Spruce Aphid in High Elevation Habitats in the Southwest U.S.

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Abstract

Spruce aphid, *Elatobium abietinum* (Walker) (Homoptera: Aphididae), is a new invasive pest in the interior Southwestern United States. This insect is causing extensive and severe damage on dormant Engelmann spruce, *Picea engelmannii* Parry, and Colorado blue spruce, *P. pungens* Engelm., in high elevation forests in late fall and winter. Engelmann spruce is more susceptible than is Colorado blue spruce. Average mortality on heavily defoliated plots is 28-42%, with 100% mortality on some plots. In other regions, where the insect develops high density populations in the spring, it's mostly parthenogenic population dynamics and damage are limited to areas where temperatures seldom fall below freezing. In the interior Southwestern U.S., populations increase in the fall, and a sexual life cycle and greater cold-hardiness are possible factors contributing to the insects success under more severe conditions. Outbreaks appear to be associated with dry winter and spring weather prior to the fall and winter in which feeding occurs.

Invasive History

In 1976, spruce aphid was found in urban Santa Fe, New Mexico, 1300 km from the Pacific coast. A wildland outbreak occurred over the 1987-1988 winter in the White Mountains of Arizona, the first outbreak documented in interior wildland forests. Since then the spruce aphid range has expanded to five mountain ranges in Arizona and New Mexico, and three of the last six winters have incurred outbreaks (Lynch *et al.* in press). The 1999-2000 outbreaks were alarming for their severity and extent. In that year, approximately 57,000 ha in the White Mountains were defoliated, with severe defoliation on 9,300 ha. At the same time, 120 km to the south, the first outbreak in the Pinaleño Mountains severely defoliated two-thirds of the host type in a single season.

The host species in the Southwest U.S. are Engelmann spruce and Colorado blue spruce. Both species occur naturally in mixed-conifer and spruce-fir forests above 2400 m. Both species, but especially Colorado blue spruce, are commonly planted in urban forests.

Spruce aphid, known in Europe as green spruce aphid, has a history of causing problems in maritime forests, principally in the United Kingdom, Fennoscandia, Denmark, Iceland, and the North American Pacific Northwest coastal areas (Day *et al.* 1998). In those areas the most important hosts are Sitka spruce, *P. sitchensis* (Bong.) Carr., white spruce, *P. glauca* (Moench) Voss, and Norway spruce *P. abies* (L.) Karst. In many areas, both the host species and the insect are exotic.

Spruce aphid has been found in North America since 1916 (Carter & Halldórsson 1998, Keen 1939, Koot & Ruth 1971), probably introduced from Europe (Bejer-Petersen 1962, Carter & Halldórsson 1998). On Sitka spruce in coastal forests of western North America, spruce aphid has been a chronic pest, but occasionally causes severe tree mortality in local areas (Koot 1992). Recently there has been some concern that the spruce aphid problem has become more extensive and severe in the North American Pacific Northwest area, contributing to decline in shore-line stands as well as defoliating stands further inland and at higher elevations than in the past.

Life Cycle And Weather

In maritime climates, spruce aphid population dynamics are limited by cold temperatures, with starvation occurring below 6°C, cold damage below 0°C, and freezing at -5°C. Outbreaks do not occur in years or places with any monthly mean temperature falling below freezing or with ambient temperature falling below -7 to -14°C (different temperatures are specified by different authors). Damage occurs from high density populations that develop parthenogenically in the late winter and spring (see various papers and references cited in Day *et al.* 1998). A critical factor in population dynamics is that aphid populations increase to damaging levels only on dormant trees.

In the Southwestern U.S. mountains, ambient and monthly mean temperatures fall well below the temperatures that limit aphid populations in maritime climates. Population increases occur in the fall and early winter, and populations may persist over the winter. Although population increases appear to be from parthenogenic reproduction, numerous sexual males are produced each year, especially in early winter (late November or December). I assume that cold-hardy eggs are produced by the sexual forms, and that this stage allows survival during the coldest winter temperatures. A holocyclic life history prevails in Scandinavia and in the native territory in Germany, where the insect is mostly innocuous (Bejer-Petersen 1962; Bevan 1966; Carter & Halldórsson 1998).

