Cone and Seed Insects of Southwestern White Pine, *Pinus strobiformis*, in Arizona, New Mexico, and Texas

BY

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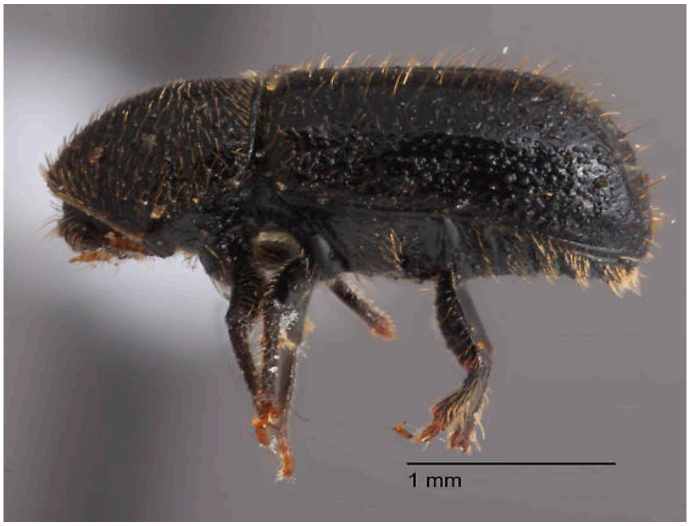

Lateral image of Conophthorus ponderosae collected from a Pinus strobiformis cone. (Photo Credit: Derek Uhey)

CONE AND SEED INSECTS OF SOUTHWESTERN WHITE PINE, *PINUS STROBIFORMIS*, IN ARIZONA, NEW MEXICO, AND TEXAS

ABSTRACT

Southwestern white pine (*Pinus strobiformis*) is one of the least studied five-needled pines in the United States and is currently threatened by both a potentially lethal invasive pathogen spreading across the Southwest and climate change. Cone and seed insects of *P. strobiformis*, along with their associated impacts, are unknown. We conducted a study to identify the cone and seed insects of *P. strobiformis* and quantify their damage, which can negatively impact annual seed production and future regeneration of *P. strobiformis*. We collected mature cones during the early fall of 2012-2015 from across Arizona, New Mexico, and the Guadalupe Mountains of Texas. Then we individually caged each cone for seven months to rear and collect emerging insects. Additionally, in the summer of 2014 we implemented methods which captured insects in situ. These methods included caging developing cones on individual trees, funnel traps supplemented with a pheromone and a volatile, and the use of Tanglefoot® adhesive at selected field sites. We collected more than 2000 insects from 70 different sites.

Pest infestation rates on individual trees varied between sites, as did insect composition. The *P. strobiformis* seed and cone insect guild included the orders of Lepidoptera, Hemipteran, and Coleoptera. To ensure a steady seed supply to serve as the basis for *P. strobiformis* conservation in the decades to come, resource managers will need to monitor and possibly manage these insects.

Introduction

The objective of this project was to identify and describe the seed and cone insect guild of *Pinus strobiformis* (southwestern white pine) and to quantify infestation rates observed across the Southwestern landscape. We identified which insects have the highest level of incidence and some possible methods for monitoring, managing, and controlling seed loss from seed and cone insects. The insects which comprise the guild have previously been identified, but none of them were specifically associated with *P. strobiformis*.

This paper begins with background information on the host, *P. strobiformis*, followed by an introduction to seed and cone insect guilds and generalized management. Next, each species that was collected and identified as a *P. strobiformis* seed and cone insect guild member is covered in detail, including their life history, behavior, geographic range, and management concerns. Finally, the paper will conclude with highlights from the findings of this study and future research needs.

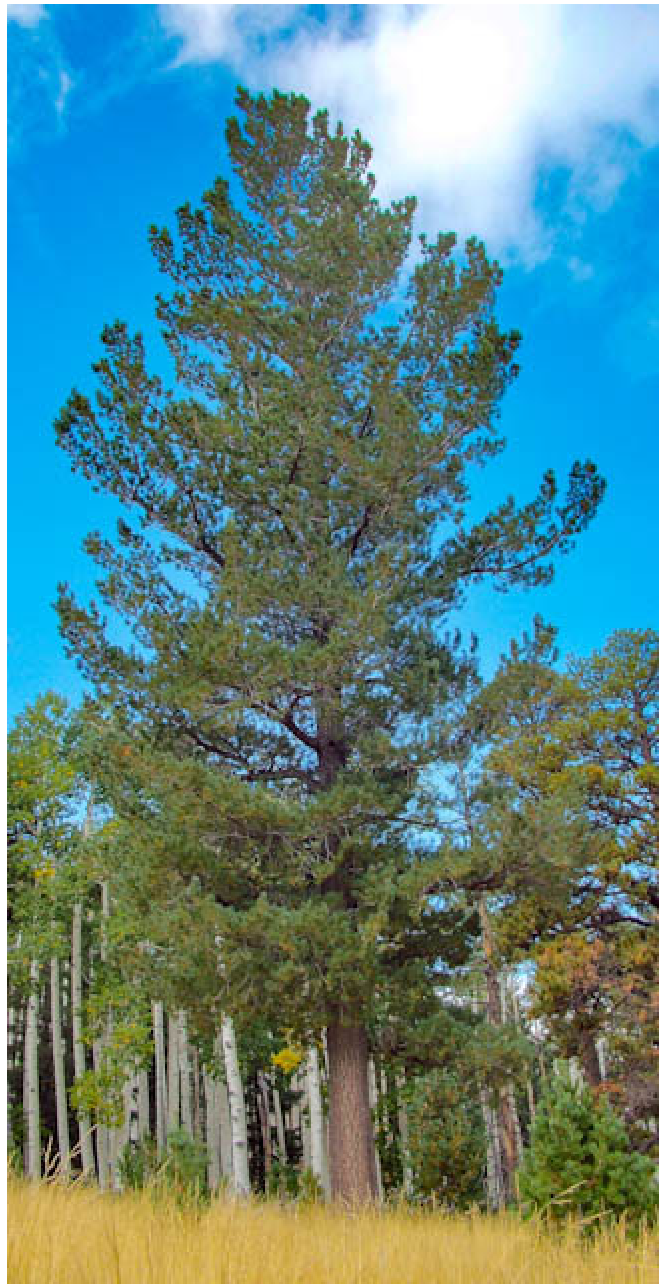

Figure 1. Southwestern white pine, P. strobiformis on San Francisco Peaks north of Flagstaff, AZ.

P. strobiformis, is a five-needled pine that can be found throughout mixed conifer forests of the American Southwest and Sierra Occidental Mountains of Mexico (Figure 1). In the United States, it can typically be found at elevations from 7,000 to 10,000 feet above sea level. *Pinus strobiformis* is an ecologically important species providing a variety of ecosystem services such as forest biodiversity, resiliency, and serves a major source of sustenance for wildlife with its relatively large, nutrient rich seeds. It is rare to find a pure stand of *P. strobiformis* (Looney and Waring, 2012). Individual, or groups of *P. strobiformis* are more commonly found co-occurring with other species. It plays a critical role in early seral stages of forest succession and is a vital component of mixed conifer forest types (Looney and Waring, 2013).

The higher elevation forests of the southwestern United States (7500 ft. to 8500 ft. above sea level) are dominated by ponderosa pine (*P. ponderosa)* and as elevation increases (>8500 ft. above sea level) the forest transitions first to a mix conifer and then to a spruce-fir forest type. Integrated with the *P. ponderosa* forests, and within the lower thresholds of the spruce-fir forests, are stands of mixed conifer forest types (Reynolds et al., 2013). In Arizona and New Mexico, populations of *P. strobiformis* are found intermixed throughout many mixed conifer forest stands (Looney and Waring, 2012). In addition to *P. ponderosa*, other tree species which comprise the mixed conifer forest type are Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), limber pine (*Pinus flexilis*), Gambel oak (*Quercus gambelii*), aspen (*Populus tremuloides*), Englemann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa* var. *lasiocarpa*), corkbark fir (*Abies lasiocarpa* var. *arizonica*), and the occasional blue spruce (*Picea pungens*) (Reynolds et al., 2013; Jones, 1971).

Populations of *P. strobiformis* are extensive across the region, but are geographically isolated from each other with lower elevation and relatively dry valleys separating the disjoint populations. The total number of *P. strobiformis* across New Mexico and Arizona is estimated to be 75 million (Conklin et al., 2009).

Pinus strobiformis is susceptible to the invasive pathogen, white pine blister rust(Kinloch and Dupper, 2002). The disease is caused by a macro-cyclic fungus, *Cronartium ribicola*, which typically alternates between *Ribes* spp. and white pine species as its host (Geils et al., 2010). The fungus, which is native to Asia, was introduced from European nursery stock in the early 1900's on both the eastern and western coasts of the United States (Mielke, 1943). The disease then started to spread across the landscape. The canker-causing disease is lethal to white pines, although some trees appear to be more resistant to the disease, and has spread throughout much of the white pine's native range in America and Canada (Hawksworth, 1990). To date, 39 U.S. states have confirmed the presence of white pine blister rust (Burns et al., 2008). Only one of the seven white pine species has not been infected yet, the Great Basin bristlecone pine (*Pinus longaeva*) (Geils et al., 2010).

White pine blister rust was first reported to be in New Mexico in 1990, although it is believed that the disease had been present and undetected since the 1970's (Conklin et al., 2009). Since its detection, the disease has intensified and successfully established itself throughout most of New Mexico and into the White Mountains of eastern Arizona and continues to move westward (Figure 2; Looney et al., 2015). It is hypothesized that many forests will eventually be infected with the invasive disease, depending on climatic conditions (Frank et al., 2008).

Natural resource professionals and researchers have begun the initial steps of managing for the pending loss of *P. strobiformis* across the Southwest. Methodically testing the genetics of trees for resistance to white pine blister rust and identifying beneficial genotypes will allow land managers to select resistant seed stock (Schoettle et al., 2014). Once the resistant trees are identified, the management and protection of the resistant tree's seed will be a critical step in the overall process. The establishment, development, and management of seed supply locations which contain the beneficial genotypes will assist in expediting the restoration process. Seed and cone pests have a direct impact on seed crop yields.

We collected insects over four years (2012-2015; Figure 3), identified insects to family and/or species when possible, and analyzed incidence patterns of the guild members. From the collection, we identified which insects were 'overflow' *P. ponderosa* seed and cone insects and which insects damage *P. strobiformis* seeds on a regular basis. Some insects, such as *Leptoglossus occidentalis* and the moth *Dioryctria abietivorella* are polyphagous seed and cone consumers (Hedlin et al., 1981), but others, such as the cone beetle *C. flexilis*, are more dependent on *P. strobiformis* for survival (Kinzer and Reeves, 1970). A few of the insects from our collection were previously associated with limber pine (*Pinus flexilis*), a close relative of *P. strobiformis* (Hedlin et al., 1981). The two pines are believed to hybridize with each other across common elevation gradients. Most literature regarding seed and cone insects pertaining to the Southwest was developed prior to 1970 with the bulk of the data collected from 1915 to 1958, which largely overlooked *P. strobiformis*. With the knowledge of the possible seed damaging causal agents, resource managers can make more informed decisions regarding management of particular stands and address seed development issues.

