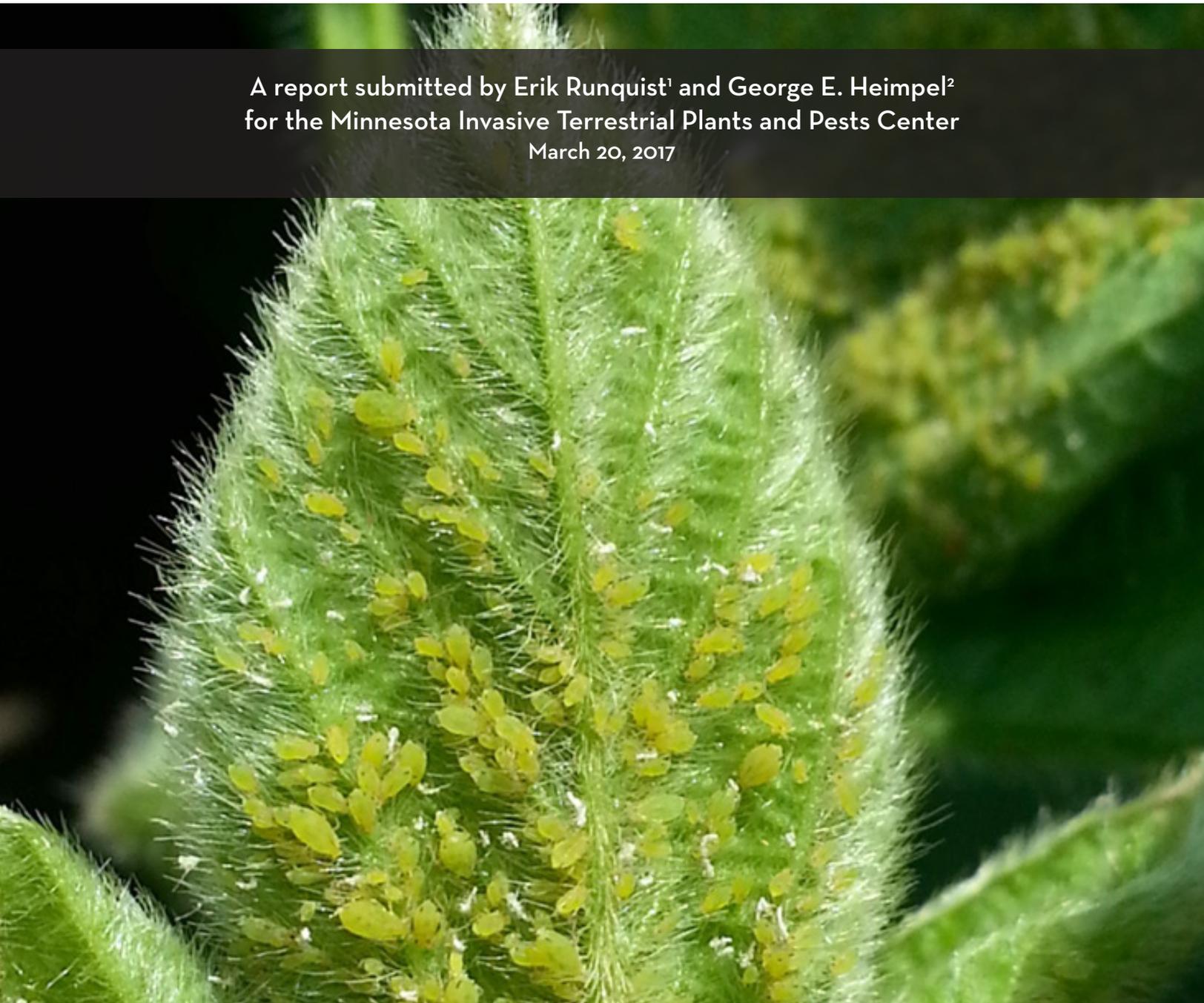


# Potential Causes of Declines in Minnesota's Prairie Butterflies with a Focus on Insecticidal Control of the Soybean Aphid

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## Overview and purpose of this report

Minnesota is home to diverse prairie butterfly fauna, but several species have recently undergone drastic population declines. For example, 10 of the 15 butterfly species classified as Endangered, Threatened, and of Special Concern by the State of Minnesota depend exclusively on native prairies. The declines of two of these, the Dakota Skipper and the Poweshiek Skipperling, have been so precipitous that they are now exceedingly rare despite having been predictably common previously. Poweshiek Skipperling is now on the verge of global extinction. Multiple regional and local factors may have contributed to these declines, and those factors are expected to have interacted in various ways. However, a working hypothesis is that these butterfly declines are at least in part the result of insecticide drift related to management of the soybean aphid, which invaded Minnesota in 2000 and led to substantial increases in insecticide applications to soybeans.

