Invasive Species in the Last Frontier: Distribution and Phenology of Birch Leaf Mining Sawflies in Alaska

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Invasive species pose a significant threat to forested ecosystems. Within the past 10 years, three nonnative birch leaf mining sawflies have been found in Alaska: *Fenusa pumila*, *Heterarthrus nemoratus*, and *Profenusa thomsoni*. Damage, caused primarily by *P. thomsoni*, is particularly notable in urban areas where the impact of browning tree crowns in mid-to-late summer raises public concern. The initial outbreak in Anchorage in 1996 increased to more than 32,000 ac by 2003. That same year, a survey was initiated to determine the extent of leaf mining sawflies throughout most of the state. Adult emergence, flight period, and larval phenology were assessed also. Surveys done through 2006 show that *P. thomsoni* is present over 20% of the surveyed area with the largest contiguous population in south central Alaska and localized populations in the Fairbanks area and on the Kenai Peninsula. The spread of *P. thomsoni* in Alaska suggests an association between establishment of new infestations, human population centers, and major travel routes.

**Keywords:** leaf miner, *Profenusa*, *Fenusa*, *Heterarthrus* Hymenoptera, Tenthredinidae

The introduction of invasive species has been identified as one of the major threats facing indigenous ecosystems (Chapin et al. 2000). Reducing the impacts of invasive species is a major goal in the US Forest Service’s National Strategic Plan (USDA Forest Service 2004). Although few introduced species cause enormous impacts, indeed, most will have little or no impact in new ecosystems, and past experience with invasive organisms, such as gypsy moth and emerald ash borer, provide reason for caution. An invasive species is defined in this article as being nonnative to the ecosystem of concern, which spreads from its point of introduction and becomes abundant (Kolar and Lodge 2001). Although geographic isolation and limited transportation corridors are thought to provide some degree of protection to Alaska ecosystems (Koons and Mlot 2003), the Forest Service in Alaska, in cooperation with other federal, state, and local organizations, monitors the populations and impacts of many invasive threats.

The risks posed by invasive species include interference with natural and managed ecosystems, increasing susceptibility to other disturbances, and reducing production of natural resource–based goods and services.
services (Chapin et al. 2000). In response to these risks, the Forest Service produced an appraisal of current and projected impacts from several taxonomic groups of invasive species in Alaska (Goldstein et al. 2005).

All species of birch leaf mining sawflies in North America are imports from Europe, arriving within the last 100–120 years (Goulet 1992). The most likely mode of import was overwintering pupae present in the root balls of horticultural stock (Digweed and Langor 2004). These species—birch leaf miner (Feusnella pumila Leach), amber-marked birch leaf miner (Profenus thomsoni [Konow]), early birch leaf miner (Feusnella nana Klug), birch leaf edgeminer (Scolioneura betuleti Klug), and late birch leaf edgeminers (Heterarthrus nemoratus Fallen)—range from minor to occasionally significant pests of birch (Betula spp.) in North America (Drouin and Wong 1984, Evans et al. 1985, van Driesche et al. 1997) and Europe (Pieronek 1995). All are internal feeders within the birch leaf, but as their common names suggest, attack the tree at different times throughout the growing season or use different parts of the leaf.

Larval biology and development are similar for all five species of birch leaf mining sawflies and are typical of the group. Female species use a sawlike ovipositor to deposit eggs singly in slits cut into the leaf’s upper surface. Five or six larval instars are spent developing within the leaf feeding alone or in groups. Most species exit the leaf to overwinter as pupae or prepupae in earthen cells constructed belowground. Development is completed the following spring, H. nemoratus differs in that it constructs its pupal cell within its mine and overwinters within the leaf (Glasgow 1932). In North America all species have one generation per year except for F. pumila, which has two or three. A typical lifecycle is shown in Figure 1. These species differ from other sawflies in that larvae are not capable of dispersal from the natal leaf. Of these five, three have been found in Alaska within the past 10 years: F. pumila, H. nemoratus, and P. thomsoni.

