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Populations of Pear Thrips, *Taeniothrips inconsequens* (Thysanoptera: Thripidae) in Sugar Maple Stands in Vermont: 1989-2005

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Abstract

Development of an effective IPM strategy for pear thrips, *Taeniothrips inconsequens* (Uzel) (Thysanoptera: Thripidae), a pest of sugar maple, *Acer saccharum* Marshall, demands an understanding of their population fluctuations over time. Pear thrips populations were monitored using a standardized soil sampling method every fall from 1989 – 2005 in 14 counties of Vermont (U.S.). Data from individual sites were combined into north, central and south regions. High numbers of thrips emerged from soil sampled in 1989, 1990, 1993 and 2001, particularly in the north region (Washington, Lamoille, and Franklin counties). The central and south regions had lower pear thrips populations over all years. These results provide, for the first time, fundamental knowledge of pear thrips populations across a wide geographical area of Vermont and will assist in the design of suitable control strategies for pear thrips in the future.

The sustained health of sugar maple, *Acer saccharum* Marsh, is critically important in the northeastern U.S. because of its economic value (Horsley et al. 2002, Werner et al. 2005). Its wood is highly valued for furniture, its sap is used to produce maple syrup and its world famous fall foliage draws millions of tourists annually. The total value of maple syrup production in New England was estimated at $34 million in 2007 (NASS 2007, Sinclair 2007). Vermont's 2007 revenue from maple syrup sales was $14 million, and exceeded $130 million when proceeds from value-added products such as maple candies, cream, and syrup repackaging for retail were added.

High maple sap yield is associated with tree health and growth as measured by the following factors: living crown ratio, width of the crown, and overall growth rate (Moore et al. 1951). Generally, sugar maple is affected by a variety of abiotic and biotic factors that cause economic loss by reducing tree vigor and causing root, stem, and crown damage. Soil moisture, extreme weather events including late spring frosts, midwinter thaw and freeze cycles, ice damage, and atmospheric deposition are among the important abiotic factors (Horsley et al. 2002). Sugar maple is exposed to a variety of rots, cankers, wilts, defoliators, borers, sucking insects, bud miners, and diseases (Godman et al. 1990). In forests from which maple syrup is produced, stands are commonly thinned to create essentially a sugar maple monoculture which encourages pest outbreaks much like what occurs with other agricultural production environments such as western corn rootworm in corn (Schroeder et al. 2005) and white pine weevil in white pine plantations (Taylor et al. 1996). Among the numerous biotic factors attacking maples, foliage-consuming insects are regarded as the most serious problem over a wide geographic area. Loss of foliage early in the growing season reduces the accumulated levels of nonstructural carbohydrates related to

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sap production. Pear thrips, *Taeniothrips inconsequens* (Uzel) (Thysanoptera: Thripidae), is an exotic invasive pest that significantly impacts maple health and the economic potential of sugar maple trees. The importance of controlling pear thrips has been documented by Kolb et al. (1992), who reviewed the thrips outbreak in the Northeast in the late 1980s.

Pear thrips was originally considered a pest of fruit trees primarily (Bailey 1944). They were first identified causing injury to sugar maple in Pennsylvania forests in 1980 (Laudermilch 1988). Thereafter heavy foliar injury to sugar maple trees occurred for several years in the Northeast, with the greatest impact in 1988 and 1989 (Parker et al. 1992, Kolb and McCormick 1993). Introduced into California around 1904 (Bailey 1944), pear thrips is now distributed widely in the U.S. Adult pear thrips emerge from soil in early spring and feed on foliar and flower tissues, often within swollen buds prior to budburst (Kolb and Teulon 1992, Bailey 1944). Synchrony between sugar maple budburst, pear thrips emergence from soil, and cool temperatures that slow budbreak promotes injury (Kolb and Teulon 1991), because most pear thrips feeding and damage is done inside the bud before the leaves expand. The bud contains multiple tiny leaves folded together, and the leaf tissue within the bud is very tender. When a pear thrips inserts its stylet into the tissue, it can damage multiple leaves simultaneously. As the buds unfold, leaves that have been heavily fed on by pear thrips are tattered, chlorotic, and misshapen. In years when there is a longer time between initial budbreak (when the bud is open enough to allow the entry of thrips) and leaf expansion, greater damage may occur because pear thrips have more time in which to feed on the tender leaflets within the protection of the bud.