On November 15, 2016, the Minnesota Invasive Terrestrial Plants and Pests Center (MITPPC) in collaboration with the University of Minnesota Institute on the Environment held a workshop to assess hypotheses that could explain the butterfly declines. The workshop featured seven speakers from the US Fish and Wildlife Service, Minnesota Department of Natural Resources, Minnesota Zoo, University of Minnesota, and Environmental Protection Agency. The presentations, which MITPPC has posted online (<http://z.umn.edu/mitppcbutterfly>), focused on three themes: (i) biology and conservation status of the endangered butterflies, (ii) the possible role of soybean aphid management in affecting butterfly populations, and (iii) risk assessment and potential solutions via conservation measures. The workshop fostered collaboration between experts in prairie conservation and agricultural pest management and featured extensive discussion between participants following the presentations. Members of the conservation and agricultural communities are typically not afforded the chance to engage in conversations of this type and discussions were particularly fruitful for information sharing and relationship building.

This document synthesizes the findings of the workshop and provides guidance to the MITPPC on a needed integrative research program studying the non-target consequences of invasive soybean aphid management on Minnesota's endangered prairie butterflies. We conclude that skipper conservation will be advanced through a new research program that includes tests of the hypothesis that soybean aphid insecticides are contributing to skipper declines. Targeted research is needed to assess 1) the extent of insecticide exposure the butterflies may experience in the wild and 2) the biological consequences of those exposures using replicated controlled experiments. Ongoing drift studies conducted by the Minnesota Zoo and US Fish and Wildlife Service (see below) have provided important preliminary links to soybean aphid insecticides, but significantly more data is needed to really understand wild exposure dynamics. Controlled exposure experiments may soon be launched by Minnesota Zoo and University of Minnesota researchers, but those experiments are currently funding- and personnel-limited and cannot address the full range of needed tests. The MITPPC can play a leading role by supporting and expanding critical comprehensive research on potential non-target effects of management against an invasive pest.

# Body of Report



A Dakota Skipper at a South Dakota prairie remnant  
Photo: Minnesota Zoo

## 1. Biology and conservation status of endangered prairie butterfly species in Minnesota

This report focuses on threats and possible conservation of two species of prairie butterflies, the Poweshiek Skipperling (*Oarisma poweshiek*) and the Dakota Skipper (*Hesperia dacotae*). The Poweshiek Skipperling is listed federally as Endangered Species, and the Dakota Skipper is listed as a Threatened Species (USFWS 2014). Both of these prairie specialists are also listed as Endangered in Minnesota.

**1.1. Biology of endangered skippers in Minnesota.** We focus here on aspects of the biology of these skippers that are relevant for understanding threats to survival and potential conservation. These include the flight period and dispersal range of adult skippers, the host plants used by the caterpillars, and overwintering strategies.

**Flight Period.** The flight period is the time in the season when adults are found in the field. Both the Dakota Skipper and the Poweshiek Skipperling have only one generation per year. Adults are active for two to three weeks from late June to mid-July, depending on yearly seasonality.

**Dispersal Behavior.** The dispersal behavior of adults refers to the distance that adult butterflies travel during their lifetimes. Both the Dakota Skipper and the Poweshiek Skipperling exhibit relatively local flight patterns within prairie sites and are not expected to leave these sites and enter adjacent agricultural habitat. Both species may spend their lives in an area only the size of a football field.