All six birch species native to Alaska: dwarf arctic birch (Betula nana L.),—resin birch (Betula glandulosa Michx.), paper birch (Betula papyrifera Marsh.), Alaska paper birch (Betula neoalaskana Sarg.), western paper birch (Betula papyrifera var. occidentalis Fern.), and Kenai birch (Betula kenaiensis WH Evans) (Viereck and Little 1972)—are recorded as being attacked by one or more of these sawflies (Pierson 1929, Martin 1960, Cheng and LeRoux 1965, Digweed et al. 1997, van Driesche et al. 1997, Hoch et al. 2000). Leaf miner host preference and birch species susceptibility or resistance are unknown in Alaska. Damage to birch from all leaf miner species is primarily aesthetic; larval feeding results in brown patches or blisters and, with some species, disrupted leaf morphology (Figure 2). As individual larval mines increase in size, they coalesce forming large hollowed-out brown areas. Chronic damage (appearing every year) is particularly notable in urban areas where the aesthetic impact of growing tree crowns in mid- to late summer raises public concern. The cumulative effect of chronic defoliation is possible weakening of trees that leaves them open to damage by secondary infections or pests (Hoch et al. 2000).

Two historic pathways for the introduction of invasive species are the movement of living plants and wood packaging material (Reichard and White 2001, Levine and D’Antonio 2003). Countless species continue to be transplanted as a consequence of international trade (Jenkins 1996). As the only port of entry with cargo material (Reichard and White 2001, Levine and D’Antonio 2003). Countless species continue to be transplanted as a consequence of international trade (Jenkins 1996). As the only port of entry with cargo processing functions, receiving over 95% of all freight entering Alaska (Port of Anchorage, 2006), the most likely point of introduction of birch leaf mining sawflies was through the port of Anchorage. Subsequent dispersal of these sawflies from Anchorage was most likely via both natural and anthropogenic means, as proposed for other related species (Gilbert et al. 2003, Digweed and Langor 2004).

The first report of leaf mining on birch in Alaska was in 1991 in Haines (USDA Forest Service 1992), but the first detailed description of birch leaf miners was made in 1996 when damage to birch was reported in Anchorage. The species was initially identified as F. pumila but was later correctly identified as P. thomsoni (E. Holsten, personal communication, Anchorage, Alaska, Sept. 1, 2003). This outbreak rapidly increased and by 2002 damage in and around Anchorage could be mapped by aerial observers (Wittwer 2003). This is significant because typically more than 50% of the affected area viewed from the air must show damage to be reliably detected (McConnell et al. 2000). In 2002, P. thomsoni accounted for more than 25,000 ac of birch defoliation in the Anchorage Bowl (Wittwer 2003). An additional infestation was noted in 2002 on the Eielson Air Force Base (AFB), 30 mi southeast of Fairbanks, where over 1,000 heavily infested trees were reported and P. thomsoni adults were positively identified.

The 2003 aerial survey detected 32,000 ac of P. thomsoni defoliation, primarily in the downtown and midtown areas, with two small incipient infestations recorded in the...
Matanuska-Susitna (Mat-Su) Valley near Wasilla (Wittwer 2004). This was not surprising because a significant flow of private and commercial vehicle traffic occurs daily between Anchorage and the Mat-Su Valley, and birch forest is continuous between these communities. The population on Eielson AFB continued to expand and an incipient population was identified also in the city of Fairbanks. During the same period, small populations of H. nemoratus and F. pumila were found also in Anchorage coincident with P. thomsoni.

Anecdotal reports of occurrence suggested that P. thomsoni was spreading beyond the known infestations in Anchorage, so a road survey was initiated to determine the extent of P. thomsoni and other leaf mining sawflies throughout the state. Adult emergence, flight period, and larval phenology were assessed also. We report the results of surveys done between 2003 and 2006 and comment briefly on the phenology of these three sawfly species in Alaska.

