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The Weed Link in Zebra Chip Epidemiology

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A major challenge in controlling zebra chip disease of potatoes is our inability to predict which potato fields are likely to be colonized by potato psyllid, the vector of the pathogen that causes zebra chip. Adding to this challenge is substantial variability in psyllid pressure among fields and years. Annual psyllid trap catches across the region can range from a few hundred to tens of thousands. The current difficulty in predicting which potato fields are at risk to be colonized by psyllids is due to not knowing the source of those colonists. Because potato is unavailable to psyllids for much of the year, colonization of potato fields must be due to movement by psyllids from other habitats and host plants. Potato psyllids are typically found on a few annual and perennial weeds related to potato in the plant family Solanaceae plus some members of the Convolvulaceae. Plant species in Washington State potentially include very common annuals such as hairy nightshade, a known weed pest in Washington row crops, as well as a number of uncommon annuals such as Jimsonweed and buffalo bur. Perennial species such as matrimony vine and bittersweet nightshade are found throughout Washington State, often growing in large patches. In addition to supporting summer populations of psyllids, some of these perennial species are now known to be important overwintering hosts for potato psyllid (Horton et al. 2014, 2015). For most potential psyllid hosts in Washington State, we have little or no information about suitability to the psyllid (Horton et al. 2015) and whether some species are more suitable than others, and we therefore struggle to predict which species are likely sources of psyllids moving into potatoes. We have even less information about whether these non-crop species are also reservoirs of the zebra chip pathogen and thus are potential sources of *infective* psyllids. Without this knowledge, growers struggle to predict whether stands of weedy Solanaceae near their fields might be sources of infective psyllids.

The Weed Link

With funding from the WSDA-Specialty Crop Block Grant and Northwest Potato Research Consortium, we examined suitability of common weeds as hosts for potato psyllid and the zebra chip pathogen. Our goal was to develop a risk-index for weedy Solanaceae and Convolvulaceae, ranking species as potential sources of potato psyllid carrying the zebra chip pathogen. Descriptions of the 10 weed species examined in this project are provided in Table 1; photographs of the species are provided in Figure 1.

Table 1. Weed species examined for host suitability for potato psyllid and the zebra chip pathogen.

Weed species	Description[a]	Habitat[a]	Seasonal availability to the psyllid[a]
Annual hosts			
Cutleaf nightshade *(Solanum triflorum)*	GENERAL: Spreading stems that branch from base, <1 m tall LEAVES: Deeply lobed, thick and leathery FLOWERS/FRUIT: Small, white with yellow stamens, arranged in groups of three, round green to yellow berries	Native. Open moist to dry habitats. Weed in disturbed soils, and cultivated fields	May to September
Hairy nightshade *(Solanum physalifolium)*	GENERAL: Erect stem <1 m tall LEAVES: Smooth to wavy margins, hairy FLOWERS/FRUIT: Small, white, similar to potato, round green to yellow berries	Introduced. Disturbed soils and unmanaged lots, cultivated fields	May to September
Buffalobur *(Solanum rostratum)*	GENERAL: Erect stem <1 m tall, stem with long spines LEAVES: 5-12 cm long, 5-7 deep lobes, long spines FLOWERS/FRUIT: Yellow, protruding anthers, 2 cm wide, fruit surrounded with spiny calyx	Native. Disturbed soils, steppe habitats, sandy soils, dry habitats	June to September
Coyote tobacco *(Nicotiana attenuata)*	GENERAL: Erect, slender, branching stems, 1 m tall. LEAVES: Slender, up to 10 cm long, covered in dense hairs FLOWERS/FRUIT: 2-3 cm long, slender, start-shaped, white with yellow center, green fruit 1 cm long	Native. Dry, often disturbed soil and sagebrush steppe.	June to September
Henbane *(Hyoscyamus niger)*	GENERAL: Erect, up to 1 m tall, rank smelling LEAVES: Toothed, simple FLOWERS/FRUIT: Occurring on long racemes, dark yellow with purple center and purple veins, lobed fruit, 2.5 cm long	Introduced. Pastures, unmanaged habitats, disturbed soils	June to August
Jimsonweed *(Datura stramonium)*	GENERAL: Erect, up to 1.5 m tall, green to purple stem LEAVES: 8-20 cm long, alternate, irregularly sinuate-lobed, petioles 3-10 cm long FLOWERS/FRUIT: Trumpet-shaped, white to purple, 9-12 cm long, fruit partially covered with spiny calyx	Introduced. Streambanks and desert washes, and disturbed soils.	June to September