**Host Plants.** The caterpillars of both skipper species feed on grasses. Although host use in the field is not completely understood, the caterpillars are known to feed on multiple species based on controlled conditions in experiments at the Minnesota Zoo and on experiments conducted by Dana (1991). Putative Dakota skipper hosts in the wild include little bluestem (*Schizachyrium scoparium*), prairie dropseed (*Sporobolus heterolepis*), side-oats grama (*Bouteloua curtipendula*), and porcupine grass (*Hesperostipa spartea*). Host use by the Poweshiek Skipperling in Minnesota is less well understood, but likely includes prairie dropseed, and possibly little bluestem, side-oats grama, and mat muhly (*Muhlenbergia richardsonis*).

**Feeding Behavior of Caterpillars.** The two skipper species differ in the feeding behavior of their caterpillars. Dakota Skipper caterpillars spend most of their time in a tubular structure that they construct by stitching together leaf blades with silk at the base of their host plant. The caterpillars only rarely leave their shelter to retrieve grass blades which they consume within the shelter. In contrast, Poweshiek Skipperling caterpillars do not construct a shelter and feed fully exposed on grass blades. This natural history difference between the species in shelter-building behavior may be related to the much steeper declines of Poweshiek Skipperlings than Dakota Skippers (see below) because Poweshiek Skipperling caterpillars may be more exposed to environmental stressors, like insecticide exposure).

**Overwintering and Pupation.** Both species overwinter as mid-stage, similarly aged caterpillars. Dakota Skipper caterpillars remain inside the shelters they had spun



A Poweshiek Skipperling at one of the world's last populations in a Michigan prairie fen  
Photo: Minnesota Zoo



A mature green Poweshiek skipperling caterpillar feeding exposed on prairie dropseed, with its location indicated by a red line.

Photo: Minnesota Zoo



A brown Dakota skipper caterpillar hidden inside the silk structure it constructed at the base of a little bluestem.

Photo: Minnesota Zoo

in late summer, while Poweshiek Skipperling caterpillars remain relatively exposed on the ground at the base of the grasses through winter. The caterpillars resume feeding on their host grasses in spring in similar locations on their host grasses that they had been in during the prior summer (Poweshiek skipperling: exposed. Dakota skipper: sheltered). The caterpillars typically mature in early-mid June, and pupate in the same places.

**Feeding Behavior of Adults.** Adults of both skipper species feed on the nectar of various prairie flower species, and this can vary locally depending on local availability. Purple coneflowers (*Echinacea* sp.) are the preferred nectar sources for Dakota Skippers, while black-eyed susan (*Rudbeckia hirta*) and sometimes *Echinacea* is preferred by Poweshiek Skipperlings. The preferences for these flower species by these butterflies is due to the accessibility of nectar in these flower species as well as a synchronization between flowering periods and the flight period of both skipper species.

## 1.2. Distribution and Population Declines of the Skippers

Both the Dakota Skipper and the Poweshiek Skipperling were historically well-distributed and abundant in tallgrass prairies and moist meadows in the north-central United States and South-Central Canada, including much of western Minnesota. The current distribution of both species is greatly restricted, however, and population densities have declined.

Dakota Skippers were historically known from dozens of localities across Minnesota, with other populations ranging from northeast Illinois to northwest Iowa, and then north across South Dakota, North Dakota, Manitoba and Saskatchewan. However, at least 75% of those populations vanished by the late 2000s (USFWS 2014). This butterfly is now believed to be extinct in Iowa, and there is only one known viable Dakota Skipper population remaining in Minnesota.

The situation for the Poweshiek Skipperling is significantly more dire. It formerly had a huge range from southeast Michigan west to Iowa, and north through Wisconsin, Minnesota, South and North Dakota to southeast Manitoba. However, the species collapsed in the early and mid-2000s, and by 2009 appears to have gone extinct in at least 95% of its global range (Minnesota, Iowa, North Dakota, and South Dakota). Only a handful of populations are known remaining - four in Michigan, one in Wisconsin, and a small cluster in southeast Manitoba. Only a few hundred individuals likely remain globally. Despite once being one of the most widespread and predictably common tallgrass prairie butterflies, it is now one of Earth's most endangered animals.