The production of cold-hardy eggs could explain population persistence in mountain areas with cold winters, but does not explain population increase and survival during the fall. Aphid populations in the Southwest U.S. are clearly surviving, increasing, and causing severe defoliation and related tree mortality under conditions that maritime populations cannot. Mountain populations appear to exhibit additional cold-hardiness than do maritime populations. At this time I do not know what contributes to the additional cold-hardiness, but suspect a) that individuals develop more cold-hardiness under fluctuating diurnal temperatures, b) that host foliage chemistry may provide additional protection (aphids lose some cold-hardiness after feeding on Sitka spruce, and Engelmann spruce is much more cold-hardy than Sitka spruce), or c) a genetic change has occurred. Understanding the mechanisms behind spruce aphid cold-hardiness is critical to determining how much of the Engelmann spruce range is at risk from this insect.

In the mountains, there is a tendency for spruce aphid outbreaks to follow dry winter and spring weather (Fig. 1). This tendency does not appear to be influenced by the amount of moisture received later during the summer monsoon. Spruce aphid populations increase when the host trees are dormant, both in maritime climate (in the spring) and in temperate climate (in the fall). I speculate that minimal snowpack accumulation, or early loss of snowpack, affects soil temperature such that tree phenology is affected: early soil warming cause trees to break dormancy early, subsequently causing them to enter dormancy early in the fall. This would provide dormant foliage as a food resource over a sufficiently long, and relatively warm, period for populations to increase before extremely low temperatures occur. Also, moisture stress early in the growing season might alter foliage chemistry so that it is a more suitable food resource. In all likelihood, susceptibility is related to a combination of factors including prior winter and spring weather, autumn temperature regimes, host response to previous feeding, and the size of the pre-existing spruce aphid population.

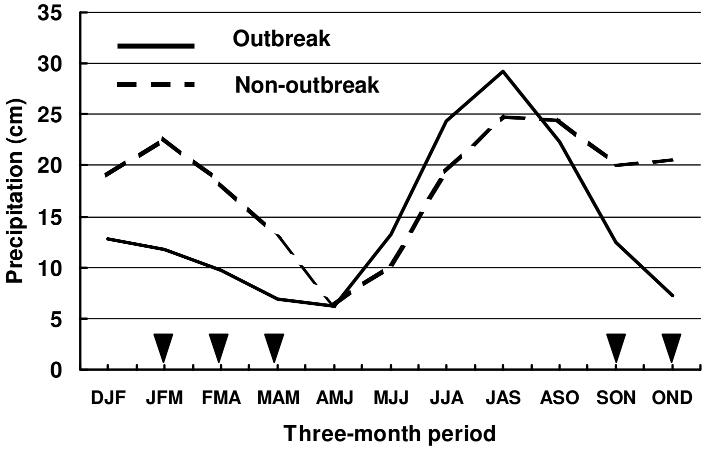

Figure 1.—Three-month running average of precipitation in the White Mountains of Arizona, for years with and without fall spruce aphid outbreaks (DJF through JJA would precede the outbreak) (1981-2001). Triangles indicate significantly different means ($P < 0.10$).

Tree and Stand Damage

Defoliation is variable from watershed to watershed, with less variability within each stand. Individual tree defoliation frequently approaches 100%. All size and age classes of trees are affected, and Engelmann spruce is more susceptible than Colorado blue spruce (Fig. 2). On trees 4 cm or larger in dbh, tree size does not influence the severity of defoliation (Fig. 2). Quantitative data on regeneration size classes is inadequate, but reconnaissance indicates that seedlings and saplings are more severely defoliated than larger trees. In the White Mountains, average plot mortality on heavily defoliated plots (mean defoliation index of 6 or greater, a rating that indicated that all crown thirds were 34% or more defoliated) was 28-42% three years after defoliation, with 100% mortality on some plots. On an individual tree basis, those most likely to die (67% mortality) were spruce of either species with severe defoliation plus heavy infections of spruce dwarf mistletoe, *Arceuthobium microcarpum* (Engelmann) Hawksworth & Wiens (Viscaceae).

Management concerns include resource values affected by tree mortality (particularly timber and recreation), increased risk of wildfire, increased risk of bark beetle outbreak, and impacts to wildlife habitats. In the long run, the possibility of repeated events leads to concerns about the loss of established regeneration and anticipated failure of defoliated trees to set viable seed, and subsequent effects on tree population dynamics.