Heavy injury by pear thrips results in nutritional deficiencies for the tree and entry points for foliar diseases (Kolb et al. 1990). Heavily damaged trees have lower levels of sap and nonstructural carbohydrates, and reduced sugar contents in sap (Kolb et al. 1992, Kolb and McCormick 1993). After attack by pear thrips, the foliage of seedlings and mature trees are highly susceptible to maple anthracnose infection caused by *Discula campestris* (Pass.) Arx (Horsley et al. 2002).

The biology of pear thrips has been studied intensively, but little information is available on population fluctuations across wide geographical areas over multiple years. The present work describes the occurrence of pear thrips in 14 counties of Vermont (U.S.) for 17 years from 1989-2005 based on sampling populations in the soil in the fall. This provided an estimate of the population level prior to emergence in the spring, eliminating confounding factors resulting from aerial migration. Several different methods of sampling for pear thrips have been used previously, including various methods of soil extraction (Parker et al. 1992, Skinner and Parker 1995, 1996), aerial trapping (Teulon et al. 1992, Coli et al. 1997) and bud sampling (Teulon et al. 1992). The soil sampling and natural forced emergence extraction method used for this study was simple, reliable and cost-effective, allowing the processing of the large numbers of samples required to conduct sampling over a wide area.

Materials and Methods

Sampling procedure. Pear thrips populations were determined by taking soil samples in forest stands throughout Vermont where sugar maple made up >75% of the basal area. The state was separated into three regions, north, central and south, and forest stands predominating in sugar maple within each county in these regions were selected for sampling (Table 1). Stands selected were 6 – 10 ha in size at elevations of ~365 to 550 m, located at latitudes from 42°47´N to 44°58´N and longitudes from 71°40´W to 73°15´W.

Samples were taken in the fall (Sept. – Nov.) according to a standardized thrips soil survey protocol developed based on extensive sampling within forest

Table 1. Geographical sampling information for the Vermont pear thrips population study.

Region	County	No. of sites sampled
North	Franklin	12
	Washington	21
	Caledonia	11
	Chittenden	7
	Lamoille	9
	Orleans	7
	Essex	5
	Grand Isle	3
Central	Orange	12
	Addison	5
	Rutland	5
South	Bennington	10
	Windham	10
	Windsor	14

stands to determine the number of samples required to obtain a reliable estimate of the population (Skinner 1993, Skinner and Parker 1995). Five dominant or co-dominant sugar maple trees (A co-dominant tree receives direct sunlight from above, not from the side due to crowding from the canopy of adjacent trees.), located at least 60.8 m apart and distributed throughout each stand, were selected for sampling. Soil samples were taken at 2 and 4 m from the bole of each sample tree with a bulb planter (10 cm long, 7.2 cm top diam., and 6.0 cm bottom diam.). Previous research has shown that >80% of the pear thrips are found to a depth of 10 cm (Skinner 1993). Samples were held in the dark at 4°C prior to inducing emergence.

Induction of pear thrips emergence in soil samples. Each soil sample (200 g) was held individually in a container (9.5 cm diam., 10 cm height) covered with a clear sticky lid, sticky-side down, ensuring that soil did not touch the sticky surface of the lid. The sticky lids were made with clear plastic sheets (1~2 mm thick, 18 cm^2) coated with a thin layer of Tanglefoot™ (Tanglefoot Co., Grand Rapids, MI). The sticky lids were secured with tight-fitting clear plastic covers or rubber bands. All containers were kept at room temperature for 35 d, away from direct sunlight and heat. After 35 d, the number of pear thrips per sticky lid was counted using a magnifying glass (10×).

Data analysis. The number of pear thrips that emerged from the two soil samples per tree was averaged to obtain the mean number of thrips per soil sample per tree. Means per soil sample per tree were further averaged for the five trees at each site to determine the mean number of thrips per soil sample per site. This provided a relative estimate of the population level within a site. Thrips population data were checked for normality with the Anderson-Darling test. Because the data were not normal, mean relative numbers of pear thrips in each site were analyzed by the generalized linear model (GzLM), assuming a Poisson error distribution linked with a logarithmic function (deviance ratio = 1.07) (McCullagh and Nelder 1989). A bubble graph showing the overall geographical distribution of pear thrips for the whole periods was generated on the Vermont map. All analyses were conducted using SPSS ver. 17.0 (SPSS Inc., 2009) or Minitab ver. 15.0 (Minitab Inc., 2008) with an α level of 0.05.