**Distribution and Phenology**

Two survey methods were used to determine the distribution of P. thomsoni in Alaska: (1) in heavily infested areas, surveys were conducted to determine the leading edge and assess damage severity; beginning at centers of urban development, we followed all major and secondary roads stopping at 1/2-mi intervals and at parks, school yards, markets, campgrounds, and RV parks as they were encountered; and (2) outside of the heavily infested areas, surveys sought to locate small incipient populations in areas where P. thomsoni was thought to likely establish, such as parks, school yards, or businesses with new birch plantings. At each survey site, crown foliage was visually inspected for evidence of mines for 10 minutes. Sawfly species were identified and damage was rated using a scale based on the percentage of mined leaves observed: 0%, not present; 1–5%, present; 6–30%, light; 31–60%, moderate; more than 60%, heavy. The primary insect of interest was P. thomsoni although F. pumilla and H. nemoratus were noted when found. All surveyed sites were global positioning system recorded along with leaf miner species present and the associated damage rating. Surveys were done in late summer when leaf mines are large and obvious but before leaf senescence, which would interfere with an observer’s ability to distinguish damage. Sampling at this time usually meant that mines had been abandoned and thus species identification was made based on mine morphology and cast skins of larval molts remaining in the mine. Fortunately, cast skins retain the diagnostic characters required to identify leaf miners to species (Martin 1960). This method was used between 2003 and 2005 to map infestations in south central Alaska (i.e., Anchorage and Mat-Su Valley) and in the Fairbanks area.

In 2006, these survey methods were applied again, this time at 10-mi intervals, across all major highways in the state, with no more than 5 mi separating surveys in heavily infested urban areas. By combining both survey methods, all major highways and communities south of Livengood (about 90 mi north of Fairbanks), west of the Canadian border, and east of the Parks Highway were surveyed. This comprises the vast majority of the road-accessible area within the state and 80–90% of the inhabited area. The only communities of significant size not surveyed were Juneau, in the southeast, and Barrow, in the far north, both outside the native range of birch (Viereck and Little 1972) and only accessible by sea or air.

Adult and larval phenology were monitored in 2003, 2004, and 2005 in Anchorage, and in 2003 and 2004 in Fairbanks and Eielson AFB. To assess adult flight period, 3 × 5 in. yellow sticky cards (Pherotech, Delta, BC, Canada) were deployed from approximately June 1 to August 31. These cards were changed every 3–7 days and the number of adults was recorded. To assess larval phenology, leaf samples were regularly taken from birch in urban parks in Anchorage. These samples were used to assess life history and mortality, details of which are presented elsewhere. Adult and larval phenologies from 2003 to 2005 are reported here.

Larval H. nemoratus and F. pumila were recovered occasionally from P. thomsoni larval development samples taken in 2003. Additional sampling in 2004 and 2005 within Anchorage was used to locate other populations. In 2005, adults of H. nemoratus were collected from two sites in Anchorage. In addition, yellow sticky cards used to monitor P. thomsoni adult flight period from 2003 to 2005 were reinspected for the presence of H. nemoratus adults.

Combining surveys from 2003 to 2006 showed that P. thomsoni was present over 20% of the surveyed highway system (Figure 3). The surveys also found that the largest contiguous population of P. thomsoni in Alaska was in the south central region, centered on Anchorage; stretching from Anchorage north along the Parks Highway to approximately 30 mi north of Talkeetna, east along the Glenn Highway to Pinnacle Mountain, and south onto the Kenai Peninsula along the Sterling Highway to Soldotna (Figure 3A). In areas of heavy infestation, as many as 20 larvae per leaf may be observed feeding at the same time. Populations in the Fairbanks area appeared to be isolated and highly localized, with the largest concentration on Eielson AFB and spot infestations located within the city of Fairbanks itself, as well as infestations 12 mi southeast in the community of North Pole, and a popular bar 30 mi south of Fairbanks (Figure 3B). In southeast Alaska leaf miner was also collected from leaves along roads leading out of the town of Haines. In 2006, new infestations were found in more remote areas on the Kenai Peninsula (Figure 3A) such as parks along the Russian River and Skilak Lake and in campsites along the Swanson River and Swan Lake roads in the Kenai National Wildlife Refuge. A small population also was found near a dock on the north shore of Trapper Lake, which is accessible only by float plane (Figure 3A). The potential for infestations to spread from these remote introduction sites into the surrounding native forests is of particular concern.