## 2. Hypotheses for the decline of endangered skippers in Minnesota

A number of hypotheses have been posed for the decline of the Poweshiek Skipperling and Dakota Skipper (as well as other declining Minnesota prairie butterflies). These include the following:



A soybean aphid  
Photo: Minnesota Zoo

- Habitat destruction & fragmentation, including the possibility of secondary succession
- Overgrazing in skipper habitat
- Fire that is too intense or too extensive in skipper habitat
- Loss of genetic diversity
- Extreme weather events
- Climate change
- Herbicide use affecting caterpillar host and/or adult nectar plants
- Insecticide use

While all of these factors may play a role in skipper declines, **insecticide use** seems particularly likely given the timing of the declines since the use of broad-spectrum insecticides against the soybean aphid in fields adjacent to prairie habitats commenced in 2001 (see below). None of the other factors involve timing that is clearly coincident with skipper decline. The potential role of soybean aphid management in leading to skipper population declines is discussed in the following section.

### 3. The potential role of soybean aphid management in affecting butterfly populations

#### 3.1 Soybean aphid and its management

**The arrival of soybean aphid in Minnesota.** The soybean aphid, *Aphis glycines*, is native to Asia and was first detected in North America in the year 2000 (Ragsdale et al. 2011). The mode of introduction is not clear but it was presumably introduced accidentally through infested soybean plants or plant parts. The soybean aphid was first found in Wisconsin and within a few years had spread throughout the soybean growing areas of the United States and Canada. The soybean aphid overwinters on European buckthorn (*Rhamnus cathartica*) and its invasion and spread were greatly aided by this invasive plant (Heimpel et al. 2010). It is currently the most important insect pest of soybeans in the north-central U.S. Until the arrival of soybean aphid in this region, the soybean crop was almost entirely free of insect pests and thus insecticides were only rarely applied to soybean acreage. Soybeans are typically rotated with corn and thus prairie habitat in Western Minnesota is often adjacent to one or both of these crops during the summer. However, insect pests of corn are difficult to manage using aerial insecticide applications and were thus traditionally managed using tractor-applied foliar or soil-applied insecticides and beginning in the mid-1990's using transgenic cultivars and insecticidal seed treatments. Thus, prior to the arrival of soybean aphid in the year 2000, acreage used to grow soybeans and corn was largely free of aerial insecticide applications. **Managing soybean aphids with insecticides.** Populations of soybean aphids in Minnesota and other north-central States reached extremely high densities – exceeding 1,000 aphids per plant – in many fields, and this greatly increased insecticide use in this region. Management of soybean aphids has and continues to rely on application



Aerial spraying for soybean aphid  
in Minnesota.  
Photo: GE Heimpel



of foliar insecticides such as lambda-cyhalothrin ('Warrior'™, a pyrethroid), and chlorpyrifos ('Lorsban'™, an organophosphate). Of these, chlorpyrifos has broad toxicity to invertebrate and vertebrate animals and lambda-cyhalothrin is less toxic to vertebrates but highly toxic to invertebrates. A research group from the University of Minnesota developed a scientifically based spray threshold of 250 soybean aphids per plant (Ragsdale et al. 2007). An insecticide application is recommended when soybean aphid densities surpass this threshold and this avoids economic damage to soybean yields which occurs at approximately 700 aphids per plant under most conditions. Research has shown that adoption of this threshold by farmers can lead to significant reductions of insecticide application while protecting soybean yield (Landis et al. 2008). Neonicotinoid (insecticidal) seed treatments are being used in an increasing acreage in Minnesota but such treatments largely target soil pests and are only effective when pests are present at the appropriate time. A temporal disconnect between pesticide efficacy and pest abundance reduces the effectiveness of the insecticide and may also be harmful to beneficial insects such as biological control agents.

**Non-insecticidal Suppression of Soybean Aphid.** Other management tactics to suppress soybean aphids have been studied and developed. Removal of invasive European buckthorn from areas near agricultural fields and sensitive habitats might produce a local reduction in soybean aphid numbers by reducing availability their overwintering host, but the range-wide impact on soybean aphid populations may be minimal. Host-plant resistance and biological control are the most promising means of suppressing soybean aphid without the use of insecticides.

