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Abstract
The non-native mile-a-minute weed, *Persicaria perfoliata* (MAM) is a serious threat to native vegetation diversity This invasive, rampant and prickly vine was initially reported in Connecticut in 2000, but has now spread to 64 towns as of 2022. As part of the federal biological control program for MAM supported by USDA APHIS PPQ, a tiny weevil, *Rhinoncomimus latipes* (Coleoptera:Curculionidae), was imported from China to feed and reproduce exclusively on MAM. This weevil was first released in Connecticut in 2009. The program of biological control of MAM ran for 10 years from 2009-2019, in collaboration with the University of Connecticut. Over 60,000 weevils have been released in 27 Connecticut towns in the most heavily infested areas to control MAM. Weevils have survived varying Connecticut winters, adapted to challenging environmental conditions, spread widely in many areas from original release sites to feed on MAM and is considered well established in Connecticut.

Introduction and Current Connecticut Distribution of Mile-A-Minute Weed
Persicaria perfoliata (L.) H. Gross (formerly *Polygonum perfoliatum* L.), more commonly known as the Mile-a-minute weed or vine (MAM), or devil's tear-thumb, is indigenous to Asia, occurring in China, Japan, India, the Himalayan countries and South East Asia (1, 2). This non-native vine was first thought to have established in the eastern US at a nursery in southern Pennsylvania in 1946 from seeds contaminating rhododendron stock imported from Asia in the 1930s (3, 4). By the mid-1990s, Mile-a-minute weed was firmly established in eight Mid-Atlantic States and is considered a serious and problematic invasive weed (5). MAM was first reported and confirmed in Connecticut in an 80 acre Audubon sanctuary in Greenwich in 2000 (Ellis pers. comm.; 6). An earlier report mentions confirmation in 1997 though the Connecticut location was not mentioned (7). It has since spread through southern New England in Connecticut, Rhode Island and Massachusetts and more recently, was found in New Hampshire in 2012 but eradicated and under regular monitoring (8). Public reports to the Connecticut Invasive Plant Working Group (CIPWG) website for MAM reporting and subsequent confirmations have led to many new Connecticut town reports. In 2009, MAM confirmed reports had expanded to 17 Connecticut towns in Fairfield, Hartford, Litchfield, New Haven and New London Counties (Figure 2a), when the MAM biological control program was newly initiated. The vine has been established in Sprague since 2011, in Stonington (2012), Groton, and Ledyard in New London County since 2015. By 2017, four more towns in Connecticut, Cromwell, Guilford, New London, and Washington were confirmed to have MAM infestations. More recently, MAM has been steadily spreading east of the Connecticut River, in Hartford and New London counties. By the end of 2019, MAM reports were confirmed in five new towns: Cheshire, Chester, Durham, Old Lyme and Trumbull, bringing the total of infested towns in Connecticut to 59, primarily in the south and west. In 2020, MAM was only confirmed in the town of Portland but in late 2021, four new town reports were confirmed in eastern Connecticut in Hampton, Manchester, Mansfield, and Voluntown, bringing the current total of Connecticut MAM infested towns to 64, approximately 38% of Connecticut towns (Figure 2b). Mile-a-minute weed continues to be detected in new Connecticut towns more than 20 years since it was first reported in Greenwich.

Identification of MAM
Mile-a-minute weed is a member of the Polygonaceae (smartweed) family. It is distinctive in several ways: triangulate bright pale green leaves that alternate down a jointed vining stem, marked by saucer-like sheaths called ocrea, which completely encircle the stem (Figure 3). The stems bear sharp, backward curving spines, the root system is shallow and fibrous and fruits are borne in clusters of bright blue berries when ripe (9). Seeds start germination in early spring, vine growth is prolific in warmer weather and can reach six inches a day. These vines are killed by the first hard frost (9). In North America, MAM behaves as an annual and dies after the first frost while in parts of Asia, it can be perennial (2). MAM is primarily self-pollinating (10) and can produce 50-100 seeds per plant (11). In a single season,

