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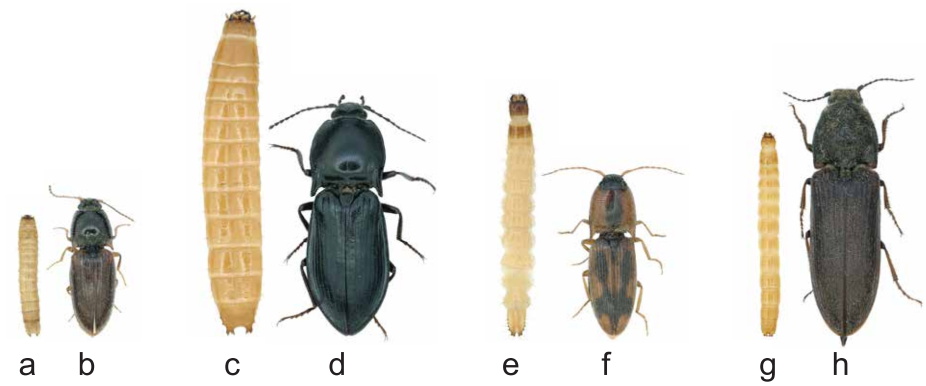
Guide to Pest Wireworms in Canadian Prairie Field Crop Production



Front cover species: *Hypnoidus bicolor* a) larva; b) adult; *Selatosomus aeripennis destructor* c) larva; d) adult; *Aeolus mellillus* e) larva; f) adult; *Limonius californicus* g) larva; h) adult

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Foreword

This guide is intended to provide information on wireworm damage, biology, management, research and challenges in crop production on the Canadian Prairies. We have summarized the knowledge of this persistent and complicated pest on the Prairies by discussing the general life cycle, behaviours, and management options for the main pest species in this region. We have also identified major gaps in knowledge and where research is needed. Our target audience include farmers, agronomists, crop scouts, extension personnel and anyone else interested in the impact of wireworms on Prairie crop production.

Note that this guide is a summary of the scientific literature. No content of the guide should be considered as an endorsement of any product.

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Four wireworm species found in the same field in southern Alberta. Clockwise starting from left: *Hypnoidus bicolor* (no common name), page 24; *Selatosomus aeripennis destructor* (Prairie grain wireworm), page 26, *Hadromorphus glaucus* (no common name), page 32; *Hypnoidus bicolor* (no common name); *Aeolus mellillus* (flat wireworm), page 30. Photo: Haley Catton, AAFC-Lethbridge

Introduction

Why worry about wireworms?

Wireworms are soil-dwelling insects that have challenged crop production on the Canadian Prairies since farming began in this region (Strickland 1927, King 1928). Wireworms damage crops by feeding on the seeds, roots or lower stems of almost all field crops, and are especially damaging to cereals. Since wireworms are often the only reason growers use insecticide-treated seed in cereals on the Prairies, understanding more about these pests can save costs and reduce unnecessary pesticide use.

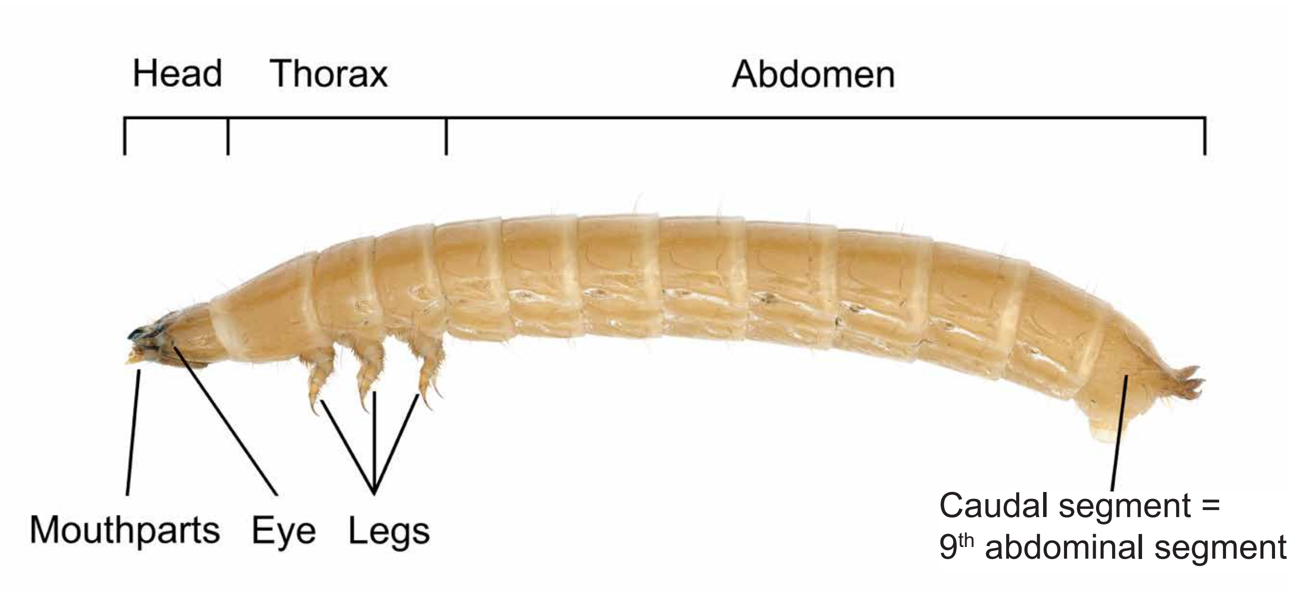

Figure 1. Side view of a wireworm showing key body sections. Photo: J. Saguez, CÉROM

What are wireworms?

Wireworms are soil-dwelling larvae that tend to be hard-bodied, segmented and yellowish in colour, with three pairs of legs (Figure 1). Despite their common name and worm-like appearance, wireworms are not actually "worms." Rather, they are the larval stage of a group of beetles called click beetles (Elateridae family) (Figure 2). [See Box A, pages 12–15 to learn which organisms can be mistaken for wireworms.]

Click beetles can be identified by the two "points" (officially called hind angles) at the back end of their pronotum (hard shield-like covering of the thorax, between the head and the abdomen, Figure B1, p. 16). Their "clicking", a defensive behaviour when placed on their backs, projects them up to 30 centimetres (12 inches) or more into the air to escape danger and literally get them back on their legs (Evans 1972). They have long segmented antennae and often have bullet-shaped bodies. [See Box B, page 15 for insects which can be mistaken for click beetles.]

Hypnoidus bicolor	*Selatosomus aeripennis destructor*	*Limonius californicus*	*Aeolus mellillus*	*Hadromorphus glaucus*	*Agriotes mancus*
No common name	Prairie grain wireworm	Sugarbeet wireworm	Flat wireworm	No common name	Wheat wireworm

Figure 2. Main pest wireworm species on the Canadian Prairies: larval stages (top), adult (click beetle) stages (bottom). Photos: J. Saguez, CÉROM

There are thousands of Elateridae species around the world. At least 100 species are economic crop pests somewhere (Vernon and van Herk 2013b). Click beetles and wireworms are a natural part of our ecosystem on the Prairies, with at least 182 known species in this region (van Herk and Vernon 2014). Eleven species, all of which are native species, have been reported as pests on the Prairies (van Herk and Vernon 2014). Two of these species are widespread major pests: *Hypnoidus bicolor* (no common name) and *Selatosomus aeripennis destructor* (Prairie grain wireworm). Several others are lesser or more regional pests, including *Limonius californicus* (sugarbeet wireworm) and *Aeolus mellillus* (flat wireworm).

On the Prairies, it is only native wireworm species that are crop pests. This is different than other areas in Canada (e.g. British Columbia, Nova Scotia, Prince Edward Island) where wireworm pests can be native (usually different from those found on the Prairies) or invasive species introduced from Europe (e.g. *Agriotes sputator*, *A. obscurus*, *A. lineatus*). **The major European pest species of wireworms have not been found on the Prairies** (van Herk et al. 2021b). The regional differences is an important point: each species has different behaviours, therefore effective wireworm control options should be designed to match the pest species and the environment found in a particular region (Vernon and van Herk 2013b).

In this guide, we use the term "wireworms" to refer to the group of four main problem species on the Canadian Prairies, unless otherwise indicated. We will describe what is known about each main pest species, how to identify them and options to manage them.

What is the problem?

It is the wireworm (click beetle larva) that damages crops; the adult click beetle itself causes no damage. Wireworm damage results from larval feeding on the seed, root, or plant. This chewing damage can reduce yield by killing young plants (crop thinning) or stunting older plants (King 1928). Sometimes the damage in a field is so extensive that re-seeding is required (Figure 3). Besides direct yield loss, crop thinning or bare spots can have a ripple effect into other agronomic factors such as weed management.

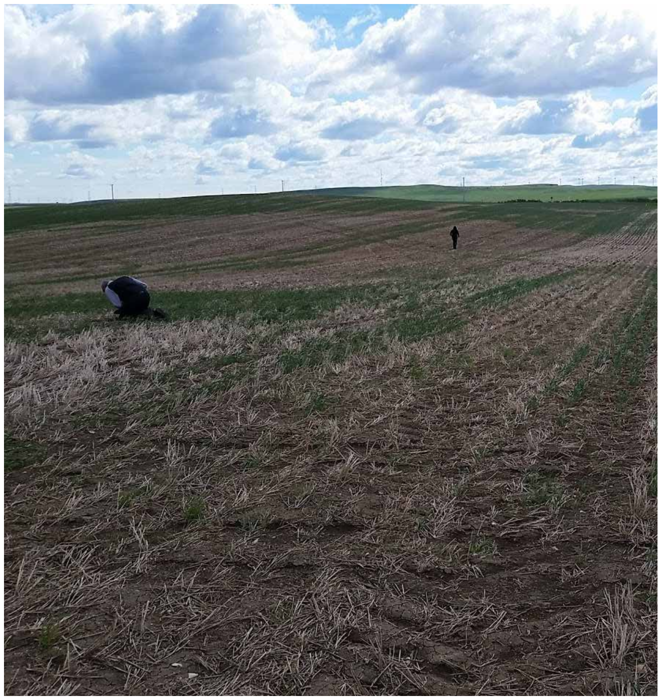

Figure 3. A winter wheat field in southern Alberta showing extensive wireworm damage. After searching, wireworms were found in and around plants on this day. The field had to be re-seeded. Photo: H. Catton, AAFC-Lethbridge

Typical wireworm damage on cereals can appear as hollowed-out seeds, or tunnelled or shredded stems (Figure 4). Affected young plants will often wilt or have yellowing or wilting centre leaves (also called "dead heart", Rashed et al. 2017). Pulses can show wilting or chewed or shredded stems from seed or stem feeding (Figure 5). In root or tuber crops such as beets, carrots and especially potatoes, wireworm feeding may not be visible in the above-ground plant (e.g. no wilting or yellowing) nor have a decrease in biomass production, but it can disfigure produce, vastly reducing the market value of the product (AAFC 2017) (Figures 6, 7). Damage can be holes, which may lead to rotting, or cause deformities when damage occurs early during growth (Vernon and van Herk 2013b) (Figure 8).

New names / Old faces

Over time, as taxonomists develop a better understanding on how species are related to each other, species are given different names – sometimes in a new genus, same genus but different species, reclassified as a subspecies, two species merged into one species, etc. This has happened several times with the Prairie grain wireworm (*Selatosomus aeripennis destructor*) and *Hypnoidus bicolor*. It adds up to some confusion when reading through older reports and species descriptions. But what doesn't change are the physical characteristics, life cycle and destructive behaviour.

Current and former Latin names for Prairie grain wireworm (*Selatosomus aeripennis destructor*) and *Hypnoidus bicolor*

Common name	Accepted Latin name	Former names (synonyms)
Prairie grain wireworm	*Selatosomus aeripennis destructor*	*Ludius aeripennis tinctus* (LeConte) *Ludius aeripennis destructor* *Ctenicera destructor* *Ctenicera aeripennis destructor* *Selatosomus destructor*
No common name	*Hypnoidus bicolor*	*Cryptohypnus nocturnus bicolor* *Cryptohypnus nocturnus* (Eschscholtz) *Hypnoidus nocturnus* *Hypolithus bicolor*

Figure 4. Close up view of wireworm feeding damage on cereal seedlings. Stems can be shredded, severed, tunneled, or deformed. Photo: Mike Dolinski

Figure 5. Wireworm feeding through a faba bean seed. Photo: C. Baan

Figure 6. Wireworm damage in carrots. Photo: H. Catton, AAFC-Lethbridge

Figure 7. Late-season wireworm damage in potatoes (left), compared to healthy potato (right). Photo: W. van Herk, AAFC-Agassiz

Figure 8. Early wireworm damage in potatoes can lead to major deformities. Photo: R. Vernon, AAFC-Agassiz

Feeding patterns can vary by species: the Prairie grain wireworm (*S. a. destructor*) shreds plants (Eidt 1959), and can attack 10 times as many seeds or make up to 20 times more potato tunnels per larvae than *Hypnoidus bicolor* (Zacharuk 1962b, Burrage 1963). In contrast, the flat wireworm (*A. mellillus*) has a different mouthpart structure and cuts plants right off (Glen et al. 1943). King et al. (1933) describe that feeding by a small or large wireworm can be equally damaging to an individual seed, because the small larvae feed on the germ of the seed or the centre of the growing stem. Small amounts of damage to these delicate structures are often lethal to germinating seeds and seedlings.

In cereals, wireworms seem to affect wheat more than barley or oats (Burrage 1964, Rashed et al. 2017, Milosavljević et al. 2019), although barley can also be severely damaged (Burrage 1964). There are a growing number of reports of pulses being damaged (Knodel and Shrestha 2018) (seed damage and shredded plants). Unfortunately for pulse growers, wireworms may prefer peas and lentil even more than cereals – these pulses have been used as trap crops to protect spring wheat in Montana (Adhikari et al. 2017, Sharma et al. 2019). Canola does not appear to suffer as much damage as other crops (based on anecdotal observations).

