figure 3.2). Elateridae (wireworm) larvae can also cause belowground damage by attacking the buds below the soil crown and girdling the stem by feeding on the bark.

Handling damage is identifiable by the absence of a terminal bud, other secondary buds and sometimes a physical peeling back of the bark on the cutting (Fig. 3.1). Non-viable cuttings have dry, crumbling buds when removed from the ground and examined. The buds of cuttings planted upside down are pointing into the ground, which often results in the destruction of the buds or a shoot that has died trying to reach the surface. Deer damage can also cause severe economic loss through both cutting mortality and tree deformation by their consumption of the apical bud of the newly flushed shoot.

*Intensive Sampling vs. Sampling by Inspection.* Sampling by inspection provided the same results as the intensive sampling. Intensive sampling confirmed that *P. decemlineata* was the main cause of belowground herbivory since several larval *P. decemlineata* were found in soil samples from cuttings with stripped bark. Sifting soil samples from around dead cuttings yielded limited information in the form of several adult individuals of *O. ovatus*, and *P. decemlineata* larvae. Thus, intensive sampling yielded little more information than sampling by inspection but was much more labor intensive. Sampling by inspection only required the researcher to examine the cutting at its point of origin before moving on to the next cutting. Based on the 2006 sampling
when both methods were used, sampling by inspection was determined to be as accurate as intensive sampling.

**Distribution of Cutting Mortality.** Visual representations of the distribution of cutting mortality in each of the sampled units were generated using SADA. These images provided the grower with an estimate of crop loss and the risk of each mortality type in a given planting block (Figure 3.3). We noted that there was no consistent pattern of cutting mortality between planting blocks. Patterns that did emerge were more closely linked to an insect’s natural history, than to the actual location of the mortality within the planting field. Cutting mortality was broken into two divisions: insect and non-insect related (see above). The three most common insects causing cutting mortality were *P. decemlineata*, *C. lapathi*, and *O. ovatus*. The prominence of these mortality types fluctuated during the sampling period of 2006-2009.

The distribution of *P. decemlineata*-caused mortality was clumped in the planting blocks in which it occurred (Figure 3.4). In the areas with cutting mortality attributed to *C. lapathi* and *O. ovatus*, the distribution was random (Figures 3.5 & 3.6). Deer browsing damage was randomly distributed in fields where it is found (Figure 3.7), although in some areas there was an apparent preference for the edges adjacent to mature stands. This type of damage became more prominent in 2008 and 2009, which we attribute mostly to the areas that were replanted occurred in areas with large deer populations. Overall non-viable sticks are randomly distributed throughout planting blocks, but there are some planting units that have more of a clumped distribution (Figure 3.8).
Visual analysis of cutting mortality suggests that replanting efforts are not justified. Our results indicate that total mortality in a square of nine trees (3 trees x 3 rows) occurred in less than 5% of the area sampled. Most often, mortality occurs in less than a quarter of the trees in the sampling area. Only in a few cases did cutting mortality exceed 6% for an entire planting block.

Discussion

Characterizing Cutting Damage. We were able to successfully describe several prominent types of mortality in hybrid poplar cuttings. The characterization of individual pest and handling mortalities provides *Populus* growers with a tool to determine the cause of crop loss in newly established stands. This work suggests that belowground herbivory may be as important as aboveground herbivory in the successful establishment of new stands in the Pacific Northwest. Insect herbivores generally had distinctive types of damage related to their documented feeding patterns. The larval stages of aboveground herbivores are easily identified by their occurrence on the leaf they are consuming. Adults of *C. scripta* are not always present, but their behavior of feeding on all parts and areas of a leaf and copious excrement allow for easy identification by damage alone. Adult *Otiorhynchus ovatus* and *P. impressifrons* have identical aboveground feeding patterns and a positive confirmation requires a specimen. These pests only cause mortality when present in large numbers during the first leaf flush of the cutting. An individual adult of either species only causes a small amount of leaf damage, while a group of adults can defoliate a cutting quickly (Brown et al. 2011 unpublished data). Mortality caused by *P. decemlineata* can be identified by both aboveground symptoms of yellowing leaves and shriveled shoots, and belowground by the stripping of bark from the cutting stem and loss of roots.
Damaged cutting terminals, non-viable cuttings, and Cervidae browsing accounted for the largest amount of non-insect caused mortality and damage. Damaged terminals resulted from improper handling of cuttings during planting, buds breaking during packing for cold storage or during transportation of the cuttings. Avoiding the planting of non-viable cuttings and preventing deer browse pose difficult challenges to establishing hybrid poplar stands. Non-viable cuttings represent an economic loss due to the time and effort invested in the overall handling of the cutting that will not be recouped. These non-viable cuttings are also hard to detect prior to their failure. Cervidae browse causes economic loss by reducing the cutting’s apical stem form, and may also cause direct mortality of the cutting. Cervidae damage is identified by the stripped petiole or shoot being clipped off so there is no leaf area remaining. Prior efforts to fence out deer from commercial production units have failed, although fencing is used to protect small stool beds and research plots within the farms.

Our results indicate that replanting cuttings two or three times may not be needed in these planting blocks. The mortality occurring in the planting blocks is scattered randomly and rarely in clumps of more than three cuttings. GreenWood Resources, Inc. has determined that a gap of three trees in a single row within a stand does not represent a significant economic loss (D. Rice pers. comm.). An area this small can easily be compensated for by the growth of other trees in the damaged row and in rows adjacent to the damaged row (D. Rice pers. comm.). For a majority of mortality types, clumps of dead cuttings large enough to justify replanting do not occur. Only *P. decemlineata* and non-viable mortality tended to occur in groups that could cause
an economic impact. During this study only these two mortality types occurred in a grouped distribution.

The clumped nature of *P. decemlineata* damage can be explained by the natural history of this pest. *Polyphylla decemlineata* females are mostly sessile as a result of their ovipositing in the vicinity of the area where they emerged (Van Steenwyk and Rough 1989). *Polyphylla decemlineata* has a multi-year life cycle, where larvae can take two to four years to pupate (Schwardt 1942, Van Steenwyk and Rough 1989, Beers et al. 1993). The larval stage of *P. decemlineata* tends to attack and feed on cuttings near the area where they were laid, creating a clumped distribution pattern of cutting mortality. Late instar larvae are the most damaging stage of this pest and are known to girdle young trees in several fruit and stone tree crops (Beers et al. 1993). Hybrid poplars are often harvested when *P. decemlineata* larvae are dormant. The larvae break their dormancy in the early summer and quickly move from the dead roots of the harvested trees to feed on the newly planted cuttings. At this time, the new cuttings have not had the chance to establish a strong root system and quickly die as larvae strip the stem’s bark and consume any root structures that may be present.

This pest is believed to be widespread across most of Boardman and Sandpiper Tree Farms, and is mainly an issue during the establishment phase. If trees survive the first year of planting, their growth is vigorous enough to acquire resources and out-grow the damage caused by this pest. But, since the effects of this pest are rarely seen in older trees and mobility of larvae is limited, it is understood that they will persist throughout the crop rotation. Beyond the natural history element of the clumped distribution of *P. decemlineata*, prior land use can be influential. A
majority of these tree farms were once planted with annual crops and irrigated using a circle pivot. In several of the mapped planting blocks, we noted that clumps of *P. decemlineata* often occurred in areas that once were the ‘corners’ of circle pivots. These areas are commonly left fallow in annual cropping systems, and rarely receive any improvements or pest management treatments. *Polyphylla decemlineata* has a wide host range and could thrive in these sage-steppe areas. When annual crops were replaced by poplar and drip irrigation, *P. decemlineata* was able to switch to consuming *Populus*. Because older trees often do not exhibit symptoms from root herbivory in this system, *P. decemlineata* has been able to persist without much response by the grower. Only during the first year of growth do the cuttings show the effects of *P. decemlineata* feeding, after that the grower is not concerned with this pest until another rotation is planted.

