Chapter 11

Insect Management Strategies

Sanford Eigenbrode, University of Idaho
Edward Bechinski, University of Idaho
Nilsa Bosque-Pérez, University of Idaho
David Crowder, Washington State University
Arash Rashed, University of Idaho
Silvia Rondon, Oregon State University
Bradley Stokes, University of Idaho

Abstract

This chapter provides an overview of the pests affecting wheat systems in the inland Pacific Northwest (PNW). The chapter begins by reviewing the principles of integrated pest management (IPM) and the challenges for insect pest management under projected climate change for the region, along with other potential changes such as biological invasions and the effects of changes in production technology. It then provides specific information about the most important of the region's pests of wheat including their life cycles, injurious stages, management, biological control, and potential responses to climate change. Each is accompanied by photographs and other information for pest identification. Key publications from scientific and Extension literature are provided at the end of the chapter for use by pest managers and others.

Key Points

- Changes in technology and production practices, as well as anticipated changes in climate, have implications for IPM in cereal production systems.

- Effective management of insect pests depends on managers having an understanding of each species distribution, life cycle, crop damage caused, and principles and practices for IPM specific to each pest.
- Evolution of cropping systems including changes in tillage regimes and rotational crops will have important implications for pest management.
- Though anticipated effects on insect pests vary by species, possible mechanisms by which climate change can impact insect pests include: changes in the timing of pest activity, shifts in the geographical range of pests, and shortened life cycle time (thus increasing the number of generations per year).
- The entire wheat system, including rotational crops and surrounding landscapes, influences pest abundance. Spatial and temporal variability in landscapes and agricultural production systems impact populations of insect pests.

Introduction and Background

Overview of Pests Affecting Inland PNW Cereal Production Systems

Cereal systems of the US are subject to economic injury from approximately 30 insect species. The PNW is home to more than 20 of these, including aphids, wireworms, Hessian fly, wheat midge, cereal leaf beetle, Haanchen barley mealybug, armyworms, and cutworms. Their collective potential to reduce yields across our region is substantial, but pressures vary across the region and among years so that relatively few are problematic at any one time or place. For this reason, however, their management requires that producers know these pests, can sample them effectively, and can make prudent decisions about treatments and management practices to minimize their impacts. This section of the handbook provides an overview of the most prevalent insect pests of the **inland PNW**, with information about their biology and life cycles, types of injury, and approaches for their management. It also considers how various farming practices can affect each pest. Finally, it takes a look forward to anticipate possible changes in pressure from these pests as the region's climate changes.

The Elements and Principles of Integrated Pest Management

Effective **integrated pest management** (IPM) depends on regularly scouting fields for the presence and abundance of **pests**. Pest presence indicates a need for vigilance to monitor pest densities to anticipate their population from reaching local economic **thresholds**. Correctly identifying pest species is critical, as many insects look alike but carry different risks and require different management approaches. This chapter provides guides for identifying common pests and citations to sources to help with identification. When in doubt, get the help of a specialist. Basic scouting principles include considering the timing of scouting (to focus on vulnerable stages of the crop and anticipated timing of infestations), scouting weekly during the vulnerable period, sampling randomly within the field to ensure accuracy, and using a sampling method that aligns with treatment thresholds when these are available. Appropriate methods must be used depending upon the goal, which might be to assess pest presence or to estimate pest densities as a basis for making treatment decisions.

Since each of the sections on individual pests discusses management options, here we provide a brief overview of the principles of IPM applicable to most pests. IPM combines nonchemical approaches with judicious use of pesticides to achieve economically viable pest control. A central principle in IPM programs is never to use pesticides as "just in case" insurance treatments or scheduled calendar applications. Rather, IPM producers look first to nonchemical controls and instead use pesticides "just in time," based on pest forecasts and economic thresholds. Nonchemical management tactics include cultural control, mechanical control, and biological control. Cultural controls (modifying the growing environment to reduce the prevalence of unwanted pests) include crop rotation, variety selection, altered planting date, fertilizer application, or fertilizer timing. Mechanical control tactics include physical removal, insect trapping, tillage, and other physically controlling management tactics. Biological controls include naturally occurring or augmented predators, parasitoids and pathogens that attack and kill pests, and any management practices designed to preserve or encourage these beneficial organisms. Chemical controls include so-called "least-toxic" biorational pesticides (that specifically target particular pests over beneficials and other nontarget species) and conventional broad-spectrum insecticides. Over the past decade several least-toxic biorational pesticides have been marketed for use in cereals. Efficacy can vary but these products, because of their narrow spectrum of activity, are environmentally safer than broad-spectrum conventional insecticides such as pyrethroids, carbamates, organophosphates, and neonicotinoids. At the same time, recent changes in application practices (seed treatments, lower rates of application, reduced frequency application) can minimize the effects of broad-spectrum conventional insecticides on beneficials and other nontarget organisms. These materials must be applied according to labels to comply with regulations and minimize environmental impacts, including disruption of biological control. While scouting for the presence of pests, natural enemies should also be noted to determine their relative abundance and assess their potential to control pest populations.

Insect Pest Management in a Diverse and Changing System

A Heterogeneous System: Eastern Idaho to Central Washington

Although inland PNW wheat production systems are united by similarities in climate, terrain, markets, and histories, they are also remarkably heterogeneous. The climate is generally Mediterranean-like, with cold, wet winters and warm to hot, dry summers, but there are significant gradients in average annual precipitation (from <7 to >25 inches) and mean annual temperatures (from 43°F to 55°F). Soils are dominated by Mollisol and Aridisol orders, but Alfisols are present in the wetter subregions. This edaphic and climatic heterogeneity can be delineated into **agroecological classes** in which specific cropping systems from wheat-fallow to continuous cropping with rotations predominate. Which cropping system is used in any parcel is also affected by many local factors. Across large parts of the region, precipitation is inadequate for crop production and irrigation is required (see Figure 1-3 in Chapter 1: Climate Considerations). The variable climate and production systems employed, in turn, can affect insect pests. The distributions of the several wireworm species in the region, for example, differ. As another example, the wheat midge is currently confined to a small portion of our region, while the wheat stem sawfly (*Cephus cinctus* Norton) is a serious problem in Montana wheat systems but with rare reports of injury in the Columbia Basin and Palouse regions.

As detailed in Chapter 1: Climate Considerations, the region's climate is dynamic, and is experiencing a warming trend accompanied by shifts in precipitation that include drier summers. Based on models, the changes will not necessarily be uniform, with warming and precipitation changes occurring at different rates and directions in different parts of the region. One motivation for this book is to anticipate the implications of a changing climate on inland PNW wheat systems and equip producers with scientific knowledge to cope with them. Climate change can affect insect pests of wheat and other crops (Eigenbrode and Macfadyen 2017; Lehmann et al. 2017). The effects can be directly on the pests, or they can be indirect, influencing biological control (Eigenbrode et al. 2015). Science-based projections of the implications of climate change for specific insect pests of inland PNW wheat systems, when available, are presented in this chapter.

Variability and Change in Technology

In addition to ongoing and anticipated changes in climate, cereal production is affected by changes in technology and production practices that have implications for IPM. Although reduced tillage methods have been adopted on much of PNW farmland (see Chapter 3: Conservation Tillage Systems), most of our wheat systems are still grown using **conventional tillage**. Adoption of reduced tillage, which is ongoing, can change pests and their management. Impending technology that could affect pest management includes remote sensing, which is just beginning to include capabilities for sensing biotic stresses in crops, like disease, weed, and insect infestations. During the useful life of this book, we anticipate these sorts of tools will become available, whether deployed via unmanned aerial vehicle (drones), tractor-mounted devices, or otherwise. For example, Russian wheat aphid (*Diuraphis noxia* Mordvilko), which causes distinctive changes in spectral reflectance of infested wheat plants, can be detected remotely based on normalized difference vegetation index imaging (Mirik et al. 2012). There has also been some success in detecting English grain aphid (*Sitobion avenae* F.) in experimental systems (Luo et al. 2013). Russian wheat aphid is of minor concern in our region and the two species differ in the economic injury they cause, necessitating a system that can discriminate between them but has not yet been investigated. Because reliable remote sensing would be such an enormous boon, allowing prudent, "just in time" pest management interventions without time-consuming sampling, its promise has been much discussed and its advent anticipated for more than 20 years. Development of successful applications is inevitable, but remains elusive.

Changing Cropping Systems

Wheat in the region is currently produced under annual crop, annual crop-fallow transition, and wheat-fallow production systems (as described in Chapter 1: Climate Considerations). In recent years there have been trends to increased incorporation of canola and legumes into crop rotation, which is facilitated in drier zones by the availability of fall-planted varieties of these commodities (see Chapter 5: Rotational Diversification and Intensification). There is also interest in other alternative crops or **cover crops**. Rotation out of wheat, which occurs in annual cropping systems, helps to break disease and pest cycles. The adoption of more diverse rotations will likely affect the abundance of insect pests and their natural enemies with implications for pest management.

Invading Pests

Most insect pests of the inland PNW cereals are non-native invaders. That is, their native ranges coincide with the origins of cereal crops and people have accidentally spread them throughout the globe. At intervals, since wheat production began here, new members of this pool of potential pests have arrived to join the inland PNW pest complex. Key aphid species—bird cherry-oat (*Rhopalosiphum padi* L.), English grain, and rose-grass (*Metopolophium dirhodum* Walker)—probably arrived with the first wheat crops grown in western Oregon in the mid-19th century. Bird cherry-oat aphid feeds on many grasses and may have been distributed globally even before European colonization. As wheat moved east into Washington, Oregon, and Idaho, aphids could readily colonize these crops on prevailing westerly winds. The Russian wheat aphid arrived in the US in 1986 and spread rapidly, reaching Washington by 1988. In 2011 an aphid new to

North America (native to the UK), *Metopolophium festucae cerealium* Stroyan ('wheat and grass' aphid in this book) was found to be abundant and widespread throughout our region. Another relatively recent invader is the cereal leaf beetle (*Oulema melanopus* L.), first detected in Idaho in 1992 and Washington in 1999. Haanchen barley mealybug (*Trionymus haancheni* McKenzie) was first detected in 2003. Hessian fly (*Mayetiola destructor* Say) was first recorded in western Washington in the 1930s and in the semiarid regions of eastern Washington in the 1960s. The yellow underwing noctuid (*Noctua pronuba* L.) has been absent from southern Idaho until very recently but is beginning to appear there. This invasion process is certain to continue as pests move throughout the world, presenting new challenges to production systems. Very rarely do pests disappear from a region, so the process is cumulative. An analogous process occurs for invasive weeds and pathogens affecting cereal crops. Insect pests that are present in the US but not yet present or that have minor pest status in the PNW include wheat stem sawfly (*Cephus cinctus* Norton), wheat stem maggot (*Memoryze americana* Fitch), and white grubs (various species).

Principal Insect Pests of PNW Cereal Production Systems

In the following sections, we provide an overview of the principal insect pests affecting cereal systems in the PNW. For each we describe its distribution, a description of the insect and its life cycle, the damage it causes, principles and practices for its management, where more information is available, and its projected response to climate change in the region. Although these sections mention insecticides and their use, please refer to the PNW Insect Management Handbook for more information: ***http://insect.pnwhandbooks.org***.

Aphids

Pest status & distribution

Although as many as 12 species of aphids (Hemiptera: Aphididae) can be found in PNW wheat production systems, six species predominate. Listed here roughly in their order of relative abundance in recent surveys

(2011–2014): English grain aphid, the newly invasive 'wheat and grass' aphid, rose-grass aphid, Russian wheat aphid, bird cherry-oat aphid, and greenbug (*Schizaphis graminum* Rondani). All are equally prevalent throughout the region except Russian wheat aphid, which is more abundant in northern Oregon. With the exception of Russian wheat aphid and 'wheat and grass' aphid, the pests have been part of wheat production systems throughout their history in the PNW. Russian wheat aphid rapidly invaded the PNW in 1988, soon after its first occurrence in North America. The 'wheat and grass' aphid has been detected in large densities throughout central Washington, northern Idaho, and Oregon since its detection in surveys in 2011, but may have been in the region since the 1990s (Halbert et al. 2013). This species has not been detected in southern Idaho or Oregon. It feeds on wheat and other grasses in the region (Davis et al. 2014a)

Pest description

Aphids are small soft-bodied, oval or teardrop-shaped insects. They can be distinguished from similar insects by the presence of a pair of cornicles, backward-projecting organs that look like "tail pipes" extending from the abdomen that extrude a defensive fluid (Figure 11-1). The species affecting wheat differ in the type and level of damage they can inflict, and

Figure 11-1. Generalized aphid body plan, the backward-facing cornicles are a unique identification characteristic only present in aphids (arrows). (Photo: Brad Stokes, University of Idaho.)

