

By Michael J. Raupp

The recent assault on urban forests by devastating insect pests like winter moth (*Operophtera brumata*), Asian longhorned beetle (*Anoplophora glabripennis*), and emerald ash borer (*Agrilus planipennis*), create the impression that non-indigenous, invasive insect pests are reaching new shores at ever-accelerating rates. But is this really the case? The history of invasion of non-native insect pests important to the discipline of arboriculture goes back a long time. In this article, I will review the record of introductions of insects as it relates to pests of woody landscape plants in the United States. Most of my focus will be on pests of woody plants, but some of the trends discussed will include insects and mites of crops and resources in general. While these patterns do not pertain directly to landscape plants, they tell us much about the phenomenon of insect invasions. Questions examined will include when different groups of insects arrived, how they were transported from their aboriginal home to the U.S., and discuss some of the implications these invasions have for our managed ecosystems and the practice of arboriculture.

As part of the larger issue of global change, invasive non-native insects are a significant threat to our managed and native forests where they directly or indirectly reduce biological diversity and disrupt ecological processes and productivity (Liebhold et al. 1995; Aukema et al. 2010). When non-native species attack valuable resources, such as nursery stock or trees growing as elements of managed landscapes, increased costs associated with growing, protecting, and removing damaged trees have resulted in huge economic losses (Footitt et al. 2006; Raupp et al. 2006; Kovacs et al. 2010). Moreover, the psychological impact of urban forests decimated by exotic insects or denuded of trees during eradication attempts leave lasting impressions of the devastating potential of exotic invaders. Urban forests suffer disproportionately in this regard, where the loss of trees means the concomitant loss of important ecosystem services provided by trees, such as cooling, water interception, and pollution mitigation.

History of Colonization

The history of colonization of North America by non-native species began shortly after the arrival of the first colonists from Europe during the early 1500s. Most of these pest introductions were unintentional, as settlers brought infested nursery stock, produce, and commodities to the New World (Aukema 2010). In some cases, insects stowed away in the ballast of ships that delivered these goods (Sailer 1978). The importance of international trade as a vehicle for distributing non-native species has recently been underscored by introductions of several lethal wood-boring beetles, such as Asian longhorned beetle, emerald ash borer, and several species of bark beetles (Scolytinae) that likely entered North America undetected via infested wood packing materials (McCullough et al. 2006; Lee et al. 2007).

Occasionally, introductions were the accidental result of intentional actions, as was the case with the

gypsy moth (*Lymantria dispar*). In the late 1860s, a misguided resident of Medford, Massachusetts, Etienne Leopold Trouvelot, returned from his native France with egg masses of the gypsy moth in an apparent attempt to bolster a sagging silk moth industry. Caterpillars escaped from his home, infested nearby trees, and thereby initiated one of the earliest and longest running arboricultural battles in the invasive insect war. In many ways, this event laid the foundation of, and was the proving ground for, many intervention tactics and strategies still used by arborists today.

The first recorded tree pest in New World was the codling moth, which was detected in 1635. The number of non-native species attacking trees increased at a glacial rate between the 1600s and the middle 1800s, when a mere 18 additional species were discovered (Aukema et al. 2010). The number of introduced forest pests mirrored the total number of insect and mite pests introduced to the U.S. during this interval of slow immigration (Sailer 1978; Aukema et al. 2010). However, this was about to change.

In the half-century between 1860 and 1920, during each decade, the number of all groups of exotic insects arriving in the U.S. increased at almost exponential rates. Sailer (1978) attributed this increase to the rapid expansion of international commerce between the U.S. and other parts of the world. Since the late 1800s, we have entered a period of steady growth in the establishment of non-native pests at the rate of 2.4 to 3.0 species per year (Aukema et al. 2010) with respect to forest insects. If there is a bright side to this depressing trend, it lies with the fact that high-impact insects and diseases are accumulating at a much lower rate. Aukema et al. (2010) defined high impact pests as those causing tree mortality, thinning and dieback of canopy, growth and reproductive loss, or other negative ecological or aesthetic effects. For more than a century, non-native, high-impact pests have been detected at the rate of approximately 0.4 per year (Aukema et al. 2010).