Planting stock is collected in January and February, packed into plastic-lined boxes and placed in cold storage until cuttings are planted in April, May or June. This long period of storage sometimes leads to some cuttings being ‘dead’ (non-viable) prior to planting. Non-viable cuttings never break bud and represent an immediate failure of the cutting. If a group of these cuttings were to be planted by a sequential group of planters it could represent an aggregation of mortality resulting in an economically important gap. Other non-biotic damage includes damaged terminal buds and upside down planting are also issues that can be attributed directly to planters. Similar to non-viable sticks, the pattern for this type of mortality can vary dramatically, although it more often occurs in rows than in clumps. Cuttings with small buds, similar to clone OP-367, that are flush to the stem generally have a greater risk of being planted upside down, while cuttings with large buds, such as clone BC-81, protruding from the stem are more likely to be damaged. When the planters are unable to readily discern the buds, they must rely on
discerning the slight taper towards top of the cutting to avoid planting the cuttings upside down. The degree of taper on a cutting is dependent on from where on the stem or branch the cutting is taken. Planters are paid based on the number of cuttings they plant, so there is an incentive for the planter to move quickly down a row. Although protruding buds on a cutting make it easy for the planter to identify which end should go in the ground, this same feature makes the bud very fragile. Unless these cuttings are handled carefully, these buds easily break off and lead to a dramatic decrease in the establishment of the damaged cutting. Both of these types of mortality are directly linked with the planters and the clone that is being planted. It is important to note that upside down plantings accounted for less than 1% of the cutting failures.

Mortality caused by *C. lapathi* and *O. ovatus* was randomly distributed across the newly established stand. These distribution patterns are most likely linked to the mobility exhibited by adults of these species. Adults that can travel across sizable distances allows these pests to select specific cuttings to attack and thus reducing the chance of causing a clumped distribution of mortality. In a solitary instance we observed a large clump of *C. lapathi* mortalities (Figure 3.9). This clump was situated on an elevated rise in the middle portion of the planting block. We hypothesized that this small change in elevation provided a microclimate that this pest preferred. In other portions of the planting block without much fluctuation in elevation, the distribution of this pest was quite scattered. In older trees we do see areas with high concentrations of damage from larval *C. lapathi*. It is our understanding that in older trees the establishment of this pest can be linked with specific areas, or epicenters, surrounding the initial infestation. These epicenters then serve as source populations from which *C. lapathi* disperses to attack other trees in subsequent years.
*Otiorhynchus ovatus* aboveground damage and mortality patterns of cuttings are very similar to those of *P. impressifrons*. Both of these pests are mobile, resulting in a random pattern of cutting mortality. The adult of both of these species is a threat to newly planted cuttings. No observations of the larval stages of these pests were made during this study. But, the biology of these pests, and that of similar species, suggest that the larval stages feed on a wide range of host plant roots (Reding and Ranger 2011, Clark et al. 2012). Because they are defoliators with similar mouthparts and leaf consumption patterns, it is impossible to determine the specific pest without the individual being present. Previous to 2008 we did not observe *P. impressifrons* attacking newly planted sticks on these tree farms, although it was present in older stands. The populations of *P. impressifrons* have increased substantially since 2009. In 2010, an estimated 30% of cuttings in a planting block were either stunted or killed by this pest. Our observations suggest that if we were to map the most recent outbreaks of this pest in establishing stands, we would see a strong correlation of mortality occurring adjacent to older stands.

Cervidae browse is more an issue of damage than mortality, but this damage does often lead to dead cuttings. Browse damage leads to poor stem form as a result of the consumption of the apical bud. The loss of the apical bud often causes the cutting to take on a bush-like form with multiple stems and noticeable lateral growth. Although damaged trees can thrive, they rarely achieve the same economic return that single-stem trees produce over the course of the crop rotation. In many ways, this economic loss is greater than if the Cervidae damage just caused mortality. The surrounding trees can exploit the space and lack of competition created by the death of a cutting, whereas if the tree does not fail, there is competition between the stunted tree
and the surrounding individuals. Also, these stunted trees may often serve as hosts, and even epicenters, of borers and other insect pests.

**Conclusions**

Cutting mortality of different types presents challenges to the establishment of hybrid poplar stands in the Pacific Northwest. This research has shown that the crop loss from most mortality types does not justify the investment in replanting by the grower. A majority of the types of mortality occur in a random pattern within plantings blocks and do not result in a significant economic loss. *Polyphylia decemlineata* poses an economic risk to the growers based on its clumped distribution of mortality. This clumped distribution can cause significant holes within a stand that the adjacent trees cannot overcome with compensative growth. A weevil, *P. impressifrons*, has recently been present in large numbers on the Boardman Tree Farm and poses a significant risk of crop loss in individual planting blocks. We suspect that *P. impressifrons* may develop into one of the major pests of hybrid poplar cuttings in the years to come. The planting of non-viable cuttings and improper handling (breaking terminal buds) by the planters are the two largest non-insect related mortalities. Although these mortality types have a random distribution, the use of skilled planters and viable cuttings can quickly reduce these failure rates.
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**Internet References**

Figure 3.1. The four most common types of cutting mortality observed on GreenWood Resources’ Boardman Tree Farm and Sandpiper Tree Farm. From left to right: Cryptorynchus lapathi (L.) (Coleoptera: Curculionidae), Otiorhynchus ovatus (L.) (Coleoptera: Curculionidae), Polyphylia decemlineata (Say) (Coleoptera: Scarabaeidae), and handling damage. Damage from C. lapathi is exhibited by a shriveled shoot having several probe holes near attachment to the stem. Adult O. ovatus damage is characterized by having scalloped leaf margins and ‘scoops’ of leaf removed from around the veins. Damage from adult Polydrusus impressifrons Gyll. (Coleoptera: Curculionidae) is indistinguishable from that of O. ovatus, unless an adult weevil is present. Cambium stripped from the stem is characteristic of larval P. decemlineata damage. Handling damage occurs when the cutting’s terminal bud is damaged.
Figure 3.2. Aboveground symptoms of larval *Polyphylla decemlineata* damage on a hybrid poplar cutting. Note the yellowing leaves, limp terminal, and shriveled shoot and stem.
Figure 3.3. Visual representation of all the mortality types recorded in a planting block (Unit # 16-4). The types of mortality shown include: *Polyphylla decemlineata*, non-viable, terminal damage, *Cryptorynchus lapathi*, *Otiorhynchus ovatus* and cuttings planted upside down. The cool colors (purple = 0 trees) indicate low cutting mortality and hot colors (red = 9 trees) indicating high cutting mortality. Each dot represents a 3 trees x 3 rows block of cuttings.
Figure 3.4. Visual representation of mortality caused by *Polyphlla decemlineata* in a planting block (Unit # 30-4). Notice the clump of mortality located in the southeastern corner of the block. The cool colors (purple = 0 trees) indicate low cutting mortality and hot colors (red = 9 trees) indicating high cutting mortality. Each dot represents a 3 trees x 3 rows block of cuttings.
Figure 3.5. Visual representation of mortality caused by *Cryptorynchus lapathi* in a planting block (Unit # 25-2). Notice how the mortality is scattered across the planting block. The cool colors (purple = 0 trees) indicate low cutting mortality and hot colors (red = 2 trees) indicating high cutting mortality. Each dot represents a 3 trees x 3 rows block of cuttings.
Figure 3.6. Visual representation of mortality caused by *Otiorhynchus ovatus* in a planting block (Unit # 30-4). Notice how the mortality is scattered across the planting block. The cool colors (purple = 0 trees) indicate low cutting mortality and hot colors (red = 1 trees) indicating high cutting mortality. Each dot represents a 3 trees x 3 rows block of cuttings.
Figure 3.7. Visual representation of the Cervidae browse in a planting block (Unit # 410-2). Notice how the mortality is scattered across the planting block. The cool colors (purple = 0 trees) indicate low cutting mortality and hot colors (red = 3 trees) indicating high cutting mortality. Each dot represents a 3 trees x 3 rows block of cuttings.
Figure 3.8. A visual representation of the non-viable cutting mortality in a planting block (Unit #16-4). Notice how the mortality is scattered across the planting block. The cool colors (purple = 0 trees) indicate low cutting mortality and hot colors (red = 7 trees) indicating high cutting mortality. Each dot represents a 3 trees x 3 rows block of cuttings.
Figure 3.9. A visual representation of the Cryptorynchus lapathi cutting mortality in a planting block (Unit # 23-3). Notice how the mortality in this case is aggregated. The area of the block where this mortality occurred is a rise in the central portion of this planting block. The mortality occurring in the rest of the block without the rise maintains the random pattern that is more typical of C. lapathi mortality. The cool colors (purple = 0 trees) indicate low cutting mortality and hot colors (red = 5 trees) indicating high cutting mortality. Each dot represents a 3 trees x 3 rows block of cuttings.
CHAPTER FOUR
Evaluating New Pest Control Strategies in Hybrid Poplar Cuttings