Wireworm management is challenging: any given field may have several wireworm species, each with its own life cycle and behaviours and with several overlapping generations. For many decades, wireworms were controlled with insecticides, specifically the organochlorine Lindane (Group 2A). However, this chemical was de-registered in Canada in 2004, and, with no effective chemicals to replace them until very recently, wireworm problems have returned.

In recent years, neonicotinoid seed treatments have been the only chemical control available in Canada. However, while these intoxicate/immobilize wireworms for weeks at a time, providing in-season crop protection, they do not reduce population numbers (Vernon et al. 2009, Morales-Rodriguez and Wanner 2015, van Herk et al. 2018b).

At the time of publishing this guide (2021), new products have entered the marketplace that may provide more effective control. However, even if chemicals are effective, it is important that non-chemical methods of integrated pest management also be investigated to achieve the most sustainable and effective control (Knodel and Shrestha 2018). A variety of management options such as cultural control (e.g. crop rotation), targeting the adult stage (click beetles), and biological control have been and continue to be investigated (see Management section).

How big is the problem?

We really don't know how big a problem wireworms pose to Prairie crop production. Certainly, in some fields, we've seen firsthand serious crop thinning and yield loss from wireworms, even with seed treatments. However, there are no recent systematic surveys describing the economic damage caused by wireworm on the Canadian Prairies. It is the seemingly patchy nature of damage that makes wireworm a harmful pest – not all fields have a problem, but in those that do, the problem can be severe and persistent (King 1928).

There are several reasons for the lack of surveys. Wireworm damage can be difficult to diagnose and can be easily confused with other types of damage (e.g. herbicide damage, frost). Or, by the time damage is done, the wireworms have moved down from the soil surface and cannot be definitely linked as the cause. In addition, bare patches can fill in with weeds which makes the damaged areas difficult to spot (King 1928).

The only economic estimates of wireworm damage on the Canadian Prairies are from Saskatchewan and are at least 50 years old, from a period when farming practices were different than now. This would have included practices such as regular tillage, summer fallowing, breaking up native Prairie sod, and often minimal to no synthetic pesticide use. King (1928) surveyed wireworm damage in Saskatchewan in the 1920s and found substantial losses in more than 1,000 fields. An estimate of the wireworm population for one severely infested field was 198 wireworms/square metre (18.4 wireworms/square foot or 1,980,000 wireworms/hectare = 801,619 wireworms/acre) over much of the field (King 1928). Yield losses from obvious wireworm damage in Saskatchewan crop districts ranged from 0.05 to 5% for a provincial average of 1.5% loss in 1926 and 1.9% loss in 1927. These crop losses were valued at $3M annually ($46.7M in 2021 dollars). These provincial damage estimates might make the problem seem minor. However, at the field level, damage could range from slight or negligible in some areas to moderate to heavy in others. That meant that many farms that had a wireworm problem had a severe problem. Individual fields had up to 100% loss. King (1928) was clear that the provincial damage numbers were likely an underestimate since mild wireworm damage was not quantified.

Burrage (1964) surveyed 230–518 Saskatchewan wheat, barley or oat fields per year in 1954–1961. In general, thinning due to wireworm damage was usually highest in medium soil textures. Average percent crop thinning for wheat and barley was highest following summer fallow (4–6%) compared to crops seeded into stubble (1–4%). The number of wheat fields following summer fallow that showed 10% or more crop thinning during the 7-year survey period decreased from 23% to 9%. This reduction was likely due to the increasing use of chemical seed treatments for wireworm which had just been introduced. However, the proportion of fields with wireworm damage remained constant during the sampling period indicating that seed treatments did not eradicate the pests.

Other surveys exist that describe presence of wireworms, but not damage. Morales-Rodriguez et al. (2014) surveyed 184 cereal fields in Montana and found wireworms in 37 of 59 fields (63%) with a known wireworm history. They also found wireworms in 46 of 125 fields (37%) with no known wireworm history; however, these fields only had one-eighth the number of wireworms (12.5%) as the fields with wireworm history.

What research is out there for the Canadian Prairies?

To develop an effective pest control program, it is important to know the biology of the target pest:

- What species is it?
- What is its life cycle?
- When and where is it active?
- What environmental conditions (soil, climate) does it favour?
- Are there any particularly vulnerable life stages?
- What type(s) of damage does it do and how severe is it?
- Does crop rotation history influence wireworm damage in the current crop?
- Does anything eat the pest?

Unfortunately, wireworms are particularly challenging pests to study. Their subterranean habitat and ability to move in the soil make them difficult to find. The long life cycles of some species (1–11 years in the soil) make them nearly impossible for entomologists to rear in the lab for study ("few of us will not fail" to do so, Strickland 1935). Their patchy distribution among fields and within fields makes sampling for them difficult and labour-intensive. As a result, economic thresholds have not been developed in Canada.

History of wireworm research on the Prairies

Wireworms are a diverse group. There has been a lot of research into their biology and life cycles around the world, especially regarding the pest species. However, the findings and the monitoring and control recommendations will only be relevant for the species, crops and growing environments (e.g. soils and climate) in which the research was conducted. They cannot reliably be applied to other regions. This is why it is especially important to develop knowledge on these questions specifically for the Canadian Prairies. Despite the difficulties of studying wireworm, a number of excellent studies over the decades has been conducted to understand wireworms here.

Most of what we know about Prairie wireworm biology is a result of the pioneering research done between the 1930s and 1970s, starting with the work of Edgar Harold Strickland and Kenneth King. Strickland, working first out of the Dominion Entomological Laboratory in Lethbridge and later at the University of Alberta, published his observations on the life history of *Selatosomus aeripennis destructor* (Prairie grain wireworm) in his 'Wireworms of Alberta' (1927) and in 'The biology of Prairie inhabiting wireworms' (1935). At the time, *S. a. destructor* was the most abundant pest wireworm species on the Prairies. In these publications, he discussed the relative susceptibilities of wheat varieties to wireworm damage, and results of long-term field cage studies to determine the life history of *S. a. destructor* and wheat plants their larvae survive on. Among his findings were that, "newly emerged larvae die from starvation in a few weeks unless they have access to suitable living vegetation [but] mature wireworms can live for at least three years in soil in which no vegetation is present." (Strickland 1939). From this he concluded that it was "impractical to attempt to starve wireworms in any year except that in which they have hatched" and that if starvation were attempted, care should be taken to "ensure all traces of grasses are destroyed before mid-June" (Strickland 1939). Regarding the life history of this species, Strickland observed the larval period of *S. a. destructor* could range from 4 to at least 11 years (Strickland 1939, 1942) depending on food availability, and that during which time larvae could moult regressively (i.e. moult, but decrease in size).

Between the 1920s to 1940s, Kenneth King started his ground-breaking work on Prairie wireworm biology, identification, and management at the Dominion Entomological Laboratory in Saskatoon. Many of the early wireworm researchers in Western Canada were mentored by King, including Arni P. Arnason (who joined his lab in 1927), Robert Glen (joined in 1928), Harold A. McMahon (1931), William B. Fox (1934), and Arthur R. Brooks (1946). Immediately after his arrival in 1922, King began an investigation into the quantitative relations between summer fallowing methods and wireworm abundance in Saskatchewan (Glen et al. 1936, King and Glen 1933, King 1928). This turned into an intensive, 18-year continuous wireworm sampling program that ended only with the labour and funding shortages caused by the World War II. This sampling program soon revealed the presence of multiple wireworm species in farmed land. As there were no existing identification keys for them, Glen developed his key to the economic wireworm species of Canada (Glen et al. 1943). This he followed with a comprehensive treatise on the "soft-bodied" wireworms (click beetle tribe Lepturoidini, species which today are placed in the Dendrometrinae) (Glen 1950). Glen's identification keys are still the main resource for identifying Canadian pest species, and King's survey is one of the chief sources of what we know about the distribution and relative importance of pest species. Other direct results of King's wireworm research program include Arnason's studies on the morphology of *Hypnoidus bicolor* (Arnason 1931) and Doug Eidt's work on the anatomy and histology of *S. a. destructor* (Prairie grain wireworm) larvae (Eidt 1958). Eidt's work revealed wireworms produce digestive enzymes to digest food extraorally (outside the mouth), then ingest the dissolved food using a 'pharyngeal sucking pump' (Eidt 1959). Due to the presence of an oral filter, *S. a. destructor* larvae cannot ingest particles > 3 micrometres (= 0.0003 centimetres / 0.00004 inches), thereby preventing the ingestion larger pathogenic bacteria (e.g. *Pseudomonas aeruginosa*) (Zacharuk 1973) and entomopathogenic nematodes (Eidt and Thurston 1995).

Other pioneering wireworm research includes the work done by Charles Lilly, G.R.F. "Dick" Davis and Robert Burrage. Lilly, working from the Lethbridge Research Centre in the 1940s and 1950s, conducted seminal work on click beetle sex attractants, focusing on *Limonius californicus* (sugarbeet wireworm) and *L. canus* (Pacific Coast wireworm), the two most important pest species in that genus in Western Canada (Lilly 1959, Lilly and McGinnis 1965, 1968, Jacobson et al. 1968). Davis, working from the Saskatoon lab, conducted numerous studies on the growth and feeding of *S. a. destructor* (Prairie grain wireworm) and its close relative *S. aeripennis aeripennis* on different foods, developed rearing methods and artificial diets, studied larval biting responses, digestive enzymes and feeding stimulants, and discovered that larvae can survive without food for 60 weeks and moult regressively (moult, but decrease in size) without decreasing head capsule size. Burrage, also working out of the Saskatoon lab, studied cultural and chemical control of wireworms and insecticide persistence in the soil and in food plants (Burrage and Saha 1967, Saha et al. 1974). Perhaps of most relevance for wireworm management today, Burrage recognized that an understanding of wireworm population dynamics is important when developing control techniques, and that the seasonal feeding patterns of key pest species (*S. a. destructor* and *H. bicolor*) are dependent on their feeding and moulting cycles, on soil moisture and temperature, on food availability and previous feeding (i.e. wireworm state) and wireworm species (Burrage 1963, Vernon and van Herk 2013b).

Most of what we know of the ecology and behaviour of *S. a. destructor* (Prairie grain wireworm), *H. bicolor*, and *Aeolus mellillus* (flat wireworm) in the Prairie provinces comes from the thorough research done by Russell Zacharuk and John Doane in the 1960s and 1970s. Zacharuk determined that *S. a. destructor* (Prairie grain wireworm) and *S. a. aeripennis* (Puget Sound wireworm) (two morphologically indistinguishable species) inhabit different soils: *S. a. destructor* (Prairie grain wireworm) is found in brown, dark brown, and black chernozems whereas *S. a. aeripennis* (Puget Sound wireworm) is found in dark grey chernozems (in Saskatchewan, roughly coincides with the Aspen Parkland). He also described wireworm sensory organs and cuticle structure and how the latter is affected by bacterial or fungal (*Metarhizium*) infection. Doane conducted ground-breaking work on the larval response to carbon dioxide. He found that wireworms follow increasing

One look / Two subspecies: *Selatosomus aeripennis destructor* vs. *Selatosomus aeripennis aeripennis*

Selatosomus aeripennis destructor (Prairie grain worm) is closely related to another pest subpecies, *Selatosomus aeripennis aeripennis* (Puget Sound wireworm) with nearly identical appearance. However, *S. a. aeripennis* (Puget Sound wireworm) lives in different soil and has more active flight behaviours. *Selatosomus aeripennis destructor* (Prairie grain wireworm) is found in the Brown, Dark Brown, and Black Chernozemic soils of the Mixed Grassland Ecoregion, Moist Mixed Grassland Ecoregion, and grassland parts of Aspen Parkland Ecoregion, whereas *S. a. aeripennis* (Puget Sound wireworm) is found in the Dark Grey Chernozems of the more wooded areas of the Aspen Parkland Ecoregion and in the soils of the Boreal Plains Ecozone (Zacharuk 1962a; Shorthouse 2010). The two subspecies coexist in the Alberta/BC Peace River region (Glen et al. 1943, Wilkinson 1963), but are not known to intermate (Zacharuk 1962a). *S. a. aeripennis* (Puget Sound wireworm) has been a notable pest in BC (Wilkinson 1963). Recent genetic research questions whether *S. a. destructor* (Prairie grain wireworm) and *S. a. aeripennis* (Puget Sound wireworm) are different species or subspecies (Etzler et al. 2014). In this guide, following current naming, we refer to them as subspecies.

carbon dioxide levels in the soil to find respiring plants or other carbon dioxide sources in the soil and that they can detect differences in concentration as low as 0.002% per centimetre (0.4 inch) (Doane et al. 1975). He also developed various trapping methods for larvae and beetles (e.g. Doane 1981), and researched egg survival. Both Zacharuk and Doane published detailed papers on *S. a. destructor* (Prairie grain wireworm) mating and egg-laying behaviour, reproductive success rates, and dispersal (Doane 1961, 1963a, 1963b, 1977a; Zacharuk 1962a, 1962b). Much of this work remains of immediate relevance for wireworm management today, and is reviewed in detail in van Herk and Vernon (2014).

Recently, Bob Vernon and Wim van Herk (AAFC-Agassiz) surveyed the wireworm species occurring across the Prairies. Following increasing reports of crop damage, mainly in southern Alberta, Vernon and van Herk conducted an extensive survey of wireworm pest species in 2004–2019 (van Herk et al. 2021b). Larvae were collected in fields by growers, agronomists, company field reps, entomologists and others, in areas where wireworms caused crop damage. The wireworms were sent to Vernon and van Herk in small containers with soil for identification, along with field and collection location data. The initiative was greatly facilitated by dedicated efforts by Syngenta Crop Protection Canada in 2010 and Bayer Crop Science in 2011, both of which developed wireworm monitoring kits and distributed them to growers and field reps. These kits included directions on how and where to locate bait traps, where to send the larvae, and other details.