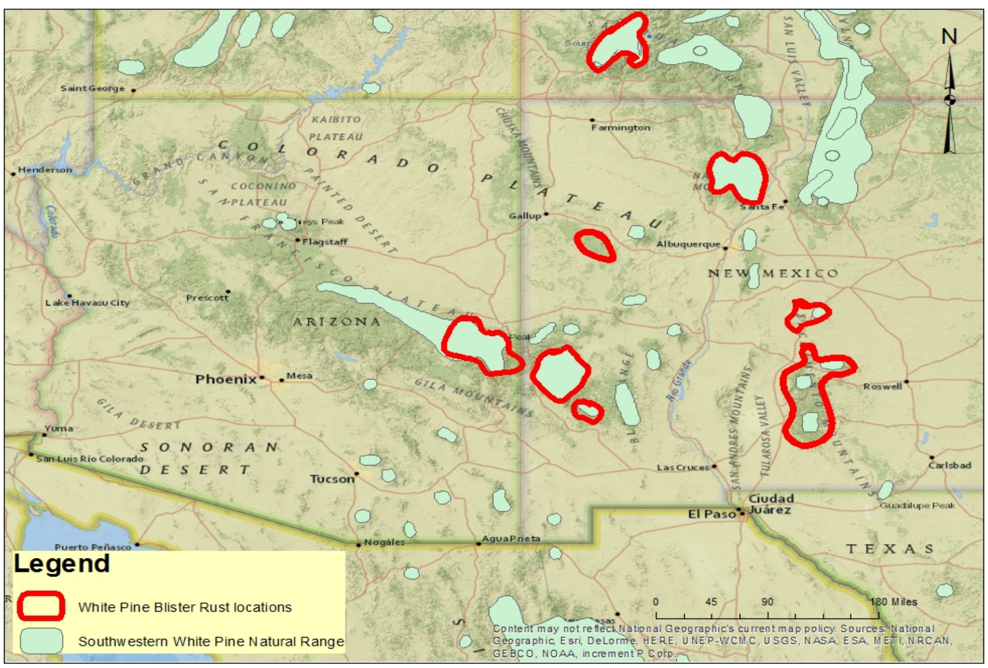

Figure 2. A map of current locations with white pine blister rust across Arizona and New Mexico (Region 3). Pinus strobiformis distribution layer from United States Geological Survey (2006) based on Little (1971). White pine blister rust locations from Forest Health and Protection, United States Department of Agriculture and evaluation monitoring plots, Northern Arizona University, School of Forestry (Looney et al., 2015; Goodrich, 2015).

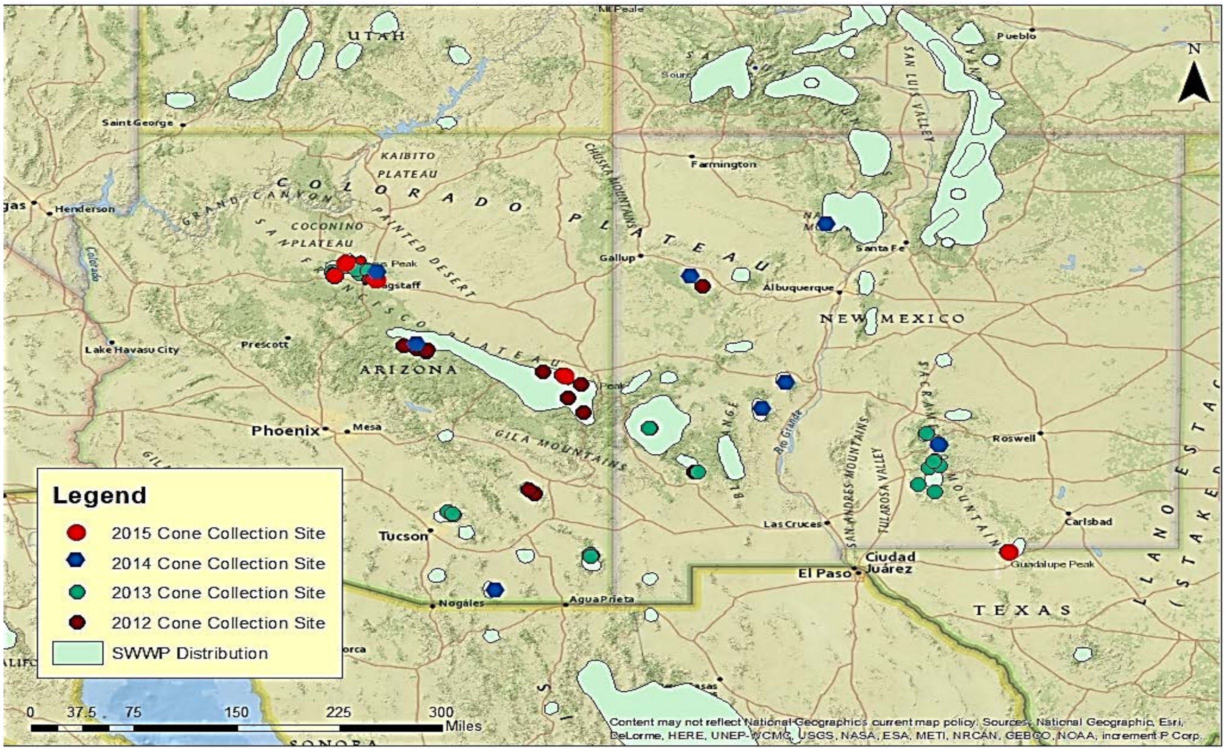

Figure 3. A map of the P. strobiformis range across the Southwest and the locations of cone collection sites used in the study. Pinus strobiformis distribution layer from United States Geological Survey (2006) based on Little (1971).

Pinus strobiformis reproduction biology

When a *P. strobiformis* tree is approximately 15 years of age it becomes reproductively mature (Jones, 1967; Krugman, 1974). *Pinus strobiformis* reproduces sexually and produces flowers in June (Pavek, 1993). *P. strobiformis* has what is known as mast seeding, or periodicity, when a species will produce high numbers of cones and is synchronized with other plants of the same species for the given region.

Figure 4. An example of P. strobiformis cone development. Starting with the first year cone on the right (~4 cm), second year cone in the middle, and third year cone (empty) on the left. The third year cone will have opened and dispersed its seed in year 2.

Cones begin to develop in July and continue developing over the next two years. In late August or early September of the second year, the cones and seeds are mature and seeds are dispersed with warmer sites and southerly aspects typically maturing first

Figure 5. Mature cones of P. strobiformis can be green or a dark purple.

(Krugman, 1974; Pavek, 1993). The mature cones can range in size from 7-25 cm in length (Pavek, 1993; Figure 4). While cones are fully mature in two years, *P. strobiformis* may not drop all mature cones in the second year, resulting in a tree retaining up to three years of cones in the crown. Figure 4 illustrates the differences between the smallest cone produced in the first year to the second year cone in which the seed becomes fully mature, and the oldest brown cone which has already dispersed its seeds. Cones can be green or a dark purple and typically exude large amounts of resin (Figure 5). Seed dispersal lasts approximately four weeks for any given tree (Pavek, 1993). The seeds require a cold stratification period of two to four weeks prior to germination (Krugman, 1974; Write, 1965). Germination rates vary between 52% and 95% (Krugman, 1974). The seeds can germinate in the spring or during the monsoon season (July-August) (Jones, 1971).

Seed and cone insect guild

There are six orders of insects which damage seeds and cones of conifers: Coleoptera, Lepidoptera, Diptera, Hemiptera, Hymenoptera, and Thysanoptera (Hedlin et al., 1981). Of those six, the Lepidoptera are typically the most observed pests and are historically known as one of the most damaging (Hedlin et al., 1981).

In the southwestern United States, ponderosa pine is a major timber species and thus, much of the previous research has focused on the seed and cone insects of *P. ponderosa*. Some of the major members of the *P. ponderosa* seed and cone insect guild are the Lepidopteran *Dioryctria auranticella, Cydia piperana, Eucosma ponderosa*, the Coleopterans *Conophthorus ponderosae, Conotrachelus neomexicana* and the Hymenopteran *Megastigmus albifron*s (Blake et al., 1985). Generalists such as the Hemipteran *Leptoglossus occidentalis* can also be found consuming the seeds of *P. ponderosa. Pinus ponderosa* grows in pure stands and is also a major component of mixed conifer stands across the Southwest, making it a dominant presence in the landscape (Reynolds et al., 2013). Occasionally, insects from the *P. ponderosa* seed and cone guild can be found on *P. strobiformis* probably due to a 'spillover' effect from neighboring *P. ponderosa.* During the course of this project, occasionally species, such as the *Eucosma ponderosa*, were captured and reared from *P. strobiformis* cones, but the frequency and abundance of these were far lower than the other seed and cone insects associated with *P. strobiformis*. For example, during 2014 we found 15 *Eucosma ponderosa* out of 165 total Lepidopterans (<10%).

Methods

Fall Cone Collections

In 2012, we initiated the first trial of rearing insects in the lab. We collected cones from a total of 49 different trees from 15 different sites across Arizona and New Mexico. Individual cones were chosen from the cone collections at random for insect rearing observations. One to ten cones per tree were isolated in individual emergence chambers. In total, 447 cones were placed into insect emergence chambers with 57 insects successfully reared. In 2013 the collection and rearing process was replicated using 29 new sites and 114 collection trees. There was a doubling of effort with 897 individual cones placed in emergence chambers. From that collection, 269 insects were successfully reared. In fall 2014, there were 57 cones collected from 43 trees across five sites. These cones successfully reared 67 insects. During 2015, there were 273 cones collected from 25 trees across eight sites. Of those eight sites, five were new, bringing the total number of sites used in this project to 70. Collections were again made in Arizona and New Mexico. In addition, one site was located in the Guadalupe Mountains National Park (GMNP), Texas. Only cones with signs of insect damage were selected, except for those from GMNP, which were individually placed in emergence chambers with or without evidence of insect damage. From the 2015 collection, 126 insects were reared in the laboratory.

Intensive Summer Cone Collection (2014)

We expanded our sampling protocol during summer 2014 to more effectively sample the seed and cone insect guild. During this field season we collected cones from ground plots, green cones from trees, used pollination bags to collect insects in situ, and used Tanglefoot® and funnel traps to collect insects not developing inside the cones. Details on all of these sampling methods can be found below.

Cones from ground plots: We collected cones from ground plots established around *P. strobiformis* in order to collect *Conophthorus* spp. from aborted cones. For trees with a diameter at breast height (dbh) less than 25.4 cm a 1/100th ha plot (5.64 m) was used and for larger trees a fixed radius of 1/50th ha (7.98 m) was created. The circular ground plots were divided into cardinal quadrants and two cones from each quadrant were collected (if available) from May to August, 2014. All together 123 cones were collected from ground plots and placed into emergence chambers or destructively sampled.

Green cone collection: In addition, green (developing) cones were collected from each tree by dividing the continuous living crown of each tree into thirds and collecting two green cones from each crown third. These cones, which were collected biweekly throughout the summer, were either destructively sampled or placed into emergence chambers. During May and early June, cones collected from the canopy were destructively sampled to observe larvae and determine insect orders associated with cone damage. From mid-June to the end of the summer cone collection, fewer cones were destructively sampled, especially cones which had signs of infestation, in order to rear larvae to adulthood. We collected 168 green cones from 28 trees across 14 sites.

Pollination bags: Pollination bags were placed around second year developing cones on the first visit to a tree in 2014 and then every following visit over the course of the summer. On each visit two bags were placed around cones in each crown third. If there were not enough cones in the lower sections of the crown, then the bags were bumped up to the next crown third so that six pollination bags per visit were installed. We observed that most cones develop in the top two thirds of the living crown. By the end of the 2014 field season 529 cones were caged in situ (max of 18/tree). The bags were then collected in the fall and brought back to the laboratory. If a cone had evidence of infestation, it was placed in an emergence chamber. Cones which did not have signs of infestation, such as entry holes, frass, or extreme curvature were destructively sampled to confirm the cone was not infested.