Abstract
Hybrid poplars planted in the Pacific Northwest are generally propagated using unrooted dormant cuttings. This lack of root system creates a challenge for the management of pests attacking the newly established cuttings. Preventing the defoliation of newly flushed leaves and the mortality caused by belowground herbivory are two major concerns of hybrid poplar growers. We compared the efficacy of a pre-planting soaking of cuttings in an insecticide (imidacloprid or thiamethoxam) solution to the common practice of foliar insecticide (indoxacarb or chlorantraniliprole) applications. We also evaluated the application of a polymer-insecticide to cuttings to prevent belowground herbivory by Polyphylla decemlineata (Coleoptera: Scarabaeidae). After twelve days, cuttings soaked in either imidacloprid or thiamethoxam resulted in a lower survivorship of Polydrusus impressifrons (Coleoptera: Curculionidae) than cuttings receiving a foliar application. Soaked cuttings grew significantly taller than cuttings treated with a foliar application (p < 0.0001). There was no difference in the amount of belowground herbivory suffered by control cuttings or cuttings treated with the polymer-insecticide mix. Cuttings soaked in either imidacloprid or thiamethoxam were protected from above and belowground herbivory longer than when cuttings are sprayed with indoxacarb or chlorantraniliprole. Trees that received the soaking treatment were also taller than those that did not. Soaking unrooted cuttings in insecticides bestows more protection than applying insecticides directly to the newly flushed leaves. Cutting soaks are an effective way of protecting planted hybrid poplars before their rooting structures are formed.
Introduction

There are over 22,000 ha of hybrid poplar planted in the Pacific Northwest and roughly 10,000 ha are located in GreenWood Resources’ Boardman Tree Farm in northeastern Oregon and southeastern Washington State (Stanton et al. 2002). Hybrid poplars in this area are propagated using dormant cuttings of various lengths (0.23 – 4.5 m), with smaller cuttings being planted in mid-April. As with most intensively managed monoculture, insect herbivory can negatively affect crop growth, survival and economic return (Bassman et al. 1982). The cutting’s first flush of leaves represents the most vulnerable stage of the tree’s life due to the lack of a rooting system, small leaf area, and preference for those leaves by common *Populus* herbivores (Bingaman and Hart 1992, Reichenbacker et al. 1996, Coyle et al. 2002). Defoliation at this stage poses serious risk to tree establishment and economic value of the planted stand through reduced growth and mortality (Anderson and Nelson 2002, Coyle et al. 2003, Tenczar and Krischik 2006). In those trees that survive the effects of a severe defoliation, the effect on biomass height can be seen as early as six weeks after a defoliation event (Kulman 1971, Bassman et al. 1982). Aboveground herbivory is not the only risk to these cuttings, as belowground herbivory by several pests also presents a challenge to successful stand establishment.

Dormant cuttings generally flush their leaves before the formation of roots. The lack of roots poses a unique challenge to conventional pest management strategies (Osborne 1986). Unlike rooted cuttings these hybrid poplar cuttings are unable to take up systemic pesticides that can provide protection to trees with established root structures (Lawson and Dahlsten 2003, Tenczar and Krischik 2007). Insecticidal foliage sprays (indoxacarb, chlorantraniliprole) are commonly
used in this system to control aboveground herbivores on all ages of trees. These foliage sprays can be applied in multiple ways (hooded sprayer, aerial application, or backpack spray) in an operational setting, but all have notable drawbacks. The first drawback is that the cutting’s initial leaf area is small, and new leaf growth post-application is often left untreated with contact or no systemic insecticides. Hooded and backpack spraying represent large investments in labor and time to treat a production area, while aerial applications treat large areas of non-target vegetation and bare ground with inherently poor pesticide spray coverage. The use of these insecticides also poses a challenge to the grower, whether it is a brief persistence (indoxacarb) that potentially requires multiple applications or leaf ingestion (chlorantraniliprole) over several days resulting in post-treatment damage. Concerns about belowground herbivory have recently emerged in hybrid poplar propagation and there are currently no management strategies to control pests that attack the roots and living tissue of new unrooted cuttings.

Dipping or soaking propagules (seed, cutting, transplant) is a common agriculture practice in both nursery and forestry crops as a pest control strategy (Neel 1969, Walstad et al. 1973, Osborne 1986, Watkins et al. 1996, Simms et al. 2002, Gajanana et al. 2006). This technique introduces a systemic or non-systemic pesticide to the cutting that can reduce both above- and belowground herbivory (Neel 1969, Walstad et al. 1973, Tenczar and Krischik 2006). Soaking dormant rooted cuttings in a systemic pesticide successfully reduced aboveground pest damage in chrysanthemum and peach crops (Lindquist et al. 1980, Shearer and Frecon 2002). Root and cutting dips have also shown promise in controlling belowground herbivory. Sidebottom (2004) illustrated that *Abies fraseri* (Pursh) (Pinales; Pinaceae) root dips of bifenthrin reduced root damage by both adult and larval insect pests. Root dips are commonly used on pine plantations
in the southern United States to prevent root damage by weevils (Walstad et al. 1973). Both Neel (1969) and Abrahamson et al. (1977) explored the use of several insecticides as cutting dips to control several herbivore and wood boring pests (Chrysomela scripta F. (Coleoptera: Chrysomelidae), Paranthrene dollii (Neumögen) (Lepidoptera: Sessidae) in Populus. Work done by Tenczar and Krischik (2007) suggests that soaking dormant cuttings in a solution of imidacloprid reduces the survivorship of the larval stage of a common Populus herbivore, C. scripta F. in both container and field experiments.