MAM can easily swamp underlying vegetation, shrubs and small trees, forming dense tangled mats of vines. It is considered a noxious invasive

weed, which can overwhelm native species, and is a serious threat to forest regeneration as it preferentially establishes in disturbed sunny sites, although it can also invade lightly shaded areas (9). Seeds can remain viable in the soil for up to 6 years (12) and this persistence of the seed bank remains a challenge for methods of effective management and control. Mile-a-minute weed spreads rapidly in Connecticut in wetland and riparian areas, fields, road sides, gardens and along power line corridors (Figure 4). The seeds are spread by birds and other animals, contaminated farm equipment, mulch and container plants. Flooding also spreads the buoyant seeds along waterways (13).

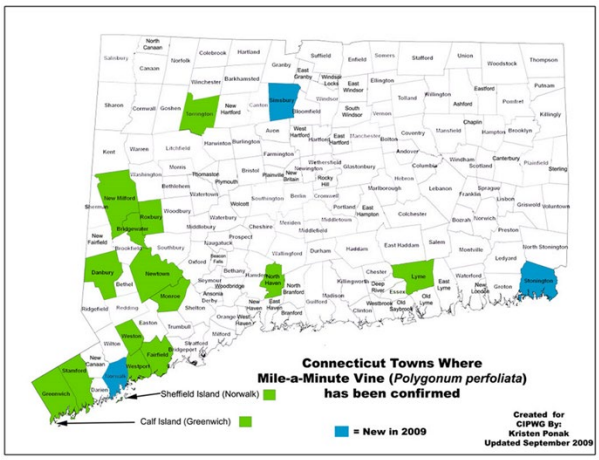

Figure 2a. Mile-a-minute weed distribution Connecticut towns in 2010.

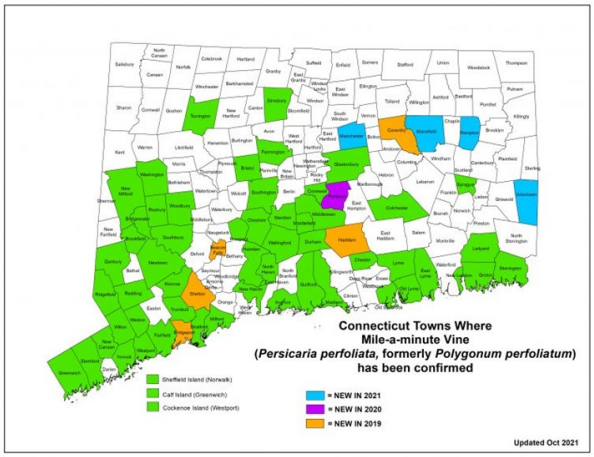

Figure 2b. Current distribution of Mile-a-minute weed in Connecticut as of fall 2021. Map by Kristen Ponack. Available at: https://mam.uconn.edu/distribution/

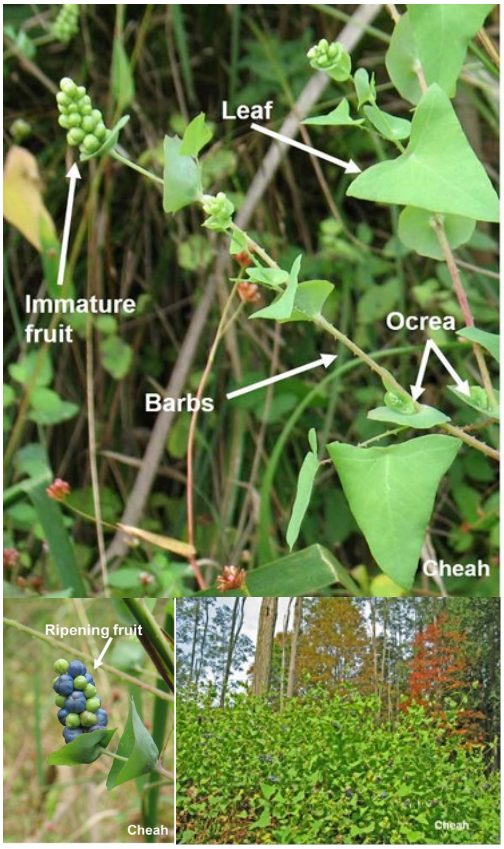

Figure 3. Identifying features of Mile-a-minute weed.