Results

Annual emergence of pear thrips. Overall, significant differences occurred among the annual numbers of emerged pear thrips (χ^2 = 1495.91, df = 16, P < 0.001). High pear thrips population levels occurred in 1989-1990 and again in 1993 and 2001 (Fig. 1). In 1989 and 1990 populations were 6.4 ± 1.2 and 6.9 ± 1.3 pear thrips/sample/tree, respectively. These population levels were significantly higher than the lowest population in 2000 (0.2 ± 0.01 pear thrips/sample/tree), which was set as a reference for annual comparisons in the analysis. Though lower than emergence levels in 1989-1990, populations in 1993 and 2001 were also relatively high, 3.1 ± 0.6 and 2.9 ± 0.7 pear thrips/sample/tree, respectively, compared to the reference.

Geographical distribution of pear thrips emergence. Significantly more pear thrips emerged from samples collected in the north than in the south (χ^2 = 15.2, df = 1, P < 0.001), whereas differences in pear thrips emergence between the central and south counties were not significant (χ^2 = 0.1, df = 1, P = 0.734) (Fig. 2). Pear thrips population levels were not consistently high in all counties within the north region. Three northern counties (Franklin, Lamoille and Washington) had significantly higher levels of emergence than Essex county which was set as a reference for the northern region [Franklin (χ^2 = 69.9, df = 1, P < 0.001), Lamoille (χ^2 = 47.5, df = 1, P < 0.001), and Washington (χ^2 = 31.6, df = 1, P < 0.001)]. Specifically, high levels of emergence were observed in the Sheldon, Bakersfield, Fairfax sites in Franklin county; the Waterbury, Barre and Duxbury sites in Washington county; and Stowe, Johnson and two Waterville sites in Lamoille county.

The highest population levels of pear thrips were found in the western and middle part of the north region of Vermont (Fig. 3). A cluster analysis indicated that counties of Vermont can be grouped into four categories according to thrips abundance: very high abundance (mean of 15 pear thrips/sample/

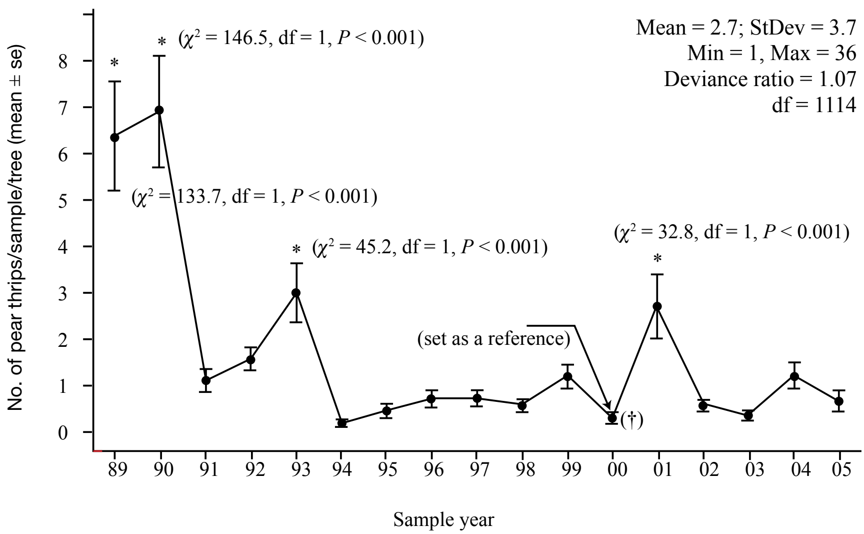

Figure 1. Mean number (± SE) of pear thrips/soil sample/tree averaged across sites and counties in Vermont from 1989-2005 (n = 1131 data points obtained from averaging the mean number of thrips per site [mean of 10 soil samples per site; 2 per tree]). Numbers marked with an asterisk (*) are significantly different from the mean number in 2000 (†), which was set as a reference in the GzLM analysis (P = 0.05).