The poplar-feeding species Polydrusus impressifrons Gyllenhal (Coleoptera: Curculionidae) and Polyphylla decemlineata (Say) (Coleoptera: Scarabaeidae) are known to cause mortality in newly planted hybrid poplar cuttings in northeastern Oregon and southeastern Washington. P. impressifrons is a European species of leaf weevil that was introduced into the United States in the early 1900’s and was quickly recognized as a pest of fruit and shade trees (Parrot and Glasgow 1916). In 1912, Parrott and Glasgow (1916) reported that P. impressifrons caused severe defoliation and mortality in a nursery planting of willow in New York. Records indicate that this pest is capable of causing economic damage and growth reduction within a nursery or plantation setting. This pest was first recorded in Oregon in 2004 on the Boardman Tree Farm (Brown pers. comm.). Our observations indicate that this pest emerges in mid-April and begins to feed on available foliage. The peak of the P. impressifrons population corresponds with the leaf flush of newly planted hybrid poplar cuttings, jeopardizing the growth and survival of entire planting blocks.
The ten-lined June beetle, *P. decemlineata* is a common pest of many crops throughout the western North America (Young 1988, Van Steenwyk and Rough 1989). This pest has been known to attack several species of *Prunus* and can cause great economic damage and failure of infested orchards (Van Steenwyk and Rough 1989). In 2006 we observed that a *P. decemlineata* population was causing mortality in newly planted hybrid poplar cuttings on the Boardman Tree Farm. *P. decemlineata* has a two-year life cycle in which it spends a majority of its life as larvae, and adults emerging in the second year (Van Steenwyk and Rough 1989). Following a harvest of mature trees this pest breaks its winter larval dormancy and begins to feed on newly planted cuttings. Feeding activity is characterized by the striping of the cambium of the cutting, effectively girdling it and causing mortality.

Because of these common pests attack when cuttings have few roots and small leaf area, chemigation is not a viable option and foliar applications are costly, time consuming and often result in treating mostly bare ground. Our objectives for this study were to examine two types of cutting dips to reduce the above- and belowground herbivory on newly planted hybrid poplars. We compared two cutting-soak treatments (imidacloprid and thiamethoxam) with three foliar applications (indoxacarb, chlorantraniliprole and indoxacarb + chlorantraniliprole tank mix) for their effects on aboveground herbivory by *P. impressifrons*, and for effects on tree growth (height). Second, we explored whether encasing cuttings in an insecticide (clothianidin + carrier polymer) reduced belowground herbivory by *P. decemlineata* and increased cutting survival in *P. decemlineata* infested areas.

**Material and Methods**
Study Site, Experimental Organisms and Materials.

Above-ground Herbivory. This study was conducted at GreenWood Resources’ Boardman Tree Farm located near Boardman, Oregon, USA. Two 16 ha planting blocks (Unit #703-2 and #705-4) scheduled to be planted as a stool bed in 2011 were chosen based on clone, planting date, and proximity to large populations of adult *P. impressifrons*. Cuttings were planted on a 3 m x 1.14 m (row x tree) spacing with approximately 120 rows per planting block. Cuttings were treated with insecticide soaks at GreenWood Resources’ mechanical shop on the Boardman Tree Farm, while foliar applications were made by Atkinson Staffing, Inc. (Hermiston, OR) personnel under the direction of Perkins Specialty Spraying (Hermiston, OR). The imidacloprid (Admire Pro®) was provided by Bayer CropScience (Research Triangle Park, NC), thiamethoxam (Platinum®) was provided by Syngenta (Basel, Switzerland), and indoxacarb (Steward®) and chlorantraniliprole (Coragen®, [DuPont, Wilmington, DE]) were provided by GreenWood Resources. Unit #703-2 was planted with clone BC-81 (TxN [*Populus trichocarpa* x *P. nigra*]) and Unit #705-4 was planted with clone OP-367 (DxN [*P. deltoides* x *P. nigra*]), and both planting blocks were planted with dormant unrooted 0.3 m cuttings on 28 April 2011. Adult *P. impressifrons* were collected from several field sites located around Boardman Tree Farm. These sites were chosen based on the large populations of *P. impressifrons* and no pesticide applications during the study period. Feeding trials were executed on 19 May and 1 June 2011 at the Washington State University’s Entomology Integrated Pest Management laboratory located at the Boardman Tree Farm.

Belowground Herbivory. This study was conducted at GreenWood Resources’ Sandpiper Tree Farm near Patterson, Washington, USA. Two planting blocks of 6 ha (Unit #274755) and 23 ha (Unit #274756) of clone PC-4 (TxD [*P. trichocarpa* x *P. deltoides*]) were chosen based on
a preliminary survey of *P. decemlineata* caused cutting mortality in May 2008. Cutting dips were done at Washington State University’s Entomology Integrated Pest Management laboratory located at the Boardman Tree Farm. Valent (Walnut Creek, CA) provided the clothianidin (Belay®) and Bayer CropScience (Basel, Switzerland) provided the pesticide carrier polymer, CelGard®.

**Experimental Design.**

*Aboveground Herbivory.* Five treatments (imidacloprid [Admire Pro®], thiamethoxam [Platinum®], indoxacarb [Steward®], chlorantraniliprole [Coragen®], and a tank mix of indoxacarb + chlorantraniliprole [Steward® + Coragen®]) were applied to three replicates within each planting block (Table 4.1). An untreated control was initiated but the pest pressure within the experimental area threatened to cause an unacceptable crop loss to the cooperator, so all stems were eventually provided with chemical protection. We were able to sample the initial control area of the feeding trial before the chemical treatment was applied. Each treatment plot was five rows wide (12.2 m) and thirty trees long (34.3 m) resulting in a plot size of approximately 0.042 ha. A buffer area of thirty trees within the rows separated adjacent plots. The imidacloprid and thiamethoxam treatments consisted of soaking 0.3 m cuttings in an insecticide solution for 48 hrs at the label rate (0.48 g (AI) / liter). The foliar treatments of indoxacarb (0.59 L / ha), chlorantraniliprole (0.22 L / ha), and the indoxacarb + chlorantraniliprole mix were applied with a Solo® 15 L backpack sprayer until the leaves were saturated (3.78 liters solution / 150 trees). For the feeding trial, samples were taken from every other tree within the middle three rows of a treatment plot, resulting in 15 trees being sampled in each row. Leaf material for the feeding trials was removed from the cutting’s secondary stems to
prevent damage to the primary stem. Leaves with a Leaf Plastochron Index (LPI) of 0 to 3 were
selected because they tend to be more palatable to *Populus* herbivores (Erickson and Michelini
1957, Larson and Isebrands 1990, Tenczar and Krischik 2007). Leaf material was collected 6 hrs
post-foliar application (19 May 2011) and 13 days post-foliar application (1 June 2011). Feeding
trials were conducted by placing 9 to 11 adult *P. impressifrons* in a 414 ml plastic container
arena with these three terminal leaves (LPI 0-3). After 120 hrs, the number of living *P.
impressifrons* was counted. Moribund individuals that were beyond recovery were added to the
mortality count. There were 36 replicates in the 19 May trial and 40 replicates in the 1 June trial
were analyzed using a 5x2 Factorial in the statistical package jmp-10. Tree growth (height) was
recorded at one-month intervals starting on 19 June 2011 until 19 Aug 2011. Only the heights
from the final measurement are reported here since patterns were the same for each date.
Analysis of variance was used to compare mean survival rate of beetle and mean tree heights
between clones and among insecticide treatments (jmp-10).

**Belowground Herbivory.** Three treatments (1- control [water], 2- polymer [CelGard®],
3- polymer [CelGard®] and clothianidin [Belay®] mix) were applied via dipping 0.3 m cuttings
into the treatment solution for 1 minute. Treatments involving CelGard® and clothianidin were
mixed as to have a 15% polymer and insecticide solution. Earlier work indicated that cuttings
were able to root in concentrations of CelGard® up to 100% (Brown, unpublished data). The
treatments were applied 1 day prior to planting so that there would be enough time for the
applications to dry before being deployed to the field. Eighty cuttings were identified that were
attacked by *P. decemlineata* in a field survey conducted in late-May in the study area. Each
cutting was then randomly assigned a treatment (1-3) and a new, treated cutting was planted in
place of the damaged cutting on 11 July 2008. The treated cuttings were evaluated for *P. deceemlineata* damage and mortality in mid-September 2008.