Table 11-1. Identifying characteristics of the principal aphid pests of PNW cereal production systems.

Common Name	Shape & Size	Cornicles	Antennae	Abdomen
Russian wheat aphid	Spindle; ~2 mm (0.08 inch)	Very short; not longer than wide	Shorter than length of the entire body	Little to no pigmentation with two-tailed appearance
Rose-grass aphid	Spindle; 1.6–2.9 mm (0.06–0.12 inch)	Long, pale & cylindrical	3/4 length of the entire body, dark between segments	Green with light pale stripe down midline
'Wheat and grass' aphid	Spindle; ~2 mm (0.08 inch)	Long, pale & cylindrical	3/4 length of the entire body, becoming darker distally	Uniformly green with no pale stripe down midline
English grain aphid	Spindle; 1.8 mm (0.1 inch)	Short, dark & cylindrical	3/4 length of the entire body, uniformly dark	Little to no pigmentation (yellow-green to reddish brown)
Bird cherry-oat aphid	Oval; ~2 mm (0.08 inch)	Short, swollen & flanged (red patches around base)	3/4 length of the entire body, uniformly dark	Dark pigmentation (olive-green to greenish-black appearance)
Greenbug	Spindle; 1.3–2.1 mm (0.05–0.08 inch)	Short, pale & cylindrical	3/4 length of the entire body, pale joints between segments	Green with dark stripe down midline

Figure 11-2. Representative photos of adult, wingless aphids. Bird cherry-oat aphid (top left), 'wheat and grass' aphid (top middle), Russian wheat aphid (top right), English grain aphid (bottom left), rose-grass aphid (bottom middle), and greenbug (bottom right). (Photos: top left, top middle, top right, and bottom left, Brad Stokes, University of Idaho; bottom middle, Claude Pilon Les Pucerons du Québec; bottom right, Kansas Department of Agriculture.)

in their distribution in the PNW, so producers should be familiar with the species as a foundation for pest management. Both winged and wingless forms occur in the same species, but during the summer months nearly the entire population on infested plants will be wingless. These wingless forms can be distinguished based on morphology and distribution within the plant, although a hand lens is often required (Table 11-1; Figure 11-2).

Life cycle

All aphids undergo periods of asexual, parthenogenetic viviparous reproduction. This means that summer populations entirely consist of females that do not lay eggs but instead give birth without mating to many dozen live nymphs; all these offspring are female and can mature into reproductive adults within a week. As a result, aphid infestations increase exponentially during the summer. Most aphid life cycles also include sexual reproduction in which males and nonparthenogenetic females are produced, mate, and lay eggs, which are winter hardy. Two PNW species, bird cherry-oat aphid and rose-grass aphid, are host-alternating (as their dual-host plant names suggest), which means the winged sexual forms migrate in the fall from cereals to a woody host where eggs are laid and overwintering occurs. All the other PNW cereal aphid species overwinter in grassy habitats including winter wheat fields, either undergoing a sexual phase and laying eggs there or as hardy asexual forms. In all cases, seasonal migrations of winged forms from overwintering locations back into the wheat crops establish the pest populations each year. These fall and spring migratory movements have been tracked over years and their timing and size vary in response to weather patterns. Due to the timing of these movements and the production cycle in the region, spring-planted cereals in the PNW are at greater risk of aphid-induced injury than fall-seeded cereals.

Host plants & damage

In the PNW, aphids feed on every commercially produced cereal crop: wheat, barley, oats, and rye. They feed on plants by inserting their mouthparts (stylet) into the phloem of the plant, extracting the nutritious phloem sap. Sufficiently high densities of aphids can deplete plant resources and reduce plant growth or kill plants outright. In addition, some aphids have toxic saliva that can injure plants and reduce yield. Russian wheat aphid, 'wheat and grass' aphid, and greenbug can cause this additional type of injury (Figure 11-3). Russian wheat aphid and 'wheat and grass'

Figure 11-3. Damage on wheat from feeding by the 'wheat and grass' aphid is evidently caused by salivary toxins. Other aphids affecting wheat with salivary toxins that cause plant injury are greenbug and Russian wheat aphid. (Photo: Brad Stokes, University of Idaho.)

aphid can cause considerably more injury per individual aphid than bird cherry-oat aphid, which is not known to introduce a toxin when it feeds.

Importantly, aphids can carry plant viruses that potentially cause much more severe plant injury than direct aphid feeding. A single aphid can transmit a pathogenic virus to the plant, which severely reduces yield. In the PNW, several different species of *Barley yellow dwarf virus* (BYDV) are the primary aphid-borne pathogens affecting cereals. Bird cherry-oat aphid, English grain aphid, rose-grass aphid, and greenbug are capable of transmitting BYDV. Recent research indicates that the 'wheat and grass' aphid is not a vector for BYDV (Sadeghi et al. 2016). Symptoms of a BYDV infection in wheat include leaf chlorosis (sometimes reddening) (Figure 11-4), leaf roll, stunted plants, small irregularly shaped seed heads, and reduced seed size after maturity. BYDV is an obligate pathogen of many grass species and overwinters exclusively in wild and cultivated grasses and volunteer cereal/corn and weedy grasses, including the newly invasive African wiregrass (*Ventenata dubia*) (Ingwell and Bosque-Pérez

Figure 11-4. Wheat with barley yellow dwarf disease caused by *Barley yellow dwarf virus* (BYDV) in southern Idaho. (Photo: Juliet Marshall, University of Idaho.)

2015). BYDV infections frequently result in the plant acquiring barley yellow dwarf disease, causing additional yield damage to wheat crops in the inland PNW.

Integrated pest management

Monitoring and thresholds

Scout for cereal aphids weekly from emergence until crop maturity since aphid populations can build rapidly. Use a standard 15-inch sweep net to detect early infestations when densities are low. When infestations are detected, frequent monitoring is advisable. Count aphids per stem to determine if the nominal thresholds for treatment have been exceeded. Both scouting for the presence of pests and monitoring for pest abundance should be done at multiple sites in field margins and interior since aphids are usually highly aggregated, especially during early infestations. Precise economic thresholds do not exist for cereal aphids in our region, but the literature provides some guidelines for the use of chemical treatments. Rules of thumb recommend treatment when aphids (regardless of species) reach two to ten per tiller, per stem, or per head, prior to dough stage. After dough stage, there are no benefits from treating aphids, as they are not damaging to yield after this growth stage. When the risk of virus is high, thresholds are not useful since a single aphid can transmit the virus. At this time, virus risk monitoring systems do not exist. In recent years, virus infection has been negligible in northern Idaho, but more prevalent in central Washington and eastern Idaho, where significant virus outbreaks have occurred.

Biological control

In our region, aphids are generally held below nominal thresholds for chemical control by generalist predators and parasitoids. Well-known aphid predators that can readily be observed at work in cereal crops include several species of lady beetles (Coccinellidae), fly larvae that specialize on aphids (Syrphidae), lacewing larvae and some adults (Chrysopidae and Hemerobiidae), big-eyed bugs (Geocoridae), assassin bugs (Reduviidae), minute pirate bugs (Anthocoridae), and rove beetles (Staphylinidae). In addition, PNW aphids are attacked by at least eight different species of parasitic wasps (Hymenoptera) (Bosque-Pérez et al. 2002). Aphids also are **susceptible** to some specific entomopathogenic fungi, but these rarely have significant impacts in dryland systems because they require persistent humid conditions to create epidemics.

Cultural control

A well-known and often used practice to reduce the risk of aphids and their associated viruses is to plant spring wheat as early in the growing season as possible, reducing the amount of time for aphids to feed and/or transmit viruses to the plant. Eliminating the **green bridge** for BYDV (wild, volunteer cereals and weedy hosts) may also reduce the number of primary infections in a given field. Aphids can also fly into the fall months, so early planting of winter wheat potentially places the crop at greater risk of virus infection.

Resistant varieties

Although sources of host plant resistance to several cereal aphid species are known, no PNW varieties carry deliberately developed resistance to any common aphid pests. This mirrors the situation globally. Research continues to improve understanding of the genetics and mechanisms of resistance to aphids, but few varieties have been released. Eventually, this knowledge, coupled with demand, may lead to adapted **resistant** varieties for our region.

Chemical control

Neonicotinoid seed treatments, often used for wireworm control, can also have some efficacy against aphids, and there is evidence that these treatments can also limit spread of BYDV for which some aphid species serve as vectors. Tighter regulations on these materials may limit their utility before long. Neonicotinoids are also available as foliar sprays for aphids in cereals, as are many pyrethroid products and a few organophosphate and carbamate products. Foliar applications especially run the risk of reducing natural enemy populations that are important for keeping aphids and other pests in check in cereals under most situations in our region. Please refer to the PNW Insect Management Handbook for current insecticide recommendations.

Climate change

Aphids potentially respond to climate variability through changes in their geographic ranges and the timing and abundance of their annual migrations, which can affect their arrival into fall- and spring-planted crops, with implications for direct injury and viral disease epidemiology. Given the relatively abundant historic data and importance of aphids, they have received considerable attention in the context of climate change. Different species respond differently to climatic drivers. In the PNW, 20-year suction trap records indicate that bird cherry-oat aphid, rose-grass aphid, and Russian wheat aphid each responded differently to climate (Davis et al. 2014b). Russian wheat aphid abundances were negatively correlated with increasing temperatures, rose-grass aphid abundance was positively correlated with increasing cumulative precipitation, and bird cherry-oat aphid abundances were unrelated to any climate variables. This heterogeneity is similar to studies of aphids and climate around the world. At this juncture, no clear projections can be offered.

There are numerous ways climate change can potentially affect the bird cherry-oat aphid and hence BYDV (Finlay and Luck 2011), but there is scant research on the topic. Only two studies exist examining effects of climatic factors on BYDV. In separate controlled studies, elevated carbon dioxide and sharply elevated temperature (+5°C; 41°F) increased virus titer (abundance of virus particles) in infected plants, leading the authors to suggest that virus spread could be enhanced under future projected climate change conditions (Trebicki et al. 2015; 2016). In a surprising twist, recent work shows that BYDV-infected wheat plants tolerate drought stress better than non-infected controls, suggesting the system-wide response to drought could be complex (Davis et al. 2015).

Hessian Fly

Pest status & distribution

The Hessian fly has been a pest of US wheat since its accidental introduction into the country over 200 years ago (Bosque-Pérez 2010). It has been present in parts of the inland PNW since the 1930s. Damaging infestations of Hessian fly have only occurred in the inland PNW over the last two decades where climatic conditions are suitable for fly survival and development. In 2015, the fly was detected in southern Idaho for the first time. Wheat is the preferred host for Hessian fly, with spring wheat more commonly damaged than winter wheat.

Pest description

Adult Hessian flies are small (1/8") dark brown-reddish colored midges (Figure 11-5). They do not feed, and die a few days after emergence as adults. Hessian fly has four life stages: egg, larva, pupa, and adult. After mating, female flies lay 200 to 300 eggs on the upper surface of wheat leaves (Figure 11-5).

Life cycle

Eggs develop in between five to ten days depending on temperature. Larvae emerge as very small, bright red, legless maggots, which migrate to a node or the crown of the plant where they begin feeding. When larvae are fully developed, their cuticle hardens and darkens to form puparia that are attached to stems under leaf sheaths (Figure 11-6). Puparia are protected from the elements during periods of unfavorable conditions. Puparia are often referred to as "flaxseeds," which they resemble. Adults emerge from puparia during favorable environmental conditions in the spring. In the inland PNW, one or two generations of the fly occur per year (Castle del Conte et al. 2005).

Host plants & damage

Damage to the plant is caused solely by larval feeding. Larvae feed on the stem under the leaf sheaths, and high infestations can result in stunted plants or plant death. Feeding also causes reductions in grain quantity and quality, and weakened stems result in lodging and decreased yields. Yield reductions due to Hessian fly infestation of spring wheat without resistance range from 11–24% (Smiley et al. 2004). If infestations are severe, primary tillers may die, but sometimes plants develop new tillers (Schotzko and Bosque-Pérez 2002). Although no visible injury to the plant may be noticeable at the feeding site, infested plants might be stunted, lodged, exhibit erratic head heights in the field, or, in some genotypes, show erect dark green leaves.