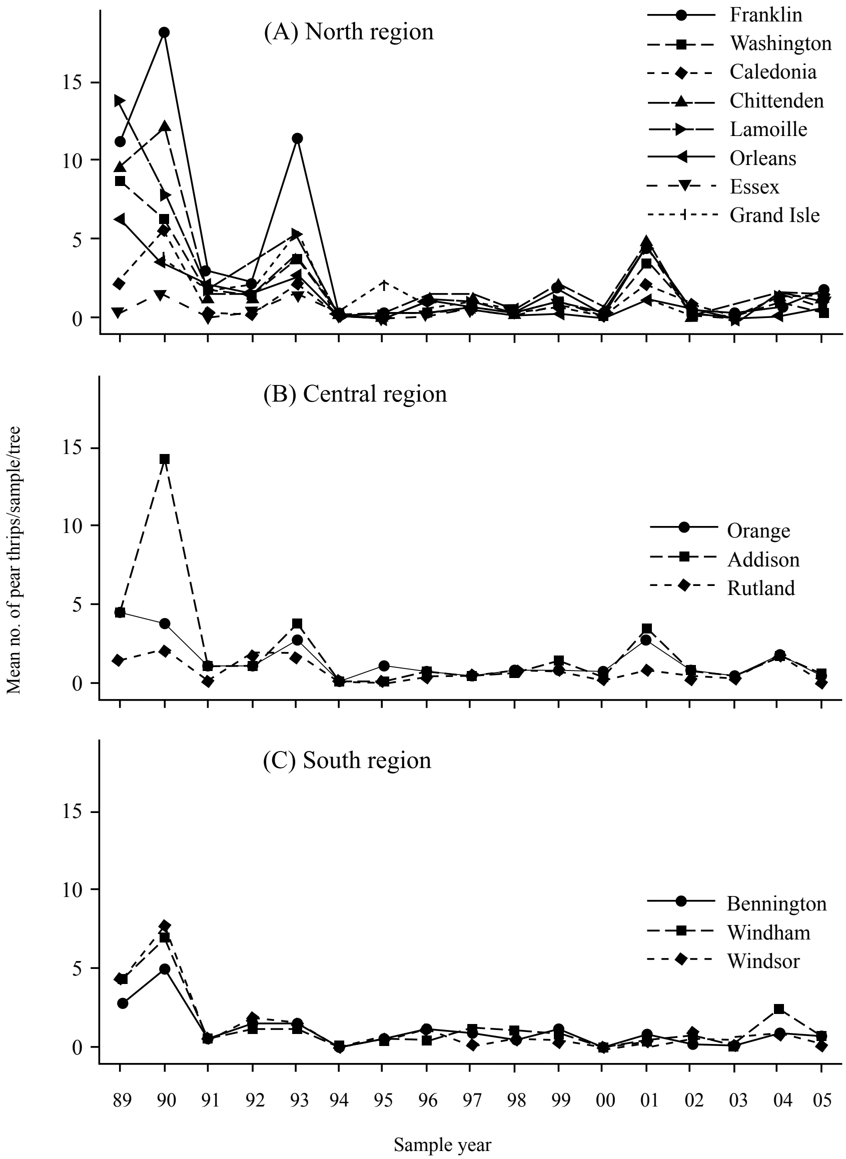

Figure 2. Mean number (± SE) of pear thrips/soil sample/tree averaged across sites within counties of the north (A), central (B), and south (C) regions of Vermont from 1989-2005 (n = 1131 data points obtained from averaging the mean number of thrips per site [mean of 10 soil samples per site; 2 per tree]).