Tanglefoot and funnel traps: The Tanglefoot® glue was used in attempts to capture nocturnal feeding insects. One bundle of cones, typically comprised of 2-4 cones, were chosen at random in each crown third, flagged, and glued applied. The following morning the cones were checked for insects. Due to the time-consuming nature of this collection method, we only used it on six trees at three sites. Lastly, Lindgren funnel traps were placed in the top third of the canopy in one tree per site and supplemented with a pheromone and a volatile to attract insects. The pheromone used was 40 mg of pityol, a sexual pheromone from cone beetles, tested in other regions although not in the Southwest, and 15 ml of alpha-pinene, a plant-based monoterpene from pines (Kegley et al., 1989).

The 2014 cone collection included 19 additional, new sites and 126 trees (Table 1). Of the 19 new sites 14 were utilized for the more comprehensive summer collection and five were also included in the fall collection. From the intensive sampling conducted over the summer, 857 insects were collected. We had varying degrees of success: from the pollination bags 303 insects were collected, 24 from the ground plots, 412 from the funnel traps, 118 from the canopy collections, and six from the Tanglefoot® glue. Infestation rates for each tree were visually estimated and varied from 0 – 80 % (Table 1).

Table 1. This table shows the 14 different sites, number of trees per site, the beginning and end of cone collection timing, and the range of total cone infestation for each site sampled from in summer 2014. N/A stands for data not available.

Site	Number of Trees	Collection Timing	Range of Infestation per Tree (%)
ASP	3	6/23/2014-6/25/2014	0
ATH	13	5/15/2014-9/2/2014	20-80
ATO	3	5/13/2014-8/5/2014	23-30
BIS	9	5/14/2014-9/9/2014	0-1
BLC/LBC	2	5/28/2014-7/28/2014	15-22
GPO	3	6/11/2014-6/12/2014	0-34
LMD	5	5/27/2014-9/3/2014	0-30
LSP	2	5/29/2014-8/6/2014	0-13
LSR	2	5/29/2014-7/9/2014	0-30
OBS	9	6/22/2014-9/15/2014	0-14
ORC	7	6/20/2014-9/19/2014	2-30
SEG	13	6/21/2014-9/12/2014	10-60
VST/VSP	2	6/2/2014-8/20/2014	11-28
WIT	7	6/23/2014-9/15/2014	N/A
Total	73	**Average Infestation**	21

Results

The most prevalent order captured during this project was Lepidoptera. From 2011 to 2014 the most prevalent species was the Lepidopteran *Dioryctria abietivorella*. From the 2015 cone collection the most prevalent species was the Lepidopteran *Eupithecia spermophaga*. The cone beetle *Conophthorus ponderosae* was the third most captured seed and cone insect which was then followed by the Hemipteran *Leptoglossus occidentalis*. . The Dipteran resin midge (*Asynapta hopkinsi*) were reared from cones, but since they do not significantly damage a large number of second year cones (>10%) not much attention will be given to these species.. The insects that were most captured and identified as major guild members will be highlighted here, with less attention given to species that were not frequently observed or are not considered important insect predators of *P. strobiformis* cones and seeds.

Due to the disjunct geographic distribution of *P. strobiformis*, we divided the range into six geographic areas to better describe our results (Figure 6; Table 2). In region 1, near Flagstaff, AZ the following insects were collected: **Lepidoptera**; *Dioryctria abietivorella*, *Eupithecia spermophaga*, *Eucosma ponderosa*, **Hemiptera**; *Leptoglossus occidentalis* and **Coleoptera;** *Conophthorus ponderosae.* From 2012-2014, *Dioryctria abietivorella* was the most prevalent insect; however in 2015 *Eupithecia spermophaga* became the most common damaging insect. This could be due to new geographic locations for cone collections or natural variation in insect composition from year to year. This region also yielded the largest collections of *Leptoglossus occidentalis* compared to the other five regions. We collected in region 1 from 2012-2015.

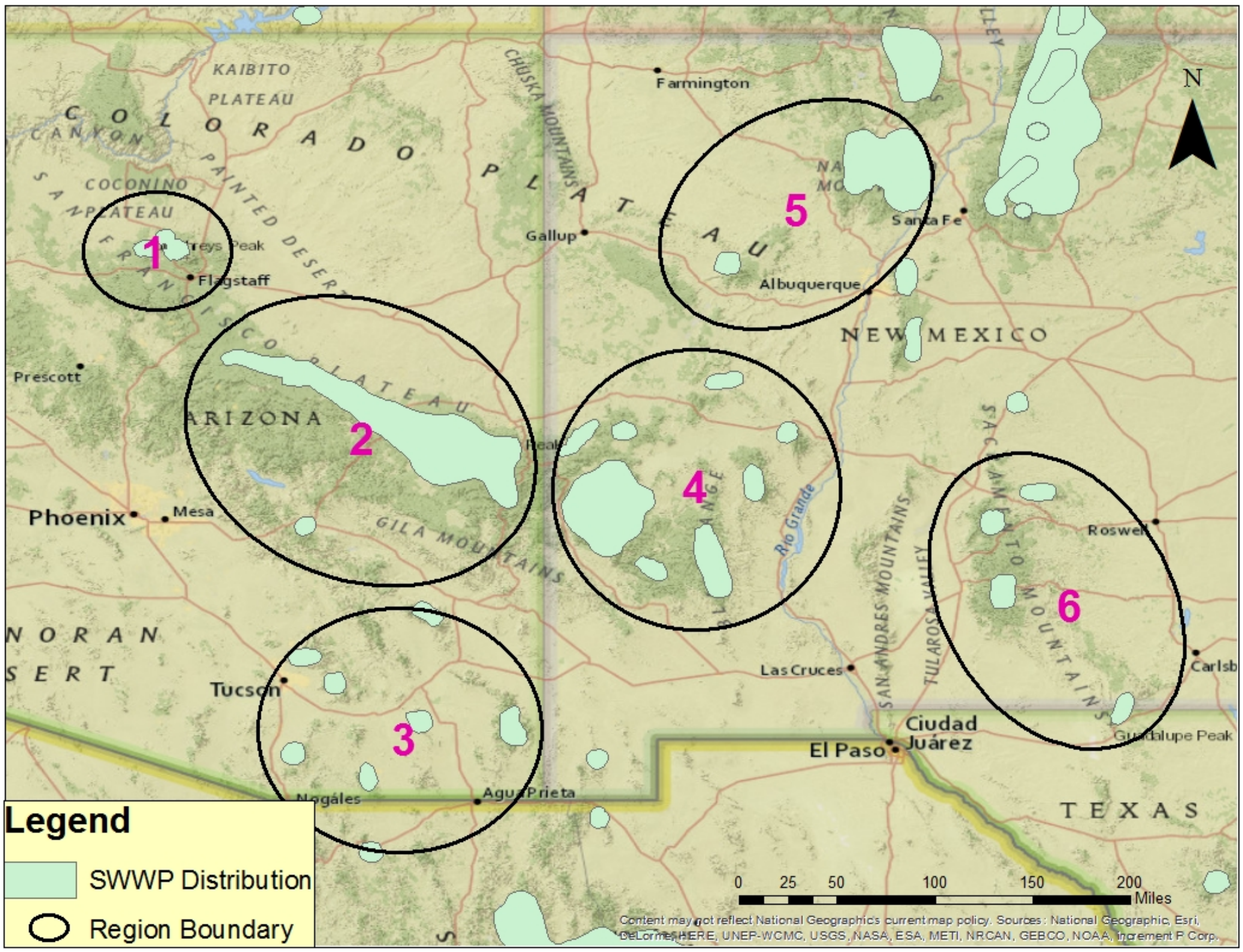

Figure 6. Map of insect collection regions in Arizona, New Mexico, and Texas. Pinus strobiformis distribution layer from United States Geological Survey (2006) based on Little (1971).

Table 2. Insects collected by region (1-6, as illustrated in Figure 6); presence marked by an 'X'.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
Lepidoptera:						
Dioryctria abietivorella	X	X	X	X	X	X
Eupithicia spermophaga	X	X	X	X	X	X
Eucosma ponderosa	X	X			X	
Hemiptera:						
Leptoglossus occidentalis	X	X		X	X	
Coleoptera:						
Conophthorus ponderosa	X	X		X	X	X

In region 2, across the Mogollon Rim, we observed the following insects: **Lepidoptera**; *Dioryctria abietivorella*, *Eupithecia spermophaga*, *Eucosma ponderosa*, **Hemiptera**; *Leptoglossus occidentalis* and **Coleoptera;** *Conophthorus ponderosae.* The most common insect in this region was *Dioryctria abietivorella.* We collected from region 2 during 2012, 2014, and 2015.

In region 3, on Arizona's southern sky islands, we observed the following insects: **Lepidoptera**; *Dioryctria abietivorella* and *Eupithecia spermophaga.* The most common insect in this region was *Dioryctria abietivorella.* We collected from region 3 from 2012-2014.

In region 4, from the Gila Mountains of New Mexico, we observed the following insects: **Lepidoptera**; *Dioryctria abietivorella*, *Eupithecia spermophaga*, **Hemiptera**; *Leptoglossus occidentalis* and **Coleoptera;** *Conophthorus ponderosae.* The most collected insect in this region was *Dioryctria abietivorella.* We collected from region 4 from 2013-2014,

In region 5, across northern New Mexico, we observed the following insects: **Lepidoptera**; *Dioryctria abietivorella*, *Eupithecia spermophaga*, *Eucosma ponderosa*, **Hemiptera**; *Leptoglossus occidentalis* and **Coleoptera**; *Conophthorus ponderosae.* The most common insect in this region was *Dioryctria abietivorella*. This area had the highest levels of *Conophthorus ponderosae* compared to the other regions. We collected form region 5 during 2012 and 2015.

In region 6, across the Sacramento Mountains of New Mexico and the Guadalupe Mountains of western Texas, we observed the following insects **Lepidoptera**; *Dioryctria abietivorella*, *Eupithecia spermophaga* and **Coleoptera**; *Conophthorus ponderosae.* The most common insect in this region was *Dioryctria abietivorella.* We collected from region 6 from 2013-2015.

Monitoring and Management

As the field of forestry evolved, the creation and development of a reliable seed supply grew in importance (Miller, 1914). Seed sources, whether found in the wild or artificially grown in seed orchards, provide not only seed but a source of known genetics which can be used for the selection of certain genotypes, such as resistance to blight (Hedlin et al., 1981). With the development of the seed orchards came increased observations on seed crops and the different variables which affect the amount of seed produced on a regular basis (Keen, 1958). Certain variables such as intervals of mast years and climate are harder to control, but loss of seed due to predators such as small mammals and insects provide avenues of control to minimize seed crop loss. The seed crops are critical to restoration following loss of tree species (as in from blight) and for large scale artificial regeneration, such as post-wildfire.

In general, the seed and cone insect guild in N. America is native. The guild plays an important role in the ecosystem as a component in stand dynamics and typically does not cause extensive problems on the natural landscape (Hedlin et al., 1981). It is usually only when a specific seed orchard has been established or high-value individual seed-producing trees are identified that management of these insects takes place to minimize seed damage and economic loss.