Figure 11-5. Adult Hessian fly with single egg on wheat. (Photo: Scott Bauer, Bugwood.org.)

Figure 11-6. Hessian fly larva and puparia on wheat. (Photo: Dennis Schotzko, University of Idaho.)

Integrated pest management

The occurrence of fly infestations is difficult to predict. Therefore, control methods are mostly preventive, with the most common being resistant varieties and earlier seeding to escape infestation (Bosque-Pérez 2010). Additionally, crop rotation and destruction of volunteer wheat are important management tools. Fly parasitoids also provide some control. Parasitism levels vary widely depending on location and year, ranging from 10% to 85% (Bullock et al. 2004). Eight parasitoids are known to attack Hessian fly in the inland PNW (Bullock et al. 2004). Although the retention of wheat residue is known to increase fly survival (Clement et al. 2003), reduced tillage practices do not increase within-field abundance of the fly and have no consistent effect on spring wheat yield (Castle del Conte et al. 2005).

Fly biotypes (or genetic variants) that attack resistant varieties are known to exist in many parts of the US including the inland PNW (Ratcliffe et al. 2000). Such virulent biotypes pose a potential risk to the durability of resistant varieties. Utilization of multiple resistance genes and control via parasitoids will increase durability of resistance. Screening and breeding for resistance to Hessian fly is a continuous effort in the wheat breeding and host plant resistance programs in Idaho and Washington, and numerous resistant varieties are available for growers. Current wheat varieties include: 'Jefferson,' 'Jerome,' 'Cataldo,' 'Diva,' 'Louise,' 'Kelse,' 'Babe,' 'Whit,' 'Hollis,' and 'JD'. Spring barley 'Baronesse' is resistant to a predominant Hessian fly biotype. Additional varieties are in the pipeline and will be released in the future. In areas of heavy Hessian fly infestations such as northern Idaho and eastern Washington, growers are encouraged to always plant resistant spring wheat varieties to avoid economic losses.

Climate change

In the inland PNW, resistant varieties are used as the primary IPM tactic to manage Hessian fly (Ratcliffe et al. 2000; Schotzko and Bosque-Pérez 2002). Although warming climates can change the timing of fly activity and even increase the number of generations per year, resistance technology should remain effective. However, currently all resistant varieties deployed are spring wheats. There is an indication that warmer falls and wetter springs associated with climate change might result in higher incidence of Hessian fly in winter wheat. This will necessitate the development of Hessian fly-resistant winter wheat varieties adapted to the inland PNW region. There is one report of a Hessian fly-resistant gene that loses its efficacy under elevated temperatures, but that gene is not important for continuing resistance to the fly in inland PNW spring wheat varieties, which currently rely on a different set of Hessian fly-resistant genes.

Cereal Leaf Beetle

Pest status & distribution

The cereal leaf beetle (CLB) is an invasive pest of cereal crops. It was accidentally introduced into Michigan in the 1960s and has since expanded its distribution westward to all of the wheat/barley/oat/rye growing counties of Idaho, Washington, and Oregon. In the US, at least 30 states have confirmed CLB populations although they may be present in other regions where cereal crops are produced (Philips et al. 2011). Crop damage by this insect may result in significant yield quantity and quality reduction and reduced economic returns to producers. In some parts of its range in the US, CLB can cause up to 75% yield loss in cereal crops (Buntin et al. 2004).

Pest description

CLB adults are small (1/4”), oval-shaped beetles with blue-to-green metallic forewings (elytra) and a brightly colored red head, thorax, and legs (Figure 11-7). CLB eggs are very small and bright yellow as they are laid by the female, and then turn to a darker brown as they near maturity. CLB larvae have a brown head with a yellowish body; often they may appear darker because larvae use their own feces to coat themselves, and it is thought this behavior helps deter natural predators and parasitoids. CLB should not be confused with the similar-looking Collops beetles (*Collops vittatus* Say), which are beneficial insects that occur in cereal fields. The Collops beetle, or “red cross beetle,” has a red thorax, but not a red head, and elytra that are metallic blue and red. Males have distinct swellings at the base of their antennae; a female is shown in Figure 11-8.

Figure 11-7. Adult cereal leaf beetle in a wheat field. (Photo: Nate Foote, University of Idaho.)

Figure 11-8. Adult female Collops beetle resting on a wheat head. (Photo: Brad Stokes, University of Idaho.)

Life cycle

CLB completes only one life cycle per season in the inland PNW. They overwinter as diapausing, non-feeding/inactive adults and start emerging in mid-April to early May depending upon climatic conditions. Under a "typical" winter in the inland PNW, the adults emerge and move onto winter wheat where they usually cause little damage; they will then move onto spring wheat where they start laying eggs. Females lay eggs on the surface of wheat (or other hosts) singly or in clusters of two to three, primarily during the latter part of May. Females deposit at least 300 eggs on the top of the leaves or margins close to the leaf-mid-rib. Within four to 23 days after oviposition, larvae begin emerging and can be active until July. There are four larval **instars** (growth stages) for this particular pest before pupation begins. Pupation occurs in the soil at a depth of one to two inches during June and July, after which adults emerge in three weeks. Adults are active until late fall when they begin to search out protected overwintering sites, often in close proximity to the infested field.

Host plants & damage

CLB has a wide range of cultivated grass host crops (wheat, barley, oats, rye, corn, sorghum, and sudangrass), and many other wild and native grasses may be acceptable as hosts. The larval and adult life stages are the only economically damaging life stages for this cereal crop pest. The fourth instar CLB larva, rather than the other life stages, causes most of the crop damage. CLB larvae feed on the upper mesophyll part of the leaves, typically between the veins of leaves, causing a characteristic "window pane" look to the infested host plant (Figure 11-9). Adult CLB chew through the entire leaf, making small slits between leaf veins.

Integrated pest management

Monitoring and thresholds

Adults should be monitored using a standard 15-inch insect sweep net during the later parts of the spring months, after they have emerged from their nearby overwintering sites. Grasses close to field margins may also be monitored during this time to get a sense of the local population. Larvae are more difficult to scout for by visually examining a number of random plants in the suspected infested field as they tend to be hidden in the field.

Figure 11-9. Cereal leaf beetle larva feeding on wheat. The "window pane" injury is characteristic of feeding by adults and larvae. (Photo: Brad Stokes, University of Idaho.)

The economic threshold for CLB on wheat in the inland PNW is three eggs or three larvae per tiller before the booting stage, and subsequently one larva per flag leaf during the remaining growth stages. Populations should be scouted after plant emergence prior to the booting stage in the inland PNW, and a control action may be justified if the population is approaching the economic threshold. Degree day models for CLB are reliable and can be used to time scouting efforts: ***http://uspest.org/cgi-bin/ddmodel.us?spp=clb&uco=1***. When determining whether to spray, it is prudent to assess potential impacts of natural enemies and to avoid spraying when these are abundant.

Biological control

Classical biological control via the introduction of parasitoids from the CLB's native range has been relatively successful. A pinhead-sized wasp, *Tetrastichus julis* Walker (Eulophidae), is known to parasitize all larval instars and is well established in the inland PNW (Figure 11-10) (Roberts et al. 2012). In the early 2000s, university and federal scientists released *T. julis* in key areas of the inland PNW to augment this parasitoid population.

Figure 11-10. Cereal leaf beetle larva (left) and its introduced natural enemy (right), the parasitoid wasp *Tetrastichus julis*. (Photo: Brad Stokes, University of Idaho.)

Several other parasitoids exist, *Diaparsis carinifer*, *Lemophagus curtus* (Ichneumonidae), and the egg parasitoid *Anaphes flavipes* (Mymaridae), though they are not as well established as *T. julis* for CLB control. Lady beetles (Coccinellidae) consume CLB larvae. Other generalist predators may also be effective, including ground beetles (Carabidae), soft-winged flower beetles (Melyridae), notably the Collops beetle, which resembles the CLB, assassin bugs (Reduviidae), damsel bugs (Nabidae), minute pirate bugs (Anthocoridae), and green lacewings (Chrysopidae). In the past, CLB control has relied heavily on insecticides and that will likely continue. Least-toxic biorational insecticides may eventually have a place in CLB pest management, but currently these are too costly for use in production agriculture.

Cultural control

Factors such as late planting, lack of nitrogen fertilization, or poor soil health can reduce field populations of the CLB; lower seeding rate in oats, mixed cropping of oats and barley, and combinations of nitrogen and potassium fertilizers have a limited effect on the CLB. Growing a strip of oats between spring wheat and winter wheat may provide a viable option of trap cropping for CLB infestations. These effects have been observed in limited studies in other parts of CLB range and there are no definitive guidelines on how to implement them. An aggregation pheromone has been identified that has potential for use as a monitoring tool for the beetle (Rao et al. 2003).

Resistant varieties

Host plant resistance is known from varieties of wheat that have higher than normal silica-rich trichomes, narrow-leaved varieties, and others that produce the secondary compound DIMBOA (2,4-dihydroxy-7-methoxy-1,4-benzaxazin-3-one) which has an antibiotic effect on the larvae. No inland PNW varieties are CLB resistant.

Insecticides

Numerous broad-spectrum, commercially available insecticides are registered and approved for use in wheat or other cereal crops for use in controlling CLB populations. Synthetic pyrethroids such as permethrin, cypermethrin, and fenvalerate have been effective in controlling leaf beetles; however, these compounds are lethal to natural enemies and should be applied judiciously. Please refer to the PNW Insect Management Handbook for current insecticide recommendations.

Climate change

The CLB has been studied for its potential response to climate change using bioclimatic models. Based on current models, CLB range in North America is expected to continue to expand northward (Olfert et al. 2004; Olfert and Weiss 2006). In much of the inland PNW, models indicate that the climate will become, in general, more hospitable for the beetle, making it a more serious pest. Furthermore, based on data from Utah, as the inland PNW climates warm, parasitism by *T. julis* is expected to be reduced, potentially releasing CLB from this very successful biological control agent and increasing its population to damaging levels (Evans et al. 2012).

Cutworms

Pest status & descriptions

The term cutworm refers to immature stages of multiple species of moths belonging to the family Noctuidae. They are relatively large and soft-bodied insects as larvae, and up to 2 inches long at their later stages of development. Cutworms are mostly active during the night and take refuge just below the soil surface during the day. Among several species of cutworms present in the inland PNW, black cutworms and variegated cutworms have been reported to emerge more frequently in numbers that may result in significant yield loss.

Black cutworm

Black cutworm (*Agrotis ipsilon* Hufnagel) adults are brownish-gray with a light silver-colored band (Berry 1998a) and "dagger-shaped" patterns (Cook et al. 2003) on the forewing (Figure 11-11). Larvae are dark gray with a dark brown or black head capsule; a lighter stripe runs along the backside of the body (Figure 11-12). In their final, largest instar, these larvae can be 1.5 inches long (Berry 1998a).

Figure 11-11. Black cutworm adult. (Photo: John Capinera, University of Florida, Bugwood.org.)

Figure 11-12. Black cutworm larva. (Photo: John Capinera, University of Florida, Bugwood.org.)

Variegated cutworm

Variegated cutworm (*Peridroma saucia* Hübner) adult moths are brown to reddish brown. They possess darker markings on the forewings as well as a kidney-shaped spot (Figure 11-13). Full-grown larvae can be up to 2 inches long. Their body color may range from light gray to dull brown, with a row of yellow dots along their back (dorsal) (Berry 1998b) (Figure 11-14).

Large yellow underwing

Large (greater) yellow underwing (*Noctua pronuba* L.) adult moths are large with brown forewings and brightly colored yellow-orange hindwings with a broad black band around the margin, though ten different color variants have been reported from Europe (Figure 11-15). Larvae are usually olive brown, though some may have a distinct reddish tinge. Larvae are also marked with a bold black and cream dash on each side of the midline; the overall appearance is a series of dark broken dashes that run the length of the body (Figure 11-16). The final, largest instar can be 1.5 inches long. This species is a recent but relatively minor invasive pest of cereal crops in the inland PNW, first reported from Oregon in 2001.