Figure 4. Typical MAM sites in Connecticut. Pictures by C. Cheah.

Figure 5. Mile-a-minute growing on a beach in Connecticut. Picture by C. Cheah

Biological Control of MAM with *Rhinoncomimus latipes*

Although physical and mechanical control methods (e.g. hand-pulling, frequent mowing) and routine chemical control with herbicides can be effective in managing MAM's persistence on smaller scales (8), biological control emerged as a key strategic long-term management tool. The exploration for natural enemies of *P. perfoliata* was initiated in China in 1996 under the direction of the USDA Forest Service Forest Health Technology and Enterprise Team, in cooperation with the Chinese Academy of Agricultural Sciences and the University of Delaware (15). Over 100 species of herbivorous insects were collected from MAM in China, and after further determination, 11 species were considered to have potential for serious damage to MAM (15). Further testing narrowed the candidates down to a tiny weevil, *Rhinoncomimes latipes* (Coleoptera: Curculionidae) (Fig. 6), native to China, which demonstrated high host plant specificity for feeding and reproduction and great damaging potential to *P. perfoliata* (13,16). Following a federal environmental risk assessment, *R. latipes* was cleared for field release in the USA as a biological control agent in 2004. Mass rearing by the Philip Alampi Beneficial Insect Laboratory (PABIL), New Jersey Department of Agriculture, has provided >600,000 weevils for releases in the mid-Atlantic states from 2004-2014 in a program initially funded by the USDA Forest Service and continued by United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine (USDA APHIS PPQ) (13). Weevils have successfully overwintered, reproduced, impacted MAM growth, decreased seed production, and widely dispersed from original release sites in the Mid-Atlantic States (13).

Life Cycle of *Rhinoncomimus Latipes* and Impacts On MAM

Adult weevils emerge from overwintering sites in the leaf litter in mid-spring and start feeding on small seedlings of MAM, which germinate a little earlier, usually in late March and April in Connecticut. Adult weevils feed on the leaves and are often found on the growing tips of MAM where the females prefer to lay their eggs. Eggs are tiny and laid on leaf surfaces, along the stems and on immature fruit. Tiny yellow larvae hatch out from the eggs and chew their way into the tender shoot tips to enter the stems where they continue to feed and develop. Highly infested stems may harbor several larvae per stem, which feed until they mature (13). Then, the mature larvae chew their way out of the stems and drop to the ground to pupate in the soil. Stages of *R. latipes* are shown in Figure 6. Development is temperature dependent and adults emerge from the soil as black adults, which then travel to MAM to feed and mature. As the adults feed, they turn orange. Adults feed on the leaves, leaving characteristic pinholes, which perforate the leaves, and intense feeding may defoliate the

leaves. Females prefer to feed on the growing tips, which are more nutritious (17). In their native China, weevils had at least 2 generations a year (13). Adult females can produce 130-180

eggs over their lifetime (13). Weevils are active on warmer days and like MAM, prefer sunny areas (19) and can fly. They feed until the first frost and then seek overwintering sites with the collapse of the MAM vines.

Weevil feeding damage has been shown to impact MAM biomass, and seed production has been reduced in experimental settings (20). When weevil populations are high, the feeding damage can be very impressive (Figure 7a and b), but this has only been occasionally observed in a few Connecticut sites.