Weed species	Description[a]	Habitat[a]	Seasonal availability to the psyllid[a]
Field bindweed *(Convolvulus arvensis)*	GENERAL: Climbing or spreading vine often forming dense mats LEAVES: Alternate, arrowhead shaped, 2-3 cm long, late June until first frost FLOWERS: Morning glory-like, white/pink/purple, 2 cm wide, very small brown inconspicuous fruit capsule	Introduced. Widespread weed that is difficult to manage, cultivated fields, disturbed soils, highly adaptable.	April to October
Perennial hosts			
Bittersweet nightshade *(Solanum dulcamara)*	GENERAL: Climbing or spreading semi-woody vine up to 3.5 m tall LEAVES: Dark green to purple, 5-10 cm long, some shallowly to deeply lobed at base FLOWERS/FRUIT: Star shaped, purple with conspicuous orange anthers, scarlet berries occurring in clusters	Introduced. Riparian habitats, wetlands, margins of irrigation canals	Year-round; foliage present March to November
Matrimony vine *(Lycium barbarum =chinense)*	GENERAL: Dense woody shrub or erect and somewhat vine-like, 1-3 m tall, occasionally with spines LEAVES: Round to oval, 2-4 cm long, dark green in spring and fall, yellow to defoliated in mid-summer FLOWERS: Small, star-shaped, purple, red elongate berries (goji berries)	Introduced. Hedges, dry sandy soils, often found near late 19th or early 20th century homesteads and cemeteries, small-scale commercial production for goji berries	Year-round; foliage present March to July and September to November
Ground cherry *(Physalis longifolia)*	GENERAL: Rhizomatous perennial, branching shrub, up to 1 m tall LEAVES: Alternate, oval, 5-7 cm long, smooth to finely toothed margins FLOWERS/FRUIT: Bell-shaped, yellow with dark centers. Green fruit enclosed in a tomatillo-like calyx	Native east of Rockies. Prairies and open woods, becoming a weed in fields and disturbed soils.	April to August

[a] Plant descriptions, geographic origins, and habitats were obtained from Strausbaugh and Core (1977), Cronquist et al. (1984), Whitson et al. (2009), www.plants.usda.gov, and personal observations in Washington State.

Suitability of each weed species for psyllid development was examined in laboratory bioassays. We assayed both haplotypes of potato psyllid that occur in the Columbia Basin (Northwestern and Western haplotypes). About 80% of potato psyllids completed development on potato. Psyllids survived at varying percentages on all the weed species we screened. Survival rates were under 50% on coyote tobacco, black henbane, jimsonweed, and field bindweed. We also observed stark differences between the two haplotypes in survival on hairy nightshade. Psyllids of the western haplotype easily completed development on this plant species, whereas nearly 100% of psyllids of the northwestern haplotype failed to complete development. Egg to adult development required 20-22 days on potato. Development rates were similar between potato and most of the plant species except for field bindweed, jimsonweed, and matrimony vine. On these plant species, egg to adult development required 30 to 40 days.

Psyllid preference for potato versus each weed species was assessed using paired-choice assays. Potato psyllids deposited a similar number of eggs on potato and most wild plant species. The exceptions to this trend occurred on cutleaf nightshade, which psyllids seemed to prefer over potato, and field bindweed, which psyllids appeared to avoid.