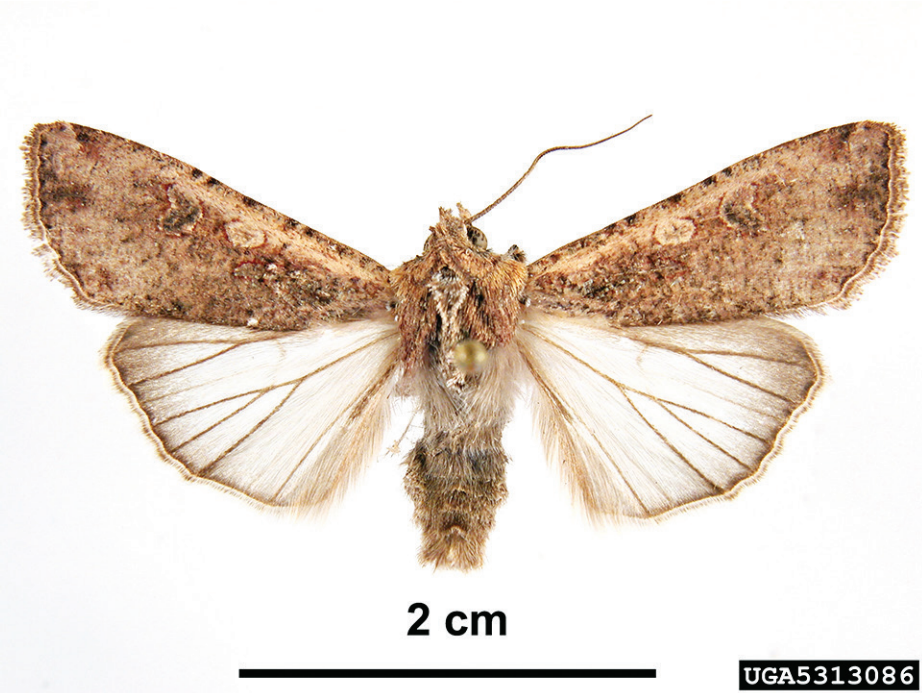

Figure 11-13. Variegated cutworm adult. (Photo: Pests and Diseases Image Library, Bugwood.org.)

Figure 11-14. Variegated cutworm larva. (Photo: John Capinera, University of Florida, Bugwood.org.)

Figure 11-15. *Noctua pronuba* adult. Upper specimen is male; lower specimen is female. (Photo: Edward Bechinski, University of Idaho.)

Life cycles

Black cutworm is present across the inland PNW. They overwinter as pupae in areas with mild winters and emerge as adults in the spring. Adults could also migrate and disperse into areas with harsher winters, where survival of the overwintering larvae might have been jeopardized (Berry 1998a). Females continue to lay eggs through June. Eggs hatch within a week. Young larvae initially utilize foliage, but older larvae remain at, or

Figure 11-16. *Noctua pronuba* larva in Nez Perce County, Idaho. (Photo: Edward Bechinski, University of Idaho.)

just below, the soil surface for about a month before pupating. Adults will emerge from the pupae within two weeks and lay eggs to start another generation that may not successfully overwinter in some localities (Berry 1998a).

Variegated cutworms may overwinter at different developmental stages, primarily as late instar larvae in the soil. Adults emerge in late spring and early summer, laying eggs in clusters of up to several hundred on the underside of leaves. Eggs will hatch within a week and larvae continue to feed for up to 6 weeks (Berry 1998b). There are two generations in the inland PNW, with the second generation forming in the overwintering stage.

Large yellow underwing cutworms overwinter as partially grown to almost full-grown larvae under plant residue. It is believed that this insect only has one generation per year in the inland PNW, though it may have two generations. This cutworm has six larval instars, each larger than the previous. Adults emerge in mid-summer, they mate, and females begin laying egg masses (up to 2,000 eggs per female) until late September before dying off. During the winter and early spring when temperatures rise above 40°F, early to mid-instar larvae begin sporadically feeding on fall- and spring-planted crops throughout the night (nocturnal feeding) (Bechinski et al. 2009). Crop damage occurs from mid-September until early May. Damage is typical of other cutworms and includes stem girdling, crown feeding, leaf feeding, and leaf clipping (plants appear to be clipped with scissors) of various plants (Bechinski et al. 2009).

Host plants & damage

Feeding damage on the foliar tissue by black cutworm could occur during the early larval instars (Figure 11-17). However, later instars of the black cutworm feed on crowns and roots during the night. While young seedlings may be cut and eliminated, damage on the older plants may present as wilting plant leaves (Berry 1998a). Damage by the variegated cutworm can be devastating when they appear in large numbers as they may defoliate the crop (Berry 1998b) and cut seedlings off at the soil level. Large yellow underwing damage varies, though currently it is a minor pest with only a few isolated infestations in the inland PNW.

Figure 11-17. Typical cutworm damage on wheat. (Photo: Edward Bechinski, University of Idaho.)

Sampling, monitoring, and thresholds

To achieve an effective control, cutworm presence must be detected early in the season when larvae are young and plants are still at the seedling stage (see the Insecticides section). Monitoring could be done on a regular basis by observing damaged plants, sweep netting for larvae (variegated cutworms), and inspecting the soil surface to find larvae. Field inspections for larvae are most effective in the dark, when larvae are most active, by using a flashlight or headlamp. No detailed studies are available on economic thresholds; however, degree days can be used to estimate time for scouting and to predict timing for the most damaging larval stages (Cook et al. 2003). For black cutworm infestations, chemical treatment is suggested where the presence of two or three damaged plants in a 10-foot row section is observed in multiple spots (Berry 1998a). In addition to field scouting, adult flight monitoring may also help with early detection of potential outbreaks (Bechinski et al. 2009).

Biological control

There are several predaceous (e.g., ground beetles, spiders, centipedes) and parasitoid (e.g., wasps and flies) arthropods, pathogens, and birds that can reduce cutworm numbers. Large populations of cutworms are highly susceptible to fungal diseases, especially under moist conditions.

Cultural control

Removal of volunteer and grassy weeds with cultivation or herbicide applications will eliminate food sources available to cutworms, prior to spring crop emergence.

Insecticides

Early detection of cutworms would also increase the likelihood of foliar insecticide application success. This is because it would facilitate targeting early instars before inflicting damage to the susceptible seedlings, and before they move down on the foliar tissue and take cover in dense crowns or under the soil surface. Insecticide applications need to be conducted after sunset or before sunrise to maximize chances of targeting active larvae and minimizing the negative impact on beneficial insects and bees. Numerous broad-spectrum, nerve-poisoning insecticides containing the active ingredients beta-cyfluthrin, carbaryl, chlorpyrifos, gamma-cyhalothrin, cyfluthrin, lambda-cyhalothrin, and zeta-cypermethrin are labeled for cutworm control in wheat. Please refer to the PNW Insect Management Handbook for current insecticide recommendations.

Resistant varieties

None are currently available.

Climate change

There are no studies we know of that suggest significant changes in pressure from these pests due to climate change. One study from wheat production systems in China detected no trend in injury by noctuid pests over a 25-year period, despite a warming trend associated with changes in aphid pressure, suggesting the cutworms may not be affected by climate change elsewhere including the inland PNW.

Wheat Head Armyworm

Pest status & distribution

The genus *Dargida* (Lepidoptera: Noctuidae) consists of eight species, which includes *D. procinctus*, *D. gramminivora*, *D. quadrannulata*, *D. diffusa* (known in the PNW as the wheat head armyworm), *D. terrapictalis* (known as the false wheat head armyworm), *D. tetera*, *D. rubripennis,* and *D. aleada*. All of these species are found north of Mexico (Michaud et al. 2007). The most prominent species in the PNW are the wheat head armyworm, the false wheat head armyworm, and more recently the olive-green cutworm, *D. procinctus*. Because of the similarity of larvae and adults within this genus, definitive identification should be left to a taxonomic expert. Nonetheless, all *Dargida* larvae feed on wild grasses, grains, wheat, or other cereal crops, and the insects matching the descriptions below should be considered potential pests of wheat.

Pest descriptions

The adult moths are yellow-brown with a brown stripe running down the length of each of the forewings. This coloration provides camouflage from predators in cereal crop fields that are drying down near the end of the season; hindwings are darker in *D. terrapictalis* compared to *D. diffusa* (Figure 11-18). The larvae vary in color but have been noted as gray, cream, or green with distinct yellow, white, and brown strips along the length of the body (Figure 11-19).

Figure 11-18. *Dargida diffusa*, the true wheat head armyworm, adult. (Photo: Luc Leblanc, University of Idaho.)

Figure 11-19. *Dargida terrapictalis*, the false wheat head armyworm, adult. (Photo: Luc Leblanc, University of Idaho.)

All three inland PNW species, *D. diffusa*, *D. terrapictalis,* and *D. procinctus* have four distinct life stages: egg, larva, pupa, and adult. Larvae go through five instars. During the winter months, the larvae pupate in the soil. When spring arrives, moths emerge and, within a few days, the moths lay eggs on wheat or barley crops. Larvae that develop from eggs feed on wheat as early as late May, with increasing numbers into mid-June. This late-spring timing coincides with wheat flag leaf development. Larvae feed on wheat heads, primarily at night, when ambient temperatures are cooler. They crawl toward the base of stalks during hot days. *D. diffusa* larvae and moths are typically active only at night. In the western US, armyworms are considered sporadic pests. They can have up to two generations per year with a second generation developing on warm season grasses in the fall, after wheat has been harvested. The appearance of a typical later instar larva is shown in Figure 11-20.

Host plants & damage

All larvae of the genus *Dargida* feed on wheat and various other grain and grass crops in the PNW. Damage is caused exclusively by the larval stages

Figure 11-20. Typical *Dargida* spp. larva. (Photo: Frank Peairs, Colorado State University, Bugwood.org.)

of these pest insects, as they will often eat into part of the wheat/barley/oat kernel causing direct damage to the product. Damage will often go unnoticed until screening at grain elevators. Damage takes the form of a small hole bored into the base of the floret. The pests are more likely to be found along field margins.

Integrated pest management

Sampling

Sampling for larvae and moths may be done with a sweep net. Focus on field margins for detection only. Once detected, sampling in the interior should be conducted if the aim is to assess field scale levels of infestation. A sex-attractant may be used to lure moths to the trap. Traps should be left in or adjacent to the field throughout the crop season and should be checked at least once per week. While no insecticides are specifically labeled for control of wheat head armyworms in the inland PNW, studies suggest pyrethroids may work well. Products specifically labelled for cereals can be legally used for *Dargida* control even though the pest is not cited on the label.

Biological control

There are confirmed accounts of parasitism of *Dargida* spp. by small wasps, but the species have not been identified. Similar to other armyworm species, wheat head armyworms are vulnerable to predation by ground beetles, spiders, birds, and rodents.

Cultural and chemical control

There are no established management plans or economic thresholds for this pest since they are sporadic. Infestations are usually concentrated around field margins, so it is recommended that scouting efforts focus on this area. There are no insecticides specifically labeled for this pest, but materials registered for other armyworms in wheat would likely provide control if applied sufficiently early. Larvae arriving with harvested wheat either die or emerge as moths, potentially surviving in storage. Please refer to the PNW Insect Management Handbook for current insecticide recommendations.

Resistant varieties

No resistant varieties are available.

Climate change

To date, there is no scientific study or associated data that would suggest a correlation with wheat head armyworms and climate change, though we could speculate based on biology alone that the number of generations per year, growth rate, or their known range may increase due to warmer overall temperatures in the inland PNW.

Wheat Midge

Pest status & distribution

Wheat midge, *Sitodiplosis mosellana* (Gehin), is a European species first detected in the inland PNW in 1991 in Boundary County, Idaho. Pest distribution in Idaho has since expanded to Benewah and Kootenai counties. Surveys in Washington confirmed wheat midge at low to potentially damaging levels in Garfield, Lincoln, Spokane, and Stevens Counties.

Pest description

Adults resemble mosquitoes but are smaller (1/8" long) and with bright orange bodies (Figure 11-21). They are most often seen at dusk resting on wheat heads during plant flowering, hence their colloquial name "orange wheat blossom midge." Mature larvae are 1/8 inches long, bright yellow-orange, legless maggots.

Life cycle

Wheat midge develops through a single generation annually. Mature larvae overwinter 2 to 4 inches in the soil, pupate during May, and begin to emerge by late-June as adult flies. Adults remain close to the soil surface during the day but fly to flowering wheat heads on warm, calm evenings when air temperature is at least 60°F and wind speed is less than 8 mph. Females lay eggs under the glumes and palea. Larvae feed on the developing kernels for 2 or 3 weeks, and then remain inactive on the head until rain or dew causes them to drop to the soil where they overwinter

Figure 11-21. Adult wheat midge resting on flowering wheat head (left) and larvae from dissected wheat head (right). (Photos: Robert Lamb, Ag and Food Canada; Diana Roberts, Washington State University.)