Adult P. thomsoni emergence typically ranged from mid-June to late August, peaking around the second week of July in south central Alaska. Adult collection efforts on Eielson AFB showed that the interior populations fly 3–4 weeks earlier on average than in Anchorage. In 2003, when eight sites were monitored, adult emergence and peak flight varied slightly with some sites delayed up to 7 days in timing of peak flight period. Eggs usually are observed on host leaves almost as soon as adults begin flying, with larvae appearing approximately 1 week later. Cast skins, indicating that larvae have completed the mining stage of development, usually were observed 14–21 days later. Results were similar for Fairbanks.

In 2004, H. nemoratus larvae were collected from five sites and F. pumila larvae were collected from four sites in Anchorage. By 2006, H. nemoratus abundance had increased such that larvae were collected easily at most sites within Anchorage. Additionally, they also were found nearly 50 mi away on the Kenai Peninsula. From 2003 to 2005, yellow sticky traps revealed an increas-
ing abundance of *H. nemoratus* (Figure 4). In 2003 and 2004, trap catches at peak activity averaged 3 individuals per card, but by 2005, over 20 individuals per card were caught. Medium-to-late instar larvae of *F. pumila* were located in abundance at one site in Anchorage. However, only a few *F. pumila* larvae were found at most sites, and those were either dead or moribund. *H. nemoratus* adults were collected from two sites in Anchorage between May 30 and June 26, 2005. No adult *F. pumila* were found on yellow sticky cards or from visual searches made during the flight period.

**Discussion**

Using the potential to alter entire ecosystems as a gauge, Goldstein et al. (2005) consider *P. thomsoni* to be the most important nonnative insect pest in Alaska. *P. thomsoni* is abundant in Alaska and appears to be increasing its range outside of urban areas. From the mapped distribution (Figure 3), the overall spread of *P. thomsoni* in Alaska suggests an association between establishment of new infestations, human population centers, and major travel routes. Long-range spread likely can be attributed to two mechanisms: passive transportation via the nursery trade of infested host material and automobile transport from heavily infested population centers to new locations. This is thought to account for new infestations not contiguous with other known infestations, such as the 2002 infestation at Eielson AFB. Within newly established infestations dispersal potentially can be very rapid because *P. thomsoni* is able to actively disperse 25–30 m a day, maneuvering easily through urban birch communities (McQueen 1996). Similar dispersal patterns also have been noted in other invasive leaf miners (Gilbert et al. 2003).
Currently, *P. thomsoni* is only found in areas of the state where the birch flora is primarily arborescent, i.e., *B. papyrifera*. However, potential exists for *P. thomsoni* to increase its range into areas of the state dominated by herbaceous dwarf birch (*B. nana* and *B. glandulosa*). Where *B. glandulosa* and *B. papyrifera* overlap in the interior, we have observed *P. thomsoni* developing in the much smaller *B. glandulosa* leaves (J.K., personal observation, Aug. 24, 2004). On the Kenai Peninsula, where *B. nana* and *B. papyrifera* overlap, *P. thomsoni* has been observed to oviposit in *B. nana* leaves (C.M., personal observation, June 15, 2004).

Finding *H. nemoratus* and *F. pumila* in Anchorage was not wholly unexpected because the species commonly co-occur in other areas in North America (Drouin and Wong 1984). A somewhat unexpected discovery was that *F. pumila* was the least abundant species. In other locales where the two occur *F. pumila* is as abundant as *P. thomsoni*, if not more so (Cheng and LeRoux 1969, Jones and Raske 1976, Drouin and Wong 1984). This suggests that *F. pumila* and *H. nemoratus* are more recent imports to Alaska and still have to establish a significant foothold. However, we have observed *F. pumila* at relatively high abundance at one site in Anchorage that was dominated by birch trees subject to intense moose (*Alces alces*) browsing. These birches are characterized by an abundance of long shoots resulting from extensive pruning and are ideal for *F. pumila* development (Friend 1931). By contrast, *H. nemoratus* appears to be increasing in abundance and range, although in most sites it appears to be outcompeted by the faster developing and more abundant *P. thomsoni*. Additional work is required to monitor the population dynamics and ranges of both species.