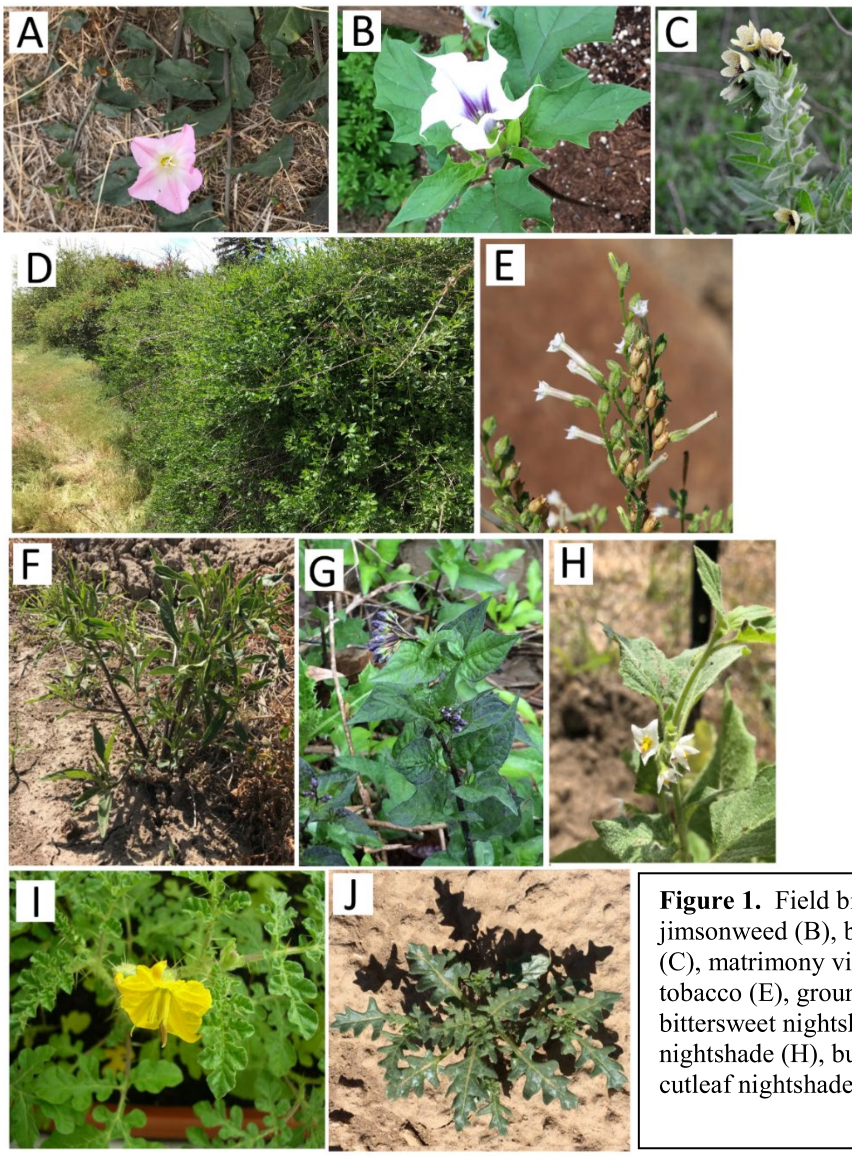

Figure 1. Field bindweed (A), jimsonweed (B), black henbane (C), matrimony vine (D), coyote tobacco (E), groundcherry (F), bittersweet nightshade (G), hairy nightshade (H), buffalobur (I), and cutleaf nightshade (J).

Susceptibility of each weed species to the zebra chip pathogen was examined by testing whether the pathogen was detected in plants exposed to infected psyllids followed by tests of whether the pathogen was acquired by uninfected psyllids fed inoculated plants. The pathogen was detected in the leaves of most inoculated potato plants and was regularly acquired by uninfected psyllids feeding on inoculated plants, confirming the high suitability of potato for the bacterium. Most of the weed species tested here were also susceptible to the zebra chip pathogen. For only two species (field bindweed and matrimony vine) did we fail to obtain plant infection.

Detailed results from these experiments have been reported by Cooper et al. (2019).