**Results**

**Aboveground Herbivory.**

*Feeding Trial.* There was a significant difference in mortality between the two feeding trials (5x2 Factorial, $F_{1,361} = 188.76$, $P < 0.0001$). The feeding trial directly following insecticide applications (19 May 2011) had a higher rate of mortality than the trail 13 days following application (1 June 2011). Within the 19 May feeding trail there was a significant difference between several of the treatments ($F_{4,167} = 54.11$; $P$-value $< 0.05$; Figure 4.1). The insecticide treatments resulted in less than 15 % survivorship of adult *P. impressifrons*, and the control treatment had 60 % survivorship. There was no difference in weevil survivorship between those fed leaves with foliar applications of indoxacarb (2 % survival) and chlorantraniliprole (10 % survival), and cuttings with a thiamethoxam soak (2 % survival), but there was a difference between the imidaclorpid soak (13 % survival) and the other insecticide treatments ($P$-value $< 0.05$).

In the 1 June feeding trial weevil survival differed among and between treatments ($F_{4, 194} = 78.42$; $P$-value $< 0.0001$; Figure 4.1). Although thiamethoxam (3 % survival) caused a lower survivorship than imidaclorpid (35 % survival), both these soak treatments resulted in lower survivorship of adult *P. impressifrons* than the foliar treatments (indoxacarb = 63 %, chlorantraniliprole = 43 % survival) and control (73 % survival). In all treatments except thiamethoxam, there was greater weevil survivorship in the 1 June feeding trial than in the 19
June feeding trial. In both feeding trials, weevils fed on leaves from the imidacloprid treatment the least.

Tree Height. The OP-367 trees were taller than those of the BC-81 clone (p-value < 0.0001; Figure 4.2). Soak treatments of imidacloprid and thiamethoxam in the OP-367 clone resulted the tallest trees at the conclusion of the study. The foliar treatments were all at least 0.15 cm shorter than the soaked treatments, with the indoxacarb treatment being the shortest (Figure 4.2), regardless of clone. The imidacloprid soaked trees were the tallest for the BC-81 clone, with the other treatments being at least 0.2 m shorter.

Belowground Herbivory.

There was no difference in cutting survivorship between the three treatments. Only six of the 80 cuttings suffered mortality during this study. This mortality was a result of *P. decemlineata* feeding damage (4 cuttings) and the planting of non-viable stock (2 cuttings). There also was no difference between the presence of *P. decemlineata* damage and the treatments. The control treatment had the most feeding damage (12 cuttings), followed by the polymer (9 cuttings) and then polymer + clothianidin mix (8 cuttings).

Discussion

The results presented here further support earlier reports that unrooted *Populus* cuttings can be protected from herbivory by soaking the cuttings in a systemic insecticide (Neel 1969, Abrahamson et al. 1977, Tenczar and Krischik 2006, 2007). These cutting soaks reduced the survivorship of *P. impressifrons* in feeding trials and promoted increased tree height more than the conventional application of foliar insecticides. Our study showed that there may be potential
for stick dips to control belowground herbivory through the use of a carrier polymer combined with an insecticide.

Tenczar and Krischik (2006, 2007) showed that imidacloprid led to control of *C. scripta* in container-grown and field-planted hybrid poplar cuttings (rooted and unrooted). Our results indicate that imidacloprid also exhibits potency against *P. impressifrons*. Another systemic neonicotinoid, thiamethoxam, also controlled *P. impressifrons* better than the foliar applications of indoxacarb and chlorantraniliprole throughout the growing season. Our results indicate that soaking dormant cuttings provided a greater level of protection over time than foliar applications. Observations from both feeding trials indicate that *P. impressifrons* fed the least on leaves from imidacloprid soaked cuttings. We attributed some of the differences in weevil survival and tree height between the soaked treatments to the lack of *P. impressifrons* feeding activity on the imidacloprid leaves during the laboratory and field trials (Figures 4.1 & 4.2). Due to the lack of leaf damage in imidacloprid treatments and generally taller trees, soaking cuttings in imidacloprid may provide better overall protection than thiamethoxam.

The foliar applications used in this experiment consisted of a non-persistent (indoxacarb) and persistent (chlorantraniliprole) pesticide. In previous studies chlorantraniliprole has been shown to provide adequate protection against *C. scripta* larvae and adults for up to 30 days in two-year old *Populus* trees (Brown et al. *unpublished data*). Our results indicate that twelve days after the foliar applications, soaked cuttings had a lower weevil survivorship than cuttings treated with a foliar application. This suggests that soaking cuttings in a systemic insecticide solution allows the cutting to incorporate, store and translocate the material in a way that provides extended
protection to newly flushed leaves. Foliar applications, are applied to the leaves that are present at the time of application; hence leaves flushed after the application would not have been exposed to the insecticide. Chlorantraniliprole is known to have trans-laminar mobility and did lead to lower weevil survivorship than the non-persistent indoxacarb, but still was not as effective as the soaking treatment. This use of a cutting soak protects the foliage from aboveground herbivores until the root system can develop. At that time, a soil drench would then be applied to the planted area.

The utilization of a cutting dip to prevent belowground herbivory showed less success in this study. Currently the risk of this type of damage causing cutting mortality is less than that caused by foliage feeders. This issue tends to be localized to small areas within planting blocks when caused by *P. decemlineata*. Success in other tree taxa with the use of imidacloprid root dips in preventing root damage by larval and adult insects (Shearer and Frecon 2002, Sidebottom 2004, Oliver et al. 2009) suggests that our soaking technique may reduce this type of herbivory in hybrid poplar cuttings. Earlier research suggests that imidacloprid soaks are potentially more effective than a polymer or polymer+clothianidin dip due to the dual (foliage and root) protection provide by the cutting’s translocation of imidacloprid (Shearer and Frecon 2002, Tenczar and Krischik 2006, Oliver et al. 2009). Both thiamethoxam and imidacloprid have been shown to reduce white grub survival in agricultural settings (Grewal et al. 2001).

Imidacloprid-treated trees of clone BC-81 were taller than the other treatments. Several studies have shown that applications of imidacloprid have led to increased biomass production in cotton and hybrid poplar when grown in containers and in the field (Oosterhuis and Brown 2003,
Tenczar and Krischik 2006, Gonias et al. 2008). Oliver et al. (2009) found that imidacloprid applications to field-grown red maple significantly enhanced the growth of the treated trees. Gonias et al. (2008) suggest that this growth response was due to imidacloprid reducing the effects of physiological stress (heat) within the plant. Gonias et al. (2008) found that cotton plants treated with imidacloprid produced less antioxidant enzyme activity (glutathione reductase) at extreme temperatures (36 and 39 °C) than untreated plants. Antioxidant activity is a defensive response to a ‘threat’, and is an expensive divergence of nutrients for plants. The properties of the unique chloropyridine side chain of imidacloprid are analogous to nicotinamide and nicotinic acid, and this may reduce ‘threat’ from high temperatures and allow the plant to divert less energy to antioxidant activity (Gonias et al. 2008). This reallocation of resources can then result in enhanced plant growth. We do find it interesting that we did not see a significant difference in height in neonicotinoid treated clones OP-367 and BC-81. Tenczar and Krischik (2007) did not see the added height associated with their imidacloprid treatments either, but they did note an increased leaf area after four months. At this time it is unclear if the application of imidacloprid in hybrid poplars provides a positive effect even beyond effective control of several common *Populus* herbivores.