Managing damage and loss in seed crops due to insects typically involves a multistep process. A basic understanding of the regenerative biology associated with the host tree of concern is critical to managing the pests associated with them. For example, it is essential to know when the tree initiates flowering for pollination, the stages of cone development, and the timing of seed dispersal (Keen, 1958). Essentially, observation of the host tree's reproductive ecology is critical for detection of non-normal cone development. This provides a foundation for the resource manager to visually assess the type and amount of insect damage occurring.

When damage occurs, a resource manager needs to identify the insects causing the damage. Detecting damage to flowers and internal seeds is far more difficult to detect than cone damage. Once the insects have been identified, a resource manager needs to understand the biology of that insect. Life cycles, behavior, and stages of development are just some of the factors which are critical for effective management and control (Hedlin et al., 1981). Identification may be difficult and a specialist may be needed to assist in the identification.

After the identification of the insects is complete, a damage appraisal is needed. Even though pests are present, damage must exceed a minimum threshold to justify the investment in management. If the value of the seed is high enough, a resource manager might want to preemptively attempt to minimize loss if known pests are present on a regular basis and a small seed crop is developing. Quantifying how many cones are developing for a given year is the first step (Hedlin et al., 1981). Depending on the size of the seed supply, a person can either take a census or use a sampling method to quantify the amount of cones developing on a monthly basis. Choosing either a census or sampling method is dependent on the time and resources a resource manager is willing to spend on estimating the seed supply. Furthermore, in the Southwest if a large seed crop is developing, then attempts of controlling seed and cone insects is not recommended since levels of damage will be negligible. After cone yield estimates are established, the monitoring of insect presence and damage needs to take place. This could be done with low level aggregation pheromones which attract and trap the insect to assess presence or methodical sampling of cones to evaluate the percent of cones damaged.

Regardless of insect pest order, there are basically two major routes to follow: insecticidal vs. non-insecticidal control (Hedlin et al., 1981). Non-insecticidal control, also known as integrated pest management, involves a variety of techniques that could utilize pheromone manipulation, biological control, fire prescriptions, smoke, and host manipulation. The use of insecticides requires investigating contemporary literature about which chemicals are considered effective for the given insect and appropriate for the location.

Protecting *P. strobiformis* seed supplies in the Southwest would involve targeting single trees or small stands. Currently, artificial seed orchards have not been developed. The trees which have been identified as having the white pine blister rust resistance would have a higher priority for protection, than non-resistant trees. Cone and seed protection would be amplified in years of low cone development because, in those years' total destruction of crop yield is possible. In general, management would be directed towards *D. abietivorella* since we observed it had the highest level of incidence and damage in cone collections across all the sites. Specific sites should be reassessed every year for insect presence and proper management protocol given the variation of insect population levels year to year and associated control methods.

Lepidoptera:

Dioryctria abietivorella

The *Dioryctria* (cone worms) are ranked as the most destructive cone pest in North America (Hedlen et al., 1981). This observation was reinforced from our collections and observations. The most common *Dioryctria* collected from this study was *Dioryctria abietivorella* (fir cone worm; Figure 7).

Figure 7. Adult Dioryctria abietivorella. Photo credit: Jerry Powell of the Essig Museum.

I. Life History and Behavior

The behavior and life history of this moth is variable depending on geographic location (Ward et al., 2009). *D. abietivorella* completes one full generation per year. Depending on the climatic conditions and genetic variability there can be two broods in the Southwest. In this case adults would emerge both in the spring and others emerging during the summer (Hedlin et al., 1981). Spring emergence occurs under favorable climatic conditions when the insect remains in diapause over the winter.

In the Southwest, in most cases, the eggs are deposited near and/or on the cones where they will diapause over winter to hatch in the spring. Upon hatching, the larvae bore into the cones and create feeding galleries. The larvae consume the seeds and internal tissue of the cones. The first instar is a pale yellow, maturing into a deep amber color with a darker brown head and the larva can grow to 18 mm in length (Figure 8). Once feeding is complete, the larvae emerge and pupate on the cone surface. The pupae are brown and measure about 10 mm in length (Figure 9). The cocoon is camouflaged by reddish brown frass that covers the protective web shell encompassing the pupa (Figure 10). They will then pupate for about two months and adults emerge between June and October.

The adult moths lay eggs shortly after emergence and they cycle begins again.

Figure 8. Larva form of Dioryctria abietivorella.

Figure 9. Dioryctria abietivorella pupa.

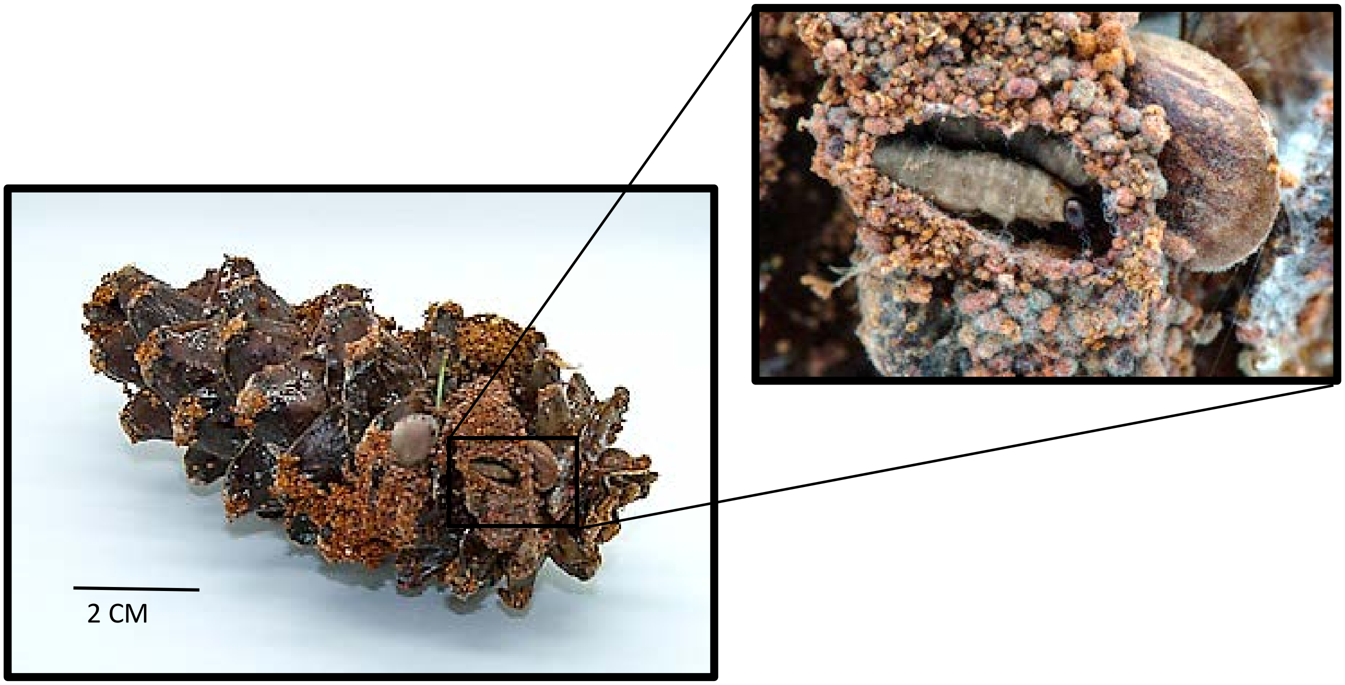

Figure 10. A frass-covered cone with the larva entering diapause to induce metamorphosis.

II. Geographic Range

The geographic range of *D. abietivorella* is quite extensive. The northern most extent starts in interior northern Alaska and stretches south to central Mexico. In Canada, it can be found from coast to coast (Hedlin et al., 1981).

III. Management

Cones damaged by *D. abietivorella* typically do not fully develop and visible damage is evident by the end of summer. Early detection is possible with a trained eye. The parts of the damaged mature cones will not open and will be brown instead of the normal green or purple color (Figure 11; a). This is due to internal damage caused by the larvae consuming the subcortical cortex of the pine cone (Figure 11; b). Additionally, the larvae will consume the scales and seeds of the cone. Estimations of average percent of viable seed destroyed were not recorded during this project, but we observed several individual destructively sampled cones that had up to 100% of the seed destroyed. Recorded observations from seed orchards in Oregon report 50% of total crop yields destroyed (Keen, 1958). The entry points can be located anywhere on the cone and, depending on the number of larvae present, can be quite numerous. Frass present on the cone is additional evidence for detecting the presence of most Lepidoptera, including *D. abietivorella*.

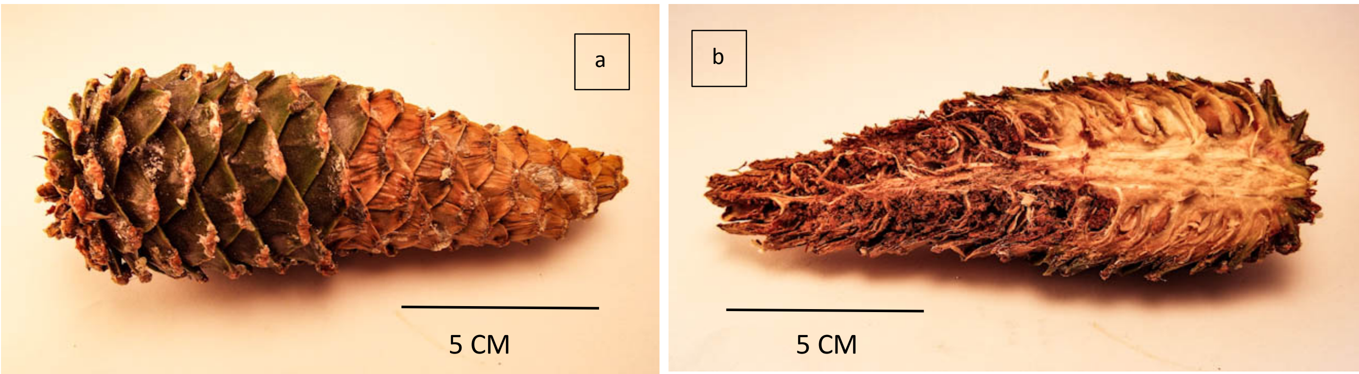

Figure 11. External (a) and internal (b) image of cones damaged by the larvae of the Dioryctria abietivorella.

Recent research in effective lure development has shown that the use of synthetic pheromones may be the best option to control damage caused by *D. abietivorella*, (Ward et al., 2009; Hanula et al., 1984). By utilizing pheromones, a resource manager could disrupt the mating cycle or use them to attract and kill the pest. Research has shown the optimal trapping method uses a ratio of the two synthetic pheromones (200µg (Z)-9-11 E-14: Ac to 2000µg C25 pentaene and (Z)-9-Tetradecen-1-yl acetate) with the Pherotech diamond trap style (Ward et al., 2009). Additional studies have shown that placing the traps higher in the crown will capture more adults than traps placed lower (Hanula et al., 1984). Since the behavior of the insect seems to change with location a study of flight periodicity and other behavioral aspects should be examined to increase the efficacy of aggregation pheromones and trapping methods (Hanula et al., 1984; Ward et al., 2009).

The use of pesticides for control is also a possibility: however, pesticides can have negative environmental impacts, such as non-target mortality and watershed contamination. In addition, only a few registered pesticides have been found to be effective (Ward et al., 2009). If their use is justified, timing of application should be coordinated with adult emergence.