Surveying has now shifted to collecting the adult or beetle form of pest wireworms using the newly developed Vernon Pitfall Trap (van Herk et al. 2018a) (Figure 9), again with the assistance of Syngenta. Now concluded, these wireworm and click beetle surveys collected approximately 5,700 specimens from nearly 600 independent sampling locations (van Herk et al. 2021b). This has allowed us to develop a comprehensive picture of the current wireworm pest complex in the Prairies (Figure 10). The vast majority of specimens (>95%) keyed to *H. bicolor*, *S. a. destructor* (Prairie grain wireworm), *L. californicus* (sugarbeet wireworm), and *A. mellillus* (flat wireworm) (Figure 11). Despite the relatively small number of larvae per location (approx. 10), it is notable that at over one fifth of the locations more than one of these economic species was collected. This is highly important, as different species vary in life history, activity periods, damage potential, and insecticide susceptibility – and therefore in the management strategies needed to protect crops from them. Prairie wireworm research continues today by AAFC researchers in Alberta and British Columbia, addressing the modern wireworm situation and possible management options. Recent research in the northwestern USA is also applicable to Prairie species (e.g. Morales-Rodriguez and Wanner 2015).

Figure 9.The Vernon pitfall trap (top); in the field (middle); lid removed to show Prairie grain wireworm click beetles and pink non-toxic antifreeze used as preservative (bottom). Photos: W. van Herk, AAFC-Agassiz (top), Haley Catton, AAFC-Lethbridge (middle, bottom)

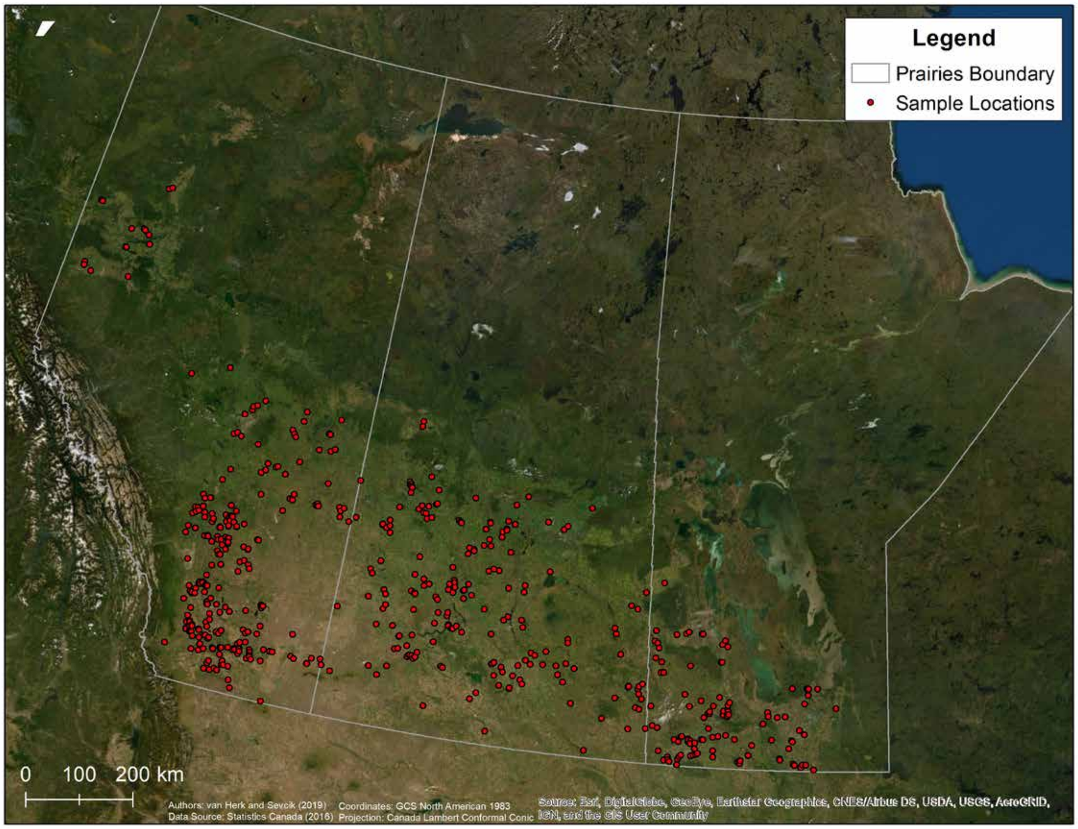

Figure 10. Locations of wireworm and click beetle sample collections in the Vernon and van Herk survey of the Prairies. Map: W. van Herk, AAFC-Agassiz.

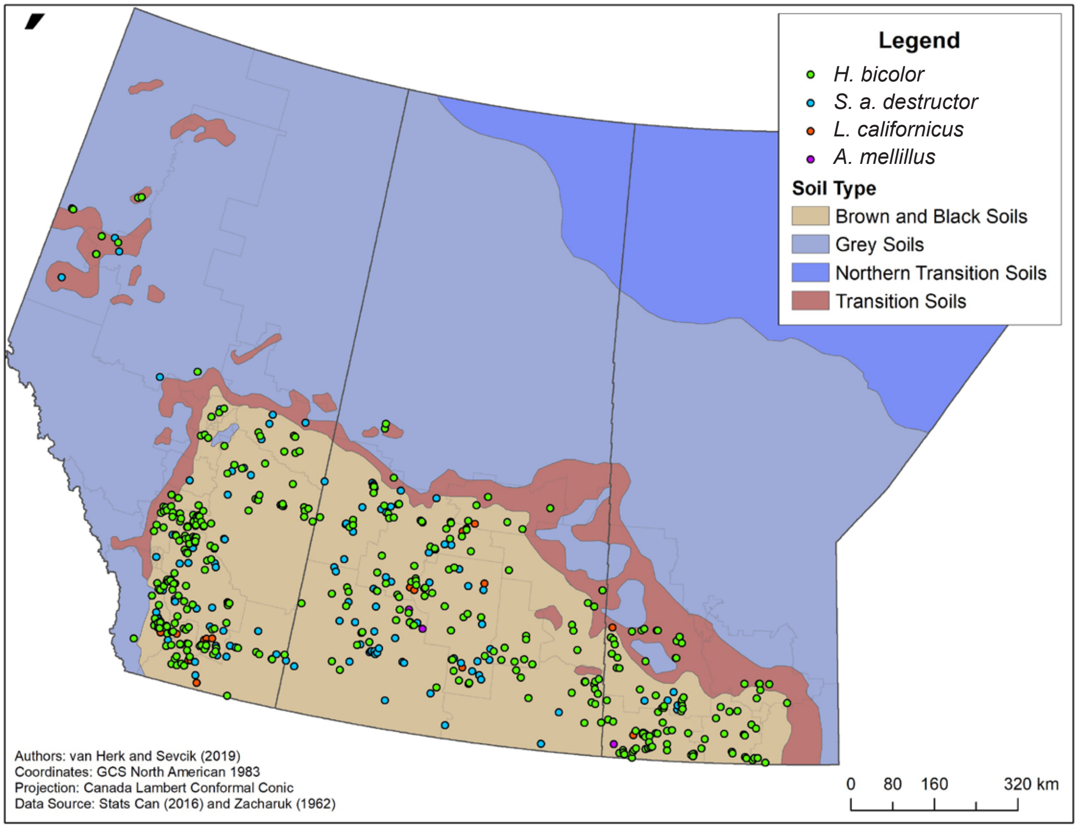

Figure 11. Species records found in the Vernon and van Herk survey of wireworms and click beetles the Prairies. Map: W. van Herk, AAFC-Agassiz.

BOX A: Identifying wireworms and insects that can be mistaken for them

Wireworms have three pairs of legs. They have an elongated, cylindrical or flattened, segmented and often shiny body (Figure 1). Depending on the species and the developmental stage, the size of the main Prairie wireworms can vary from 2 to 23 millimetres (0.08–0.9 inches). Their colour can vary from white to orange-brown depending on the species and the larval stage. The body is divided in three parts – head, thorax and abdomen. The three pairs of legs are connected to the three thoracic segments (prothorax, mesothorax and metathorax). The abdomen is composed of ten abdominal segments. Identifying a wireworm to the genus or species level is usually based on distinguishing characteristics of the ninth abdominal segment (caudal segment) or its head. For some species, identification by molecular biology techniques may be necessary (Benefer et al. 2013, Vernon and van Herk 2013b).

There are many organisms that live in the soil, most of which are beneficial for soil health. A few organisms are crop pests, but many others are important predators or decomposers that help cycle nutrients. Seeing an insect or invertebrate in the soil does not automatically mean there is a pest problem. When scouting for wireworms with bait traps, several other organisms can be observed in the soil and in the traps, and are sometimes confused with wireworms. Wireworms always have three pairs of legs, no more and no less, and they do not curl up tightly into a C-shape like some other insect larvae. Non-wireworm invertebrates in the soil can often be distinguished by a few obvious features.

Carabid (ground beetle) larvae
These are beneficial predators, not pests. There are many carabid species in Prairie crop fields, and the larvae come in various colours and sizes. Like wireworms, they have three pairs of legs. But look for very prominent mandibles and two long forked projections on the tail to distinguish them from wireworms (Figure A1).

Figure A1. Carabid (ground beetle) larva. Photo: CÉROM

Centipedes
Have many more than three pairs of legs. Important decomposers, centipedes are not crop pests (Figure A2).

Figure A2. Wireworm (left), centipede (right). Photo: J. Gavloski, Manitoba Agriculture and Resource Development

Crane fly larvae
Stout, light-brown insects without legs. They develop into large flies that look like mosquitoes but do not bite. Crane fly larvae are rarely crop pests on the Prairies (Figure A3).

Figure A3. Crane fly larva. Photo: J. Gavloski, Manitoba Agriculture and Resource Development

BOX A: Cont'd

Cutworms

These are juvenile moths, and have too many legs to be wireworms. Cutworms have three pairs of true legs plus five pairs of fleshy false legs at the rear of their abdomen. Cutworms curl up into a tight C-shape when disturbed; wireworms do not do this. Cutworms are often pests, see Floate (2017) for more information (Figure A4).

Figure A4. Cutworm. Photo: J. Gavloski, Manitoba Agriculture and Resource Development

False wireworms

These soil-dwelling larvae look a lot like true wireworms (Elateridae), but are actually larvae of a different family of beetles, darkling beetles (Tenebronidae). False wireworms are serious pests in some areas of the world like Australia. However, on the Canadian Prairies they are only an occasional and localized economic pest, not as serious or widespread as the true wireworms. While several species of false wireworms have been found in Prairie crop fields, only one species (*Eleodes extricatus*) has been noted as an economic pest, especially areas in dry areas with sandy soil like southwest Saskatchewan (King 1928). However, because they are easy to misidentify, some damage attributed to wireworms may in fact be from false wireworms (Strickland 1927). Both true wireworms and false wireworm larvae have hard segmented bodies and can vary from yellow to dark brown in colour. They can be told apart by several subtle features that may require a trained eye to see. False wireworms have small differences in their heads such as more pronounced antennae with the last antennal section getting wider at its tip. Their ninth abdominal segment is turned up at the tip and has a row of spines on its edges (Glen et al. 1943). They may have longer legs than true wireworms, especially the first pair of legs. Larval *E. extricatus* are 15–33 milliimetres long and mostly a light tan colour (Smith et al. 2014).They have a 2-year life cycle on the Prairies (Strickland 1927) (Figures A5).

Figure A5. False wireworm. Photo: Wim van Herk, AAFC-Agassiz

Stiletto fly larvae (Therevid)
These are long and thin, with a whitish body, dark head capsule, and no legs. These are active creatures and are predators of wireworms. They often "wiggle" around vigorously when disturbed (Figure A6).

Figure A6. Stiletto fly larva (Therevid) Photo: J. Gavloski, Manitoba Agriculture and Resource Development

True worms
Wireworms are not true worms: they are the larval form of a beetle. There are many true worms in the soil, and they never have legs or a head. One group that could easily be confused with wireworms is a group of pale, small worms called Enchytraeid worms. These are important for soil health and are not crop pests (Figure A7).

Figure A7. True worm. Photo: T. Buss & E. Bargen, Manitoba Agriculture and Resource Development

White grubs
These are larvae of scarab beetles and can sometimes be crop pests. Like wireworms, they have three pairs of legs. However, unlike wireworms they are C-shaped, have 5-segmented antennae, and the end of their abdomen is shiny (Figure A8).

Figure A8. White grub. Photo: J. Saguez, CÉROM

BOX B: Identifying click beetles and insects that can be mistaken for them

There are hundreds of beetle species in Prairie crop fields. While a few are pests (like some click beetles), many are beneficial predators and decomposers. It is important to distinguish between pests and beneficials, and to preserve these beneficial insects for a healthy agro-ecosystem.

Click beetles (Figure B1) are found on or in the soil. Click beetles can be identified by the two “points” at the back end of their pronotum (officially called hind angles, Figure B1), and their “clicking” defensive behaviour when placed on their backs, which launches them into the air. They have long segmented antenna and often have bullet-shaped bodies.

The most likely insects to be mistaken for click beetles in crop fields are ground beetles (Figure B2). Ground beetles, also known as carabid beetles, are beneficial insects and are important predators and scavengers. There are at least 398 species of carabids on the Prairies (Holliday et al. 2014). Like click beetles, ground beetles are found on the soil surface, have hard bodies, can be dark coloured with lines down their wing covers (elytra), and can have slender body shapes and long segmented antennae.

To tell ground beetles from click beetles, look for hind angles. Click beetles have hind angles and ground beetles do not. Ground beetles also have prominent mandibles, and a different body shape than click beetles. In click beetles, the widest part of the pronotum (visible part of the thorax from above) is about the same width as the abdomen. In ground beetles, the visible part of the thorax is wider than the head, but usually narrower than the abdomen. Ground beetles are usually fast moving but do not have the clicking behaviour seen in click beetles.

Another species that may be confused for a click beetle is the darkling beetle (adult false wireworm, *Eleodes extricatus*, Figure B3). They are flightless,11-15 millimetres long (Triplehorn et al. 2009), lack hind angles on the pronotum, and are rounder and more robust than click beetles. Unlike click beetles, adult darkling beetles are active in mid- to late summer and fall (Calkins and Kirk 1975). Note the rounder body shape than click beetles.