What arrived when?

With respect to the kinds of non-native insects arriving in the United States, has the taxonomic affiliation of introduced insects remained the same, or shifted through time? In his comprehensive treatment of all immigrant insects and mites, Sailer (1978) noted that the beetles dominated the list of non-native invaders to this country between 1820 and 1860. He attributed this trend to the transport of beetles as stowaways in the ballast of ships. After 1860, sucking insects in the order Hemiptera supplanted beetles in dominance, as steamships allowed nursery stock to be easily transported from Europe and Asia in relatively short periods of time, and as explorers scoured the world for interesting new species of edible and ornamental plants (Sailer 1978).

The four decades between 1890 and 1930 were especially dark times for trees and shrubs susceptible to a major scourge of landscape plants—the scales. As trees

INVASIONS

by
Non-native
Insect
Pests

Invasions by Non-native Insect Pests (continued)

valued for fruit and beauty arrived in the U.S., they brought with them small, cryptic, sucking insects, particularly armored scales (Diaspididae), mealy bugs (Pseudococcidae), and soft scales (Coccidae) that escaped detection when they entered the country. Because many of these had broad host ranges, they moved to native trees with relative ease and became important pests (Miller et al. 2005). Even specialized pest species from Europe and Asia have been able to find closely related, often congeneric species of woody North American plants to attack (Aukema et al. 2010). The lack of evolved defenses in North American hosts and the lack of a well developed complex of natural enemies, likely contributed to the pest status of these invaders (Raupp et al. 2010; Raupp et al. *in press*). This legacy continues to the day, as scales collectively remain one of the most egregious groups of pests in arboriculture.

Another taxon of sucking insects closely related to the scales is the aphids. The three decades between 1900 and 1930 were the watershed years for the arrival of aphids in the United States, if largely for the same reasons scales enjoyed their glory years just decades prior (Footitt et al. 2006). While different groups of sap-suckers enjoyed separate peaks of arrival, when taken collectively, sap-sucking forest insect pests have invaded the U.S. at a relatively steady rate since the 1860s (Aukema et al. 2010). Following the peaks of scales and aphids was a surge of foliage feeders, including caterpillars (Lepidoptera), sawflies (Hymenoptera), and beetles (Coleoptera) between 1900 and 1940.

As introductions of defoliators waned toward the middle of the 1900s, arrival and establishment of punishing boring insects that attack phloem, cambium, and woody tissues increased dramatically. Between 1800 and 1930, phloem feeders and borers accounted for only 11 percent of all detections, but between 1980 and 2006, 56 percent of new detections were represented by this highly destructive guild (Aukema et al. 2010). The overwhelming preponderance of the phloem and wood borers are beetles (63 species), followed by caterpillars (5 species), sawflies (2 species), and termites (1 species) (Aukema et al. 2010). It is noteworthy that in his seminal study of non-native species, Sailer (1978) found Hymenoptera, bees and wasps, to be one of the largest groups of newcomers to the U.S. He attributed this pattern to vigorous biological control programs that introduced parasitic wasps to help manage many of the non-native insect pests that arrived during the previous decade (Sailer 1978).



Wax scales were part of a large invasion of scales that arrived in the United States during the late 1800s and early 1990s



Although their escape from culture was accidental, gypsy moths were deliberately transported from France to the United States.

What were the worst offenders?

Of the various groups of non-native insect pests, which are the worst? Aukema et al. (2010) provide insight into this question by classifying different taxa of insects according to their level of impact as forest insect pests. Although thrips constitute a very small group of invaders, only four species important to trees have established; therefore, 50 percent of these species are high-impact pests (pear thrips and basswood thrips). Several taxa of invaders, such as the Orthoptera (grasshoppers and their relatives) and Prosorrhyncha (true bugs), had no members on the high impact list. In ascending order of importance, the worst offenders reaching U.S. shores were the Diptera (flies) (7.7 percent), Lepidoptera (caterpillars) (11.5 percent), Sternorrhyncha (scales and kin) (13.8 percent), Coleoptera (beetles) (16.8 percent), and Hymenoptera (sawflies) (26.8 percent) (Aukema et al. 2010).