(Knodel and Ganehiarachchi 2008).

Host plants & damage

Wheat midge is primarily a pest of wheat. Non-economic infestations sometimes occur in barley, rye, and intermediate wheat grass.

Larvae are the sole damaging stage. They feed externally on the developing kernels but are hidden under the bracts that surround the seed and cannot be seen without dissecting the wheat plant head. Damaged wheat heads may lose their green coloration early in the field maturation, thus appearing unhealthy relative to the rest of the field. Injury ranges from shriveled, cracked, and underweight kernels to complete abortion of the seed (Figure 11-22).

Wheat is only susceptible to larval injury when eggs are laid on flowering heads from emergence to full flowering; larvae cannot complete

Figure 11-22. Wheat midge larval feeding injury to spring wheat as seen at crop harvest. (Photo: Dennis Schotzko, University of Idaho.)

development if oviposition occurs earlier or later than crop flowering. Infestations seldom develop in winter wheat because the crop flowers before midge ovipositional flights during late June and early July. In contrast, severe infestations can develop in spring wheat because flowering more likely coincides with midge oviposition.

Integrated pest management

Adult monitoring and thresholds

Larval management with foliar insecticides depends on field scouting for adult midges because applications must be timed to kill females before they lay eggs on flowering wheat heads.

Field studies by the University of Idaho showed that foliar insecticide applications are justified if sweep net sampling in flowering wheat fields at twilight on warm, calm evenings detects an average of 1 to 4 adult midges per five sweeps. This threshold is conservative and has a low probability of failing to treat an economic infestation, but a 1-in-3 chance of needlessly treating a non-economic infestation. Sweep net sampling during daylight hours has no value for IPM decisions because midge adults remain close to the soil surface during the day and so escape collection.

Commercial sticky traps baited with the female wheat midge sex pheromone are highly attractive to adult males. North Dakota State University tentatively recommended insecticide treatment if cumulative midge captures with pheromone traps exceed 10 per trap at 3 days after heading, but those thresholds have not been validated in our area.

Forecasting the timing of midge ovipositional flights

Research by the University of Idaho showed that 80% of seasonal midge flight activity occurs between 735 and 915 cumulative degree days above 5°C (41°F; $DD_{5°C}$) since January 1, with seasonal maximum flight at 820 $DD_{5°C}$. Hence, it is not necessary to monitor spring wheat fields before 735 $DD_{5°C}$ or after 915 $DD_{5°C}$ because oviposition does not occur before or after those periods.

Biological control

Carabid ground beetles can be important natural predators of midge larvae in the soil. Surveys have failed to detect any parasitoids of the wheat midge in Idaho and Washington.

Cultural control

Rotate crops to reduce likelihood of midge damage to spring wheat. The most effective rotation is spring wheat planted after canola or some other non-cereal crop; spring wheat after barley poses minimal risk, and spring wheat after winter wheat poses some but overall low risk. The worst cropping sequence is continuous spring wheat.

Plant spring wheat varieties as early as agronomically possible so that crop flowering does not coincide with peak seasonal midge oviposition during July. Midge-free seeding dates that allow spring wheat crops to escape egg-laying are given in Table 11-2 for Boundary County, Idaho. During “average years” (i.e., temperatures that occur 4 years in 5), seeding earlier than 11–20 of April allows the wheat crop to grow beyond the susceptible flowering stage before midge activity reaches seasonal peaks.

Table 11-2. Relative risk of wheat midge infestation as a function of spring wheat seeding date, Boundary County, Idaho.

infestation risk	temperature scenario (1 Jan - 31 Jul)		
	colder-than-normal	average year	warmer-than-normal
LOW: seed before	20 April	11 April	23 March
HIGH: seed during	2 May	25 April	5 April
LOW: seed after	13 May	7 May	17 April

LOW RISK	flowers before 10% seasonal midge flight (735 $DD_{5°C}$) or after 90% seasonal midge flight (915 $DD_{5°C}$)
HIGH RISK	flowers during maximum (50%) seasonal midge flight (820 $DD_{5°C}$)

Resistant varieties

Montana State University released a midge-resistant spring wheat variety in 2016, 'Egan,' which incorporates the *Sm 1* gene and causes plants to respond to larval feeding injury with elevated levels of phenolic acids that halt larval feeding. Midge-resistant *Sm 1* red spring and hard red spring wheat varieties have been commercially available in western Canada since 2010.

Insecticides

The following insecticides are labelled as foliar sprays applied to wheat for control of wheat midge or orange blossom wheat midge or orange wheat blossom midge: chlorpyrifos, dimethoate, gamma-cyhalothrin, lambda-cyhalothrin, and malathion. All are broad-spectrum insecticides that potentially disrupt biological control of aphids and CLB. Please refer to the PNW Insect Management Handbook for current insecticide recommendations.

Climate change

Bioclimatic models (Olfert et al. 2016) suggest that the present climate of the inland PNW is marginally conducive to wheat midge outbreaks and that pest expansion is unlikely beyond currently known distribution in the Idaho panhandle and adjoining eastern Washington. Based on 2030 and 2070 climate change projections, these same models predict that the future climate of the inland Northwest will remain marginal with no pest expansion westward or southward into adjoining inland PNW wheat production regions.

Mites

Pest status & distribution

Mites, also called spider mites, are not technically insects but instead are classified as arachnids. Some mites feed exclusively on plants and can impact yield in agricultural crops, such as spring and winter wheat, barley, oats, or Timothy hay. Mite distribution is widespread, occurring across all the counties of Idaho, Washington, and Oregon. Several mite species of economic agricultural importance occur in these states: brown wheat mite (*Petrobia latens* Müller), Banks grass mite (*Oligonychus pratensis* Banks), winter grain mite (*Penthaleus major* Duges), and the wheat curl mite (*Aceria tosichella* Keifer). In addition to feeding on plant material, the wheat curl mite successfully vectors *Wheat streak mosaic virus* (WSMV), causing even more yield damage.

Pest descriptions

Mites are minute creatures. The use of a hand lens is essential for assessing a suspected mite infestation and attempting to identify the species involved.

Brown wheat mite

Brown wheat mite (*Petrobia latens*) adults have a dark brown ovoid body with yellow-orange to slightly reddish legs and are 1/50 inches in total length (Figure 11-23) (Blodgett and Johnson 2002). They have a lighter stripe that extends from the head (cephalothorax) to the end of the body (abdomen). Larvae and nymphs resemble adults. As with most mite species this is difficult to see unless there is at least some magnification available.

Banks grass mite

Banks grass mite (*Oligonychus pratensis*) adults are dark green to a

Figure 11-23. Brown wheat mite adult. (Photo: Phil Sloderbeck, Kansas State University, Bugwood.org.)

Figure 11-24. Banks grass mite adult. (Photo: F.C. Schweissing, Bugwood.org).

darker brown color and are 1/32 inches in total length (Figure 11-24) (Brewer 1995). They have a row of spots on each side of their abdomen that distinguishes them from other mites that feed on wheat. Larvae and nymphs resemble adults.

Winter grain mite

Winter grain mite (*Penthaleus major*) adults are iridescent black in color (cephalothorax and abdomen) with yellow, orange or more often red-colored legs. They often have a red stripe, and unusually have an anal pore on the upper side of the abdomen (Bauernfeind 2005). This pest species only has two generations per year in Idaho, Washington, and Oregon. The first starting in late fall, September or October, with population and economic peaks in December or January. The second generation reaches high populations in the field during the months of March and April. This species excels in low temperature environments; females lay oversummering eggs as temperatures exceed their developmental limit. Larvae hatch later in the season and begin feeding on leaf tissue near the ground, wandering up the plant during cooler nights.

Wheat curl mite

Wheat curl mite (*Aceria tosichella*) adults are nearly microscopic white and 1/100 inches in total length. This species has a cigar-shaped body with only four legs (as opposed to eight in the other mite species listed above) pointed forward and a fleshly lobe located posterior. Even under a hand lens this species may be unrecognizable in the field. The wheat curl mite is unlike other mites because its main method of dispersing is wind. The most economically important factor with this species of mite is the ability of it to vector WSMV. WSMV was first detected in Kansas in 1987, with more infections found during the subsequent year (Townsend et al. 1996). It has since moved east into Montana, North and South Dakota, Idaho, Washington and Oregon. Plants infected with WSMV appear to have bright yellow or orange streaking, often most severely near the tip of the leaf (Figure 11-25). WSMV also facilitates injury by seed-borne *Wheat mosaic virus* and mechanically transmitted *Triticum mosaic virus*; severity and yield losses in individual fields is greater when all three viruses are present. Symptoms of each virus are nearly identical, making proper identification difficult at best. The wheat curl mite is the only

Figure 11-25. *Wheat streak mosaic virus* (WSMV). (Photo: Mary Burrows, Montana State University, Bugwood.org.)

known vector of WSMV, the mite remains infective for approximately a week after it obtains the virus.

Life cycles

Mites have a total of five life stages: the egg, larva, nymph (two nymphal stages), and the adult. Eggs are very small (1/200”), oval, and translucent on the plant, they are laid on the underside of leaves. Larvae are small (1/100”), green, yellow, or pale in color and have a total of six legs. Nymphs are slightly darker in color than the larvae and have a total of eight legs; there are two quiescent stages: one after each of the nymphal stages. Adults are small (1/50”), oval, and darker than the larval and nymphal stages. Eggs hatch in 3 to 10 days after they are laid, and numerous generations occur throughout the year; a complete generation may only take a total of 10 days during the summer.

Host plants & damage

Mites are often polyphagous, feeding on numerous different host plants. All commercially grown cereal crops (oats, barley, spring wheat, winter wheat, and Timothy hay) in Idaho, Washington, and Oregon are susceptible to each species of mites. Fields infested with mites typically have a silver or gray coloration. Individual plants may have chlorotic lesions (yellow speckling) from feeding damage or have silk strung between leaves, a sure sign of a mite infestation. Feeding damage causes reduced photosynthetic potential and reduced yield. WSMV vectored by the wheat curl mite is an additional factor in host plant damage. Younger plants are more susceptible to mite damage and can result in stunted plants with reduced foliage and smaller yield potential.

Integrated pest management

Management of each mite infestation is dependent upon which species is present in the field as each mite has a slightly different biology/ecology/behavior.

Adult monitoring and thresholds

Monitoring for mites should be done throughout the season depending upon your location and its history of mite infestation. Winter grain mite scouting should begin in October and go until April, when small populations start infesting plants. Brown wheat, Banks grass, and wheat curl mites should be scouted from April throughout mid-summer, especially if local climatic conditions are hot and dry. Plants should be visually inspected early in their development when they are more susceptible to mite infestation damage. Scouting should take place in several parts of the field with multiple replications; often mite infestations start near the margin of the field where they are coming from adjacent host plants. Examining the newest leaf tissue, the base of the plant, as well as the soil surface is advisable for examining plants for mites. Visible silk (webbing) on plants is typically found in moderate to severe infestations. Plants without silk should be looked over carefully for the beginnings of an infesting population. Plant samples may also be taken by shaking leaves over a white piece of paper to inspect for mite activity. Chlorotic plants that may show a silvery appearance indicate a mite infestation. A 10× or 20× hand lens is very useful for examining mite infestations, as these pests are very small. Specific thresholds (economic injury levels) are sparse for mite pest species in cereal crops; though if populations are high early in the growing season (October → winter grain mite; April → brown wheat, Banks grass, and wheat curl), an acaricide treatment may be justifiable.

Biological control

Numerous predatory arthropods attack mites and can readily keep mite infestations below economic importance in agricultural fields. Some species of predatory mites (*Phytoseiulus* spp. and *Neoseiulus* spp.) and predatory thrips (*Scolothrips* spp.) are typically present and prefer to feed specifically on pest mite species. Additionally, several insects also predate on these mites, including damsel bugs, minute pirate bugs, big-eyed bugs, green/brown lacewing larvae, and some small black lady beetle species (*Stethorus* spp.). The listed arthropod predators all feed on each and every life stage of pest mite species.