Figure B1. Click beetle, *Selatosomus aeripennis destructor.* Photo: J. Saguez, CÉROM

Figure B2. Ground beetle, *Pterostichus melanarius.* Photo: H. Goulet, AAFC.

Figure B3. Darkling beetle, *Eleodes extricatus*. Photo: Whitney Cranshaw, Colorado State University, Bugwood.org

Prairie wireworm life cycle and activity

Prairie wireworms follow a general life cycle, with key differences between species. They spend most of their lives (1–11 years) as larvae in the soil, and just a few weeks each at the egg, pupal, and active adult stages. The activity of adult click beetles and larval wireworms are quite seasonal, meaning that they occur at fairly predictable times of the year. However, seasonal activity can vary between species (King et al. 1933, Doane 1981, Milosavljević et al. 2017). Summaries of the life stages of 3 common pest species on the Canadian Prairies are summarized in Table 1 (page 59).

Adult click beetles and eggs

Adults overwinter in the soil, and emerge in the spring to lay eggs for several weeks before dying (Figure 12). With a few exceptions, adults do not cause damage to crops directly (Brooks 1960), and are active from April to late July or longer (Zacharuk 1962a). Of the four species of interest, *S. a. destructor* (Prairie grain wireworm) and *L. californicus* (sugarbeet wireworm) need to mate to reproduce, while *A. mellillus* (flat wireworm) and some populations of *H. bicolor* are "parthenogenetic", meaning they are all or mostly females and do not need to mate. For those species that do mate, it is common for female beetles to emit mating "pheromones" to attract males (Lilly 1959, Doane 1963a).

Depending on the species, adult click beetles may or may not fly. *S. a. destructor* (Prairie grain wireworm) generally does not (Strickland 1927, Doane 1963a), while *H. bicolor* (Doane 1963a), *L. californicus* (sugarbeet wireworm) (Lilly 1959), and *A. mellillus* (flat wireworm) (Doane 1977b) do. Female *S. a. destructor* (Prairie grain wireworm) beetles can walk at least 110 metres (360 feet) in 9 days (Doane 1963a), meaning that most will deposit their eggs in the same field in which they emerge as adults. *H. bicolor* can walk up to 55 metres (180 feet) within 6 days (Doane 1963a), but their flight distances are unknown.

Soil surface trapping for adult *S. a. destructor* (Prairie grain wireworm) activity in 1959–1960 in Saskatoon showed a male:female ratio of approximately 7:1 (Doane 1961), but this skewed ratio may be an artefact of trapping method and time period. Over a season in 2019, Catton and van Herk (unpublished data) collected an approximate 1:1 sex ratio of *S. a. destructor* adults in southern Alberta. In Saskatoon, males were active from mid-April to mid-May; females emerged in April or early May to attract mates, but did not move around the soil surface much until mid-May to late June (Doane 1961). In contrast, *H. bicolor* had a male:female ratio of 1:2 and adults were active from late April to as late as mid-August. Adult beetles hide from high temperatures under soil lumps, litter and especially in soil cracks (Doane 1967).

An average adult female *S. a. destructor* (Prairie grain wireworm) can lay between 264 and 946 eggs (Doane 1963b), mostly before the end of June (Doane 1963b). *S. a. destructor* (Prairie grain wireworm) females dig 3–15 centimetres (1–6 inches) in the soil to deposit eggs (Strickland 1927), but they are not strong diggers and so often rely on cracks in the soil to access deeper areas (Doane 1967). The egg-laying preferences of Prairie wireworm species are not well known,

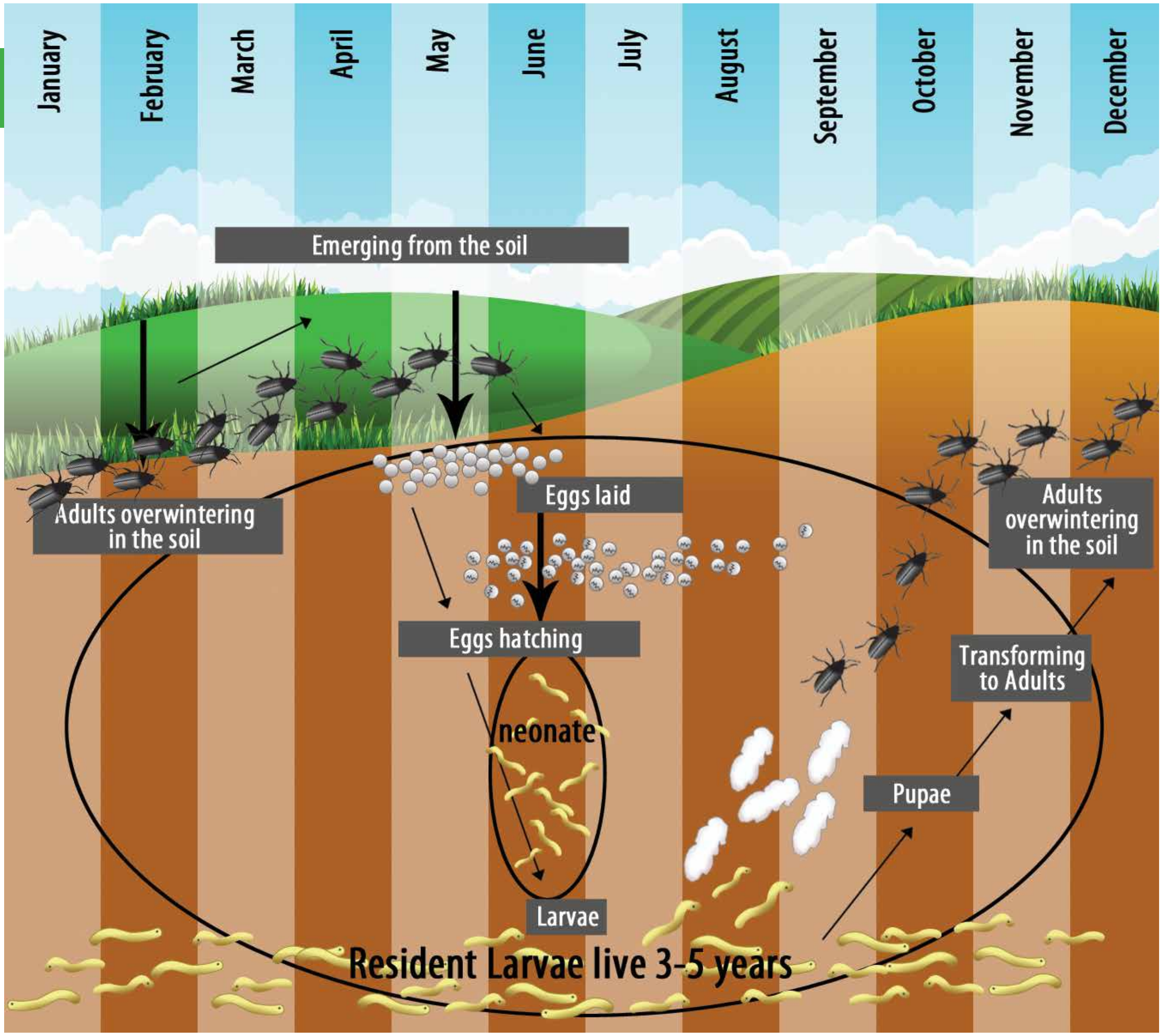

Figure 12. General wireworm life cycle. Photo: Top Crop Magazine, used with permission

except that they prefer moist soil to dry soil, with the ideal moisture being halfway between the permanent wilting point and field capacity (Doane 1967). Eggs are covered in a fluid that soil adheres to, coating them and making them nearly impossible to see. In order to survive, the eggs need to absorb moisture from the surrounding soil (Doane 1966). Eggs hatch within 14 or more days (Doane 1969), and the tiny newly hatched wireworms (neonates) begin feeding.

Newly hatched wireworms (neonates) — a vulnerable stage

Neonate wireworms hatch in the summer and feed on root tissue in the soil. They are not usually directly damaging to field crops as they are as small as 1.5 millimetres (0.06 inches) (Strickland 1927) (Figure 13) and plants are well-established by this time. However, neonate feeding in the early fall can damage root crops like potatoes. Larvae find food by moving toward carbon dioxide gas produced by living plant tissue (Doane et al. 1975). They can detect the source of the gas from at least 20 centimetres (8 inches) away (Doane et al. 1975).

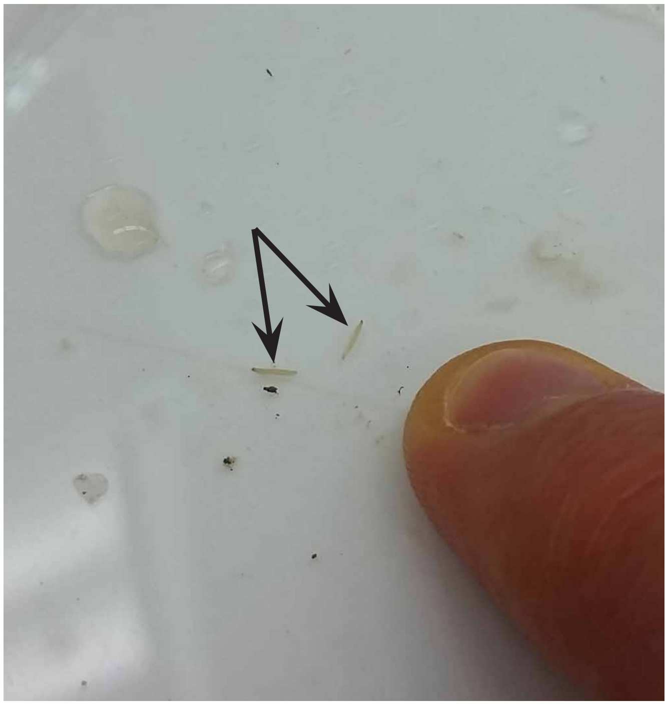

Figure 13. Wireworm neonates are very small (arrows). Photo: H. Catton, AAFC-Lethbridge

The neonate stage is one of the most vulnerable in the wireworm life cycle. At this stage, in at least *S. a. destructor*'s (Prairie grain wireworm) case, neonates are vulnerable to starvation, cannibalism and poor conditions, and require food to survive their first year (Strickland 1939, Davis 1958). In a series of multi-year field experiments with larvae caged in the soil (Strickland 1939), >90% of *S. a. destructor* (Prairie grain wireworm) neonates died within the first two years after hatching, often from cannibalism (Strickland 1939). Neonates require specific host plants to survive (Davis 1958), with highest survival on perennial grasses and cereals, and low or no survival on buckwheat and non-grassy weeds (Strickland 1939, see Crop Rotation section). With the exception of *A. mellillus* (flat wireworm), which is thought to complete its entire life cycle in one to two years, a neonate wireworm will overwinter in the soil, where it will become a "resident" wireworm the following spring.

Resident wireworms — resilient and damaging

After their first winter, wireworms become part of the "resident" population and will usually remain so for several years, depending on species and conditions. Resident wireworms are resilient to stress, and can move up, down and sideways through the soil to find food and suitable soil conditions. They range in size from 2 to 23 millimetres (0.08–0.9 inches), depending on growth stage (Figure 14) and species (Figure 15) (Strickland 1939). The resident stage is the most damaging life stage as these wireworms are active in the spring when cereal and pulse crops are seeded, and in the fall when root crops are harvested. At this stage, attempting to starve wireworms is not effective. For example, *S. a. destructor* (Prairie grain wireworm) can survive at least three years without food as long as moisture is adequate (Strickland 1939). They can also moult to become smaller and delay pupation when conditions are poor (King et al. 1933, Strickland 1939).

Figure 14. Wireworm size varies within a species depending on age. Photo: W. van Herk, AAFC-Agassiz

Figure 15. Size of resident wireworms can vary with species. *Selatosomus aeripennis destructor* (left) and *Hypnoidus bicolor* (right). Photo: W. van Herk, AAFC-Agassiz

The resident stage in the wireworm life cycle is quite flexible. Growth, especially in the first three years, varies from individual to individual, even in good conditions (Strickland 1939, Zacharuk 1962a). Depending on the species and the conditions, wireworms will moult through 9 to 24 or more larval stages (*S. a. destructor*, Strickland 1939) ("instars") as they grow, which will take 3–11 years in the field, depending on the species and the growing conditions. Strickland (1939) reported that some *S. a. destructor* beetles that took two years to mature were the same size as others who took eight years.

In general, there are two feeding seasons for larval wireworms on the Prairies – spring/early summer and fall – when soils are at intermediate temperatures, although feeding in summer is possible with suitable soil conditions (Zacharuk 1962b, Burrage 1963, Doane 1981). Resident *S. a. destructor* (Prairie grain wireworm) wireworms become active in the spring once soil temperatures reach 7°C (45°F), usually in late April or May (Zacharuk 1962a). Their feeding activity peaks at this same time, when temperature and soil moisture are suitable for seed germination (Zacharuk 1962b). Wireworms are attracted to the carbon dioxide produced by germinating seeds and growing plants (Doane et al. 1975). As they moult, they alternate between 1–2 weeks periods of heavy feeding and resting (Zacharuk 1962a).