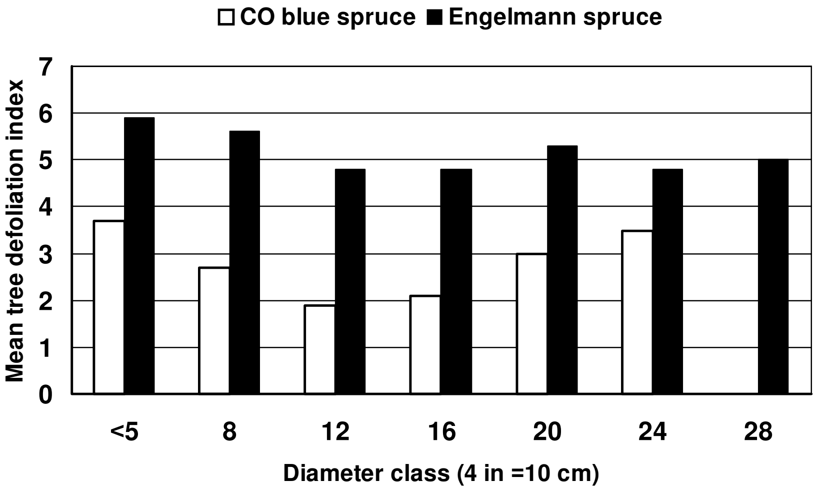

Figure 2.—Defoliation of spruce with dbh of 4 cm or greater in the White Mountains. Over the 1996-1997 outbreak. Defoliation Index is a sum of three ratings, where each crown third is rated as 0, 1, 2, or 3, by 33% defoliation (an index of 9 indicates that each crown third was 67-100% defoliated).

Future Prospects

If outbreak frequency is low, then many trees should be able to survive and reproduce. Spruce aphid feeds on foliage that was produced in the growing season prior to autumn feeding (years *n*-1, *n*-2, etc.). The current year's foliage (year *n*) is not a suitable food resource until at least late autumn. This feeding pattern allows trees to gather nutrients and set buds prior to defoliation. In some less severe episodes, not all of the year *n* foliage is lost. Therefore, in year *n*+1, buds will flush on surviving trees and branches, and some of year *n* foliage might be retained as well, providing a photosynthetic base until the next defoliation episode. The fate of spruce, particularly Engelmann spruce, is dependent upon the frequency of spruce aphid outbreaks. Repetitive outbreaks will result in extensive mortality, loss of established regeneration, and loss of reproductive potential. Outbreaks can occur two years in a row in the same general area, but I do not yet know if the same trees are heavily defoliated in both outbreaks.

Research is needed on this insect, focusing on insect biology, population dynamics, insect-host physiology, impact, disturbance ecology, and host resistance. Population dynamics on interior host species under mountain conditions are obviously different than population dynamics on coastal species under maritime climatic conditions. The association of epizootic population behavior with prior weather conditions makes it likely that outbreaks can be predicted 6 months in the future with good confidence, and even longer with less confidence. Such prediction would require a more detailed model than "aphid outbreaks tend to follow dry winters", but is realistically attainable and would allow managers take protective action. This information would also allow us to evaluate the frequency of outbreaks that is likely under contemporary climatic patterns. Population dynamics need to be modeled in both ecosystems, and the weather and cold hardiness mechanisms determined Insect-host interaction research should focus on insect cold-hardiness and reproductive capacity and on foliage phenology, chemistry, and seasonal suitability as a food resource. Sap sucking causes additional tree damage than does defoliation from a leaf chewing insect, as the tree replenishes and subsequently loses more sap before the needles die. Impact assessment studies need to quantify the relationships between feeding pressure, needle death, and tree mortality. A metric for relating a relatively easy field observation to the likelihood of tree mortality is needed. Local risk and hazard conditions as well as geographic areas of the host range that are at risk need to be identified. The impact of defoliation on seed production and viability needs to be known in order to project long-term effects of this new disturbance agent to mixed-conifer and spruce-fir disturbance ecology. Resistant trees should be identified (there appear to be some, but spruce beetle outbreaks threaten mature individuals), and used either for developing planting stock or for a tree improvement program. Also, coastal aphid populations should be evaluated to determine if the greater extent and severity of damage seen in those areas is due to altered population genetic character or to weather patterns.

This insect will likely impact the natural disturbance regimes in mixed-conifer and spruce-fir forests. It will alter fuels accumulation, bark beetle hazard, and future stand development. Long-term stand effects may be severe. Repeated defoliation events on all size classes of trees will not only remove regeneration, but will in all likelihood prevent viable seed from being produced. If this is the case, Engelmann spruce representation in the forest will be greatly diminished over time.

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