Cultural control

Proper crop rotation with non-host crops should reduce or eliminate previously infested fields. Destroying volunteer wheat or other green bridge host plants in early spring will reduce food availability for developing mite larvae and nymphs. Planting winter wheat later in the fall, as well as reducing any potential green bridge plant, would reduce the population of winter grain mite in certain fields and the amount of time they spend there.

Resistant varieties

Many varieties of spring and winter wheat may have partial resistance to WSMV and/or wheat curl mite.

Acaricides

Several commercially available acaricides are registered for use in treating mite infestations in cereal crops. Mite feeding is often on the underside of leaves, making acaricides difficult to directly apply to the pest in question. Please refer to the PNW Insect Management Handbook for current pesticide recommendations.

Climate change

With increasing temperatures and hotter/drier summer days in the not-so-distant future expect some mite species to become increasingly more abundant and economically important for cereal crop producers. Life cycles of all the pest species in our area may be sped up from increasing temperatures, hence lowering the total development time (from egg to adult) and increasing the number of generations per year.

Wireworms

Pest status & distribution

Wireworms are the larval stage of click beetles and common pests of field and row crops across the contiguous US and Canada, including inland PNW and Intermountain West cereal crops (Andrews et al. 2008; Milosavljević et al. 2016b). Surveys in the inland PNW found that the distribution and abundance of individual wireworm species varies across the region (Rashed et al. 2015; Milosavljević et al. 2016b). Wireworms are usually found in the greatest abundance in fields that have been planted to grasses, grains, or sod for several years (Andrews et al. 2008; Milosavljević et al. 2016b).

Pest descriptions

Wireworm adults are elongated, parallel-sided, brown, reddish-brown, or black beetles with serrate (saw-like) antennae (Figure 11-26) (Milosavljević et al. 2015; Rashed et al. 2015). Wireworm larvae are cylindrical, slender, flattened, and often elongated light yellow to dark brown and resemble mealworms (Figure 11-27). Wireworm larvae have fixed urogomphi (tails at the tip of the abdomen). The sugar beet wireworm [*Limonius californicus* (Mannerhein)], the western field wireworm (*L. infuscatus* Motschulsky), the Pacific Coast wireworm (*L. canus* Le Conte), the Great Basin wireworm [*Selatosomus pruininus* (Horn)], and the green wireworm [*S. aeripennis* (Kirby)] are some of the most commonly found wireworm species in the inland PNW (Milosavljević et al. 2015; 2016b; Rashed et al. 2015). Other genera in the region include *Agriotes* and *Melanotus*.

Life cycles

Overwintering adult click beetles generally emerge during spring and early summer and lay eggs on the surface or in the soil (Andrews et al. 2008). Soon after hatching, larval wireworms move within the soil until

Figure 11-26. Wireworm adult (click beetle). (Photo: Arash Rashed, University of Idaho.)

Figure 11-27. Wireworm larva feeding at the base of a wheat plant. (Photo: Arash Rashed, University of Idaho.)

they orient themselves by detecting volatiles and carbon dioxide released from sprouting seeds and root tissue. Wireworms may persist as larvae in the soil for 1 to 11 years, depending upon nutrition, host plant quality, and climatic conditions (Andrews et al. 2008).

Host plants & damage

Wireworms cause considerable damage to cereal crops by feeding on germinating grains, roots, and stems (Figure 11-28) (Andrews et al. 2008; Higginbotham et al. 2014; Esser et al. 2015). Crops attacked have poor stands that deteriorate over time because wireworms bore into underground portions of the stem. Early signs of damage may be characterized by the presence of a dead central leaf in developing seedlings (Esser 2012). Depending on the growth stage, this injury can cause eventual plant death. Plants affected at later stages of development would suffer from delayed growth/maturity (Andrews et al. 2008).

Factors affecting wireworms

The seasonal feeding activity of wireworms varies considerably across species, mediated by the crop and environmental conditions (Andrews et al. 2008; Milosavljević et al. 2016a; 2016b). For instance, in the inland PNW, while the sugar beet wireworm (*Limonius californicus*) remains active

Figure 11-28. Wireworm damage to wheat. (Photo: Arash Rashed, University of Idaho.)

throughout the season, other species such as *L. infuscatus* and *L. canus* show peak activities earlier in the season and cause significant damage to the planted seeds and/or young roots (Milosavljević et al. 2016a). Ambient temperature drives wireworm development. Larger larvae can withstand higher temperatures during the summer if there is plenty of moisture, whilst younger larvae tend to burrow downward into the soil if it becomes too warm (Andrews et al. 2008). The responses of wireworms to soil temperature are species-specific. For example, in Washington, optimal temperatures for *L. canus* and *L. californicus* are 70–74°F. *Selatosomus pruininus*, *S. aeripennis*, *S. destructor*, and *Hadromorphus glaucus* can withstand lower soil temperatures, and thus attack crops early in the season. Wireworm species in the inland PNW also differ in their moisture needs; *L. californicus* inhabits mostly damp soil, while *S. pruininus* is an obligate dryland species (Andrews et al. 2008; Milosavljević et al. 2016a).

The tolerance of wireworms to soil pH also varies among and within genera (Milosavljević et al. 2016a). Previous studies have suggested that *Limonius* larvae cause most injury in more alkaline soils, whereas *Agriotes* and *Melanotus* species usually prefer acidic soils. *Limonius* species can survive a considerable range of soil pH and can thus cause significant damage to the crops on both alkaline and acidic soils if other factors are favorable (Milosavljević et al. 2016a).

Integrated pest management

Adult and larval monitoring and thresholds

Random soil sampling and solar bait traps have been the two approaches used for monitoring larval presence (Esser 2012; Rashed et al. 2015). Establishing a solar bait trap consists of burying a mixture of germinating/soaked cereal and corn seeds 6 inches deep in the soil, which is then covered by a dark plastic (Esser 2012). As the dark plastic cover absorbs heat from the sun and keeps carbon dioxide, moisture, and volatiles localized, it provides an environment that would attract wireworms to the bait. The number of wireworms collected in the trap could be counted in about 10 to 14 days after placement. Ideally one to two solar bait traps per acre would provide a good assessment of wireworm situation. Trapping is most effective early in the season when soil temperatures reach 45°F (Esser 2012; Rashed et al. 2015). Using this method, an average of 1–2 wireworms per trap indicates insecticide treatments are merited (Esser 2012). Consult the PNW Insect Management Handbook for materials and rates.

Biological control

Biological control of wireworms has been a subject of very few studies, and more work is needed to evaluate the effectiveness of various biocontrol agents in reducing wireworm populations (Ansari et al. 2009; Reddy et al. 2014). While entomopathogenic nematodes have been isolated from wireworms, recent studies have indicated several species of entomopathogenic fungi can be effective in reducing wireworm populations and increasing stand counts in spring wheat (Reddy et al. 2014), although further studies are needed. Ground-foraging beetles like carabids and some birds are predators that might provide some biological control of wireworms (Andrews 2008).

Cultural control

To date, multiple studies have been conducted to examine effects of crop rotations in wireworm management; however, results have been context-dependent and differ based on the wireworm species present, cropping system, and region (Esser et al. 2015). Winter wheat-fallow rotations in the inland PNW have been shown to reduce wireworm populations by 50% compared to continuous spring wheat systems, suggesting that incorporating

fallow into rotations will provide benefits for wireworm control (Esser et al. 2015). Studies have also indicated that dense soil would have a negative impact on wireworms. Thus, proper seedbed preparation, in which the soil is well packed, will not only support healthy and vigorous plant growth but will also limit wireworm movement and reduce feeding damage. Repeated years of **no-till** planting may cause an increase of wireworm damage, creating a central linear furrow in fields where wireworms may concentrate and cause even more damage than usual.

Results of several studies have also shown that wireworm damage is not uniform across crops. Oats are highly **tolerant** of wireworms, with no insecticides needed for wireworm control in this crop (Higginbotham et al. 2014). Barley seems to be fairly tolerant of wireworms as well, although insecticides can increase yield compared to controls. In contrast, wheat is highly susceptible to wireworms, and insecticides will provide significant economic benefits for multiple wireworm species present (Higginbotham et al. 2014; Esser et al. 2015).

Resistant varieties

Although variation in susceptibility to wireworm damage has been documented among wheat genotypes, no resistant varieties are currently available. One study that evaluated 163 wheat genotypes found some genotypes were consistently tolerant (performed well in the presence of wireworms), but the mechanisms or whether the effect was genetically based are not known (Higginbotham et al. 2014).

Insecticides

Seed treated with neonicotinoids can provide stand and yield protection from certain wireworm species. In the inland PNW, applying thiamethoxam and imidacloprid as seed treatments can reduce wireworm populations and increase yields and economic returns in areas with *Limonius* spp. (Esser et al. 2015). However, it is also known that not all species respond similarly to insecticidal treatments. Higher rates of neonicotinoids are more effective against *L. californicus*, possibly because this species has a higher susceptibility to these compounds, as compared with other wireworm species (Esser et al. 2015). Please refer to the PNW Insect Management Handbook for current insecticide recommendations.

While insecticides can be effective tools for managing wireworms in cereals, neonicotinoids do not eliminate, but may reduce, populations to non-economically important infestations from fields (Esser et al. 2015). IPM strategies are likely to be most effective when cultural management practices are combined with insecticides.

Climate change

To date there is no scientific study or associated data that would suggest a correlation with wireworms and climate change, though we could speculate based on biology alone that number of generations per year, developmental time, life cycle, growth rate, or their known range may increase due to warmer overall temperatures in the inland PNW.

Haanchen Barley Mealybug

Pest status & distribution

Haanchen barley mealybugs (*Trionymus haancheni* McKenzie) were officially reported from California in the 1960s (McKenzie 1962). They were later found in other states including Montana, Wyoming, and the PNW states of Idaho and Washington (e.g., Garfield County). In Idaho, their distribution has been mainly limited to dryland production in eastern (e.g., Bonneville and Madison Counties) and southeastern (e.g., Caribou County) parts of the state. Haanchen barley mealybugs feed on a wide variety of grass crops, including barley, wheat, rye, and oats, but in our region have become pests on barley.

Pest description

Adult females are oval-shaped, 1/5 inches long, and may be covered with white powdery secretions (Figure 11-29), forming hair-like filaments along their body outline. Eggs are pinkish-red, microscopic, and protected in cottony wax secretions, also known as an ovisac. Immature stages of the mealybugs are named crawlers. There are several nymphal instars. Overall they resemble adults, as they are also oval-shaped and have three pairs of legs. Their presence, however, is hard to spot with the naked eye due to their very small size. Crawlers are also the most mobile stage of the mealybug life cycle; they may disperse short distances to nearby plants by crawling, or they may travel long distances by wind (Alvarez 2003).

Figure 11-29. Haanchen barley mealybug adult. (Photo: Juan Manuel Alvarez, University of Idaho, Bugwood.org.)

Life cycle

The Haanchen barley mealybug life cycle is yet to be described in detail. To date, observations indicate that they may overwinter as eggs, protected by soil and plant residue, in eastern Idaho (Alvarez 2003). The presence of adults and cottony secretions are detectable later in the spring and early summer at the very base of the infested plants. As plants grow, insects may move up the stem to feed on fresh leaf tissues. Their presence in late summer, under the upper leaf sheaths, can be spotted in the form of visible brownish water stains.

Females lay eggs in protected areas of the plant close to the stem bases and roots, as well as leaf sheaths. Females are capable of ovipositing up to several hundred eggs in a relatively short period of time; the presence of males does not appear to be necessary for reproduction. Following egg hatch, crawlers disperse via crawling, by wind, and/or by assistance from animals and human traffic passing through infested fields. Haanchen mealybug outbreaks seem to be associated with mild winter conditions and dry summer months (Alvarez 2003). The exact number of generations is yet to be determined.

Host plants & damage

Although Haanchen barley mealybugs are known to be primarily damaging in barley, they also feed on wheat and other grasses. Later into the spring and early in the summer, the presence of the mealybug can be detected by the formation of white cottony elements at the very base of stems right around the soil surface (Figure 11-30). Adults can also be seen at the base of a leaf sheaf (Figure 11-31). Direct damage, in forms of excessive yellowing, may be caused by both adult and immature stages of the mealybug, as they use their piercing sucking mouthparts to utilize phloem sap (Mani 2016). Damage appears in fields as irregular bare patches and/or patches of weak plants. Although the exact cause of the reduction in chlorophyll content is yet to be determined, toxic saliva compounds injected into the plant tissue during the feeding process may be a contributing factor (Alvarez 2003;

Figure 11-30. Mealybugs on the plant, showing the white cottony elements. (Photo: Juan Manuel Alvarez, University of Idaho, Bugwood.org.)