Wireworms have preferred ranges of soil temperature and moisture. This varies with species, season, nutritional state or condition of the insect (e.g. preparing to moult), and availability of food (Campbell 1937, Zacharuk 1962b, Burrage 1963). It also determines where the wireworms are in the soil, when, and how active they are. For example, *S. a. destructor* (Prairie grain wireworm) wireworms are more willing to tolerate unsuitable soil conditions when food is present than when it is not (Zacharuk 1962b). But they also may have sudden changes in feeding activity, even under favourable soil conditions, perhaps because they are preparing to moult (Burrage 1963). Burrage (1963) sampled soil cores in fallow and spring wheat to 30 centimetres (12 inches) and found that more than 85% of *S. a. destructor* (Prairie grain wireworm) and *H. bicolor* larvae were within 15 centimetres (6 inches) of the soil surface during most of the growing season until mid- to late August. Small wireworms were found in the 15- to 30-centimetre (6- to 12-inch) depth indicating they do not tolerate harsh soil conditions (i.e. hot, dry). Milosavljević et al. (2017) found both large and small *Limonius californicus* (sugarbeet wireworm) at 70- to 105-centimetre (27- to 41-inch) soil depth in Washington state, with larger *L. californicus* (sugarbeet wireworm) being able to stay closer to the soil surface to feed continuously throughout the growing season. Feeding activity can stop when soil temperatures become too high or low or when soil moisture is too dry. Wireworms then move deeper to more favourable soil conditions. More surface level activity may resume again in the fall as temperatures drop. Laboratory experiments with mature larvae showed that *S. a. destructor* (Prairie grain wireworm) preferred higher soil temperatures (median 17°C (63°F), 50% of wireworms in 11–24°C (52–75°F)) than *H. bicolor* (median 14°C (57°F), 50% of larvae in 9–19°C (48–66°F)) (Zacharuk 1962b). But field collections showed that *S. a. destructor* (Prairie grain wireworm) temperature preference varied with fields in wheat versus summer fallow, time of the growing season and year (Zacharuk 1962b). In spring and fall, wireworms were fussier about temperature and moved away from soil 32°C (90°F) or warmer, while in summer, wireworms were active in soil up to 35°C (95°F). *S. a. destructor* (Prairie grain wireworm) tolerated higher soil temperature when food was available than when it was not.

Wireworm preferences also depended on soil moisture, with both *S. a. destructor* (Prairie grain wireworm) and *H. bicolor* avoiding overly dry soil. However, *S. a. destructor* (Prairie grain wireworm) has a lower soil moisture threshold (4–23%) than *H. bicolor* (14–23%) (Zacharuk 1962b). However, *S. a.*

destructor (Prairie grain wireworm) decreased feeding when soil moisture was greater than 20% (Zacharuk 1962b). *Limonius californicus* (sugarbeet wireworm) also avoids dry soil, and prefers 16% soil moisture and a temperature range of 13–28°C, depending on the time of year (Campbell 1937).

Not much is known about overwinter hibernation in Prairie wireworms, except that hibernating larvae of *S. a. destructor* (Prairie grain wireworm) around Saskatoon were found at depths of 1 to 46 centimetres (0.5 to 18 inches) (Zacharuk 1962a).

Pupal stage and overwintering adult

In the year when the appropriate size is reached, a mature resident larva will come near to the surface of the soil in mid-late July, usually 5–8 centimetres (2–3 inches) from the surface, and pupate (Zacharuk 1962a) (Figure 16). New *S. a. destructor* (Prairie grain wireworm) adults (click beetles) emerge from their pupal cases in August. Most remain dormant in the soil until spring when they seek mates to reproduce. Adult *A. mellillus* (flat wireworm) overwinter on the soil surface under litter (Jewett 1940). Adults will emerge in the spring to begin their reproductive activities.

Figure 16. A wireworm pupa in its soil chamber. Note the shedded “skin” from the larva. Photo: K. Shamash, AAFC-Lethbridge

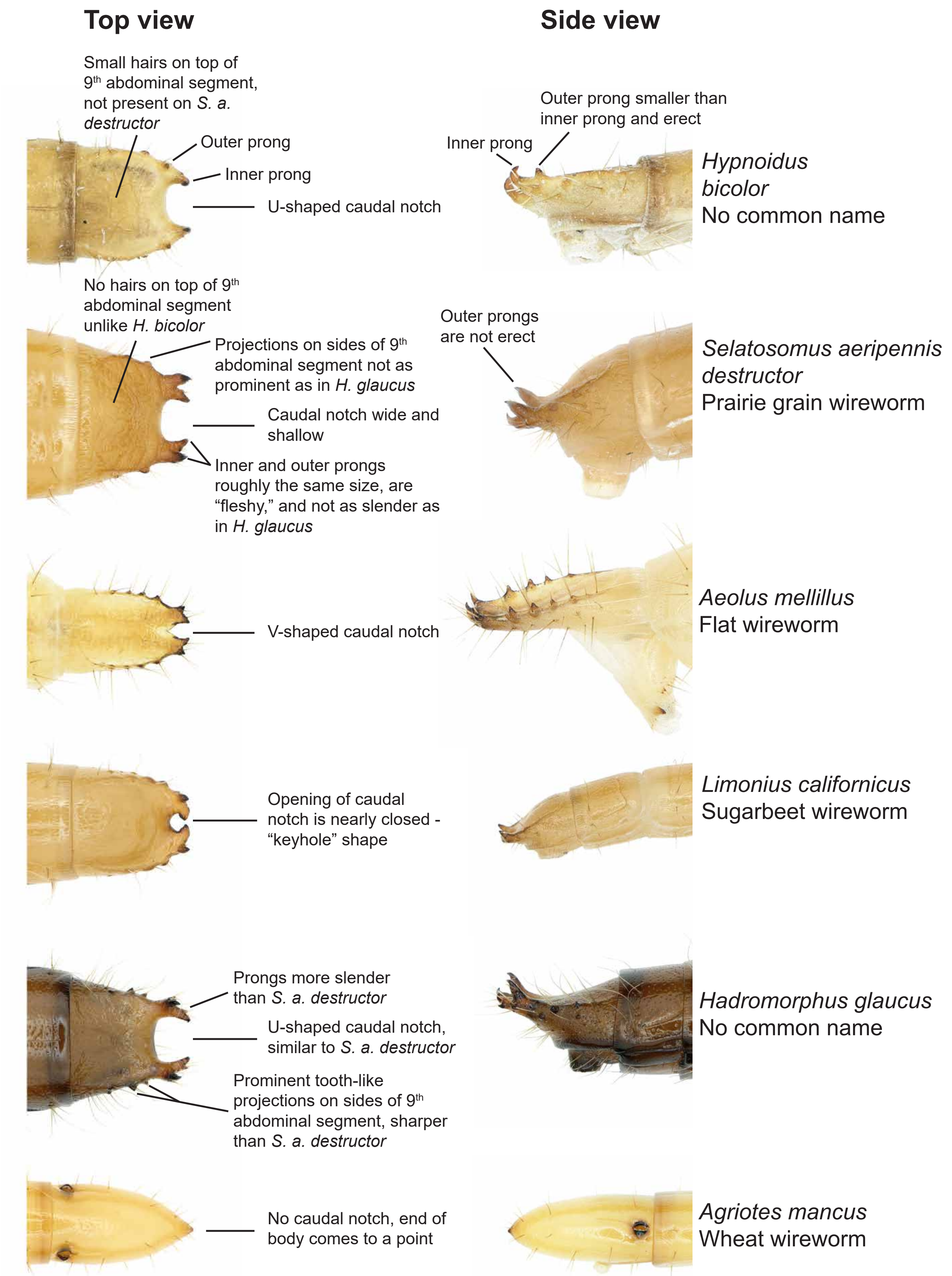

Figure 17. The 9th abdominal segments of main Prairie pest wireworms. Note differences in the shape of the notches and the 2 pairs of prongs surrounding the notch. Photos: J. Saguez, CÉROM

PROBLEMWIREWORMSPECIES ON THE PRAIRIES

The survey conducted by van Herk et al. (2021b) found four dominant wireworm species on the Prairies, all of which are native species: *H. bicolor*, *S. a. destructor* (Prairie grain wireworm), *L. californicus* (sugarbeet wireworm), *A. mellillus* (flat wireworm) (Figures 10, 11). Any field can have one, some or all of these species. Knowing what mix of species you have in your field is important for making management decisions (Strickland 1935, Glen et al. 1943), as these species differ in life cycle history, damage potential, insecticide susceptibility and soil temperature and moisture preferences (Vernon and van Herk 2013b).

There are at least 11 additional wireworm species reported as regional or minor pests on the Prairies (van Herk and Vernon 2014). Besides the four main species listed here in this guide (and *Agriotes mancus*, detailed in van Herk and Vernon (2014)), the biology most of other pest wireworms is generally unknown. We haved included *Agriotes mancus* (wheat wireworm) and *Hadromorphus glaucus* (no common name) here due to their regional importance in the literature (van Herk and Vernon 2014), and to show the variation in how wireworms can look (morphology).

Other wireworm species reported as lesser or regional pests on the Prairies include *Agriotes criddlei* (no common name), *Hypnoidus abbreviatus* (abbreviated wireworm), *Limonius canus* (Pacific Coast wireworm), *Limonius pectoralis* (no common name), and *Selatosomus aeripennis aeripennis* (Puget Sound wireworm) (van Herk and Vernon 2014).

The following section is a summary of the main species attributes of the four main pest wireworm species and two others (more detailed summary available in van Herk and Vernon 2014). The information for the larval and adult stages of the four main pest species is further summarized in Tables 2a and 2b.

Identifying the main problem wireworm species on the Prairies

It is important to note that the identification features described here are for preliminary species identification. To confirm your identification, send samples to your provincial entomologist (or the authors of this guide). They will run specimens through binomial keys of all known Prairie pest species, and consider subtle microscopic features such as small hairs and the shape of part of the head. Some identification may even require DNA analysis. Elateridae is a complicated group of insects, and species names are constantly changing as our understanding of their relations develop (Etzler et al. 2014, van Herk and Vernon 2014).

A key feature that distinguishes wireworm species in the larval stage is the ninth abdominal segment. This is the location of the “caudal notch” and its surrounding prongs. The notch and prongs differ in shape between the species (Figure 17) (see Tables 2a and 2b, pages 60–61 for summary comparisons of larvae and adults of the four main pest wireworm species).

Hypnoidus bicolor (no common name) – Major widespread pest

Area where reported as pests: Alberta, Saskatchewan, Manitoba (van Herk and Vernon 2014; van Herk et al. 2021b).

Wireworm (larval) stage: *Hypnoidus bicolor* is the most abundant pest wireworm on the Prairies (Figure 11). The pale-yellow mature wireworms are 10–12 millimeters (0.4–0.5 inches) long (Figure 18). Mature *H. bicolor* wireworm can look like early growth stages (instars) of *S. a. destructor* (Prairie grain wireworm). However, *H. bicolor* are distinguished by a U-shaped caudal notch, and the small erect outer pair of prongs on their ninth abdominal segment (Glen et al. 1943) (Figures 18b, 18e).

Beetle (adult) stage: Adults are small (4.5–6.0 millimetres / 0.18–0.24 inches) (Brooks 1960) and dark-coloured. From the top (dorsal) view, their pronotum (thorax covering) is black, but the antennae, hind angles, legs, and elytra (wing coverings) are brown with a reddish tinge. The beetles are covered in short fine hairs (Figure 18).

Life cycle: *Hypnoidus bicolor* is thought to have a 2- to 3-year larval period, but possibly longer under adverse conditions (King et al. 1933). *H. bicolor* larvae tend to be more active (King et al. 1933) and patchy in a field compared to *S. a. destructor* (Prairie grain wireworm) (Doane 1977a). The beetles (adults) generally become active later in the season, lay fewer eggs and live longer than *S. a. destructor* beetles (Prairie grain wireworm) (Doane 1977a). Beetles are found on the soil surface from late April to early August in Saskatchewan. In spring, beetles are often found crowding together in tight groups of up to 15 under stones, lumps of soil, or without any cover (Doane 1961, 1963c).

Reproduction: Both parthenogenetic (can reproduce without fertilization = clonal reproduction) and sexual forms exist in Canada. The parthenogenetic form is found with *S. a. aeripennis* (Puget Sound wireworm) in the northern and western (Aspen Parkland) parts of Saskatchewan; the sexual form found with the *S. a. destructor* (Prairie grain wireworm) (Zacharuk 1958a) to the south. Genetic differences between the two populations of *H. bicolor* are large enough that they would typically be considered separate species (Etzler et al. 2014) – more research is underway to determine whether this group is more than one species (Drahun et al. 2021).

Feeding/damage: Not as aggressive a feeder as *S. a. destructor* (Prairie grain wireworm, see below), attacked 1/10th as many seeds and made 1/20th the number of potato tunnels per larvae than *S. a. destructor* (Prairie grain wireworm) in previous studies (Zacharuk 1962b, Burrage 1963). *H. bicolor* does not respond as well to bait traps as *S. a. destructor* (Prairie grain wireworm) (Doane 1981), and surprisingly is more spatially aggregated (clumped) in mature larval stages than early stages (Doane 1977a).

Dispersion of beetles in spring: Female *H. bicolor* beetles disperse by walking as quickly as males. They fly readily, and their flight activity is not thought to be related to the number of eggs they are carrying (as is the case with the flat wireworm [*Aeolus mellillus*]), since flight begins soon (1–5 weeks) after emergence from the ground in spring (Doane 1963a, 1977a).