Figure 6. Stages of *Rhinoncomimus latipes*, specialist herbivorous weevil on Mile-a-minute weed, *Persicaria perfoliata*. All pictures by C. Cheah.

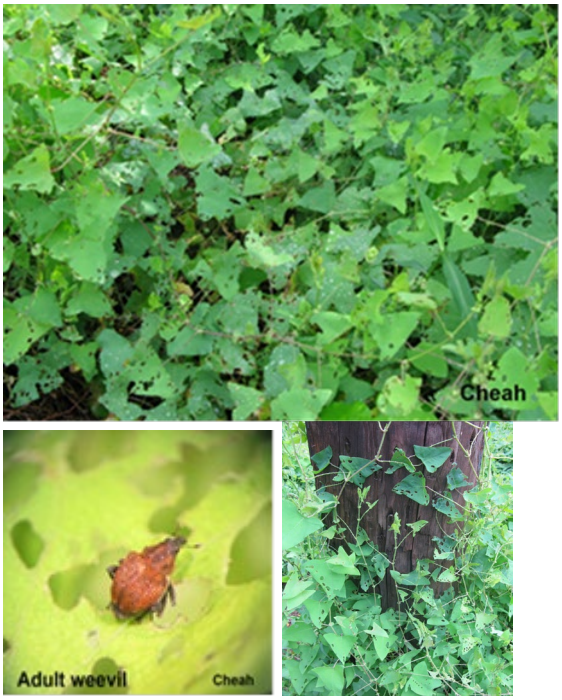

Figure 7a. Weevil feeding and summer damage to MAM leaves. Pictures by C. Cheah.

Figure 7b. Feeding damage intensified in the fall.

In 2009, Connecticut joined the regional biological control program for the first releases in New England in a joint collaboration between The Connecticut Agricultural Experiment Station and the University of Connecticut, funded by USDA APHIS. This program of implementation of MAM biological control in Connecticut ran for 10 years and was supported through federal funds from USDA APHIS PPQ from 2009-2019. The majority of *R. latipes* weevils released in Connecticut were reared and provided by the Philip Alampi Beneficial Insect Laboratory (PABIL), New Jersey Department of Agriculture, supplemented by the University of Rhode Island from 2012-2014, under the same funding by USDA APHIS PPQ. At the end of the weevil release program, a total of 60,166 weevils had been released in 27 towns (45 sites) in Connecticut from 2009-2019. New towns in 2019 where weevils were released were Old Lyme and Durham, with additional sites in Fairfield, augmentations on Calf and Sheffield Islands, Stewart B. McKinney National Wildlife Refuge, and Greenwich. These sites represented the last areas of MAM targeted with federally funded releases of *R. latipes*. All infested counties received weevils (Table 1), with the heaviest concentrations of weevil releases occurring in Fairfield County (46.6%), where infestations of MAM have been concentrated for many years. Thousands of weevils were also released throughout southern Litchfield County where MAM is also spreading aggressively (Table 1). More recent weevil releases have targeted the spread of MAM in shoreline towns (Figure 8).

Releases of *R. latipes* in Connecticut from 2009-2019 are shown in the map (Figure 8). The objectives of the project were to release and evaluate the establishment, overwintering ability, spread, and impact of the weevil, *R. latipes* on

MAM weed through annual monitoring and assessments of weevil activity. In the first 5 years of biological control releases

in Connecticut, monitoring of sites during spring, summer and fall was conducted in cooperation with the University of Delaware, supported by funding from the USDA Forest Service and USDA APHIS PPQ. Researchers from the CAES and the University of Connecticut collaborated with many town, state and federal conservation officials and volunteers to implement and monitor releases of *R. latipes* and assess its impact on MAM in Connecticut. Annual summer visits were made when release sites were greatly expanded. Weevils were released in many diverse habitats throughout infested areas in Connecticut. Types of release sites included state parks and forests along rivers and edges of fields, town open space and parks, golf courses, utility and railroad corridors, bird sanctuaries, unmanaged areas in urban areas and around school playing fields, private properties, off shore islands in Long Island Sound, including in the Stewart B. McKinney National Wildlife Refuge, and the Naval Submarine Base New London (Figs. 4, 9, 10)