**Host-plant resistance** is based on identification of natural resistance in Asian soybean varieties and incorporating these traits into commercial soybean lines using traditional plant breeding techniques. A number of genes conferring resistance to soybean aphid have been identified and named *Rag* genes (*Resistance to Aphis glycines*) (Hesler et al. 2013). While soybean varieties incorporating *Rag* genes show promise in experimental field trials, they are not widely available in Minnesota (Hanson et al. 2016a), and additionally, strains ('biotypes') of soybean aphids have been discovered that can counter *Rag* resistance and feed and reproduce normally on 'resistant' soybean varieties. To increase the availability and adoption of host plant resistance for soybean aphid management, researchers are actively working to identify additional sources of resistance (Hanson et al. 2016b) and to incorporate multiple *Rag* genes into well-adapted soybean lines for use in Minnesota and other parts of the Midwest. Research shows that multiple genes are more effective at suppressing aphid abundance and protecting yields, and will be more resilient to development of virulent biotypes of aphids.

**Biological control** is the suppression of pest organisms by living organisms. Naturally occurring predators of the soybean aphid such as lady beetles already greatly reduce soybean aphid pressure from what it would otherwise be (Ragsdale et al. 2011). However, this suppression is not sufficient to consistently keep soybean aphids below economically damaging levels. Thus, biological control needs to be strengthened and better integrated with other management tactics in order to substantially reduce or eliminate the need for insecticide application.



The soybean aphid parasitoid  
*Aphelinus certus* stinging a  
soybean aphid.

Photo: Matthew Kaiser

The development of biological control against the soybean aphid has mainly been focused on Asian parasitoids. Aphid parasitoids are miniscule wasps that specialize in laying their eggs within the bodies of aphids. The resulting parasitoid larvae feed on the aphid from the inside, killing it. Parasitoids of aphids and other insects have been used successfully as biological control agents of hundreds of pest species throughout the world (Heimpel & Mills 2017). These insects are incapable of stinging humans or any animals other than aphids and do not overwinter within homes. A number of Asian parasitoids of the soybean aphid have been investigated at the University of Minnesota over the past 15 years, but it is only in the last three years that a species has been discovered in Minnesota that has the clear potential to strongly suppress soybean aphid populations.

*Aphelinus certus* is a soybean aphid parasitoid wasp that became introduced to North America accidentally during 2005 or shortly prior (Heimpel et al. 2010). It was first found in Pennsylvania and over the next five years became a dominant biological control agent of soybean aphid in Ontario and Quebec. *Aphelinus certus* was found in Minnesota in 2011 and it has spread throughout the soybean-growing areas of the state since then and has steadily increased in population size as well. In 2015 an experiment done on the St. Paul campus of the University of Minnesota showed that natural populations of this parasitoid suppressed soybean aphid populations below the spray threshold (J. Kaser & G.E. Heimpel unpublished). This exciting result shows that *Aphelinus certus* has the capability of reducing or eliminating the need for insecticide applications against the soybean aphid.

### 3.2 Potential impacts of soybean aphid insecticides on skippers

The US Fish and Wildlife Service and the Minnesota Zoo have begun collaborating on efforts to understand the extent of insecticide drift into Minnesota prairie remnants. Five prairie remnants in Minnesota and South Dakota sites have been studied since 2014, with paired grass and soil samples collected along prairie-crop borders and in the interiors of prairies in both late spring (after the crop planting season when neonicotinoid insecticides may be most common) and in late summer (during insecticide applications against soybean aphids). All samples have been analyzed by the U.S. Department of Agriculture's National Sciences Laboratory (Gastonia, NC) for the precise measurement of 165 insecticides, herbicides, and fungicides and their secondary residues using the rigorous and established QuEChERS method (AOAC OMA 2007.01). Insecticides applied against soybean aphids have been found at all sites in late summer, while almost no insecticides have been recorded from these prairies shortly after spring crop plantings. Many sampled points have had no or low detected insecticide residues, but significant drift of the three most commonly applied insecticides against soybean aphid, chlorpyrifos, bifenthrin and lambda-cyhalothrin, have also been recorded. For example, Zoo staff collected samples immediately before and the day after an airplane-applied spray in August 2014 of a soybean field immediately adjacent to the northwest corner of the Prairie Coteau Scientific and Natural Area. This prairie formerly sustained large populations of both Poweshiek Skipperlings and Dakota Skippers, and is federally classified as Critical Habitat for these protected species (USFWS 2015). Moderate to high residue levels of these three insecticides were