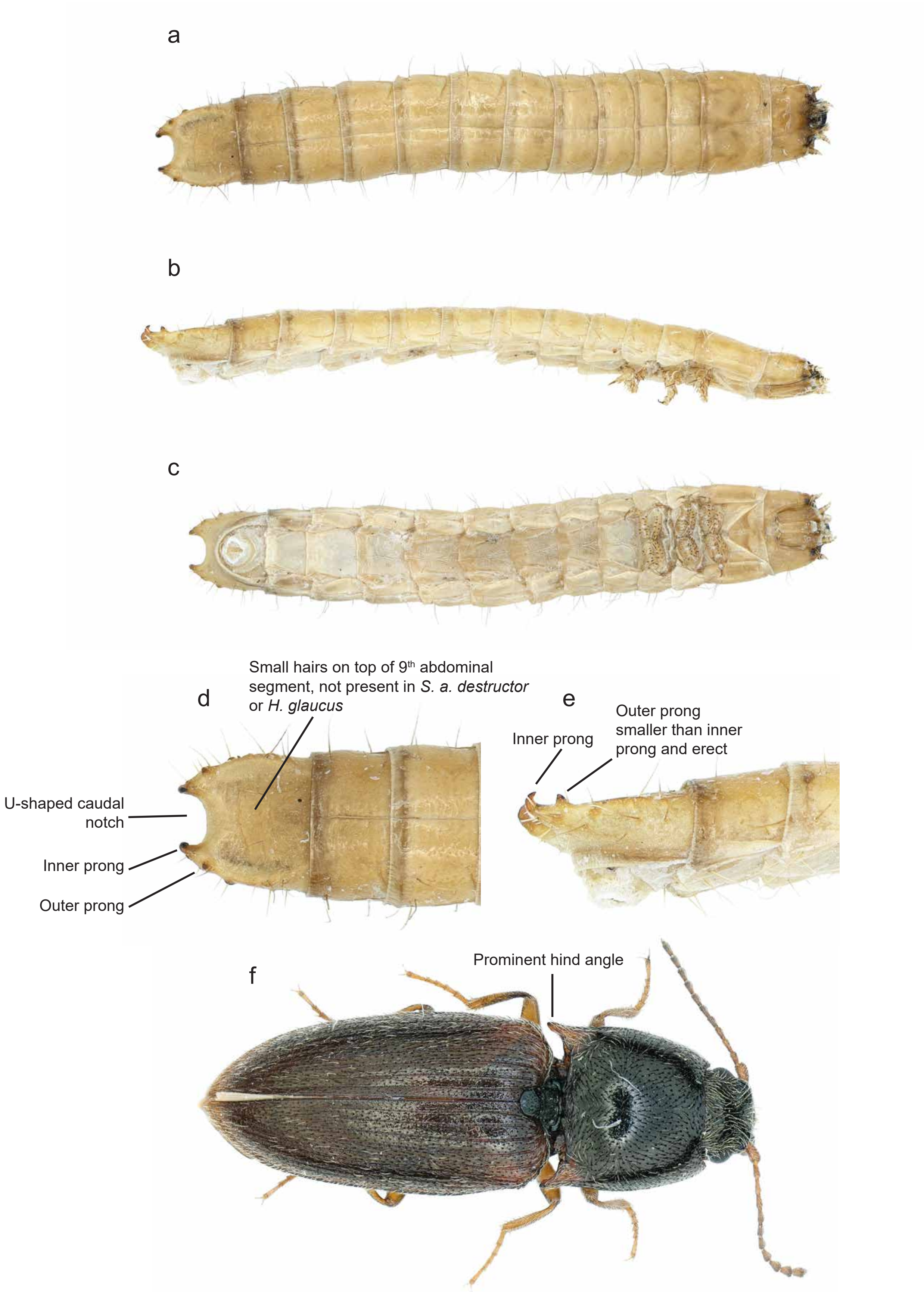

Figure 18. *Hypnoidus bicolor*. a) larva - top view b) larva - side view; c) larva - bottom view; d) larva - caudal notch, top view; e) larva - caudal notch, side view; f) adult. Photos: J. Saguez, CÉROM

Selatosomus aeripennis destructor (Prairie grain wireworm) – Major widespread pest

Area where reported as pests: Alberta, Saskatchewan, Manitoba (van Herk and Vernon 2014; van Herk et al. 2021b).

Wireworm (larval) stage: *Selatosomus aeripennis destructor* are the largest wireworms of the Prairie pest wireworms, reaching up to 23 millimetres (0.9 inch) long at larval maturity and having quite a stout build (Figure 19). The wireworms are shiny, hard-bodied, and a yellowish-orange colour (Figure 19). They are distinguished from similar looking species by their ninth abdominal segment; the caudal notch is wide and shallow with stout, 'fleshy' urogomphal prongs. The outer urogomphal prongs are not erect as they are in *H. bicolor*.

Beetle (adult) stage: Adults are black, sometimes with a blueish-greenish metallic sheen, hairless, and have distinct hind angles. The beetles have a robust body shape, and are 8–13 millimetres (0.3–0.5 inches) long (Brooks 1960), with females on the larger size (females 10.8–13.3 millimetres (0.4–0.5 inches), males 7.8–11.5 millimetres (0.3–0.4 inches), Strickland 1927) (Figure 19).

Life cycle: *S. a. destructor* (Prairie grain wireworm) wireworms normally pass through 9–11 instars (growth stages) in 3–4 years in the soil. However, development can last much longer, up to 11 years (Strickland 1939, 1942). Also, (1) wireworm growth rate is highly variable (some wireworms are twice the size of others of the same age after two years of growth; Strickland 1927), (2) wireworms can moult regressively (become smaller; Zacharuk 1962a), and (3) late instar larvae can delay pupation by a year or more (King et al. 1933). Consequently, head capsule width, body length or other measurements cannot be used to reliably identify wireworm developmental stages (Doane 1977a). Wireworms that have reached the appropriate size, or have reached some other internal trigger, will move to the top 10 centimetres (4 inches) of the soil surface in late July and August and pupate (transform to adult beetles) (Zacharuk 1962a; Doane 1977a). Those new beetles will remain dormant in the soil until the following spring.

Reproduction: Beetles emerge from dormancy in late April and May, when the soil temperature reaches 10°C (Strickland 1935, 1939; Zacharuk 1962a). Males immediately try to locate a mate after emergence. Neither sex mates more than once. Males die 1–3 weeks after mating while females remain in soil cracks until they began to lay eggs (oviposition) (Zacharuk 1958b, 1962a; Doane 1977a). Egg-laying begins 1–2 weeks after mating, generally in mid-May to mid-June and can last up to three weeks or even until late July (Zacharuk 1962a; Doane 1977a). Female activity increases after most of their eggs are laid (Doane 1961). Eggs, probably well over 200 per female (though estimates vary, see Zacharuk 1962a; Strickland 1927; Doane 1963b), are likely laid near where they emerge from dormancy as flight is rarely observed (Doane 1963a, Zacharuk 1962a, Strickland 1935). Eggs are laid in batches of a few to several hundred, usually under soil lumps or other places where there is sufficient soil moisture, sometimes up to 15 centimetres (6 inches) deep (Doane 1967, 1977a). Soil moisture is extremely important for egg survival, as eggs need to absorb water from the soil after being laid (Doane 1966, 1977a). Eggs hatch after 3–4 weeks.

Feeding/damage: Feeding behaviour may provide an indication of developmental stage: early instar wireworms feed on root hairs and fungal mycelia while older instars attack seeds (Zacharuk 1962a), culminating in the last instar pupating in late July and August. This species shreds plants (Eidt 1959), and can attack 10 times as many seeds or make up to 20 times more potato tunnels per larvae than *Hypnoidus bicolor* (Zacharuk 1962b, Burrage 1963).

Related subspecies: See *Two subspecies / One look: Selatosomus aeripennis destructor vs. S. a. aeripennis,* page 9.

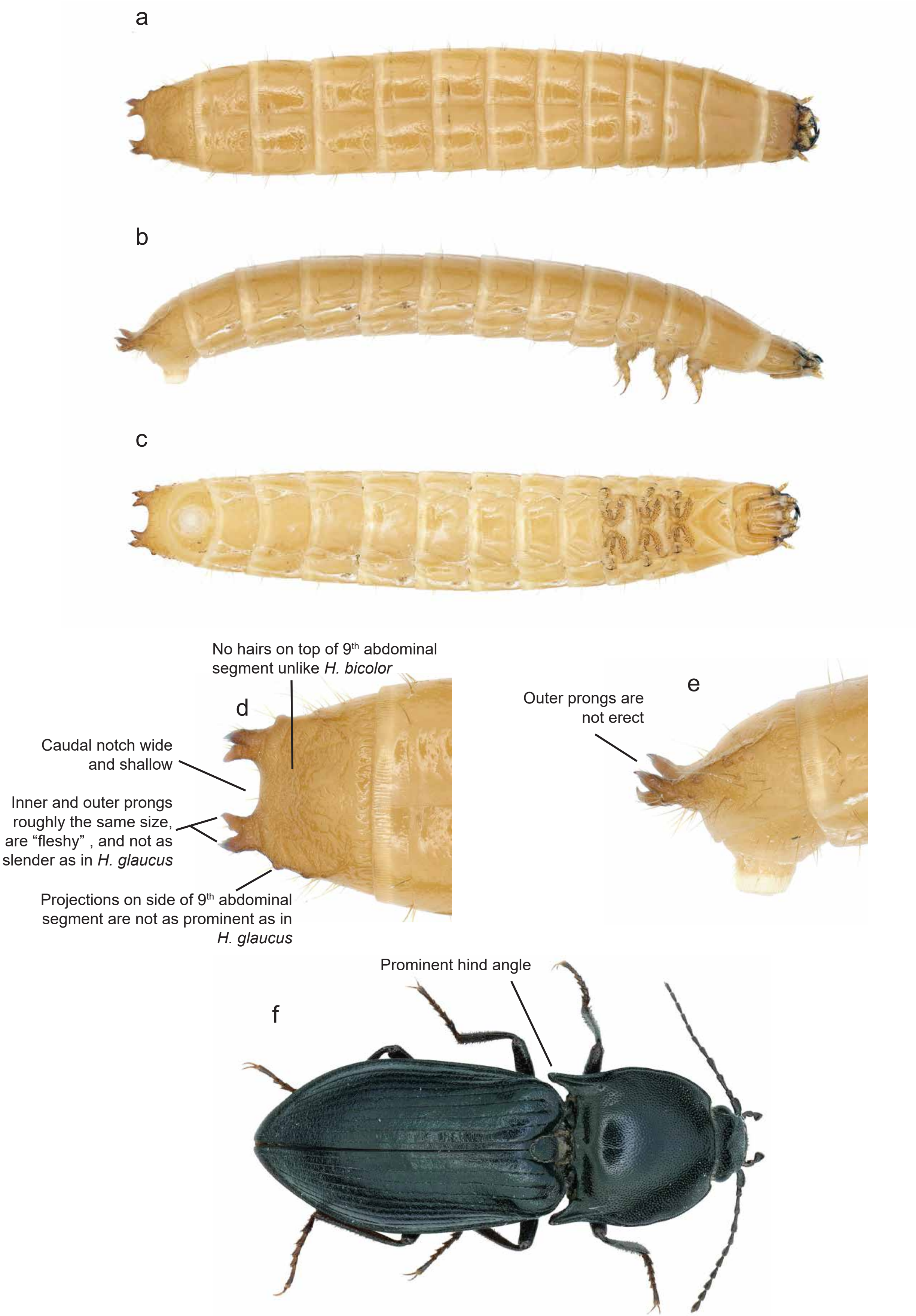

Figure 19. *Selatosomus aeripennis destructor* a) larva - top view; b) larva - side view; c) larva - bottom view; d) larva - caudal notch, top view; e) larva - caudal notch, side view; f) adult. Photos: J. Saguez, CÉROM

Limonius californicus (sugarbeet wireworm) – Lesser or regional pest

Area where reported as pests: southern Alberta, Saskatchewan, Manitoba (van Herk and Vernon 2014). Found mostly on irrigated land (Brooks 1960).

Wireworm (larval) stage: Wireworms (larvae) of this species are yellow, hard-bodied and, interestingly, have no eyes (Lanchester 1946). At maturity, they are 17–22 millimetres (0.7–0.9 inches) long (Glen et al. 1943). Different from the other main pest wireworm species, the caudal notch of *L. californicus* (sugarbeet wireworm) is nearly closed, like a keyhole shape (Figure 20). The urogomphal prongs are much smaller than those of *H. bicolor* and *S. a. destructor* (Prairie grain wireworm).

Beetle (adult) stage: The slender adult beetles are 8.5–11 millimetres (0.3–0.4 inches) long and have very short hind angles. Their pronotum (thorax cover) is black and their elytra (wing covers) are reddish brown. Both are covered in dense white or yellow hair. (Figure 20).

Life cycle: The biology of *L. californicus* (sugarbeet wireworm) in the Prairies is not well known, and what is presented here is based on studies done in California by Stone (1941). *L. californicus* (sugarbeet wireworm) wireworms pass through 10–13 instars and, in California, complete development in 2–3 years (Stone 1941). It is likely that development lasts longer (probably 3–4 years) on the Prairies due to colder climate. In Stone's (1941) studies, pupation occurred in summer and fall, 17–30 centimetres (7–12 inches) below the soil surface, and lasted approximately 21 days. The new adults overwinter in the soil and emerge in the spring. Females become active several days after males, and mate soon after.

Reproduction: Males can apparently mate more than once, dying approximately one month after mating. As with other species, the adult life span can last longer under cold conditions (Stone 1941). In southern Alberta, adult males are active in May, starting when mean daily temperatures are still low (4°C / 39°F) (van Herk et al., unpublished data).

Females begin laying eggs (oviposition) approximately one week after mating and are largely finished after one week, but, depending on temperature, can continue up to nine weeks. Females produce an average of 250 or more eggs, and die after completing egg laying. Eggs are laid in soil with 10–20% soil moisture, generally in cracks in the soil surface, but female beetles will burrow 10 centimetres or more to find suitable soil moisture to lay in. Egg laying in fields does not appear to be affected by the type of vegetation present. Eggs hatch on average 30 days after they are laid (Stone 1941).

Feeding/damage: A study in Washington state and Idaho found that *L. californicus* (sugarbeet wireworm) wireworm feeding, especially by small wireworms, is aggressive from May to August (Milosavljević et al. 2017). This was different than the close relative *Limonius infuscatus* (western field wireworm), for which feeding activity dropped off as the summer went on.