Parasitoids and natural predators could be supported and utilized as a part of a long term integrated pest management plan. We reared Ichneumonidae wasps from *D. abietivorella* larvae during the course of this project (Figure 12). Additionally, we found the Hemipteran minute pirate bugs (*Anthocoridae spp*.) were associated with larval mortality in destructively sampled cones (Figure 13). Other possible parasitoids include Encyrtidae, *Copidosoma* spp., Eulophidae, *Hyssopus* spp., and *Tachinidae* spp. (Keen, 1958).

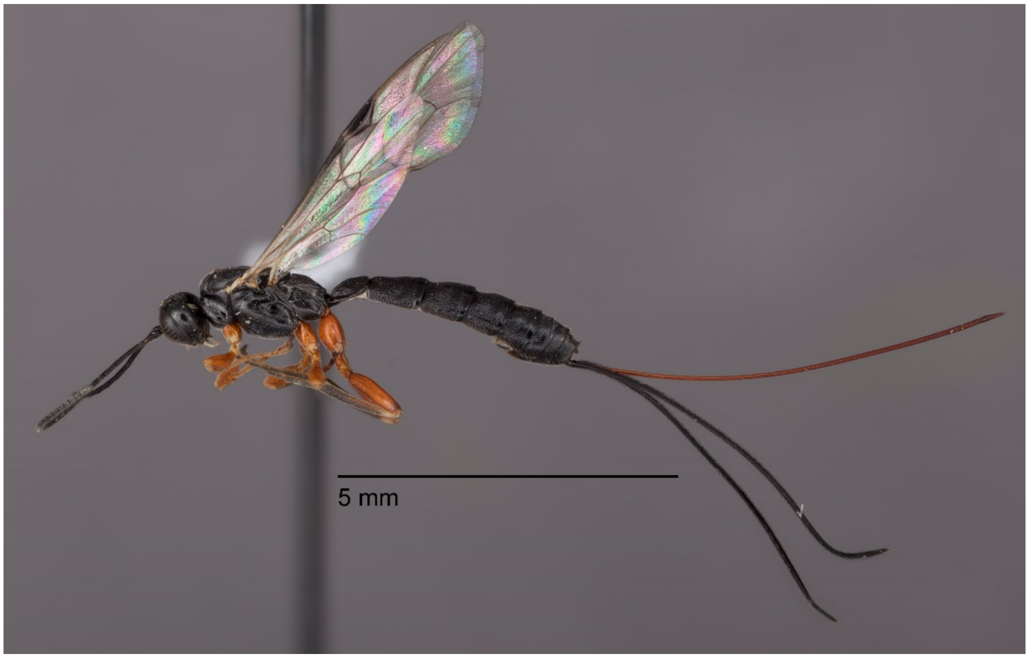

Figure 12. Adult female Ichneumonidae species reared from D. abietivorella larvae. (Photo credit: Derek Uhey)

Figure 13. The adult Hemipteran minute pirate bug, a predator of D. abietivorella larvae. (Photo credit: Derek Uhey)

Eupithecia spermophaga

I. Life History and Behavior

Figure 14. Adult form of Eupithecia spermophaga collected in Arizona, 2014.

Figure 15. Eupithecia spermophaga larva collected in Arizona, 2015.

The second-most abundant cone or seed insect in our collections was the fir cone looper (*Eupithecia spermophaga*; Figure 14). *Eupithecia spermophaga* tunnels into the cones as larvae in early spring, shortly after hatching from eggs. The larvae grow to 20 mm in length (Figure 15). The first instar is a pale greenish to grey color turning to a light green color with a brown head as they mature.

Eupithecia spermophaga larvae consume the seeds and internal tissue of the cone during spring and summer creating tunnels. In late summer, the larvae will emerge prior to seed dispersal. The larvae produce a web covered cocoon, which, by the end of summer, is typically camouflaged in the frass piles that coat the pine cone. The pupae are brown and about 11 mm in length. Generally, most moths pupate for about two months and emerge in September and October. The adult moths then lay eggs near and/or on the cones where they will diapause over winter and hatch in the spring. Some *E. spermophaga* may pupate over winter and emerge as adults in spring. Shortly after adult emergence the adults mate and lay eggs (Hedlin et al., 1981).

II. Geographic Range

Eupithecia spermophaga can be found from the lower coastal range of Alaska southward to the interior mountain West. The range continues down the Rocky Mountains to the Sierra Occidental Mountain range of central Mexico (Hedlin et al., 1981).

III. Management

Generally, in the U.S. this species is not considered a major pest, typically only consuming up to 10% of the seed in each cone (Hedlin et al., 1981). Further studies focused on damage appraisals are however needed to fully quantify damage and regional infestation rates.

Cones damaged by *E. spermophaga* generally do not fully develop and visible damage is evident by the end of summer; early detection is difficult. The more mature cones will not open and become brown in color instead of the normal green or purple. The external and internal damage of the cone is similar to that caused by *D. abietivorella*. Both insects consume the subcortical cortex of the pine cone (Figure 16). The cone can have one to eight entry points, depending on the number of larvae. Additionally, the holes can be located anywhere on the cone.

Figure 16. Observed damage to P. strobiformis cone from Eupithecia spermophaga.

Eupithecia spermophaga are destructive pests of *P. strobiformis* cones across the southwestern United States. Control techniques are presently limited to broad spectrum insecticides. Use of these chemicals results in loss of non-target species and may result in biological backlash. Integrated pest management programs targeting *E. spermophaga* will need to be established. Future research could build a framework for effective and sustainable management options. A basic review of evolutionary ecology, behaviors, and host-generated semiochemicals is needed to fill major gaps in our current understanding with this species (Whitehorse et al., 2011). Additionally, future research should address knowledge gaps in population distributions at multiple spatial and temporal scales, since effectiveness of many integrated pest management schemes depends on proper timing.

Eucosma ponderosa

Eucosma ponderosa adults, commonly known as the western pine cone borer, have mottled wings that are covered in splotches of orange tones, browns, and rust colors with a light pale background (Hedlin et al., 1981; Figure 17). Larvae are pale yellow as first-instars and mature to a light tan. The larvae can grow to 15 mm in length. The damage caused to the cone is very similar to the *Dioryctria spp*. *Eucosma ponderosa* was captured and reared on *P. strobiformis* cones, but due to extremely low numbers of incidence (15 in total from 2012-2015) it is considered an overflow species that prefers *P. ponderosa*. Therefore, we will not include methods of managing this species since it is not seen as an important predator of *P. strobiformis* seeds and cones.

I. Geographic Range

The moth can be found from British Columbia, Canada south throughout the Rocky Mountains and Southwest to the middle of the Sierra Occidental Mountains of Mexico.

Figure 17. Adult form of Eucosma ponderosa. (Photo credit: Jerry Powell)

Coleoptera: Scolytinae:

Conophthorus species, collectively known as western cone beetles, attack the cones of *Pinus* species during the second year of development (Page et al., 1990). Reportedly, during severe infestations, up to 75% of cone crops have been destroyed, a significant reduction in seed crop yields (Furniss and Carolin, 1977). Most *Conophthorus* species are monophagous and were historically divided into subgroups based on the association with their principle host (Cognato et al., 2005; Furniss and Carolin, 1977). The exception to this pattern is *Conophthorus ponderosae* (Hopkins) which has been reported to breed in cones of 13 different *Pinus* species (Hedlin et al., 1981; Wood, 1982). In California, Jeffrey (*P. jeffreyi*) and sugar pines (*P. lambertiana*) have been identified as principle hosts for this species. In the Pacific Northwest, the western white pine (*P. monticola*) has been observed as the principle host. Across the interior mountain West, the beetle has been associated with seed destruction on lodgepole (*P. contorta var. latifolia*) and ponderosa pine (*P. ponderosa*) (Van Driesche et al., 2013). More recent studies have suggested that speciation events have occurred, or are ongoing with the western cone beetles (Cognato et al., 2005; Page et al., 1990). Speciation might be associated more with geographic isolation instead of genetically driven host selection (Van Driesche et al., 2013). *Conophthorus ponderosae* is a beetle with high potential for speciation since there are several isolated groups (Page et al., 1990).

Conophthorus ponderosae became synonymous with five other species of *Conophthorus*; (*C. contortae*, *C. scopulorum*, *C. flexilis*, *C. monticolae*, and *C. lambertianae)* due to the lack of proper taxonomic identification and heavy dependences on host tree association (Wood, 1977). Furthermore, the beetles do share a similar biology (Van Driesche et al., 2012). The beetles captured from this project were identified as *Conophthorus ponderosae* due to the generalized classification but it should be noted that since the beetles were captured from a *P. strobiformis* these particular beetles could be *Conophthorus flexilis*. Kinzer and Reeves (1970) observed behavior between *Conophthorus flexilis* and *Conophthorus ponderosae* suggesting that speciation has occurred. For purposes of this paper these two species will be recognized individually because the differences in their behavior affect management decisions.

One behavioral difference between the two species is the inability of *Conophthorus flexilis* to reproduce in *P. ponderosa*. *Conophthorus flexilis* is obligated to reproduce in *P. strobiformis*. *Conophthorus ponderosae* is able to reproduce in both *P. ponderosa* and *P. strobiformis* (Kinzer and Reeves, 1970). The other significant observation from Kinzer and Reeves (1970) is that *Conophthorus ponderosae* will completely girdle the cones of the pine resulting in the abortion of the cone, compared to *Conophthorus flexilis*, which will only girdle half of the cone causing a larger proportion of the infested cones to stay attached to the tree (Kinzer and Reeves, 1970). During a four-year study from New Mexico *Conophthorus flexilis* was observed destroying 22% of a trees seed crop on average (Kinzer and Reeves, 1970).

Conophthorus ponderosae

Conophthorus ponderosae is the most destructive seed consumer of all the western cone beetles (Hedlin et al., 1981). It can devour up to 75% of a seed crop (Van Driesche et al., 2013).

I. Life History and Behavior

Conophthorus ponderosae only produces one generation per year (Van Driesche et al., 2013). In late spring, a single adult beetle will bore into the base of the immature (second year) cones (Figure 18). Research in New Mexico found peak adult emergence occurred from May 5 to May 18 over a three-year observation (Figure 23; Kinzer and Reeves, 1970). Adults attack cones within two to three days after emerging (Kinzer and Reeves, 1970). The female enters the cone approximately two millimeters up from the stem of the cone (Figure 19; Kinzer and Reeves, 1970). The beetle will enter the subcortical cortex and dig a tunnel down the entire length of the cone's axis (Figure 20; Van Driesche et al., 2013; Kinzer and Reeves, 1970). The girdling of the cone's axis sometimes causes the cone to excessively curl (Figure 21).

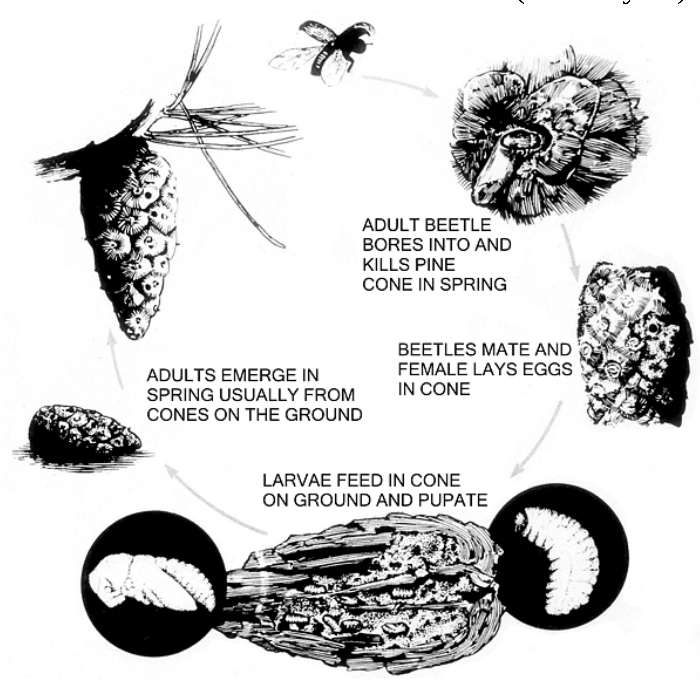

Figure 18. Life cycle of Conophthorus ponderosae (from Hedlin et al., 1981).