Figure 11-31. Mealybug at the base of a barley leaf sheath. (Photo: Juan Manuel Alvarez, University of Idaho, Bugwood.org.)

Mani 2016). Indirect damage can be caused through honeydew production by the insect during feeding. Excessive honeydew (sugar-laden excretions) left on the plant tissue can reduce grain quality, interfere with harvest (Alvarez 2003), and facilitate fungal infections.

Integrated pest management

Currently, there are no established economic thresholds, registered pesticides, or effective integrated management programs for the Haanchen barley mealybug. Although variations in the degree of susceptibility have been reported among various barley varieties, studies are yet to screen for resistance to Haanchen barley mealybugs.

Biological control

Parasitoids and predators have been shown to provide the most effective, and relatively more sustainable, management option with other species of mealybugs. *Rhizopus* spp. (Encyrtidae) has been the predominant parasitoid species found on Haanchen barley mealybugs in Idaho (Blodgett 2009; Mani 2016). Generalist predators, such as lady beetles, have been frequently encountered in infested field plots and may provide some control of the mealybug.

Given current information on the life history traits of Haanchen barley mealybugs, proper rotation with non-cereal crops and proper seeding bed preparation (e.g., cultivation) is expected to interrupt the continuity of the insect life cycle in affected fields.

Chemical control

Currently there are no recommended foliar insecticides for managing Haanchen barley mealybugs in cereals. Having a concealed feeding habit, protective waxy cover, likely asexual reproduction capability, short generation time, and high dispersal potential, chemical control of Haanchen barley mealybugs is greatly challenging. In other crops, targeting crawlers with foliar insecticides, timed approximately a week after egg-laying, may offer a relatively greater chance of success in effectively reducing populations (Alvarez 2003). While seed treatments, foliar spray applications (with a surfactant), and systemic chemistries may help to reduce mealybug populations (Mani 2016), they may not be cost-effective especially under dryland production systems. In addition, excess use of broad-spectrum pesticides can potentially lead to subsequent outbreaks due to the elimination of the natural enemies (Alvarez 2003). Please refer to the PNW Insect Management Handbook for current insecticide recommendations.

Climate change

There are no scientific studies or indications of potential response to climate change by the Haanchen barley mealybug. Its range as a pest of wheat is very limited and it has not been well studied.

A Bigger Picture

Space – Production Landscapes

Cereal crops are grown in heterogeneous landscapes. Even in the most wheat-intensive portions of the inland PNW, wheat fields occur within matrices of other habitat types including fallow or rotational crops with wheat, perennial grasses (pasture or Conservation Reserve Program), and a variety of other crops especially in irrigated areas, scablands, and forests. Insect pests and beneficial organisms live within varied landscapes that include agricultural fields and other habitats. They move among these while foraging and during their annual life cycles. Aphid species, like bird cherry-oat aphid, must overwinter on woody hosts while other aphids overwinter in grassy habitats, and both types then recolonize wheat. Similarly, predators and parasitoids that attack aphids and other pests move into wheat fields out of this larger landscape. The benefits of this free and natural pest control are enormous. A simple experiment in which cereal aphids are protected from natural enemies by exclusion cages reveals that the unprotected populations can exponentially increase and kill wheat plants in just a few weeks. When feasible, natural or perennial habitats can be conserved to help sustain these benefits on or near production fields. The viability of inland PNW cereal systems in future decades will continue to depend upon these biological services.

Complexity – The Wheat Agroecosystem

Just as individual fields are part of a larger landscape-scale system, within each field, the crop, soil organisms, weeds, pathogens, and insects constitute an interactive system. The interactions among the components of this system contribute to its net productivity. A schematic of the continuous winter wheat systems in the inland PNW (Figure 11-31) illustrates the direct effects and interactions among its components. Some of these interactions are characterized well enough to be managed, like biological control of pests by parasitoids and predators. Others remain less well understood but potentially important. For example, evidence is accumulating that soil organisms and the conditions they promote can have emergent effects on pests and diseases that affect the aerial portions of plants. Disease-causing agents, like plant viruses, can affect the insects that are vectors of these pathogens or even the responses of plants to environmental stressors like drought. Going forward, we expect to gain a better understanding of these interactions and to find management approaches that exploit this knowledge to improve plant protection and productivity.

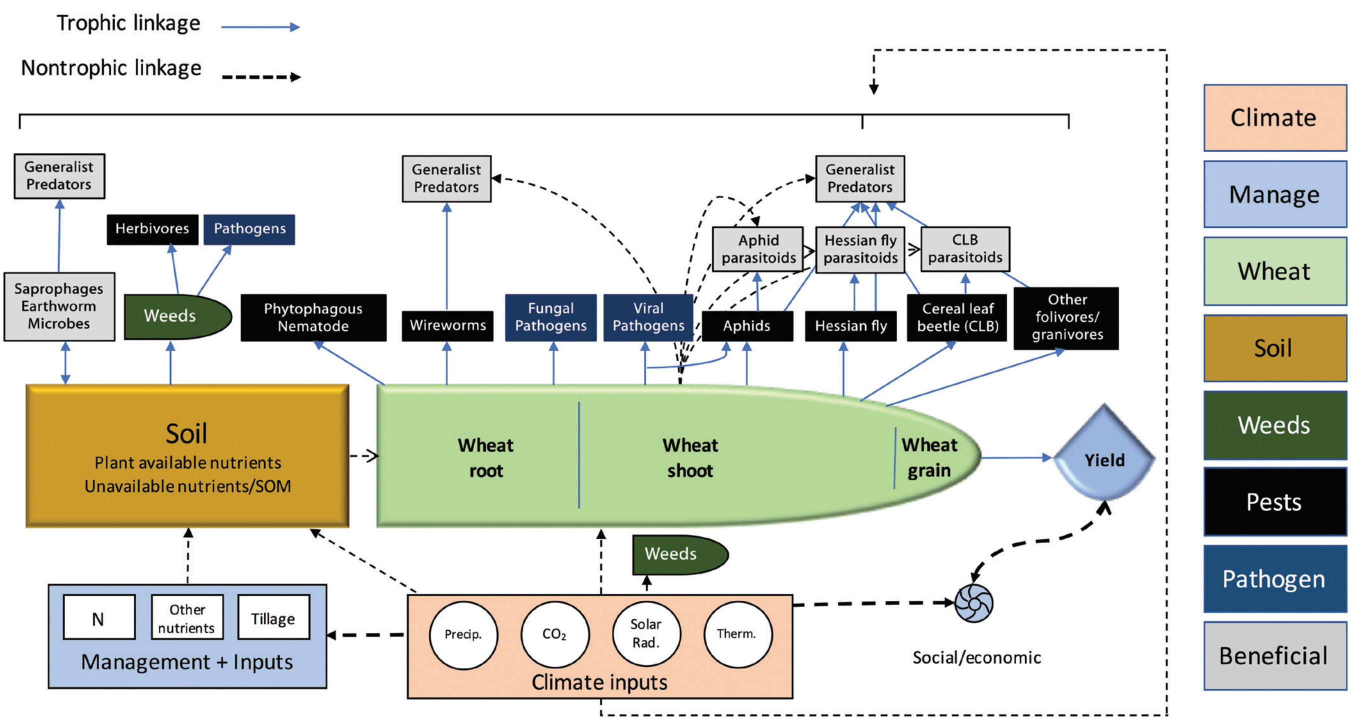

Figure 11-32. Schematic representation of the community of organisms associated with a wheat plant in a typical PNW winter wheat production system. Linkages among organisms are indicated with arrows. Trophic or feeding linkages are shown with solid arrows pointing towards the consumer. Nontrophic linkages, which are various sorts of indirect effects, are shown with broken-line arrows pointing towards the affected group. The portal to social/economic factors indicates that inputs and economic yield from the system are mediated by the human systems in which the production system isolated here exists. Also not shown here are potential biotic interactions between the focal crop (wheat) and conventional or alternative rotational crops occurring in the same landscape or in different years within the same field.

Time – Changing Conditions

Production conditions are always in flux. As climate, insect pests, weeds, diseases, technology, markets, and cultures change, agricultural systems must adjust to the new conditions. The scales of operation, extent of the influence of global markets, and types of technology in use on today's farms would have been difficult or impossible to imagine a few generations ago. We can be certain that the same will be true a few generations hence. To the credit of our farmers and partnerships between industry and agricultural universities, cereal production has continued to thrive in the US and the inland PNW. These dynamics may present significant challenges in the coming decades, but building on traditions, healthy partnerships, and new science should enable resilience and continued productivity.

Resources and Further Reading

Hessian fly

Bosque-Pérez, N.A. 2010. Hessian Fly. In Compendium of Wheat Diseases and Insects 126–128, 3rd ed. W.W. Bockus, R.L. Bowden, R.M. Hunger, W.L. Morrill, T.D. Murray, and R.W. Smiley, eds. The American Phytopathological Society Press, St Paul, MN.

Wheat midge

Knodel, J., and M. Ganehiarachchi. 2008. Integrated Pest Management of the Wheat Midge in North Dakota. North Dakota State University Extension Service.

Cereal Leaf Beetle

Kher, S.V., L.M. Dosdall, and H. Cárcamo. 2011. The Cereal Leaf Beetle: Biology, Distribution and Prospects for Control. *Prairie Soils and Crops Journal* 4: 32–41.

Armyworms, cutworms, and headworms

Bechinski, E.J., Smith, L.J., Merickel, F.W. 2009. Large Yellow Underwing, a New Cutworm in Idaho. University of Idaho Current Information Series 1172.

Berry, R.E. 1998a. Black Cutworm Factsheet. Modified from Insects and Mites of Economic Importance in the Northwest, 2nd ed. p. 221. ***http://mint.ippc.orst.edu/blackcutfact.pdf***.

Berry, R.E. 1998b. Variegated Cutworm. Modified from Insects and Mites of Economic Importance in the Northwest. 2nd Ed. p. 221. ***http://mint.ippc.orst.edu/vcfact.pdf***.

Cook, K.A., S.T. Ratcliffe, and M.E. Gray. 2003. Black Cutworm (*Agrotis ipsilon* Hufnagel). Insect Fact Sheet, University of Illinois IPM. ***https://ipm.illinois.edu/fieldcrops/insects/black_cutworm.pdf***.

Peairs, F.B. 2006. Crops: Caterpillars in Small Grains. Insect Series 5.577. Fort Collins, CO: Colorado State University Cooperative Extension.

Royer, T. 2007. Armyworms and Wheat Head Armyworms: How to Tell the Difference. Oklahoma State University Plant Disease and Insect Advisory 6(15).

Wireworms

Esser, A.D. 2012. Wireworm Scouting: The Shovel Method and the Modified Wireworm Solar Bait Trap. Washington State University Extension Fact Sheet FS059E.

Milosavljevic, I., A.D. Esser, and D.W. Crowder. 2015. Identifying Wireworms in Cereal Crops. Washington State University Extension Bulletin F5175E.

Rashed, A., F. Etzler, C.W. Rogers, and J.M. Marshall. 2015. Wireworms in Idaho Cereals: A Guide to Monitor Numbers and Identify Predominant Species in the Intermountain Region. University of Idaho Extension Bulletin 898.

Haanchen barley mealybug

Alvarez, J.M. 2003 Haanchen Barley Mealybug, A New Pest of Barley in Idaho. University of Idaho Current Information Series 1109.

Blodgett, S. 2009. High Plains Integrated Pest Management Guide. ***http://wiki.bugwood.org/HPIPM:Haanchen_Mealybug***.

Mani, M. 2016. Management of Mealybugs in Agricultural and Horticultural Crops, Barley. In Mealybugs and their Management in Agricultural and Horticultural crops, p. 249. M. Mani and C. Shivaraju, eds. Springer India.

Mites

Bauernfeind, R. 2005. Winter Grain Mites. Kansas State University. Extension Publication MF-2073.

Brewer, M.J. 1995. Banks Grass Mite *Oligonychus pratensis*. University of Wyoming Extension Publication B-1013.

Blodgett, S., and G.D. Johnson. 2002. Brown Wheat Mite. Montana State University Extension Publication MT200212 AG 12/2002.

References

Alvarez, J.M. 2003. Haanchen Barley Mealybug, A New Pest of Barley in Idaho. University of Idaho Current Information Series 1109.