Weed Risk Index

We summarized results of our assays in a visual reference that shows *potential* risk of each weed species as a source of infective psyllids (Figure 2). Weed species were considered as potentially "high risk" if they were susceptible to both potato psyllid and the zebra chip pathogen (Figure 2, red). Matrimony vine (Figure 2, yellow) was ranked as a potential high-risk source of potato psyllids, but a low risk as a source of infective psyllids due to lack of suitability for the zebra chip pathogen. Field bindweed (Figure 2, green) was found to rank as "low risk" for both psyllids and the zebra chip pathogen. This risk index does not account for local abundance of weeds, so field bindweed could be a higher risk for psyllids if large stands of this plant occur in or near a potato field.

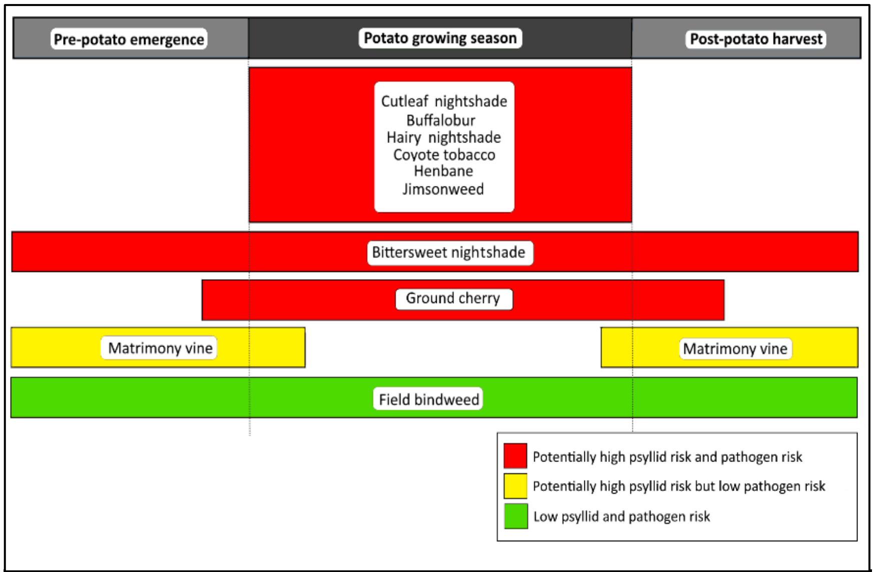

Figure 2. Risk index graphic. Relative potential ability of plant species examined to be sources of infected psyllid that vector the zebra chip pathogen to potato.

Figure 2 also illustrates the availability of each weed species through the potato growing season. The annual Solanaceae are available for psyllids at about the same time of the year as potato (summer). Populations of psyllids with the zebra chip pathogen could potentially increase on these weed species during the growing season, and colonize potato from weedy areas including ditches, roadsides, fallow land, and corners of crops circles. The perennial hosts, bittersweet nightshade, matrimony vine, and potentially ground cherry are available to psyllids before potato emergence and after potato harvest. All four species occur in potato-growing regions of the Pacific Northwest and are therefore potential developmental hosts for potato psyllid in spring before potato or other annual hosts are available. Psyllids appear capable of at least one full generation in spring on these perennial hosts, where they may build to large populations that are then available to colonize potato during the summer growing season (Horton et al. 2015, 2016).

Matrimony Vine: The Psyllid Forecaster

While each of these perennial weeds may support potato psyllid, matrimony vine appears to have phenological traits which increase this plant's risk as a source of psyllids (Thinakaran et al. 2017). Matrimony vine shuts down and loses its leaves in response to hot and dry conditions of summer, forcing psyllids to disperse and colonize other host plants (Horton et al. 2016). We believe that potato is the primary destination for these dispersing psyllids. This idea is suggested by observations showing that the initial appearance of psyllids in potato fields occurs at the very same time that psyllids begin disappearing from matrimony vine (Horton et al. 2016).