Mating is believed to occur in the cone. Throughout the tunnel the female will deposit her eggs, exit the cone, and possibly attack more cones (Kinzer and Reeves, 1970). On average, the female will lay 12 eggs per cone (Kinzer and Reeves, 1970).

The larvae hatch and, during the summer, feed on the inner tissue and seeds of the cone (Figure 22). Pupation occurs over winter in cones on the forest floor or in the ground (Figure 23; Van

Figure 19. A P. strobiformis cone with arrow pointing to a pitch tube located near the stem.

Driesche et al., 2013). Complete destruction of a seed crop has been attributed to *Conophthorus ponderosae* in white pine blister rust resistant western white pine seed orchards of the Pacific Northwest (Bennett, 2000). In New Mexico, *P. strobiformis* seed crop destruction rates were observed to be 28% on average (Kinzer and Reeves, 1970).

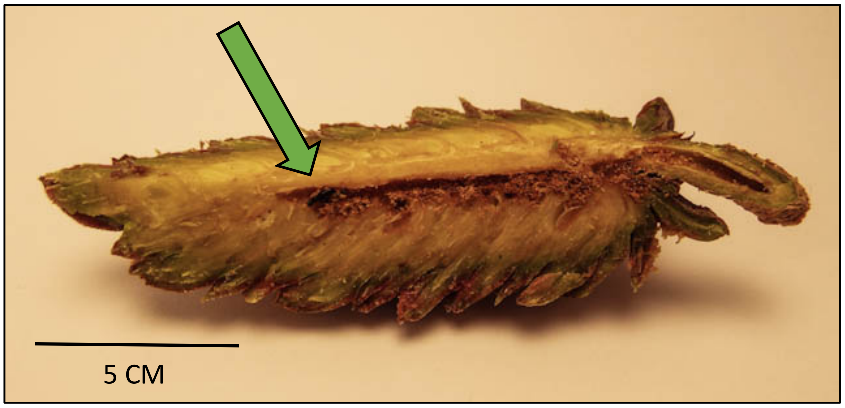

Figure 20. Adult female Conophthorus sp. (arrow pointing to beetle) tunneling up the axis of a P. strobiformis cone where she deposits her eggs.

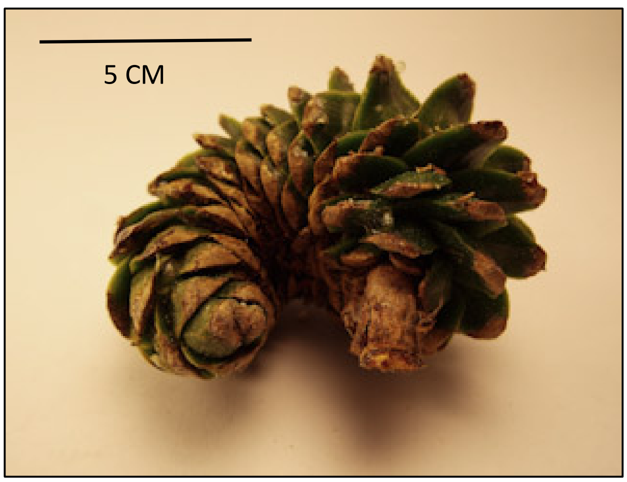

Figure 21. Due to the girdling of the cone axis, damaged P. strobiformis cones will occasionally curl excessively.

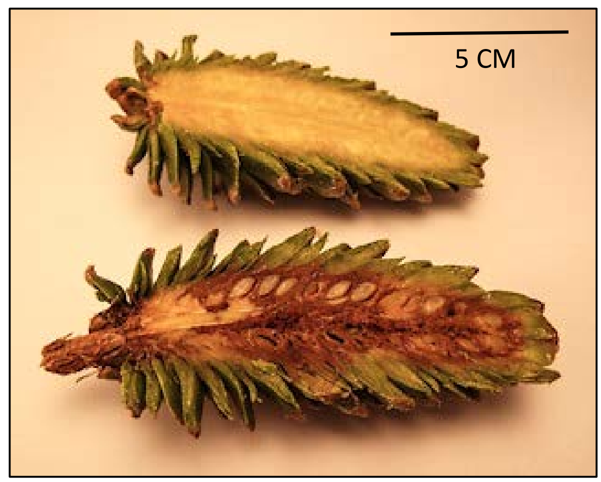

Figure 22. Internal comparison of a healthy P. strobiformis cone (top), with the internal damage associated with Conophthorus ponderosae and Conophthorus flexilis (bottom).

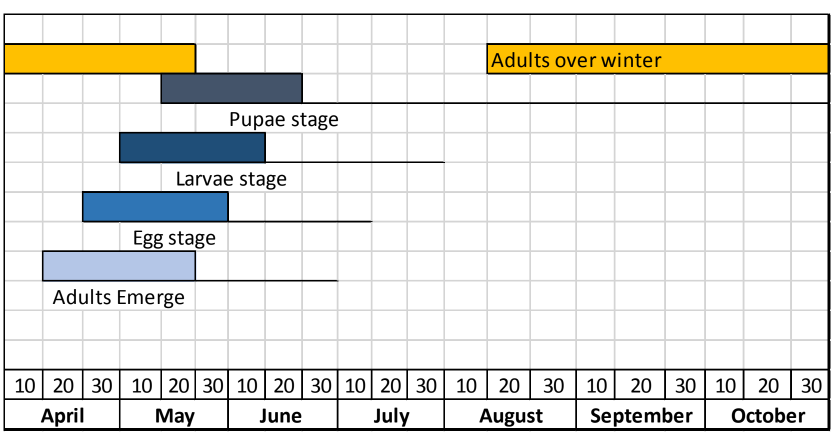

Figure 23. Generalized temporal life cycle of Conophthorus ponderosae (Kinzer and Reeves, 1970).

II. Distribution

Conophthorus ponderosae beetles can be found from the Sierra Nevada Mountains in California north to British Columbia. The range extends eastward to Idaho and back south throughout the Rocky Mountains and throughout the Southwest (Van Driesche et al., 2013).

III. Management

Visual detection of cone damage from this species is difficult in the spring but becomes more evident as the summer continues. Infested cones fail to grow normally and are obviously stunted when compared to the healthy cones. In the early spring, look for single pitch tubes with red frass located at the base of the cone (Figure 19). Summer through fall, the infested cones will remain stunted, turn brown, and drop to the forest floor (Kinzer and Reeves, 1970). Dissecting infested cones should reveal small, c-shaped pale legless larvae, about 2-5 mm in length. The larvae go through two instars before metamorphosis occurs (Kinzer and Reeves, 1970). Use of species specific attractant lures could assist in detection of beetles for a given site (Van Driesche et al., 2013).

Lures used for beetle control and monitoring are often a combination of beetle pheromones and host plant volatiles. Olfactometer tests indicated that male *Conophthorus ponderosae* are attracted to female pheromones, but not to plant-based volatiles (Kegley et al., 1989). Conversely, female beetles were not attracted to male pheromones, but instead responded to ponderosa pine resin, cone tunnel shavings, and beta-pinene, which is a component of pine resin (Kinzer and Reeves, 1970). Trees and branches where previous attacks have occurred are more likely to be reattacked after winter (Kinzer and Reeves, 1970).

Use of beetle traps with the terpene alpha-pinene and the beetle pheromone, pityol for purposes of detection have shown promise in other parts of the country (Bennett, 2000). We used these lures in 20 Lindgren funnel traps at 20 different sites across Arizona and only captured 12 *Conophthorus sp.* during summer of 2014. Low rates of capture were most likely due to late placement of traps in the forest, missing the peak emergence flight. The earliest date we hung our traps was May 13. Further research is needed for optimal lure development, understanding of beetle seasonality, and relative efficacy for the beetle populations found in the Southwestern region. Knowledge of spring emergence dates are the critical first step for efficient and effective use of attractant lures for detection, monitoring, and control. Observed first days of emergence in New Mexico were April 21st and peaking around the 5th of May (Kinzer and Reeves, 1970) but data from multiple locations is needed to make management recommendations across the Region.

Once damage or presence of the beetle is detected, removal of infested cones has been shown to be the most effective way to reduce infestation rates the following year (Bennett, 2000). Mechanical removal of cones from the forest floor can significantly reduce the likelihood of infestation and lower incidence levels (Bennett, 2000). Additionally, if the site and climatic conditions permit, a light ground fire is an option for eliminating populations located on the forest floor since they overwinter as adults in aborted cones (Hedlin et al., 1981; Bennett, 2000). The prescribed ground fire must occur during the period of time when the beetles are in cones on the forest floor and conditions are conducive to a light ground fire. Populated aborted cones can be found on the ground from the fall to the early spring (Kinzer and Reeves, 1970).

No aggregation pheromones to date have been found to be effective enough to attract large numbers of beetles, thus trap and kill methods have not been developed. Additionally, the use of insecticides has been found to be ineffective (Bennett, 2000).

Prevention of cone infestation has been successfully implemented in highly valuable blister rust resistant western white pine trees of the Northwest by placing protective bags over developing second year cones, but this is a costly practice (Bennett, 2000). Bags must be placed prior to early spring adult emergence. We found pollination bags do not last over winter on trees in situ necessitating that bags would need to placed early in the year, every year of low seed production, likely prior to snowmelt in many areas where *P. strobiformis* is found.

Natural predators and parasitoids do exist and could be utilized as a possible biocontrol agent to an integrated pest management plan, but current knowledge gaps exist and further research is needed to transform this from theoretical to practical management. *Ichneumonidae* spp. parasitoids were reared from cones infested with *Conophthorus* spp. during the course of this project. Additionally, the pteromalid wasp *Tomicobia tibialis* has been observed parasitizing *C. ponderosae* (Van Drieshe et al., 2013). One other known natural enemy of the *Conophthorus lambartianae* larvae (a similar cone beetle species) is the bethylid wasp *Cephalonomia utahensis.* Lastly, adult cone beetles have been observed being attacked by the predatory clerid beetle *Enoclerus lecontei* (Van Drieshe et al., 2013).

Figure 22. Adult Conophthorus ponderosae frontal view. (Photo Credit: Derek Uhey)

Figure 23. Adult Conophthorus ponderosae top view. (Photo Credit: Derek Uhey)

Figure 24. Adult Conophthorus ponderosae lateral view. (Photo Credit: Derek Uhey)

Conophthorus flexilis

IV. Life History and Behavior

Similar to *Conophthorus ponderosae*, a single adult beetle will bore into the base of the immature (second year) cones. The female does not completely girdle the cone, but does construct an egg gallery along one side of the cone's axis (Kinzer and Reeves, 1970). Mating is believed to occur in the cone but this has not been confirmed (Hedlin et al., 1981). Throughout the tunnel, the female will deposit her eggs, emerge, and attack up to three more cones (Kinzer and Reeves, 1970). On average, the female will lay 12 eggs per cone (Kinzer and Reeves, 1970). Only one generation per year is produced (Driesche et al., 2013). The larvae hatch and feed on the inner tissue and seeds of the cone and go through two instars of development (Kinzer and Reeves, 1970). Peak emergence of adults in New Mexico occurred around April 18th (Kinzer and Reeves, 1970), slightly earlier than that of *Conophthorus ponderosae*. Adults have been observed attacking cones the day of emergence (Kinzer and Reeves, 1970). Pupation occurs over winter in cones on the tree and on the forest floor (Figure 25; Van Driesche et al., 2013).