Insecticide soaks provide a viable alternative to conventional controls for protecting unrooted cuttings from above- and belowground herbivores, which are often ineffective and costly (Osborne 1986). Soaking reduces environmental risks and the amount of material required to achieve protection (Walstad et al. 1973, Bassman et al. 1982, Watkins et al. 1996, Gajanana et al. 2006). Despite the ease of soaking cuttings, this technique may pose operational difficulties when utilized at a production scale. Production scale planting of hybrid poplar stool beds and
production stands can involve over 500,000 cuttings/yr. Some clones (e.g. BC-81) have large buds that protrude away from the stem, making them susceptible to breaking off when manipulated during the soaking procedure, while others (OP-367) have small buds flush with the stem, and are more amenable to handling. Although we used a 48-hour soak in this experiment, studies of several plant taxa suggest the duration of the soak/dip is less important than the concentration of the insecticide solution (Osborne 1986, Oliver et al. 2009). This may be a result of the insecticides coating the cutting as opposed to being incorporated into the cambium and translocated, but trials to determine the minimum soaking time required for control are merited.

In conclusion, cuttings that had been soaked in imidacloprid or thiamethoxam caused reduced survivorship of feeding herbivores and increased growth (for clone OP-367) throughout the growing season. Further, based on work in both hybrid poplars and other tree crops these two products may be able to protect cuttings from belowground damage from *P. decemlineata* and other root feeders (Walstad et al. 1973, Shearer and Frecon 2002, Sidebottom 2004, Oliver et al. 2009). By using a pre-planting soaking treatment, growers of hybrid poplars can protect their crop without using expensive and environmentally unfriendly broadcast sprays, followed with systemic insecticides applied via chemigation once roots have formed.

**Acknowledgements**

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References


Tenczar, E. G. and V. A. Krischik. 2007. Comparison of standard (granular and drench) and novel (tablet, stick soak, and root dip) imidacloprid treatments for cottonwood leaf beetle (Coleoptera: Chrysomelidae) management on hybrid poplar. J. Econ. Entomol. 100: 1611-1621.


Table 4.1. Treatments and rates of chemical applied to the above- and belowground herbivory experiment. Soak treatments were applied on 26 April 2011 and foliar applications were made on 19 May 2011.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Product</th>
<th>AI (%)</th>
<th>Application Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soak</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Imidacloprid</em></td>
<td>Admire Pro</td>
<td>42.8</td>
<td>0.48 g (AI)/L</td>
</tr>
<tr>
<td><em>Thiamethoxam</em></td>
<td>Platinum</td>
<td>75</td>
<td>0.48 g (AI)/L</td>
</tr>
<tr>
<td>Topical Spray</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Indoxacarb</em></td>
<td>Steward</td>
<td>15.84</td>
<td>8 oz (AI)/acre</td>
</tr>
<tr>
<td><em>Chlorantraniliprole</em></td>
<td>Coragen</td>
<td>18.4</td>
<td>3 oz (AI)/acre</td>
</tr>
<tr>
<td><em>Indoxacarb + Chlorantraniliprole</em></td>
<td>Steward + Coragen</td>
<td></td>
<td>8 oz (AI)/acre + 3 oz (AI)/acre</td>
</tr>
</tbody>
</table>
Figure 4.1. *Polydrusus impressifrons* individuals were exposed to five cutting treatments in a 120 hr no-choice feeding trial of clone OP-367. Significantly more weevils perished in the 19 May 2011 feeding trials than in the 1 June 2011 trials (5x2 Factorial, $F_{1,361} = 188.76; P < 0.0001$). Thiamethoxam, Chlorantraniliprole, and Indoxacarb had a significantly greater mortality rate than either Imidacloprid or the control in the 19 May 2011 trial (ANOVA, $F_{4,167} = 54.11; P < 0.0001$), while Thiamethoxam and Imidacloprid treatments in the 1 June 2011 trial also had significantly greater mortality than the other treatments (ANOVA, $F_{4,194} = 78.42; P < 0.0001$). Means were compared via Fisher’s PLSD at $\alpha = 0.05$. Treatments and the number of replicates (#) are as follows: 19 May – Imidacloprid (36), Thiamethoxam (36), Indoxacarb (32), Chlorantraniliprole (32), and Control (36); 1 June – Imidacloprid (40), Thiamethoxam (42), Indoxacarb (38), Chlorantraniliprole (39), and Control (40). Bars indicate one standard error from the mean.
Figure 4.2. Tree growth (height) of the two study clones, BC-81 and OP-367 versus treatment.

Data from 19 August 2011 were analyzed with an ANOVA (BC-81: \( F = 22.65; \text{df} = 4, 662; P < 0.0001 \); and OP-367: \( F = 21.13; \text{df} = 4, 681; P < 0.0001 \)). Means were compared via Fisher’s PLSD at \( \alpha = 0.05 \). Columns marked with different letters represent statistically different groups. Each tree was measured from the base flush with the ground to the start of the terminal bud using a 3 m cloth measuring tape.
CHAPTER FIVE

Mass Trapping of *Prionoxystus robiniae* in Hybrid Poplars

Abstract

Larval galleries of wood boring insects and the associated bacteria staining of the wood surrounding their galleries significantly reduce the potential value of a hybrid poplar tree. *Prionoxystus robiniae* (Peck) (*Lepidoptera*: Cossidae) is a native pest that attacks several hardwood species, such as *Populus* sp., throughout the United States. This pest poses a direct threat to hybrid poplar plantations in northeastern Oregon and other parts of the Pacific Northwest. Since the majority of this species’ development takes place within the non-living heartwood of the tree, the pest is not very susceptible to insecticide applications. Fortunately, the natural history of *P. robiniae* (ie: brief peak flight period, multi-year development, etc.), suggests that it may be a good candidate for a mating disruption strategy. But the high cost of synthesizing *P. robiniae* sex pheromone prohibits poplar growers from applying a microencapsulated formulation. A trap out strategy is a compilation of techniques (mass trapping, attract-and-kill, and mating disruption) that does not require the same amount of fiscal commitment as an aerially strategy. This strategy was successfully deployed in two planting fields on GreenWood Resources’ Boardman Tree Farm in northeastern Oregon in 2008 and 2009. During the two years of treatment, a trap-out effort significantly reduced populations of *P. robiniae* in both the treated fields and in untreated adjacent fields. Furthermore, populations of this pest were suppressed for at least three years after application in treated fields, although in the untreated fields populations did not remain suppressed. Based on these findings a trap out strategy was conducted in localized areas of known populations of *P. robiniae* populations. Results of these trials have prompted the recommendation that Pacific Northwest hybrid poplar
growers incorporate this strategy for *P. robiniae* control into their Integrated Pest Management programs. In addition this strategy employs the use of bucket traps, which allows one to quantify the number of moths killed. The bucket traps also reduce the potential for negative environmental impacts through confining the killing agent to the trap rather than having it aerial broadcasted.

**Introduction**

Wood boring insects pose the greatest threat to defect-free lumber, which is the highest value product that is produced on a hybrid poplar plantation. Hybrid poplar growers in the Pacific Northwest face many challenges to wood quality throughout the 8-15 year rotation. Wood boring insects not only threaten tree vitality, these insects can significantly reduce quality and value of the crop. Holes and bacterial staining associated with larval galleries directly effect what end product the grower can provide the buyer. Trees known to contain galleries or discolored wood are immediately downgraded to ‘character-wood,’ pulp, or biomass feedstock (Brown et al. 2006, Hannon et al. 2008). The resulting loss of value from this lower board grade is economically significant to the grower. If damaged wood is downgraded to pulp, discoloration further reduces the value due to the additional bleaching required to provide the white feedstock. Since 2001, several wood boring insects have been identified within the poplar plantations of eastern Oregon and Washington. The most common of these pests are the poplar-and-willow borer, *Cryptorhynchus lapathi* (L.) (Coleoptera: Curculionidae), the western poplar clearwing moth, *Paranthrene robiniae* (Hy. Edwards) (Lepidoptera: Sessidae), and the carpenterworm moth, *Prionoxystus robiniae* (Peck) (Lepidoptera: Cossidae) (Brown et al. 2006, Hannon 2006,
Kitelson 2006). *Prionoxystus robiniae* galleries are noticeably larger than those of the other two species and often result in the lodging of older trees or even a rejection of logs at the mill.