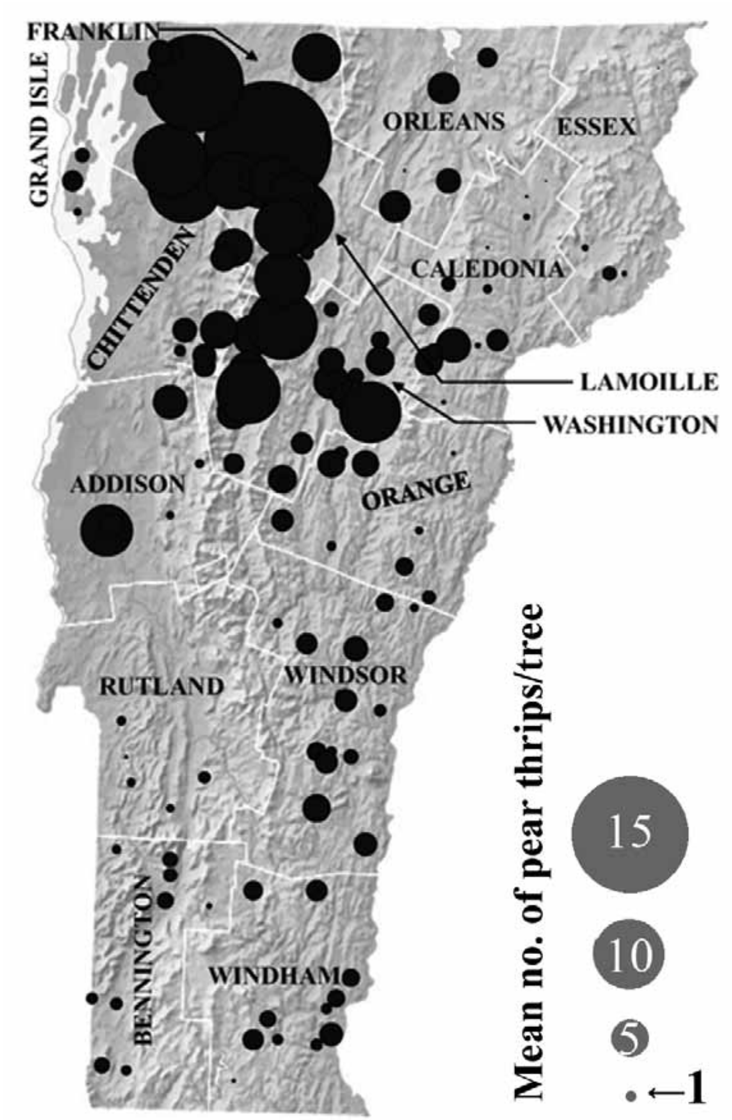

Figure 3. Geographical distribution of the relative abundance of pear thrips averaged over 1989-2005, based on soil sampling in different sites throughout Vermont, displayed as circles of different sizes relative to thrips numbers within counties in Vermont (n = 1131 data points obtained from averaging the mean number of thrips per site [mean of 10 soil samples per site; 2 per tree]) and results of the clustering analysis (Ward's method, with correlation coefficient distance) for the pear thrips distribution based on county.

tree) in Franklin, Lamoille, Washington, Orleans, and Orange counties; high abundance (mean of 10 pear thrips/sample/tree) in Bennington, Windham, and Windsor counties; moderate abundance (mean of 5 pear thrips/sample/tree) in Caledonia, Chittenden, and Rutland counties; and low abundance (mean of 1 pear thrips/sample/tree) in Addison, Essex, and Grand Isle counties.

Discussion

This project provided a long term evaluation of trends in pear thrips over 17 years. Population levels of pear thrips fluctuated slightly from year to year, while high populations occurred in some sites sporadically. Specifically, relatively high thrips populations occurred in 1989-1990, and again in 1993 and 2001. In general, the highest thrips populations were found in the north region. Relatively low pear thrips populations were observed in 1994-2000 and 2002-2005, but a few thrips were generally found each year in every site, which served as a source for subsequent higher populations in some sites. A clear cyclical pattern in the populations of pear thrips was not evident, though the pest was present throughout the state over the entire sample period.

Extensive research has been done previously in an attempt to understand the factors that influence the population dynamics of thrips, including pear thrips (Kirk 1997, Teulon et al 1998). Because of their small size and cryptic behavior, determining the reasons for fluctuations in thrips population levels is particularly challenging. In addition, in the case of pear thrips, heavy foliar damage is not a reliable way to assess population levels because of the influence of the timing and duration of maple budbreak. The number of pear thrips in the soil was not consistently correlated with damage in the spring (Skinner et al. 1996). When budbreak is delayed due to cold temperatures late in the spring, pear thrips can feed within the partially open buds for a longer time causing serious damage, even if populations are low (Kolb and Teulon 1991). The insect's biology, host plants and multiple environmental factors interact to influence the population dynamics of pear thrips in sugar maple forest stands. The complexity of these interactions, and the costs associated with measuring these factors prevent their study over a long time period or over a wide geographical area. This study focused solely on measuring the number of pear thrips emerging from the soil to better understand the pattern of fluctuations in their population levels over time. These emerging pear thrips represented the population that would be present in the spring to feed on and damage sugar maple foliage, and ultimately reproduce.