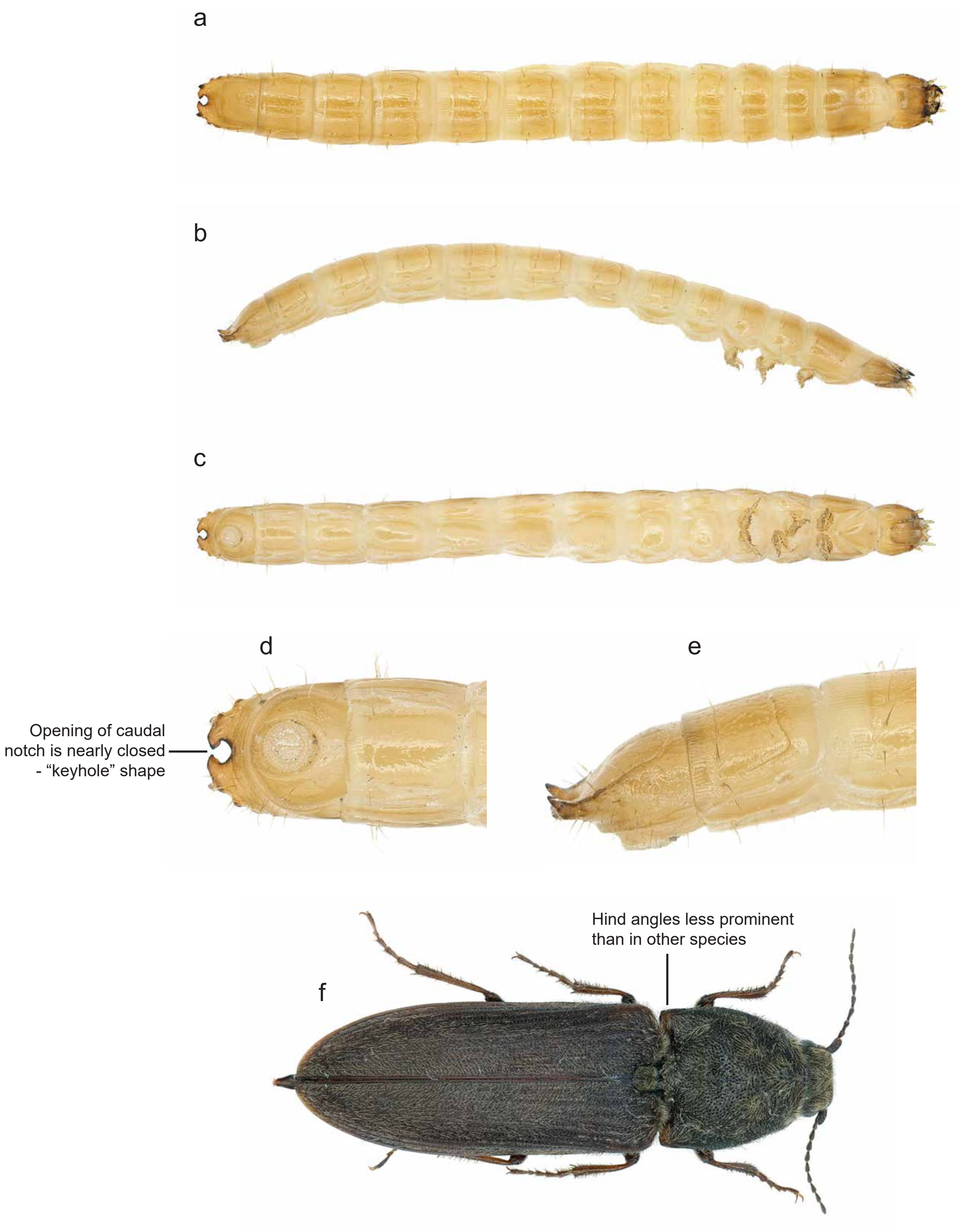

Figure 20. *Limonius californicus*. a) larva - top view; b) larva - side view; c) larva - bottom view; d) larva - caudal notch, top view; e) larva - caudal notch, side view; f) adult. Photos: J. Saguez, CÉROM

Aeolus mellillus (flat wireworm) – Lesser or regional pest

Area where reported as pests: southern Alberta, Saskatchewan, Manitoba (van Herk and Vernon 2014; van Herk et al. 2021b).

Wireworm (larval) stage: *Aeolus mellillus* (flat wireworm) is distinguishable from other pest wireworm species by its brown or reddish-brown head and prothorax (portion of thorax closest to head, bearing the first pair of legs), while the rest of its body is a pale yellow and soft (Glen et al. 1943) (Figure 21). Wireworms are 15 millimetres (0.6 inches) long or less, and flattened, especially the ninth abdominal segment. The caudal notch is V-shaped, and urogomphal prongs are reduced. These wireworms are quite active and crawl so quickly that it can be difficult to keep them in the palm or your hand.

Beetle (adult) stage: Beetles are small, 5.5–8 millimetres (0.2–0.3 inches) long (Brooks 1960) and are reddish-yellow with dark brown spots on the pronotum (thorax cover) and elytra (wing covers), giving a mottled appearance. The beetles have long sharp hind angles and very short fine, hair (Figure 21).

Life cycle: *Aeolus mellillus* (flat wireworm) is thought to have up to one generation per year in Canada, and can overwinter in both adult (beetle) and larval (wireworm) forms (Stirrett 1936, Jewett 1942). Beetles become active in late May, reaching peak activity between mid-June and mid-July (Doane 1977b).

Reproduction: Only a parthenogenetic (all female) form of *A. mellillus* is known in Canada (Glen et al. 1943). This means that monitoring and management approaches based on female sex pheromones are not possible. Females appear to lay on average 18–51 eggs (Jewett 1940, 1942), which is far fewer than other wireworm species.

Dispersion: Dispersal is primarily by walking, but females will fly later in the season (Doane 1977b).

Feeding/damage: *A. mellillus* (flat wireworm) wireworms are more active than most wireworms and can be predacious (Glen et al. 1943). This tendency may help reduce populations of the other pest wireworm species (Doane 1977b). However, *A. mellillus* wireworms also feed on plants: they attack cereal stems at the soil surface and cut them off completely. This is in contrast to other wireworm species that bore into or shred cereal stems (Glen et al. 1943).

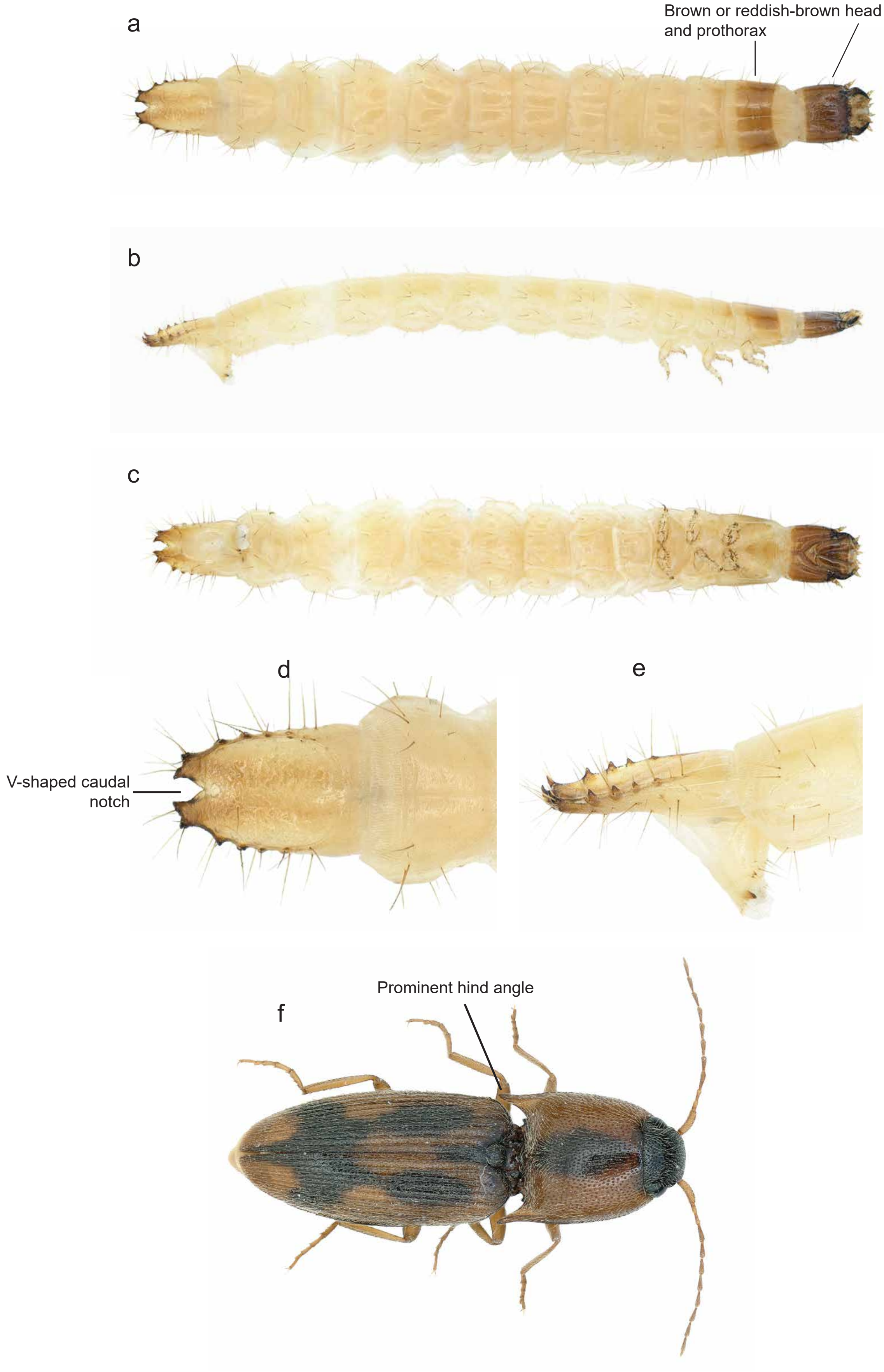

Figure 21. *Aeolus mellillus*. a) larva - top view; b) larva - side view; c) larva - bottom view; d) larva - caudal notch, top view; e) larva - caudal notch, side view; f) adult. Photos: J. Saguez, CÉROM

Hadromorphus glaucus (no common name)

Area where reported as pests: southern Alberta (van Herk and Vernon 2014).

Wireworm (larval) stage: *H. glaucus* wireworms can get quite large (18.5 millimetres / 0.7 inches) (Glen et al. 1943) (Figure 22). They are hard-bodied and stout in shape. Like *S. a. destructor* (Prairie grain wireworm), it has a wide caudal notch, but the notch is typically deeper, as the urogomphi are slender and long. Unlike the other Prairie pest species with wide caudal notches, *H. glaucus* has tooth-like projections on the side of its ninth abdominal segment. The *H. glaucus* wireworm photographed for this guide became brownish in colour after preservation, but it was more yellowish when it was first collected from the field (Figure 22).

Beetle (adult) stage: Adult *H. glaucus* are 7-9 millimetres (0.3-0.4 inches) long (Brooks 1960), black but with dense white hair, and distinct hind angles (Figures 22).

Life cycle: Unknown.

Reproduction: Unknown.

Dispersion: Unknown.

Feeding/damage: Interestingly, Brooks (1960) reported that adult *H. glaucus* are leaf-feeders and were observed causing “considerable” damage to beans and alfalfa.

NOTE: The wireworm pictured to the right turned brown during preservation. Live specimens are yellow, similar to other species.

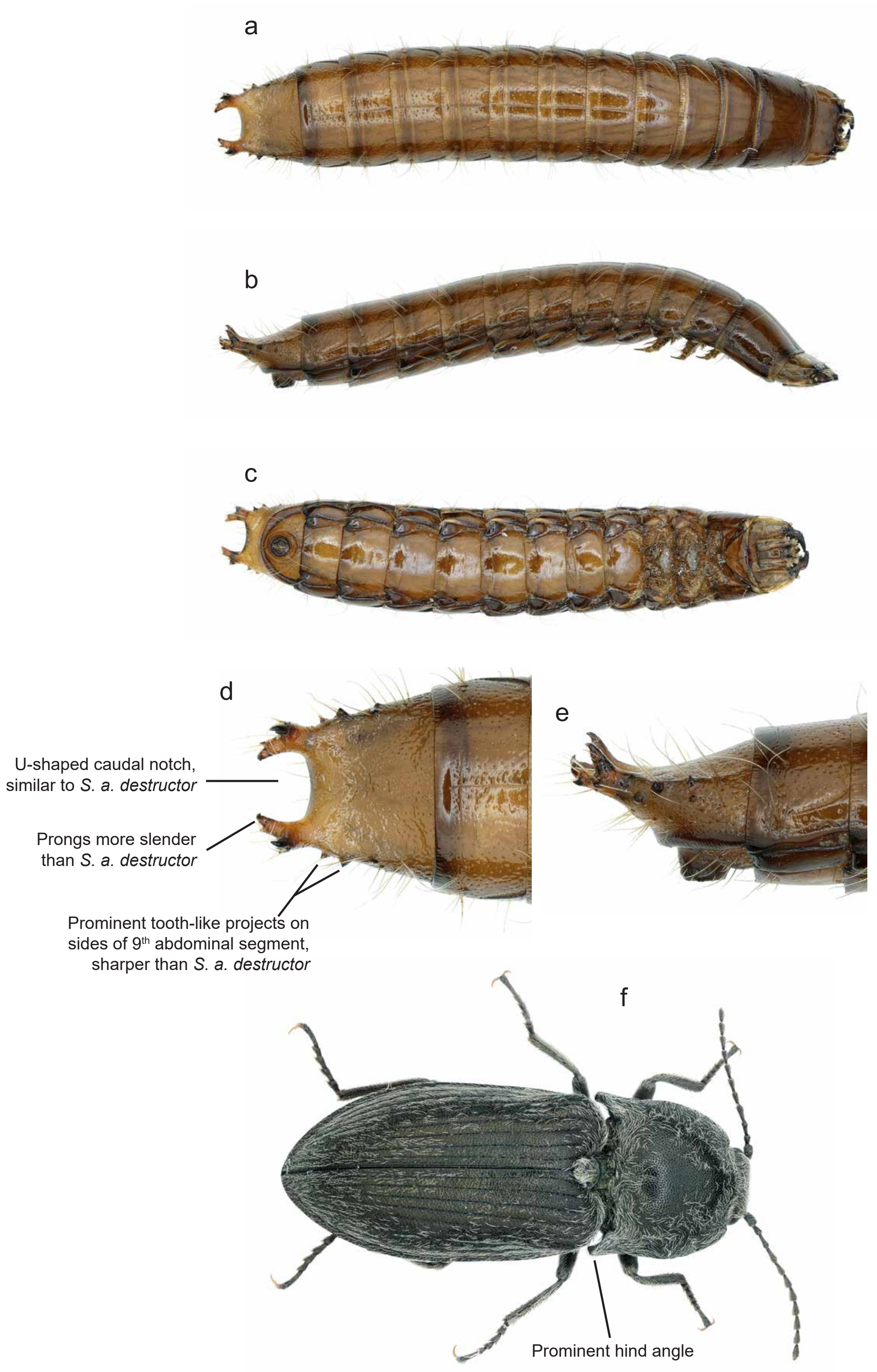

Figure 22. *Hadromorphus glaucus*. a) larva - top view; b) larva - side view; c) larva - bottom view; d) larva - caudal notch, top view; e) larva - caudal notch, side view; f) adult. Photos: J. Saguez, CÉROM

Agriotes mancus (wheat wireworm)

Area where reported as pests: southeastern Saskatchewan, Manitoba, Ontario, Quebec, and northeastern USA, mostly in moist soils (van Herk and Vernon 2014, Saguez et al. 2017).