Minnesota Zoo staff collecting little bluestem grass and soil samples for pesticides residue analysis from the interior of a Minnesota remnant prairie where Poweshiek skipperlings and Dakota skippers have apparently recently gone locally extinct.  
Photo: Minnesota Zoo.

found. The concentration of chlorpyrifos on grass samples rose dramatically from a range 8.3-48.0 parts per billion (ppb) before the observed spray to a range of 51.8-278.0 ppb after the observed spray. Similarly, lambda-cyhalothrin rose from a range of 2.7-7.2 ppb to a range of 8.4-83.3 ppb before and after the spray. In contrast, the residue concentration of bifenthrin may have dipped slightly between the first (12.0-74.5 ppb) and second (9.4-69.8 ppb) days, suggesting this pyrethroid was not present in the observed aerial application. Most importantly, these high concentrations were observed as far as 1 kilometer from the prairie's edge (i.e. the soybean field). These residues were mainly found on grass vegetation, where the skipper caterpillars would be feeding. Ranges of these three insecticides at the four other sampled prairies have generally been lower (chlorpyrifos: range of 0-26.7 ppb; lambda-cyhalothrin: range of 0-7.7 ppb; bifenthrin: range of 0-71.7 ppb), but the temporal and geographic separation between the application date(s) and the sampling date(s) are not known and residue levels immediately after spraying could have been higher. The key finding for the work to date is that variable levels of insecticides are showing up in all of these native prairie remnants, and there often is not a strong correlation with distance from row crop operations.

## 4. Risk assessment and conservation

In this section we will outline the main research objectives that need to be achieved in order to understand the risk of soybean aphid insecticide applications to populations of endangered skippers and to plan effective conservation measures.

### 4.1 Pesticide risk assessment

Pesticide risk assessment is composed of two elements – estimation of the likelihood of **exposure** of a given organism to the insecticide, and estimation of the **effect** (toxicity) of individuals that are exposed. These two elements are combined to estimate the risk of insecticide application to populations of vulnerable organisms. Current data on both of these elements however are not adequate to conduct a scientifically credible risk assessment for the effects of chlorpyrifos, bifenthrin, or lambda-cyhalothrin on populations of Dakota Skipper, Poweshiek Skipperling, and other prairie butterfly.

#### 4.1.1 Exposure of skippers to insecticides

Studies are needed that will estimate the risk that individual skippers will come into contact with insecticides applied against soybean aphid in fields adjacent to prairie habitat. Elements of this estimation will include the following:

- Geographic proximity of soybean fields needing insecticide applications to sensitive habitats.
- Temporal and geographic dynamics of insecticide drift from various application methods (tractor, airplane, helicopter), including the distance of drift under various environmental conditions, as well as the likelihood of each application method being used on fields adjacent to sensitive habitats.
- Temporal overlap between insecticide application and life-history stages of the skippers.



Interface of a soybean field with a South Dakota prairie remnant.  
Photo: Minnesota Zoo.



- Presence of insecticide residues on various substrates (e.g. skipper host and nectar plants), including the spatial overlap of skipper caterpillars and where residues may be present on their host plants.
- Temporal decay of insecticide residues on various substrates.

#### 4.1.2 Toxicity

Toxicity studies comprise controlled experiments in which various stages of the insect of interest are exposed to various concentrations of the insecticide. Data from these studies produce metrics such as the 'LD50', the dose of insecticide at which half of the insects are killed. Sublethal effects are also important; while an insect may not be killed outright by the insecticide it may suffer lower fecundity or exhibit non-adaptive behavior.