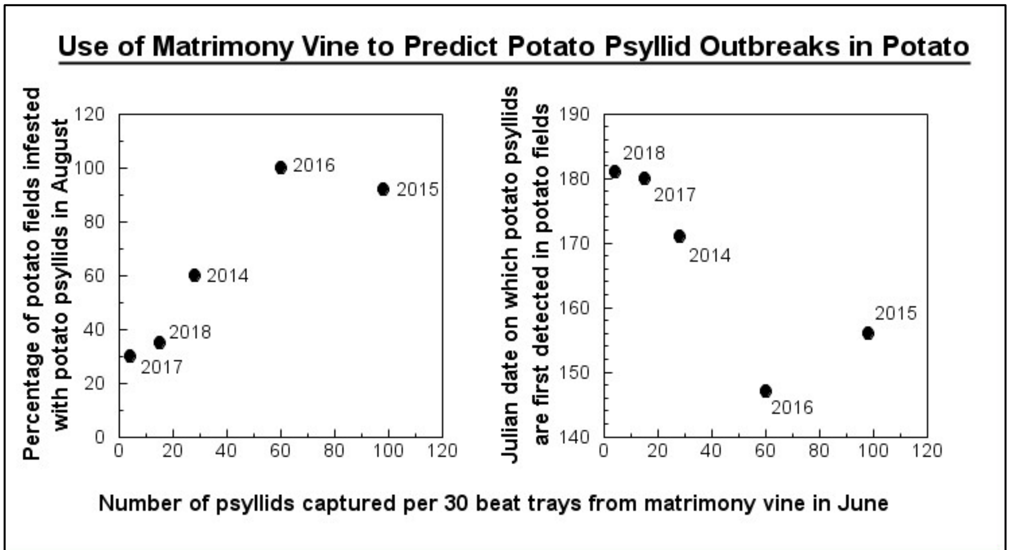

Figure 3. Psyllid populations occurring on matrimony vine in June correlates with the percentage of potato fields infested with psyllids in August, and with the date on which psyllids first occur in potato.

Psyllid density on matrimony vine in June is highly correlated with the percentage of potato fields showing psyllid infestation the following August (Figure 3A) and with the Julian date on which psyllids are first captured in potato fields (Figure 3B; for reference: Julian date 182 = July 1 and Julian date 152 = June 1). Our sampling has also revealed that psyllid populations can be detected on matrimony vine in March or April during high population years (2015 and 2016), but not during low population years (2017 and 2018). We therefore believe that monitoring stands of matrimony vine for psyllids in late spring would allow growers to predict what level of psyllid pressure is likely to occur in potato that summer. In fact, we correctly predicted that psyllid pressure in potato would be only slightly elevated from 2017, and substantially lower than experienced from 2014 to 2016, based on psyllid populations on matrimony vine in June of 2018 (Figure 3). Our goal is to further develop this predictive tool to allow growers to tailor their management approaches based on these psyllid forecasts.

Ornamental Host Plants

There are several plants within the Solanaceae and Convolvulaceae that are widely planted as ornamentals. We previously reported that the Solanaceous ornamental plant, *Nolana*, is a suitable host for both potato psyllid and the zebra chip pathogen (Horton et al. 2017). We have also reported that some but not all ornamental morning glories (Convolvulaceae) are hosts for potato psyllid (Kaur et al. 2018), but plants in the family do not appear to be hosts for the zebra chip pathogen. *Petunia* is an ornamental Solanaceae that is popular among homeowners and is often included in landscaping of downtown city streets. We found that *Petunia* does not support egg to adult development of potato psyllid in laboratory assays. Sampling in South Dakota, Montana, Idaho, and most extensively in Washington failed to collect potato psyllid from ornamental *Petunia* planted in various city centers (Cooper unpublished). All other plants within the Solanaceae that have been tested so far have been shown to support potato psyllid development, making *Petunia* the only known Solanaceous plant on which at least one potato psyllid haplotype is unable to complete development. The zebra chip pathogen was detected in 25% of *Petunia* plants that were challenged with infected potato psyllids suggesting that this plant is susceptible to the pathogen even while not allowing psyllid development. Since most ornamental Solanaceae and Convolvulaceae are not hosts for both potato psyllid and the zebra chip pathogen, they are not likely to be important contributors in zebra chip epidemiology.

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