Results to Date

The weevils have been established in many Connecticut towns impacted by MAM, in all variety of habitats (Figs. 4, 5). Weevils have successfully overwintered, reproduced, and impacted MAM growth to varying degrees in different sites and appeared to delay fruit production in some instances. Dispersal of the weevils has been widespread over many miles from original release sites. Many new release sites in later years were augmentations of weevils that had already dispersed to these new locales. At least two overlapping generations have been observed in the field in Connecticut. Weevils, including newly emerged adults, have been observed on vines freshly killed by frost in the fall, indicating their survival. In several release sites, habitat clearing or disturbance has occurred, negatively impacting weevil populations. Removal of vines will impact and kill eggs and larvae feeding within, but adults can fly away to other sites. Weevil establishment has been compromised in such instances and also by natural weather conditions in riparian areas that were subject to severe flooding and storm damage in past years. Overall, *R. latipes* has survived droughts, tropical storms, flooding and severe winters, with or without snow cover, and are firmly established in Connecticut. Factors that influence the efficacy of the weevils in different MAM sites are unknown, as their impact is quite variable. But it is hoped that in the future, the weevils will continue to expand their populations

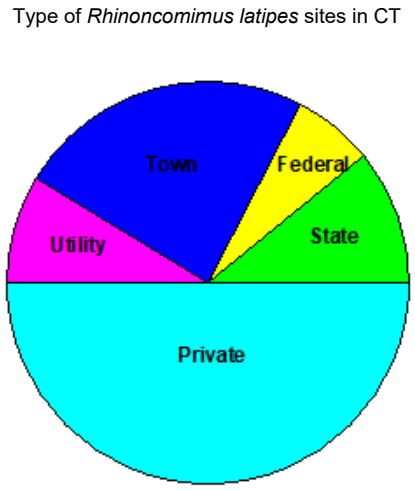

Figure 9. Categories of *R. latipes* release sites in Connecticut

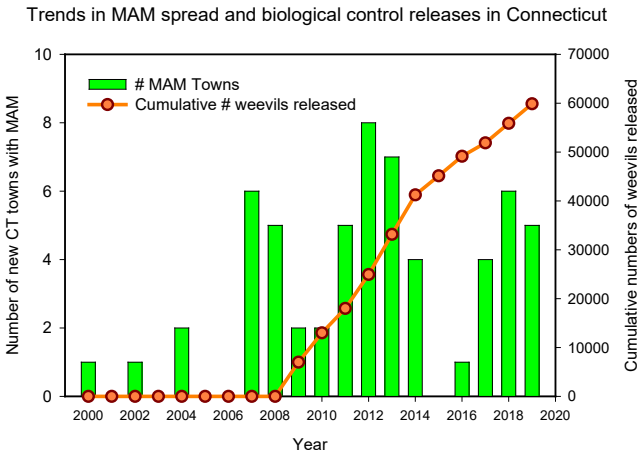

Figure 11. Yearly new town reports of MAM since 2000 and cumulative releases of *Rhinoncomumus latipes* in Connecticut 2009 - 2019.

(Figure 11) to help reduce MAM infestations and that biological control can be integrated with other management strategies to curtail the spread and impacts of MAM.

Acknowledgments

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for their work in releasing and monitoring the weevils. This program was funded by cooperative agreements with the USDA APHIS PPQ, and also USDA Forest Service FHTET. All pictures by C. Cheah unless indicated.