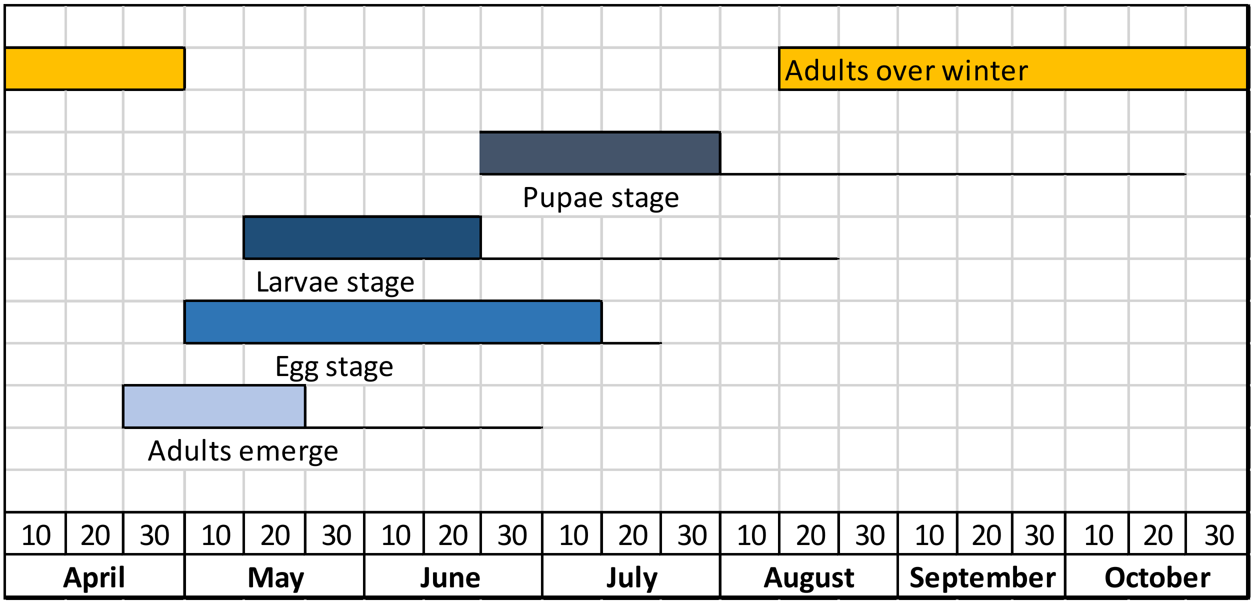

Figure 27. Generalized temporal life cycle of C. flexilis (Kinzer and Reeves, 1970).

II. Distribution

Due to the official inclusion of *Conophthorus flexilis* to the synonym *Conophthorus ponderosae,* which is currently the officially recognized name, the range of *Conophthorus flexilis* is unknown. This project observed possible *Conophthorus flexilis* beetles from the San Francisco Peaks, of northern Arizona to the Guadalupe Mountains of west Texas. Further research is warranted before official species status is reinstated.

III. Management

Apparently, *Conophthorus flexilis* is not as destructive as *Conophthorus ponderosae* in the western parts of the United States due to the monophagous behavior of the species. However, it can devour up to an average of 28% of a seed crop, making it a significant cone pest of the *P. strobiformis* and *P. flexilis* (Kinzer and Reeves, 1970).

Similar to *Conophthorus ponderosae,* visual detection of cone damage from this species is difficult in the spring and becomes more evident as the summer continues due to abnormal cone growth. In the early spring, look for single pitch tubes located at the base of the cone with red frass (Figure 20). Later in the year, summer through fall, the infested cones will remain stunted and turn brown while the healthy cones will continue to grow, making damage appraisals easier. Infested cones can be opened and small c-shaped pale legless larvae about 2-5 mm in length should be present.

Olfactometer tests indicated that male and female *Conophthorus flexilis* are attracted to plant-volatiles, specifically alpha-pinene (Kinzer and Reeves, 1970). Specific trees and even branches from which previous attacks have occurred are more likely to be reattacked after winter

(Kinzer and Reeves, 1970). Alpha-pinene yielded few results in the current project, possibly due to late placement of baited traps. We captured only 12 *Conophthorus* beetles from 20 pheromone baited Lindgren funnel traps which were placed in the tops of trees at 20 different sites across Arizona. Historically, setting up beetle traps with the lure composed of alpha-pinene and pityol for purposes of detection have shown promise in other parts of the country (Bennett, 2000). Similar to *Conophthorus ponderosae*, knowledge of spring emergence dates is critical for effective use of pheromones for detection purposes. Observed first days of emergence in New Mexico was April 7th peaking around the 15th of April with 90% of the emergence complete by the end of April (Kinzer and Reeves, 1970). We captured seven beetles on June 3rd and single beetles were caught in traps sporadically after that until August 5th. All trap captured beetles were from sites on the San Francisco Peaks, north of Flagstaff, AZ.

Similar to *Conophthorus ponderosae*, once presence of the beetle or associated damage is detected in the stand, removal and destruction of infested cones has been shown to be the most effective in reducing infestation rates the following year (Bennett, 2000). Physical removal of cones from the tree and forest floor can significantly reduce the likelihood of infestation and lower incidence levels (Bennett, 2000). Since a higher portion of *P. strobiformis* infested cones remain in the canopy compared to *P. ponderosa* cones, the use of a prescribed ground fire will likely not be as effective in controlling cone beetles in *P. strobiformis* as it is in ponderosa. Only one site from this project had observed cone beetles from ground plot collections.

Unfortunately, the climbing of trees for removal of infested cones is expensive, but the window of opportunity is wide and it can be done from late spring to early winter. Prevention of cone infestation has been successfully implemented in highly valuable white pine blister rust resistant western white pine trees by climbing trees and placing protective bags over developing second year cones. (Bennett, 2000). Bags must be placed prior to early spring adult emergence. This may be the most cost effective and practical method to ensure the collection of a viable seed crop for a given year on a specific tree. We found that pollination bags do not last over winter on trees in situ.

No aggregation pheromones to date have been found to be effective enough to attract large numbers of beetles, thus trap and kill methods have not been developed. Furthermore, use of insecticides have been found to be ineffective (Bennett, 2000).

Natural enemies and parasitoids present on the landscape can help to maintain an acceptable level of damage and seed loss. Research and development is needed to move this from a natural phenomenon to a practical management option. Several species of wasp have been observed parasitizing the larvae of the *Conophthorus ponderosae*. The bethylid wasp *Cephalonomia utahensis* has been identified as a parasitoid (Van Driesche et al. 2013). Adult beetles may be parasitized by the pteromalid wasp *Tomicobia tibialis* and predatory clerids, such as *Enoclerus lecontei* consume *Conophthorus spp*. (Van Driesche et al. 2013). During the rearing of beetles in infested cones we found a possible association with an *Ichneumonidae* wasp. This species may also be a parasitoid of the *Conophthorus flexilis.*

Hemiptera: Coreidae

Leptoglossus occidentalis

The western conifer seed bug, *L. occidentalis*, is a serious pest of conifer seed production (Koerber, 1963), especially *Pinus spp.* (Connelly and Schowalter, 1991) and has been observed consuming the seeds of *P. strobiformis* throughout Arizona and New Mexico. The *L. occidentalis* has hind legs which expand out horizontally, giving rise to its other common name, the leaf-footed bug (Figure 28).

Leptoglossus occidentalis feeds on the seeds and ovules of cones (Hedlin et al., 1981). The long beak-like proboscis, which is usually folded under the entire length of the body unless feeding, is comprised of several syringe-like stylets covered by a protective sheath (Hedlin et al., 1981).

When warmer weather permits, generally in the spring, adults resume consumption focusing on the first year cones and the male conifer flowers. All stages of *L. occidentalis* will pierce the freshly developed pollen sacs and consume them, causing necrosis in the flowers and reducing overall pollen production (Hedlin et al., 1981).

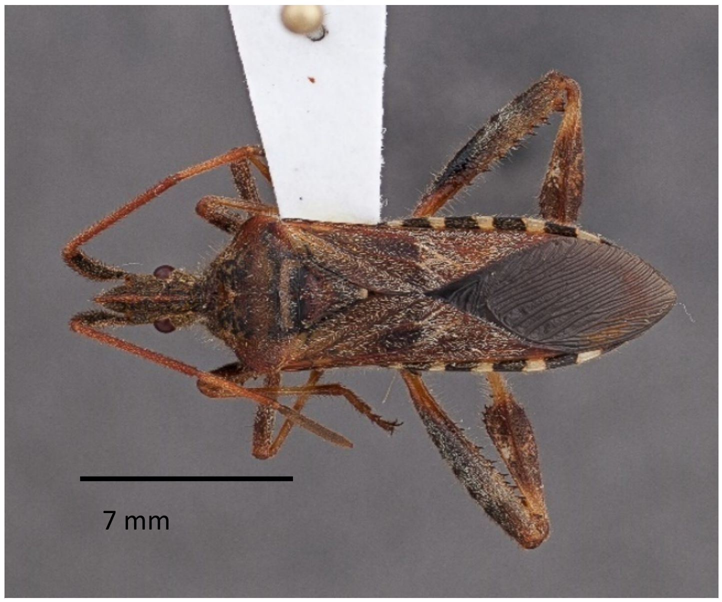

Figure 28. Top view of adult Leptoglossus occidentalis found in Arizona.

In summer, adults and nymphs will penetrate young and mature cones with the stylet, consume the internal seed and leave little external evidence. The cone continues to mature and only when the seed is exposed or internally evaluated can the damage be observed. Per cone seed damage estimates have not been established, but average damage appraisals on overall seed crops on western white pines have been observed around 26 percent (Hedlin et al., 1981).

I. Life History and Behavior

Figure 29. Early instar form of L. occidentalis. Photo credit: www.flickr.com/photos/bodorjanos40/5792554132

Leptoglossus occidentalis lays barrel shaped eggs from May until July (Kegley, 2006). Eggs hatch into nymphs which feed on seeds in developing cones. They develop through five nymphal instars and reach maturity by late August when they lay eggs on pine needles and overwinter as adults (Hedlin et al., 1981). The insect produces one generation per year (Koerber, 1963). The early instar nymphs are orange with two black dots on the dorsal portion of their abdomen (Figure 29). Nymphs will hide on the underside of foliage or cones when disturbed (Kegley, 2006) or jump to branches below to avoid being captured. Adults can fly away to avoid disturbance and produce a foul smell to avoid predation (Kegley, 2006). The adults can grow to be relatively large and are typically 15 to 18 mm long and 4 to 6 mm wide (Hedlin et al., 1981; Figure 28).

II. Geographic Range

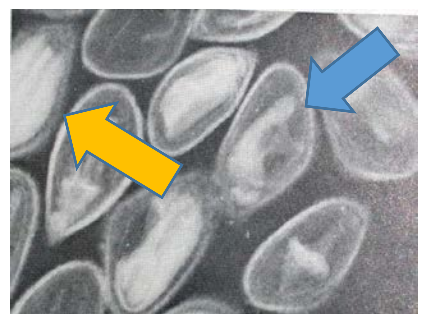

Figure 30. Image of damaged seeds (blue arrow) verses healthy seed (orange arrow) captured by radiographs. Photo from Forest Health and Protection, 2006 (Kegley, 2006).