Andrews, N., M. Ambrosino, G. Fisher, and S. Rondon. 2008. Wireworm Biology and Nonchemical Management in Potatoes in the Pacific Northwest. Pacific Northwest Extension Publication 607. Oregon State University.

Ansari, M.A., M. Evans, and T.M. Butt. 2009. Identification of Pathogenic Strains of Entomopathogenic Nematodes and Fungi for Wireworm Control. *Crop Protection* 28: 269–272.

Bauernfeind, R. 2005. Winter Grain Mites. Kansas State University Extension Publication MF-2073.

Bechinski, E.J., L.J. Smith, and F.W. Merickel. 2009. Large Yellow Underwing, A New Cutworm in Idaho. University of Idaho Current Information Series 1172.

Berry, R.E. 1998a. Black Cutworm. Modified from Insects and Mites of Economic Importance in the Northwest, 2nd ed., p. 221. ***http://mint.ippc.orst.edu/blackcutfact.pdf.***

Berry, R.E. 1998b. Variegated Cutworm. Modified from Insects and Mites of Economic Importance in the Northwest, 2nd ed., p. 221. ***http://mint.ippc.orst.edu/vcfact.pdf***.

Blodgett, S. 2009. High Plains Integrated Pest Management Guide. ***http://wiki.bugwood.org/HPIPM:Haanchen_Mealybug***.

Blodgett, S., and G.D. Johnson. 2002. Brown Wheat Mite. Montana State University Extension Publication MT200212 AG 12/2002.

Bosque-Pérez, N.A. 2010. Hessian Fly. In Compendium of Wheat Diseases and Insects, 3rd ed., p. 126–128. W.W. Bockus, R.L. Bowden, R.M. Hunger, W.L. Morrill, T.D. Murray, and R.W. Smiley, eds. The American Phytopathological Society Press, St Paul, MN.

Bosque-Pérez, N.A., J.B. Johnson, D.J. Schotzko, and L. Unger. 2002. Species Diversity, Abundance, and Phenology of Aphid Natural Enemies on Spring Wheats Resistant and Susceptible to Russian Wheat Aphid. *BioControl* 47: 667–684.

Brewer, M.J. 1995. Banks Grass Mite *Oligonychus pratensis*. University of Wyoming Extension Publication B-1013.

Bullock, D.G., N.A. Bosque-Pérez, J.B. Johnson, and F.W. Merickel. 2004. Species Composition and Distribution of Hessian Fly (Diptera: Cecidomyiidae) Parasitoids in Northern Idaho. *Journal of the Kansas Entomological Society* 77: 174–180.

Buntin, G.D., K.L. Flanders, R.W. Slaughter, and Z.D. DeLamar. 2004. Damage Loss Assessment and Control of the Cereal Leaf Beetle (Coleoptera: Chrysomelidae) in Winter Wheat. *Journal of Economic Entomology* 97: 374–382.

Castle del Conte, S.C., N.A. Bosque-Pérez, D.J. Schotzko, and S.O. Guy. 2005. Impact of Tillage Practices on Hessian Fly-Susceptible and Resistant Spring Wheat Cultivars. *Journal of Economic Entomology* 98: 805–813.

Clement, S.L., L.R. Elberson, F.L. Young, J.R. Alldredge, R.H. Ratcliffe, and C. Hennings. 2003. Variable Hessian Fly (Diptera: Cecidomyiidae) Populations in Cereal Production Systems in Eastern Washington. *Journal of the Kansas Entomological Society* 76: 567–577.

Cook, K.A., S.T. Ratcliffe, and M.E. Gray. 2003. Black Cutworm (*Agrotis ipsilon* Hufnagel). Insect Fact Sheet, University of Illinois IPM. ***https://ipm.illinois.edu/fieldcrops/insects/black_cutworm.pdf***.

Davis, T.S., Y. Wu, and S.D. Eigenbrode. 2014a. Host Settling Behavior, Reproductive Performance, and Effects on Plant Growth of an Exotic Cereal Aphid, *Metopolophium festucae* subsp. *cerealium* (Hemiptera: Aphididae). *Environmental Entomology* 43: 682–688.

Davis, T.S., J. Abatzoglou, N.A. Bosque-Pérez, S.E. Halbert, K. Pike, and S.D. Eigenbrode. 2014b. Differing Contributions of Density Dependence and Climate to the Population Dynamics of Three Eruptive Herbivores. *Ecological Entomology*.

Davis, T.S., N.A. Bosque-Pérez, T. Magney, N.E. Foote, and S.D. Eigenbrode. 2015. Environmentally Dependent Host-Pathogen and Vector-Pathogen Interactions in the *Barley Yellow Dwarf Virus* Pathosystem. *Journal of Applied Ecology*.

Eigenbrode, S.D., and S. Macfadyen. 2016. Insect Pests of Wheat Under Changing Climates – An Assessment of the State of Knowledge and Needs for Research. In Achieving Sustainable Wheat Cultivation. P. Langridge, ed. Burleigh Dodds, Cambridge.

Eigenbrode, S.D., T.S. Davis, and D.W. Crowder. 2015. Climate Change and Biological Control in Agricultural Systems: Principles and Examples from North America. In Climate Change and Insect Pests, p. 119–135. C. Bjorkman and P. Niemela, eds. CABI, Oxon.

Esser, A.D., I. Milosavljević, and D.W. Crowder. 2015. Effects of Neonicotinoids and Crop Rotation for Managing Wireworms in Wheat Crops. *Journal of Economic Entomology* 108: 1786–1794.

Esser, A.D. 2012. Wireworm Scouting: The Shovel Method and the Modified Wireworm Solar Bait Trap. Washington State University Extension Publication FS059E.

Evans, E.W., N.R. Carlile, M.B. Innes, and N. Pitigala. 2012. Warm Springs Reduce Parasitism of the Cereal Leaf Beetle through Phenological Mismatch. *Journal of Applied Entomology* 137: 321–400.

Finlay, K.J., and J.E. Luck. 2011. Response of the Bird Cherry-Oat Aphid (*Rhopalosiphum padi*) to Climate Change in Relation to its Pest Status, Vectoring Potential and Function in a Crop-Vector-Virus Pathosystem. *Agriculture, Ecosystems & Environment* 144: 405–421.

Halbert, S.E., Y. Wu, and S.D. Eigenbrode. 2013. *Metopolophium festucae cerealium* (Hemiptera: Aphididae): A New Addition to the Aphid Fauna of North America. *Insecta Mundi* 0301: 1–6.

Higginbotham, R.W., P.S. Froese, and A.H. Carter. 2014. Tolerance of Wheat (Poales: Poaceae) Seedlings to Wireworm (Coleoptera: Elateridae). *Journal of Economic Entomology* 107: 833–837.

Knodel, J., and M. Ganehiarachchi. 2008. Integrated Pest Management of the Wheat Midge in North Dakota. North Dakota State University Extension Service.

Mani, M. 2016. Management of Mealybugs in Agricultural and Horticultural Crops, Barley. In Mealybugs and their Management in Agricultural and Horticultural Crops, p. 249. M. Mani and C. Shivaraju, eds. Springer India.

McKenzie, H.L. 1962. Third Taxonomic Study of California Mealybugs, Including Additional Species from North and South America. *Hilgardia* 32: 637–687.

Michaud, J.P., P.E. Sloderbeck, and R.J. Whitworth. 2007. Wheat Insect Management. Kansas State University Research and Extension.

Milosavljević, I., A.D. Esser, and D.W. Crowder. 2016a. Seasonal Population Dynamics of Wireworms in Wheat Crops in the Pacific Northwestern United States. *Pest Science*.

Milosavljević, I., A.D. Esser, and D.W. Crowder. 2016b. Effects of Environmental and Agronomic Factors on Soil-Dwelling Pest Communities in Cereal Crops. *Agriculture, Ecosystems & Environment* 225: 192–198.

Milosavljević, I., A.D. Esser, and D.W. Crowder. 2015. Identifying Wireworms in Cereal Crops. Washington State University Extension Publication F5175E.

Olfert, O., and R.M. Weiss. 2006. Impact of Climate Change on Potential Distributions and Relative Abundances of *Oulema melanopus*, *Meligethes viridescens* and *Ceutorhynchus obstrictus* in Canada. *Agriculture, Ecosystems & Environment* 113: 295–301.

Olfert, O., R.M. Weiss, and R.H. Elliot. 2016. Bioclimatic Approach to Assessing the Potential of Climate Change on Wheat Midge in North America. *Canadian Entomologist* 148: 52–67.

Olfert, O., R.M. Weiss, S. Woods, H. Philip, and L. Dosdall. 2004. Potential Distribution and Relative Abundance of an Invasive Cereal Crop Pest, *Oulema melanopus* (Coleoptera: Chrysomelidae), in Canada. *Canadian Entomologist* 136: 277–287.

Philips, C.R., D.A. Herbert, T.P. Kuhar, D.D. Reisig, W.E. Thomason, and S. Malone. 2011. Fifty Years of Cereal Leaf Beetle in the U.S.: An Update on its Biology, Management, and Current Research. *Journal of Integrated Pest Management* 2: 1–5.

Rao, S., A. Cossé, B. Zilkowski, and R. Bartelt. 2003. Aggregation Pheromone of the Cereal Leaf Beetle: Field Evaluation and Emission from Males in the Laboratory. *Journal of Chemical Ecology* 29: 2165–2175.

Rashed, A., F. Etzler, C.W. Rogers, J.M. Marshall. 2015. Wireworms in Idaho Cereals: A Guide to Monitor Numbers and Identify Predominant Species in the Intermountain Region. University of Idaho Extension Bulletin 898.

Ratcliffe, R.H., S.E. Cambron, K.L. Flanders, N.A. Bosque-Pérez, S.L. Clement, and H.W. Ohm. 2000. Biotype Composition of Hessian Fly (Diptera: Cecidomyiidae) Populations from the Southeastern, Mid-Western, and Northwestern United States and Virulence to Resistance Genes in Wheat. *Journal of Economic Entomology* 93: 1319–1328.

Reddy, G.V.P., K. Tangtrakulwanich, S. Wu, J.H. Miller, V.L. Ophus, J. Prewett, and S.T. Jaronski. 2014. Evaluation of the Effectiveness of Entomopathogens for the Management of Wireworms (Coleoptera: Elateridae) on Spring Wheat. *Journal of Invertebrate Pathology* 120: 43–49.

Roberts, D. 2012. Extension Leads Multi-Agency Team in Suppressing a Pest in the West. *Journal of Extension* 50. ***https://www.joe.org/joe/2012april/a10.php***.

Sadeghi, S.E., J. Bjur, L. Ingwell, L. Unger, N.A. Bosque-Pérez, and S.D. Eigenbrode. 2016. Interactions between *Metopolophium festucae cerealium* (Hemiptera: Aphididae) and *Barley yellow dwarf virus* (BYDV-PAV). *Journal of Insect Science* 16: 1–6.

Schotzko, D.J., and N.A. Bosque-Pérez. 2002. Relationship between Hessian fly Infestation Density and Early Seedling Growth of Resistant and Susceptible Wheat. *Journal of Agricultural and Urban Entomology* 19: 95–107.

Smiley, R.W., J.A. Gourlie, R.G. Whittaker, S.A. Easley, and K.K. Kidwell. 2004. Economic Impact of Hessian Fly (Diptera: Cecidomyiidae) on Spring Wheat in Oregon and Additive Yield Losses with Fusarium Crown Rot and Lesion Nematode. *Journal of Economic Entomology* 97: 397–408.

Townsend, L., D. Johnson, and D. Hershman. 1996. Wheat Streak Mosaic Virus and the Wheat Curl Mite. University of Kentucky Extension Publication ENTFACT-117.

Trebicki, P., N. Nancarrow, E. Cole, N.A. Bosque-Pérez, F.E. Constable, A.J. Freeman, B. Rodoni, A.L. Yen, J.E. Luck, and G.J. Fitzgerald. 2015. Virus Disease in Wheat Predicted to Increase with a Changing Climate. *Global Change Biology* 21: 3511–3519.

Trebicki, P., R.K. Vandegeer, N.A. Bosque-Pérez, K.S. Powell, B. Dader, A.J. Freeman, A.L. Yen, G.J. Fitzgerald, and J.E. Luck. 2016. Virus Infection Mediates the Effects of Elevated CO_2 on Plants and Vectors. *Nature Scientific Reports* 6: 22785.