Currently, in Alaska, *P. thomsoni* defoliation is primarily a concern in urban areas where birch trees dominate. However, the potential for expansion within urban centers and into native forest is such that *P. thomsoni* has been proposed as a significant threat to Alaskan forests (Goldstein et al. 2005). In 2004, hot, dry weather was suspected as the primary cause of increased damage to forested slopes along the Seward Highway southeast of Anchorage (C.S. personal observation, Aug. 7, 2004) (Figure 5). If similar conditions are experienced in future years, *P. thomsoni* could pose a significant threat to forest health in the region. Because the primary effect of *P. thomsoni* defoliation is to decrease the photosynthetic capacity of birch, there is potential for lasting impacts on tree health. Although there are no studies on the long-term effect of leaf mining on birch, others have observed effects on radial growth, photosynthetic performance, and leaf–water relations in response to *Camera-ria ohridella* Deschka et Dimic leaf mining on horse chestnut (*Aesculus hippocastanum* L.) in Europe (Nardini et al. 2004). Long-term effects on tree physiology via the loss of photosynthetic tissue subsequently could impact other forest processes, such as carbon and nitrogen cycling (Kosola et al. 2001). Furthermore, the impact of additional defoliation by *F. pumila* and *H. nemoratus* could further impact tree health in the region.

Systemic insecticides are commonly used to manage *P. thomsoni* in high-value trees in Anchorage. A number of products have been tested against *P. thomsoni*, *F. pumila*, and *H. nemoratus* with varied success (Drouin and Wong 1984). In 2004 a biological control program was launched to introduce the ichneumonid parasitoid *Lathrolestes luteolator* Gravenhorst to Alaska. This species was first observed attacking *P. thomsoni* in Edmonton, Alberta, Canada, in the early 1990s and was likely responsible for the suppression of a 20+ year outbreak of...
the species (Digweed et al. 2003). Extensive trapping using yellow sticky cards (3 × 5 in.; Pherotech) in 2002 failed to locate *L. luteolator* in Alaska, suggesting it was not introduced with *P. thomsoni* (E. Holsten, unpublished data, internal briefing paper, Jan. 29, 2003). The first releases of *L. luteolator* were made in 2004 and continued through 2006, with additional releases planned for subsequent years. Should *F. pumila* and *H. nemoratus* abundance increase, similar chemical control options would be available (Drouin and Wong 1984), as would the release of biological control agents. *Lathrolestes nigricollis* (Thompson) has been released in at least four locations in North America against *F. pumila* with moderate to very good success at achieving suppression (Cheng and LeRoux 1969, Fuester et al 1984, Raske and Jones 1975, van Driesche et al. 1997, Langor et al. 2000). There are no known species-specific parasitoids of *H. nemoratus* in North America; however, some degree of control could be achieved culturally via the removal and destruction of infested leaves after pupation and before the emergence of adults.

A number of invasive species pose significant environmental and economic threats to forested ecosystems. It appears from the introduction of three species of birch leaf mining sawflies and the rapid dispersal of *P. thomsoni* that Alaska is not as isolated as previously thought (Koons and Mlot 2003, Goldstein et al. 2005). The effects that an alien species can have on fragile northern ecosystems have already been documented for fox introduced on the Aleutian Islands (Williams et al. 2003). Because birch is both a valuable horticulture and forest species, there is potential for current species of birch leaf miners to have serious impacts. Furthermore, both *F. nana* and *S. betuleti* are now recorded from British Columbia (Digweed, personal communication, Edmonton, Alberta, Canada, Oct. 1, 2006) and are a risk for introduction to Alaska, which could further threaten birch.

The long-distance accidental spread of introduced invasive species can be a serious environmental threat to native ecosystems (Chapin et al. 2000). The reduction of such spread may be aided by tighter controls of the trade of landscape and nursery stock (Reichard and White 2001, Levine and D’Antonio 2003). The Forest Service has programs for the management of invasive species. These often are accomplished through partnerships across jurisdictional boundaries and founded on integrated pest management principles. Increasing public awareness is extremely important because people can be helpful in detecting new infestations and controlling populations in urban areas or unknowingly contribute to the spread by moving infested material or, with the birch leaf miners, the actual pests.

**Literature Cited**


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