The biology of *P. robiniae* has been studied extensively in the Southeast and in the Pacific Northwest (Hay, 1968; Leppla et al., 1979; Solomon 1973, Solomon 1988; Solomon and Hay, 1974; Solomon and Neel, 1972; Hannon, 2006). *P. robiniae* typically completes its development in 1-3 years in northern hybrid poplar systems (Hannon, 2006). Doolittle et al. (1976) first described the sex attractant in the female sex pheromone of *P. robiniae* as (Z,E)-3,5-tetradecadienyl acetate. Later, Doolittle and Solomon (1986) would further examine this chemical and determined it to be a suitable, powerful attractant for male *P. robiniae*. The natural history, population dynamics, and distribution of this pest within the Pacific Northwest poplar plantations suggest that this pest may be managed by using a mating disruption strategy, similar to the industry’s management strategy for *Paranthrene robiniae* (Hannon 2006, Kittelson 2006). Even though this pest has a relatively short peak flight period (3 weeks) (Hannon 2006), the cost of producing this pheromone is quite high. For example, Washington State University contracted Dr. Mike Chong, University of Waterloo, Canada, to produce 100 g of *P. robiniae* sex pheromone for $ 6,000 (John Brown pers. comm.). At an annual use rate of 2.47 g per hectare, this amount formulated in microcapsules for aerial application would only be enough to protect 40 hectares for one season. The cost of producing a kilogram of this material would be roughly $ 60,000, while the cost of producing the *Paranthrene robiniae* pheromone is approximately $ 2,200/kg (Suterra Corporation, Bend, Oregon). Recognizing that the development of a microencapsulated formulation of (Z,E)-3,5-tetradecadienyl acetate may be cost prohibitive for poplar growers, a different management strategy must be employed.
Another option for pheromone control of *P. robiniae* populations in this system would be an attract-and-kill approach. This technique utilizes an attractant integrated with a chemical killing agent (Thacker 2002, Carde 2007, Pedigo and Rice 2009). These baits incorporate a fast acting killing agent, such as pyrethroids, to provide rapid knockdown and prevention of further crop injury. But, the Forest Stewardship Council (FSC) certification prohibits the use of broad spectrum, persistent, and highly toxic pesticides, including pyrethroids (FSC 2007). Both Hannon (2006) and Brown (*unpublished*) explored the potential for attract-and-kill for *P. robiniae* in hybrid poplars. Hannon (2006) utilized pheromone-impregnated grease droplets laced with a killing agent placed directly on the tree bole, but this approach was determined to be relatively ineffective. Dr. Pete Landolt of the USDA suggests that the use of multiple droplets (‘release points’) may be acting as a mating disruption technique by inundating the target area with sex pheromone and preventing the male moths from locating calling females (Brown 2008).

Brown (2008) re-examined the concept of attract-and-kill with a novel proprietary device denoted as a ‘MA&KD’ (Modified-Attract-and-Kill-Device) (Figure 5.1). This dispenser featured an FSC-approved neonicotinoid insecticide (acetamiprid) known to be effective against adult moths (Brunner *et al.* 2005) incorporated into food-grade grease (DuPont, Wilmington DE) and placed on the inside edge of the MA&KD. This allowed male males to contact the insecticide when they entered the MA&KD to investigate the pheromone source. Test results suggested that acetamiprid was effective against adult *P. robiniae*, but the deployed device was not as effective as universal bucket traps deployed at a similar density.
Work by Brown et al. \textit{(unpublished 2005-2010)} investigated the use of a localized trapping effort, or ‘trap out’ in the hybrid poplar system. This ‘trap out’ technique combines three common uses of pheromone: mass trapping, mating disruption, and attract-and-kill. A trap out strategy lowers the pest’s population below the economic injury level (\textit{mass trapping}) by saturating a defined area with bucket traps baited with female sex pheromone (\textit{mating disruption}) to remove males from the breeding population (\textit{attract-and-kill}) (Ridgeway \textit{et al.} 1990, Thacker 2002, Carde 2007, Baker 2009, Pedigo and Rice 2009).

A similar strategy has also been used with documented success in several tree-cropping systems in Europe to control other Cossidae pests. A European hardwood pest, \textit{Cossus cossus} (L.) (Lepidoptera: Cossidae), was successfully controlled in apple plantations by deploying pheromone-baited traps at a density of ~10 traps per hectare (Faccioli \textit{et al.} 1993). Hefazi \textit{et al.} (2009) placed pheromone-baited, solar powered UV light traps with a sticky surface in Mediterranean olive orchards to capture male and female leopard moths, \textit{Zeuzera pyrina} (L.) (Lepidoptera: Cossidae). This trap out-style effort resulted in a 90\% decrease in active larval galleries (Hegazi \textit{et al.} 2009). Further, areas that received this trapping effort also saw a significant increase in olive fruit production (Hegazi \textit{et al.} 2009). Based on the success of these studies and previous work by Brown \textit{et al.} \textit{(unpublished 2005-2010)} and Hannon (2006), this strategy should be viable within the hybrid poplar system.

Research by Hannon (2006) explored the optimal trap density required to reduce \textit{P. robiniae} numbers in areas with elevated populations. It was determined that five traps per hectare would effectively manage \textit{P. robiniae}, and ultimately reduce the numbers of this pest in the treated area.
Hannon (2006) also concluded that universal bucket traps were more effective at capturing *P. robiniae* than delta-wing type traps, and they also required less maintenance throughout the pest’s flight period. Work by Brown et al. (*unpublished 2005-2010*) investigated an apparent preference of *P. robiniae* for a specific style of bucket trap but determined that there was no significant difference among trap types in capture rate of *P. robiniae*.

The objective of this study was to determine if a two-year trap out control strategy would be an effective tool to control *P. robiniae* in areas deemed to be at-risk or with large endemic populations. These areas were deemed high risk through the use of a monitoring program in place since 2002. Here we present the results from two investigations: 1) Does a trap out effort reduce the population of the target pest (*P. robiniae*) within the treated area? & 2) Are pest populations reduced at a landscape scale where a trap out has been implemented?

**Methods**

**Location.** Boardman Tree Farm is a 10,000 ha hybrid poplar plantation in the Columbia River Basin of eastern Oregon. Two mature stands of ~100 ha in the northern portion of the plantation adjacent to I-84 were chosen to receive the trap out treatment to investigate if a trap out effort would reduce *P. robiniae* in the treated areas. These fields were chosen based on above average historical trap captures of moths. Concurrently, a second investigation was undertaken to examine how this trap out effort affected the populations of *P. robiniae* within the local landscape. This was accomplished by tracking *P. robiniae* populations in the stands adjacent to the treated areas with centrally located monitoring traps.
**Pheromone-baited Bucket Traps.** Universal bucket traps [Suterra Corporation, Bend OR] were deployed at a density of five traps per hectare along the perimeter of each field. As both fields were bisected by access roads, traps were also placed along those internal borders too. Traps were stapled or tied to every fourth tree along each edge, with traps along the interior roads alternated from one side to the other. Each trap was positioned approximately 2m above the ground. Dr. Mike Chong, University of Waterloo, Canada, synthesized *Prionoxystus robiniae* sex pheromone. The synthesized (Z,E)-3,5-tetradecadienyl acetate was then loaded onto red 1F sleeve stoppers (1535 Red PEP I, Item #10600258, West Pharmaceuticals, Inc. Jersey Shore, PA) at a 1 mg/septum at Washington State University. Stoppers were rinsed in methylene chloride (Fisher Scientific, Pittsburgh PA.), dried, and the pheromone was delivered to each septum in hexane (Fisher Scientific, Pittsburgh PA.), 10µl/1mg. Once loaded, stoppers were grouped in lots of 100 and inundated with nitrogen and kept frozen at -47 °F until their deployment. Pheromone baits were placed in the traps the day of trap placement. Each trap also contained a three-millimeter section of a dichlorvos kill strip [Hot Shot® No-Pest Strip [United Industries Corporation, St. Louis, MO]) at the bottom of each bucket.