Toxicity studies that quantify dose-dependent lethal and sublethal effects are needed for the Dakota Skipper and the Poweshiek Skipperling when challenged with the main insecticides applied against soybean aphid and that have been found within federally designated critical habitat for these protected species: chlorpyrifos, lambda-cyhalothrin and bifenthrin. It is imperative that this research be conducted using the most appropriate life stage(s). In this case, applications of these insecticides generally occurs in the second half of summer (late July through August), at which time the listed skippers are young caterpillars. As noted earlier, Poweshiek Skipperling caterpillars do not construct shelters, while Dakota skippers do, and this may mean that Poweshiek Skipperlings are more exposed a wide range of environmental stressors, including potential exposure to insecticides. Given the threatened and endangered species status of these butterflies, studies will likely need to rely on closely-related, and/or ecologically similar skipper species. No comparable insecticide-toxicity studies exist for any skipper or other closely related group of butterflies, so these studies using non-model organisms would be foundational. This research should be comprehensive and extend beyond single species x single insecticide toxicity studies. Complementary experiments testing toxicity effects should employ factorial combinations of exposures of skipper caterpillars (of multiple species) to variable concentrations of insecticides (both individual pesticides and in combination, as are commonly applied commercially and observed in the field data) in both direct contact and in indirect contact (through the spraying of their host grasses, not necessarily the caterpillars themselves) exposure experiments. Ultimately, this integrative toxicity research should provide a framework against which the toxicity effects of observed insecticide drift on imperiled prairie skippers can be predicted. This foundational research is critically needed to inform management and conservation prescriptions, as well as reviews of these pesticides.

#### 4.2 Conservation measures

Conservation measures will depend on the main causes for skipper decline. We focus here on measures that are relevant *if* soybean aphid insecticides are determined to be an important risk factor.



#### **4.2.1 Rearing and Re-introduction of skippers**

Both the Dakota Skipper and the Poweshiek Skipperling are currently being reared at the Minnesota Zoo as part of formal conservation plans supported by the US Fish and Wildlife Service for these two listed species (Delphey *et al.*, 2016). Re-introductions and population augmentations have been identified as key long-term conservation tools to recover these species. Those efforts should be planned for places and times that minimize risk of insecticide exposure.

#### **4.2.2 Reducing insecticide applications in key locations**

Regulations or recommendations could be established that reduce insecticide use within a certain distance of sensitive prairie sites, including sites targeted for re-introductions of skippers. This also would inform best management practices to help agricultural operators minimize unnecessary applications of insecticides and reduce drift losses.

#### **4.2.3 Taking advantage of biological control**

Sampling of soybean aphid parasitoids adjacent to sensitive prairie sites early and mid-season could give information on whether particular fields would be likely to reach threshold aphid infestation densities and thus be sprayed. This information could be used to plan re-introductions or predict which sites are most vulnerable.

#### **4.2.4 Establishing buffers around sensitive habitats**

The planting of aphid-resistant soybean varieties should be supported, particularly adjacent to sensitive habitats, to reduce the need for insecticide applications. Buffers using non-soybean crops could also be created near sensitive habitats.

## **Synthesis and Recommendations**

The potentially harmful effects of soybean aphid insecticide drift is one of the strongest and most testable hypotheses to explain the rapid decline in populations of the Poweshiek Skipperling and Dakota Skipper in the mid-2000's. This is because of the temporal coincidence between the initiation of insecticide use against this invasive agricultural pest and the rapid range-wide declines of the skippers, particularly given that those declines have been most pronounced in portions of the ranges where row crop agriculture is in closest proximity to remnant native prairie patches. Correlation certainly does not mean causation though, and we recognize that other hypotheses may also have merit. The skippers may be suffering from multiple interacting stressors, and these stressors (including the degree of insecticide exposure) may vary locally and temporally. However, testing the insecticide hypothesis presents the most expeditious and cost-effective way to make progress in this area for a number of reasons. First, the insecticide hypothesis is relatively easy to evaluate. Hypotheses based on habitat fragmentation and loss of genetic diversity are notoriously difficult to assess, particularly given the paucity of historical specimens. Similarly, understanding how the butterflies respond to changes in climate (such as increasingly snow-free winters or



extended extreme summer heat) would require experimental manipulation of microclimatic conditions that are only possible with larger populations maintained under Zoo conditions than currently exist. The overgrazing, fire, and herbicide hypotheses could be explored using manipulative studies and retrospective analyses, but these would be difficult given the extremely low levels of skippers currently in prairies and the low resolution of historical data. These hypotheses are also difficult to test because they additionally rely on indirect interactions in the form of stressors on host plants rather than the skippers themselves. The insecticide hypothesis is more tractable from an experimental standpoint because the risk assessment is based on direct effects of the insecticides on the skippers. The direct link between soybean aphid density and insecticide application makes the exposure relatively easy to conceptualize. Second, disproving the insecticide hypothesis would constitute an important step towards determining the real cause(s) of decline by process of elimination. Third, having information on the insecticide hypothesis is particularly urgent since applications continue to occur on a yearly basis across Minnesota.