Several biotic and abiotic factors have been reported to impact pear thrips population levels, based on short term research (Kirk 1997, Teulon et al. 1998). These studies help to explain why fluctuations in the populations sampled over 17 years lacked evidence of a cyclical pattern. The tree species composition in a forest is one factor that is likely to influence pear thrips populations. Historically, when forests are managed for production of maple syrup, non-maple species are removed to achieve a basal area of >75% sugar maple. While improving maple health, this monocroping favors the buildup of pests such as pear thrips (Kirk 1997). Because all of the stands sampled in this study had similar proportions of sugar maple, this should not have influenced the results directly. However, thrips readily fly long distances and thus could migrate from forests surrounding the stands where samples were collected. Therefore, tree species composition in nearby forests could have an influence on population levels and may help explain the geographical distribution of pear thrips on a statewide basis. The species distribution of sugar maple is fairly constant throughout the state, but distribution of conifers and other hardwoods vary greatly statewide. For example the forest composition of Essex, Orleans, Caledonia, and parts of Bennington counties, where low levels of pear thrips populations were observed, have relatively high proportions (20-49%) of balsam fir, *Abies balsamea* (L.) Miller, which is not a pear thrips host (Wharton et al. 2003). The potential impact of forest composition on pear thrips populations support current forest management recommendations that encourage promoting a diverse forest composition that includes conifers such as balsam fir.

Pear thrips, like many other thrips species, feed on pollen as well as plant sap, and the reproduction potential of thrips is enhanced when pollen is a significant component of their diet. While every year some flowers can be found on maple trees, in some years they produce particularly large numbers of flowers, providing pear thrips with an abundant source of pollen on which to feed. Teulon et al. 1998 found the amount of maple flowers to be an important factor influencing pear thrips population levels. It is unknown what stimulates maples to produce more flowers, and this phenomenon can sometimes occur in an individual stand or in an entire area. It is likely the amount of flowers in a stand influenced population levels in the stands sampled for this study as well.

Pear thrips spend about 10 months of the year within the top 10 cm of the soil, which provides protection from most extreme weather conditions that could affect population levels (Skinner et al. 1991). Though this segment of the soil may freeze over the winter if snow cover is insufficient to insulate it, there is no evidence to suggest pear thrips are killed by freezing. They readily emerge when the ground thaws. However, heavy rain has been reported to negatively impact survival of many thrips species (Kirk 1997). In the early summer pear thrips larvae drop from the tree canopy, crawl over the forest litter for a few days and then enter the soil where they aestivate over the summer and overwinter. This usually occurs over a relatively short period of about one week, during which time large numbers of soft-bodied larvae can be seen clinging to the undersides of leaves on the forest floor. Heavy rains during that time could greatly reduce populations. State climate data are of little value for understanding the pear thrips population fluctuations because weather conditions vary greatly from site to site. Droughts are relatively rare in Vermont's forests, and therefore are not likely to affect pear thrips populations. However, some maple forests at high elevations occur on ledge sites where the soil and litter layer is relatively shallow, which could contribute to pear thrips mortality.

Though a wide range of general predators occur in the sugar maple ecosystem, none have been observed in sufficient numbers to affect pear thrips populations. However, the entomopathogenic fungus, *Lecanicillium lecanii* (Zimmermann) Viegas, was found infecting pear thrips larvae extracted from forest soil. In 1989, around 12% of the pear thrips extracted from forest soil were infected, compared to only 2 and 4% from northern and central Vermont (Skinner et al. 1991).

In conclusion, relatively high populations of pear thrips were observed in the north region of Vermont over several years in the early 1990s, which likely impacted sugar maple tree health for several subsequent years. For the past 17 years after the initial outbreak, soil samples were taken throughout the state, showing that pear thrips populations fluctuate somewhat, but have not reached the high population levels first observed. Due to the multiple complex interacting biotic and abiotic factors, it is impossible to identify the specific conditions that contribute to the fluctuations in pear thrips populations from year to year. Though population levels since the outbreak have been comparatively low, pear thrips continue to survive in Vermont forests, and remain a threat to the sugar maple resource.

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