The historic range of the *L. occidentalis* was anywhere west of the Mississippi from southwestern Canada to northwest Mexico, but since the 1970's it has extended its range eastward across North America. It is now a common pest in the Great Lake States and Ontario (Gall, 1992; Katovich and Kulman, 1987; Marshall, 1991; McPherson et al., 1990). Additionally, the insect has become an invasive pest across most of Europe. The pest was first introduced in Northern Italy and has spread all the way to Poland (Liz et al, 2008).

III. Management

Leptoglossus occidentalis is particularly difficult to observe, detect, and manage. The cryptic feeding leaves practically no observable damage until the cone has fully developed and dispersed the seeds, at which point the damage is evident on the shells of the seeds. Research has shown that the use of marker-based biochemical techniques, which utilizes synthesized polyclonal antibodies, could be implemented to detect lightly or severely damaged cones and estimate accurately the loss of seed crops due to *L. occidentalis* feeding (Lait et al., 2001).

Additionally, staining techniques and radiographs can be used on collected seed stock to detect damaged seeds (Kegley, 2006; Figure 30).

Leptoglossus occidentalis has been known to naturally aggregate in large numbers (Blatt, 1994). In these instances, pheromone baited traps can be used to detect their presence. Research done by Blatt and Borden (1996) suggests that the males produce a sexual aggregation pheromone that significantly attracts more insects of both sexes. We observed an aggregation of *L. occidentalis* once during this study on the San Francisco Peaks outside of Flagstaff, AZ where 16 *L. occidentalis* were found on the outside of a pollination bag that was covering a bundle of cones *in situ*. To date, no specific pheromone has been identified or synthesized; thus in order to attract this insect the use of live males could be utilized (Blatt and Borden, 1996). The limited use of Tanglefoot® we used to capture this elusive seed and cone guild member did successfully capture four *L. occidentalis*. We also used Lindgren funnel traps supplemented with alpha-pinene and pityol lure and found these were the most successful method for capturing *L. occidentalis* (57 collected by the end of the summer). Further research could be done on the attractiveness of the plant-based terpene alpha-pinene compared to other terpenes, such as beta-pinene.

If an effective attractant becomes available, then trap and kill methods could be deployed. The synthetic pesticide pyrethroid: permethrin, has been used successfully to control *L. occidentalis* in north Idaho western white pine seed orchards (Kegley, 2006). There are natural predators and parasitoids of *L. occidentalis* that could be used for biological control (Bates, 2004). In the Northwest three parasitoid species have been identified for the *L. occidentalis*: *Gryon pennsylvanicum, Anastatus pearsalli* and *Ooencyrtus sp.* (Bates, 2004; Burks, 1979; Gordh, 1979; Masner, 1983; Mitchell, 1983; Yasuda, 1990; Daane et al., 2001).

Coleoptera; Curculionidae

Conotrachelus neomexicanus

The adult pine cone weevil can be easily identified by their long snout. The adults are gray-brown and can grow to a length of 6 mm. Larvae are light-brown in color, curved, legless, and can grow to 10 mm in length (Keen, 1958, Hedlin et al., 1981). We only collected weevils from ground plot collections of the *P. strobiformis* and did not observe it in the cones collected from the canopy. Due to low numbers of incidence they are considered overflow from the *P. ponderosa* hosts.

I. Host Range

The principal host of this species is the *P. ponderosa* and infrequently the *P. strobiformis*.

II. Geographic Range

The pine cone weevil can be found from the west coast of Canada southward through the interior mountain west and into central Mexico's Sierra Occidental Mountain range. Isolated pockets have been identified in the mountains of Chihuahua, Mexico as well (Hedlin et al., 1981).

Diptera: Cecidomyiidae:

Asynapta hopkinsi

The cone resin midge was observed sporadically on the cones of *P. strobiformis*. The larvae are bright red to orange and typically 1-2 mm in length. The larvae feed between the cone scales on the sap excreted from the cones and do not appear to damage the seed crop. Due to the low levels of damage attributed to the resin midge they are considered of little concern in *P. strobiformis* seed development.

Figure 4. Larval form of Asynapta hopkinsi consuming a cone. (Photo credit: Steven Katovich, USDA Forest Service, Bugwood.org)

Table 3. Host range of selected cone and seed insects collected in this project (Hedlin et al., 1970; personal observations)

Insect Host Range

Tree Species	Conophthorus ponderosae	Dioryctria abietivorella	Eucosma ponderosa	Eupithecia spermophaga	Leptoglossus occidentalis	Asynapta hopkinsi
Pinus strobiformus (Southwestern white pine)	X	X	X	X	X	X
Abies amabilis (Pacific silver fir)				X		
Abies balsamea (balsam fir)		X				
Abies concolor (white fir)		X		X		X
Abies grandis (grand fir)		X			X	X
Abies lasiocarpa (subalpine fir)		X		X		X
Abies magnifica (California red fir)		X		X		X
Larix occidentalis (western larch)		X				
Picea glauca (white spruce)		X				X
Picea mariana (black spruce)		X				
Picea pungens (blue spruce)		X				
Picea rubens (red spruce)		X				
Pinus attenuata (knobcone pine)					X	
Pinus banksiana (Jack pine)		X				
Pinus contorta (lodgepole pine)	X	X			X	
Pinus flexilis (limber pine)	X	X		X	X	X
Pinus jeffreyi (Jeffrey pine)	X		X		X	X
Pinus lambertiana (sugar pine)	X					X
Pinus monticola (Western white pine)	X	X		X	X	
Pinus mugo (Swiss mountain pine)		X				
Pinus ponderosa (ponderosa pine)	X	X	X	X	X	X
Pinus radiata (Monterey pine)					X	
Pinus resinosa (red pine)		X				X
Pinus strobus (Eastern white pine)		X			X	
Pinus sylvestris (Scotch pine)		X				
Pseudotsuga menziesii (Douglas-fir)		X		X	X	
Tsuga mertensiana (mountain hemlock)				X		X

Conclusion

We documented what we believe are the first recorded associations between some insects with *P. strobiformis*. None of the Lepidopteran species had been previously documented damaging the cones of *P. strobiformis*. Furthermore, *Conphthorus ponderosae* and *Conophthorus flexilis* had not been specifically associated with the *P. strobiformis* in prior research. *Leptoglossus occidentalis* is considered a generalist feeder and previous literature reports that it feeds on all *Pinus* species, but this is the first report of it feeding on *P. strobiformis*. Impacts from *P. strobiformis* seed and cone insects vary annually depending on climatic events, predatory success, and cone/seed production, but the damage can be significant.

Research is underway to identify stands and individual trees with some level of genetic resistance to the white pine blister rust. Once these individual trees are identified then the protection and reproduction of their genetics will be amplified in importance. Now that the *P. strobiformis* seed and cone insect guild has been identified and possible management techniques for minimizing seed loss associated with them has been established, resource managers can begin implementing different techniques to create an adaptive and integrated pest management scheme.

Seed collections are currently being conducted in natural stands of *P. strobiformis* instead of artificial seed orchards. When specific trees have been identified with beneficial traits, such as increasing the likelihood of surviving climate change or resistance to white pine blister rust, then protection of their seed will be a priority. In years of heavy cone production, the seed and cone insects that comprise the *P. strobiformis* guild typically do not damage enough cones to warrant active management. Conversely, in years when cone production is low the need for protection of the seed increases. It is quite possible that resource managers will need to develop seed orchards in the mountains of the Southwest to accelerate the restoration process from potential losses of *P. strobiformis* to white pine blister rust.

The effects of climate change and white pine blister rust will increasingly impact *P. strobiformis* across the Southwest. Seed from resistant trees will be the foundation for a conservation program to manage loss of this critical forest species. Protection of the seeds from natural predators will increase seed supplies and expedite the restoration and conservation of *P. strobiformis*. This study shows that the seed and cone insect guild do impact *P. strobiformis* cone and seed production across the Southwest. Resource managers should consider protecting cones on high-value *P. strobiformis* trees that have been identified with beneficial genetics, from seed and cone predators.

Further research is needed in applied protection and control methods in the Southwest for successful and efficient *P. strobiformis* cone protection.

Glossary of Terms

canker: A defined area of diseased tissue, especially in woody stems.

cone: The female strobilus of pines during the second season of development or of most conifers during the single season of development.

conelet: The female strobilus of: (a) pines during the first season of development following pollination, and (b) early stage of cone development of conifers n which cones develop in one season.

cortex: a. The portion of a stem between the epidermis and the vascular tissue; bark.
b. Any outer layer, as rind.

diapause: A condition of suspended animation or arrested development during the life cycle of an insect.

frass: The solid excrement of an insect, particularly of larvae.

instar: The form of an immature insect between molts.

invasive: Not native to and tending to spread widely in a habitat or environment. Invasive species often have few natural predators or other biological controls in their new environment. Although not always considered harmful to an environment, invasive species can become agricultural or ecological pests and can displace native species from their habitats.

macrocyclic: Fungi that produce all five spores (sometimes excluding pycniospores).

metamorphosis: The process of change through which an insect develops to maturity: *Complete Metamorphosis* is that process in which four insect stages occur: egg, larva, pupa and adult. In this type of metamorphosis, the larva usually differs greatly in appearance, feeding, and often in habitat niche from the adult. *Gradual metamorphosis* is the process in which only 3 stages occur: egg, nymph and adult. Nymphs in general resemble the adult both in form and habits, although wings are generally not fully formed until the adult stage.

moth: Any of numerous insects of the order Lepidoptera, generally distinguished from the butterflies by having feathery antennae and by having crepuscular or nocturnal habits.

necrosis: Death of a circumscribed portion of animal or plant tissue.

nymph: The immature feeding stage of insects that develop to the adult without a pupal stage. Nymphs are usually similar in form to the adult, but generally do not have fully formed wings.

parasitoid: Any of various insects, such as the ichneumon fly, whose larvae are parasites that eventually kill their hosts. The adult parasitoid deposits an egg on or inside the body of its host, typically the larva of another arthropod. When the egg hatches, the parasitoid larva feeds on the host's tissues, gradually killing it.

pathogen: Any disease-producing agent, especially a virus, bacterium, or other microorganism.

pest: An insect or other small animal that harms or destroys garden plants, trees, etc.

phenology: The study of recurring phenomena, such as animal migration, especially as influenced by climatic conditions

pheromone: A chemical substance, secreted externally by certain animals, such as insects, affecting the behavior or physiology of other animals of the same species

pitch tube: An extrusion of resin and often frass or borings at the point of entry of an insect tunnel into bark, cones, etc., of various conifers.

polyphagous: The habit of subsisting on many different kinds of food.

proboscis: Any extended mouth structure.

pupa: Resting stage of insets having complete metamorphosis.

range: The limits within which a person or thing can function effectively.

seed coat: The hard covering of a seed.

speciation: The formation of new species as a result of geographic, physiological, anatomical, or behavioral factors that prevent previously interbreeding populations from breeding with each other.

stylet: Any small pointed bristle-like part.

subcortical: Situated beneath the cortex.

*Term definitions taken from [Internet] http://www.dictionary.com/, Cone and seed insects of North American conifers (Hedlin et al., 1980), and [Internet] www.thesciencedictionary.com, [Internet] www.for.gov.bc.ca

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