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Table 1. Summary of 2009-2019 weevil releases by Connecticut county, town and first year of release. *242 weevils (2017) and 300 (2019) were collected from the mainland for release on Sheffield Island

County	Town	# Major Release Sites	Year of First Releases	# Weevils Released per Town
Fairfield	Greenwich	5	2009	6,100
	Westport	7	2010	6,468
	Stamford	2	2010	5,100
	Fairfield	3	2010	4,077
	Norwalk	1	2011	2,042*
	Wilton	1	2012	1,000
	Stratford	1	2013	1,000
	Ridgefield	1	2013	2,364
Total	8	21		28,051 (46.6%)
Litchfield	Newtown	4	2009	4,000
	New Milford	1	2009	1,100
	Bridgewater	1	2009	1,000
	Roxbury	1	2013	2,000
	Woodbury	1	2013	1,000
	Washington	1	2018	2,500
Total	6	9		11,600 (19.3%)
New Haven	North Haven	1	2009	2,800
	Wallingford	1	2015	1,488
	Southbury	1	2015	400
	Milford	1	2016	1,000
Total	4	4		5,688 (9.4%)
Middlesex	Middlefield	1	2012	2,414
	Middletown	1	2016	900
	Durham	1	2019	1,000
Total	3	3		4,314 (7.2%)
Hartford	Southington	1	2014	1,015
	Glastonbury	2	2015	3,500
Total	2	3		4,515 (7.5%)
New London	Sprague	2	2011	3,065
	Stonington	1	2013	1,433
	Ledyard	1	2016	1,000
	Old Lyme	1	2019	500
Total	4	5		5,998 (10%)
Grand Total	**27**	**45**		**60,166**

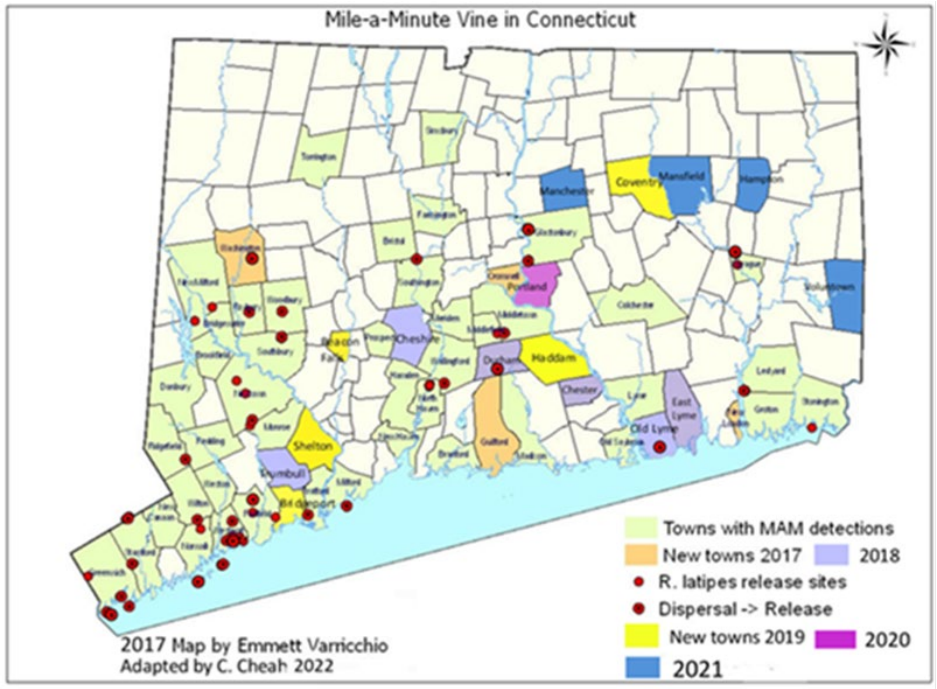

Figure 8. Map showing releases of *Rhinoncominus latipes* in Connecticut with new town MAM detections in recent years. Base map produced by Emmett Varricchio (2017); adapted by Cheah.

Figure 10. Weevil releases and monitoring in Connecticut through the years. Team picture lower row by Brad Horrigan, Hartford Courant 2015.