Traps were deployed in treated fields by mid-May 2008 and 2009. Traps were checked and emptied once in early-July, at which time the pheromone bait was replaced and the number of moths captured in each trap was recorded. Missing or fallen traps were replaced during this sampling period. In mid-August a final capture count was made and all traps were removed. We used 543 traps in Field #15 and 435 traps in Field #22. Throughout the experiment monitoring traps were placed at the center of each field to provide a measure of the moth population within each field. These monitoring traps were checked on a weekly basis throughout the experiment.
Captures from the centralized monitoring traps in the treated and adjacent untreated fields were recorded continuously from 2002-2012.

**Results**

Prior to conducting this experiment moth captures in all four fields were similar (Figure 5.2). The trap out treatment in 2008 and 2009 resulted in decreased male *P. robiniae* captures in monitoring traps positioned in the middle of both treated and untreated blocks (adjacent fields) (Figure 5.2). Although this trap out effort resulted in fewer moths being captured by the central monitoring trap in all fields, this parity ended abruptly the year after the trap out treatment concluded. The monitoring trap in the treated fields caught significantly fewer *P. robiniae* in three years (2010-2012) following the trap out treatment than those monitoring traps in the adjacent fields (paired *t* test: *t* = -3.45, df = 11, *P* = 0.0055). The experiment was terminated in 2013 because the treated blocks were harvested.

**Discussion**

manage with mating disruption. But, a high cost of synthesis paired with relatively low demand for this sex pheromone inhibits the technique from being adopted. Thus alternative management strategies need to be explored. Recognizing that mating disruption would not be a viable control measure, two alternative strategies (attract-and-kill & trap out) were evaluated by Hannon (2006) and Brown (unpublished). These studies suggested that a multi-year trap out effort might afford the greatest measure of control. A multi-year effort was needed in order to exert continuous pressure on a generation of *P. robiniae* in a localized area. Because of the 1-3 year life cycle of this pest in the Pacific Northwest, the only way to ensure the removal of the males from a generation (and potentially other generations as well) is to continue the effort at least 2 years.

Implementation of a two-year trap out technique has shown to successfully reduce *P. robiniae* populations in treated areas and may be a viable option in controlling this pest. This trap out effort significantly reduced monitoring trap captures in treated fields for three subsequent years when compared to similar traps in untreated adjacent fields. A secondary effect from the trap out application is that untreated adjacent fields also experienced a decline in trap captures during the trap out effort (Figure 3.1). Based on the small number of moths captured in three subsequent years in treated fields, we can surmise that the populations of *P. robiniae* were sufficiently reduced and posed a minimal threat to the trees in those planting blocks for several years.

We need to be measured in our belief that this strategy is the ultimate control for this pest. This strategy is straightforward, easy to implement and seemingly cheap to employ. But, this strategy tends to demand a substantial investment in infrastructure and labor. First, a grower must
purchase bucket traps in a quantity to ensure a deployment of five traps per hectare. Once obtained, traps must be assembled and loaded with both sex pheromone and killing agent. Traps are then transported to the location where they are to be installed. Installation at a minimum will require each trap to be hung from a previous year’s sylleptic branches. But, more likely traps will need to be attached to the tree bole with twine, bungee cord, staples, or any other device that will not downgrade the quality of the tree. Pheromone lures should be replaced with new lures midway (after approximately 30 days) through the trap out effort. Ideally growers would also take this opportunity to record how many moths they have caught as an added measure of control. These counts can be delayed until the end of the season when the traps are retrieved, but our experience in this system indicates that moths degrade and prevent an accurate count of captured individuals. The conclusion of the trap out effort provides another opportunity for the grower to record the number of moths captured. The final requirement of this effort is to collect the traps, wash, and then store them during the off-season. Approximately 215 (Table 5.1) man-hours are required to conduct a trap out effort targeting 200 hectares, and when combined with the initial cost of universal bucket traps, pheromone lures, and a killing agent (Table 5.2), a trap out of this magnitude would cost $125.22 per hectare the first year, and $74.10 each year thereafter. This cost is equivalent of two aerial applications of FSC-approved insecticide to control folivores in similar aged stands. But, the average cost of this technique over a three-year treatment period is over four times greater than the mating disruption strategy employed to manage Paranthrene robiniae on the Boardman Tree Farm. Such a large discrepancy in price of control can be directly attributed to the higher production costs of P. robiniae pheromone.
Pest managers must realize the limitations of integrating this technique broadly across the 16,000 ha. A trap out effort is most likely to be successful when it is employed to protect small, to moderately sized cropping areas known to harbor an existing high population of the pest. Implementing a monitoring program prior to the use of this strategy would allow growers to identify areas of high risk and sizable populations of this pest. It is imperative when implementing this technique that it continue for a minimum of two year to remove as many males from each generation as possible. Not utilizing this technique for the proper period will result in the failure to remove enough individuals of a given generation to provide extended control of *P. robiniae*.

This trap out technique significantly reduced *P. robiniae* populations in hybrid poplar plantations for at least three years following application. In addition, nearby untreated fields also had reduced populations of this pest during the application period. But, this technique did not successfully control populations in the adjacent untreated areas once treatments ended. Trap out efforts are a good alternative pheromone control measure when mating disruption strategies are not a viable option. Finally, trap outs could be utilized in areas where there is potential for pesticide drift into residential areas or concerned stakeholders. This strategy allows for control in localized areas without requiring the use of mechanized chemical applications that could induce a negative response from stakeholders and the general public.
REFERENCES


**Table 5.1.** Man hours required for a trap out effort targeting 200 ha.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Estimated Man Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assemble Traps</td>
<td>15</td>
</tr>
<tr>
<td>Deploying Traps</td>
<td>66</td>
</tr>
<tr>
<td>Replace Pheromone Lure</td>
<td>30</td>
</tr>
<tr>
<td>Collection of Traps</td>
<td>44</td>
</tr>
<tr>
<td>Disassemble &amp; Cleaning Traps</td>
<td>60</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>215</strong></td>
</tr>
</tbody>
</table>

**Table 5.2.** Quantity and cost of materials required for a trap out effort targeting 200 ha.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Quantity</th>
<th>Cost ($) / Unit</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Universal Bucket Trap</td>
<td>1,000</td>
<td>10</td>
<td>10,000</td>
</tr>
<tr>
<td><em>P. robiniae</em> Pheromone Lure</td>
<td>2,000</td>
<td>6</td>
<td>12,000</td>
</tr>
<tr>
<td>Hot Shot Kill Strip</td>
<td>34</td>
<td>7</td>
<td>221</td>
</tr>
<tr>
<td><strong>Total Cost ($)</strong></td>
<td></td>
<td></td>
<td><strong>22,221</strong></td>
</tr>
</tbody>
</table>
Figure 5.1. Diagram of Modified Attract and Kill Device constructed from PCV pipe and a scintillation vial. The inside of each opening was coated with a food grade grease mixed with 4% acetamiprid and a red rubber pheromone lure was placed in the scintillation vial.
Figure 5.2. Annual number of *Prionoxystus robiniae* captured in a centrally located monitoring trap in trap out treated fields and the untreated, adjacent fields. The trap out treatment was applied to Fields #15 and #22 in 2008 and 2009. Field #15 was directly north of Field #16, and Field #22 was directly north of Field #23. Significantly fewer moths were captured in fields that were treated with a trap out (paired *t* test: *t* = -3.45, df = 11, *P* = 0.0055).