For these reasons, we recommend support for a research program in which the insecticide hypothesis is rigorously assessed and tested. This includes both improved understanding of the extent and variability of drift into prairie remnants and the initiation of controlled laboratory exposure studies. If this work excludes detrimental effects of exposure of soybean aphid insecticides as an important factor leading to the decline of the endangered skippers, then we will be an important step ahead in determining the real cause(s). Such a finding would also broaden the pool of candidate prairie remnants where reintroductions of the endangered species may occur. If on the other hand, soybean aphid insecticides are implicated as major causes for the declines, we will have a clearer path toward conservation.

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## References Cited

- Dana, R. P. 1991. Conservation management of the prairie skippers *Hesperia dacotae* and *Hesperia ottoe*. Minnesota Agricultural Experiment Station, University of Minnesota, St. Paul, Minnesota. 63 p.
- Delphey, P., E. Runquist, T. Harris, C. Nordmeyer, T. Smith, K. Traylor-Holzer, and P.S. Miller (eds.) 2016. Poweshiek Skipperling and Dakota Skipper: Ex-situ Feasibility Assessment and Planning Workshop. Apple Valley, MN: IUCN/SSC Conservation Breeding Specialist Group.
- Hanson, A., S.J. Bhusal, A. Lorenz and R.L. Koch. 2016a. Aphid-resistant soybean varieties for Minnesota. University of Minnesota Extension. <http://www.extension.umn.edu/agriculture/soybean/pest/soybean-aphid/aphid-resistant-soybean/>
- Hanson, A.A., J.H. Orf and R.L. Koch. 2016b. Sources of soybean aphid resistance in early-maturing soybean germplasm. *Crop Science* 56(1): 154-163.
- Heimpel, G. E. and N. J. Mills. 2017. *Biological Control: Ecology and Applications*. Cambridge University Press, Cambridge, U.K.
- Heimpel, G. E., L. E. Frelich, D. A. Landis, K. R. Hopper, K. A. Hoelmer, Z. Sezen, M. K. Asplen, and K. Wu. 2010. European buckthorn and Asian soybean aphid as components of an extensive invasional meltdown in North America. *Biological Invasions* 12:2913-2931.
- Hesler, L.S., Chiozza, M.V., O'neal, M.E., MacIntosh, G.C., Tilmon, K.J., Chandrasena, D.I., Tinsley, N.A., Cianzio, S.R., Costamagna, A.C., Cullen, E.M. and DiFonzo, C.D., 2013. Performance and prospects of Rag genes for management of soybean aphid. *Entomologia Experimentalis et Applicata*, 147(3), pp.201-216.
- Lands, D. A., M. M. Gardiner, W. van der Werf, and S. M. Swinton. 2008. Increasing corn for biofuel production reduces biocontrol services in agricultural landscapes. *Proceedings of the National Academy of Sciences of the United States of America* 105:20552-20557.
- Ragsdale, D. W., D. A. Landis, J. Brodeur, G. E. Heimpel, and N. Desneux. 2011. Ecology and management of soybean aphid in North America. *Annual Review of Entomology* 56:375-399.
- Ragsdale, D. W., B. P. McCornack, R. C. Venette, B. D. Potter, I. V. Macrae, E. W. Hodgson, M. E. O'Neal, K. D. Johnson, R. J. O'Neil, C. D. Difonzo, T. E. Hunt, P. A. Glogoza, and E. M. Cullen. 2007. Economic threshold for soybean aphid (Hemiptera: Aphididae). *Journal of Economic Entomology* 100:1258-1267.
- U.S. Fish and Wildlife Service. 2014. *Endangered and Threatened Wildlife and Plants; Threatened Species Status for Dakota Skipper and Endangered Species Status for Poweshiek Skipperling*. 50 CFR Part 17. Final Rule. pp. 63672-63748.
- U.S. Fish and Wildlife Service. 2015. *Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for the Dakota Skipper and Endangered Species Status for Poweshiek Skipperling*. 50 CFR Part 17. Final Rule. pp. 59248-59384.