Where did they come from?

Immigration sources of non-native species to the United States demonstrate clear and in some cases shifting patterns through time. For much of the history of invasion, the Palearctic Region, Europe, and Asia dominated the source pool of non-native species (Sailer 1978; Miller et al. 2005; Footitt et al. 2006; and Aukema 2010). When all insects are considered, and for scale insects in particular, introductions of non-native species from Australia, Oceania, Central and South America were relatively rare (Sailer 1978; Miller et al. 2005). Aphids show a shifting pattern of origin. Early introductions came mostly from Europe, but recently, Asia has been a dominant source of immigrating aphids (Footitt et al. 2006). Several egregious wood boring beetles, such as emerald ash borer, Asian longhorned beetle, and granulate ambrosia beetle (*Xylosandrus crassiusculus*) are recent introductions from Asia.

Combating Non-native, Invasive Species

Mitigating the enormous economic and environmental impacts of non-native insect pests will require a multifaceted, integrated approach involving government agencies, scientists, and arborists. Government agencies must create and enforce stronger regulations to prevent the introduction of invasive species into the U.S. (Aukema et al.

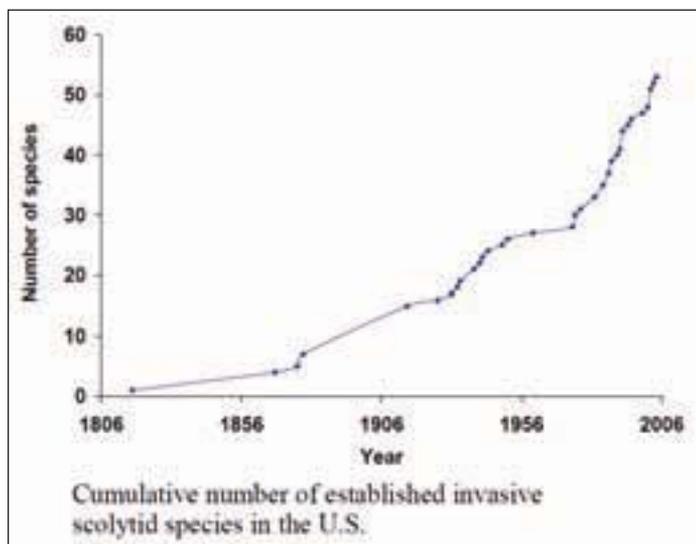
2010). The value of the regulatory process, notably the passage of the Plant Quarantine Act of 1912, is cited as one of the key reasons why the rate of introduction of exotic species did not remain exponential during the early 20th century (Sailer 1978; Footitt et al. 2006).

Due to a lack of biotic diversity, our urban forests are highly susceptible to catastrophic loss when lethal non-native pests such as Asian longhorned beetle and emerald ash borer arrive (Raupp et al. 2006). Increasing the diversity of urban forests may act as a buffer against catastrophic loss and help increase their sustainability by enhancing a variety of ecological processes (Raupp et al. 2010; Raupp et al. *in press*).

Finally, current analyses point to the continued arrival and establishment of non-native species in the United States at a steady, if not increasing, rate for the foreseeable future (Aukema et al. 2010). The prospect for an end to the invasive onslaught is not in sight. Ongoing research is needed to discover new chemical, cultural, and biological tactics to smack down these invaders. The need for educational tools, resources, and training programs to help arborists detect and manage these non-native pests continues.

Additional Reading

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Like many other phloem feeders and borers, the introduction of bark beetles has increased dramatically in recent decades.



MICHAEL J. RAUPP

The emerald ash borer (*Agrilus planipennis*) is one of the most devastating invaders to have ever reached the United States.

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