Wireworm (larval) stage: The life history of this species is similar to that of the invasive European *Agriotes* species which have been better studied in Canada (but not found on the Prairies): *A. obscurus*, *A. lineatus*, and *A. sputator.* First-year larvae are susceptible to starvation, but those in their second and third years could remain alive without a food source (i.e. living plants) for at least two years, during which time little change in larval size may occurs (Rawlins 1940). Larvae grow up to 22 millimetres (0.9 inches) long before pupating. Unlike the other species described, the tip of the abdomen does not have a caudal notch nor prongs. Instead, it comes to a rounded point. On the sides of the last segment are two large dark "eye-spots" which are characteristic of this group of species (Figure 23).

Beetle (adult) stage: Beetles are 6.5–8.5 millimetres (0.26–0.33 inches) long, and generally brown (sometimes reddish-brown) in color, with gold colored hairs (pubescence) (Brooks 1960) (Figure 23).

Life cycle: Neonate larvae grow to approximately 6 millimetres (0.2 inches) long in their first year (Quebec) and remain in the top 15 centimetres (6 inches) of soil until the soil dries out in mid-summer, then retreating to lower, moister soil. Larvae migrate back near the soil surface in September to feed, and move down again when the soil began to freeze (Rawlins 1940; Lafrance 1967). In their second year, during which most growth occurred, larvae moult twice, once in May-June and again in August-September. Most larvae pupate in mid-July (Quebec) in their third year, but some larvae require an additional one to two years of growth (Rawlins 1940; Lafrance 1967). After pupation, adult beetles overwinter in their pupal cells 2.5–17 centimetres (1–7 inches) deep (southwestern Quebec), emerging in early May when soil temperatures reach around 10°C (50°F) (Lafrance 1967).

Reproduction: Beetles mate soon after emergence, provided the air temperature is between 14–27°C (57–81°F). Eggs are laid from mid-June to mid-July (Quebec) (Lafrance 1967). Females can lay up 194 eggs in the top few centimetres of soil (Lafrance 1967), either singly or in groups (Rawlins 1940). Eggs hatch after three to four weeks.

Dispersion: Dispersal is primarily by walking, but both sexes will fly on warm days (Rawlins 1940, Lafrance 1967).

Feeding/damage: Larvae can cause serious injury to cereals, corn, potato, strawberry, and field-grown vegetables through tunnelling (Rawlins 1940, van Herk and Vernon 2014).

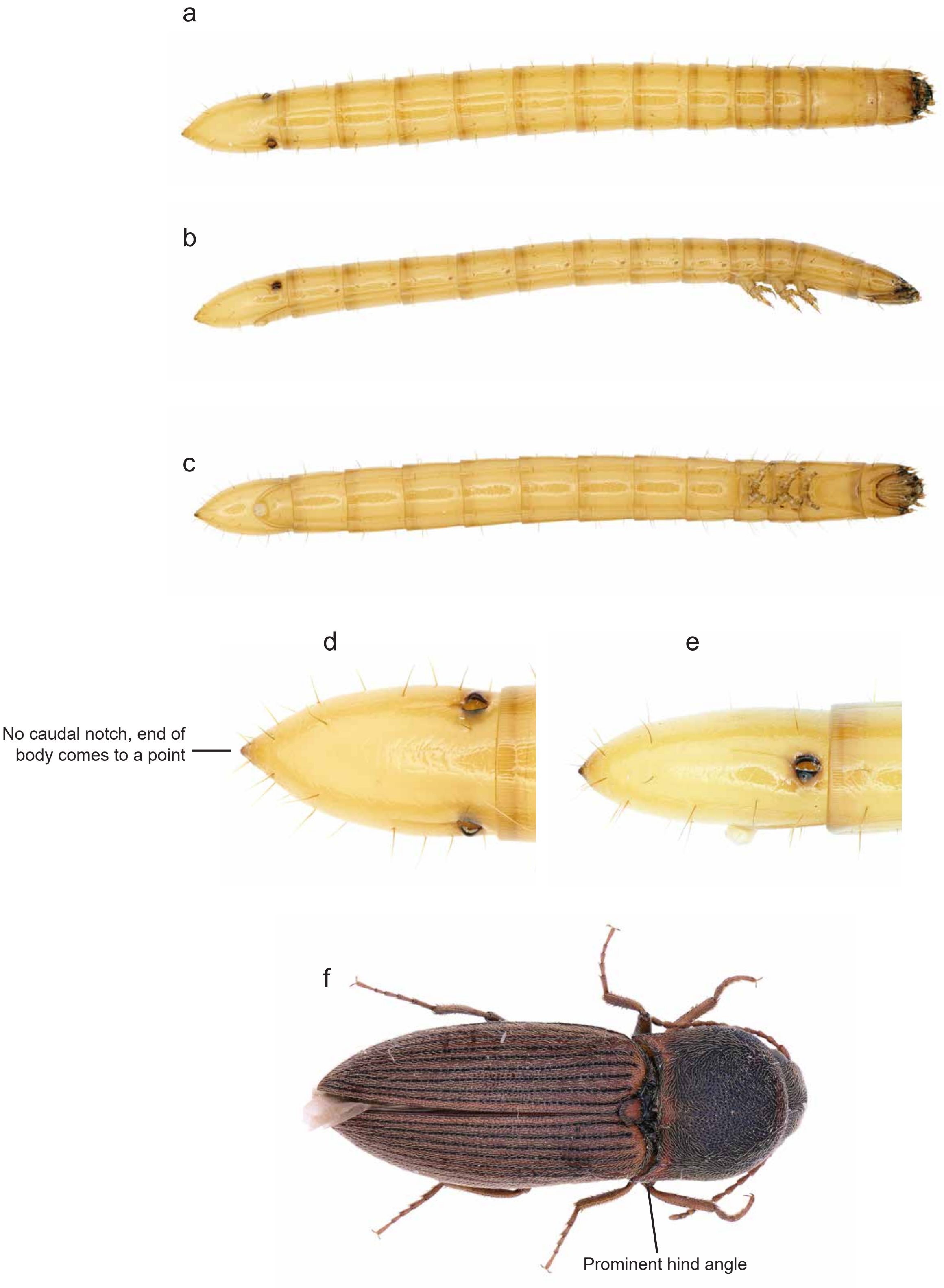

Figure 23. *Agriotes mancus*. a) larva - top view; b) larva - side view; c) larva - bottom view; d) larva - caudal notch, top view; e) larva - caudal notch, side view; f) adult. Photos: J. Saguez, CÉROM

Figure 24. When crop thinning is seen, post-emergence scouting by digging up plants and soil can reveal if wireworms are there (top). A wireworm found around roots of yellowed spring wheat seedling (bottom). Photos: H. Catton, AAFC-Lethbridge

Monitoring

Monitoring is an important component in any pest management program. The purpose of monitoring is to correctly identify which pests are present, track population numbers, and connect the pest directly to the observed crop damage. An error at the monitoring stage could lead to the incorrect management attempts, which wastes time and money, and does not help solve the problem. [Note: With multiple pests, you may observe different kinds of damage.] As an example, treating a cutworm infestation will be different than treating a wireworm infestation (in-season rescue options are available for some cutworm species; no such option exists for wireworms); and even within a pest group like cutworms, effective treatment will depend on correct species identification.

Wireworm damage can appear similar to other damage such as from cutworm, herbicide or frost. Therefore, as a first step, pay attention to patches of dead or weak plants, especially during early crop establishment (May to early June). Dig up live plants around the edges of the patch to catch wireworms in the act of feeding or nearby in the soil (Figure 24).

Wireworm trapping

Unfortunately, there is no easy method to reliably assess the extent of wireworm problems. Because the larvae are in the soil and have patchy distributions, sampling requires effort. Importantly, finding wireworms in a field does not necessarily mean there are enough wireworms to cause economic damage. They may be there in low levels, causing only minor damage. Or, they may be causing moderate or severe damage, requiring control. However, economic thresholds are not yet available for wireworms, leaving producers to make their best guess if management is needed. More research is needed in the area of monitoring and economic thresholds. We describe monitoring options below and the pros and cons of each.

Bait trapping for wireworms

Numerous approaches have been described for monitoring wireworm species and numbers, nearly all of them focussed on collecting wireworms in traps. But without a robust trapping strategy, you may fail to collect any wireworms in your traps, even in severely infested fields. There are three main factors you should take into account when developing a trapping strategy: (1) competition for attracting wireworms in the soil (carbon dioxide), (2) time of year (proximity to soil surface) and (3) wireworm population distribution.

Competition for attracting wireworms: All effective trapping methods are based on the same principle – a wireworm's ability to detect and move toward carbon dioxide-producing sources in the soil. According to AAFC's Todd Kabaluk in a recent factsheet, a good bait trap for monitoring wireworms is 'any point source of [carbon dioxide] that can be easily inspected for wireworms or evidence of their presence' (Kabaluk 2017). However, since wireworms are attracted to all carbon dioxide sources in soil, it is important to place the bait trap when other competing food sources (decaying organic matter, respiring plant roots, germinating seeds, etc.) are not present. For example, a bait trap placed in pasture or in germinating crop will likely be less effective (if at all) than the same trap placed in a summer fallowed field without competing vegetation or decaying plant matter within a 0.5-metre (20-inch) radius (discussed in Vernon and van Herk 2013b).

Bait trap tip 1:

Place bait trap at least 50 centimetres (20 inches) away from competing vegetation or plant matter (e.g. before seeding, or in a summer fallowed field)

Time of year: Wireworms move up and down through the soil profile throughout the year (King et al. 1933) depending on soil temperature, soil moisture content, and their need to feed. In general, they have two main periods of activity when they are feeding near the soil surface. Trapping outside of these periods may result in not detecting wireworms, even in severely infested fields. The first period, in spring, typically begins when the soil temperature warms to approximately 10°C (50°F), and appears to peak around mid-June for both *S. a. destructor* (Prairie grain wireworm) and *H. bicolor* (Doane 1981, Burrage 1963). The second period is harder to predict, but often occurs in early to mid-August. However, this timing depends on the age of the larvae and may vary among species. Hence Doane (1981) recommended two consecutive trapping periods, each of two weeks' duration [see Vernon and van Herk (2013b) for more on this].

Bait trap tip 2:

In spring, have two consecutive 2-week trapping periods starting when soil temperatures reach 10°C (50°F).

Population distribution: Wireworm populations tend to have a very patchy distribution across the field. This means you should place multiple traps per field. The recommended number of traps per field varies with field size, but we suggest a minimum of 20 traps for fields between 4 and 10 hectares (10–25 acres) to get a reasonable estimate of wireworm risk. For large fields (e.g. a quarter section) you may wish to begin with 20–40 traps if concerned about wireworm, but care should be taken that these are placed so as to represent the whole field.

Bait trap tip 3:

Place a minimum of 20 bait traps in fields 4–10 hectares (10–25 acres) in size. For larger fields (e.g. quarter section), start with 20–40.

Types of bait traps

A number of different kinds of wireworm bait traps have been developed: potato and other vegetables (e.g. Kabaluk 2017); rolled oats, flour and bran; and germinating cereal seeds (Vernon and van Herk 2013b). [See Box C, pages 40–44 for instructions on how to make these traps.]

A recent method used by Syngenta (Syngenta 2018) uses bait balls made of oatmeal or wheat flour mixed with honey and water (Figure 25). The bait ball is placed 10–15 centimetres (4–6 inches) deep in the ground either directly (i.e. without any covering) or in a mesh bag/ cheesecloth for easier retrieval. It is then dug up 10–14 days later to count the number of wireworms inhabiting it. Esser (2012) describes a similar approach, but uses a 1:1 whole seed wheat:corn mixture. The mixture is put in a nylon stocking and soaked in water for 24 hours before putting in the ground (see detailed photos in Esser 2012).

Figure 25. Oatmeal, flour and honey baitball wrapped in cheesecloth. Photo: David Shack, AAFC-Lethbridge

However, Vernon and van Herk (2013b) point out that methods such as above are likely to be inconsistent as baits will vary in how much carbon dioxide they produce, leading to increased variability in wireworm counts. Furthermore, decomposing oatmeal can cause wireworms to be attracted to soil around the bait, but not reach the bait itself. Doane (1981) found more wireworms in the surrounding 4.25 centimetres (1.7 inches) of soil around the oatmeal bait traps than around enclosed germinating seed bait traps. He suggested this effect was likely because the wireworms were feeding on fungus growing around the decomposing oatmeal.

Vernon and van Herk developed a standardized, easy to use, baiting method that ensures consistency and allows comparisons of wireworm catch between fields and years (Vernon et al. 2009, 2013a). Their method uses a 10-centimetre (4-inch) diameter plastic plant pot filled with medium grade vermiculite with a 100-millilitre (just less than ½ cup) layer of untreated hard red spring wheat in the middle (Box C). The bait trap is soaked to runoff twice with lukewarm water immediately before being buried in a 15-centimetre (6-inch) deep hole. The pot is covered by approximately 5–7 centimetres (2–3 inches) of soil. The buried bait trap is then covered with an upside-down 20-centimetre (8-inch) diameter plant pot saucer, sunk in the soil so its base is level with the ground. The bait trap is left in the ground for 14 days before being dug up. Researchers place the pot contents in a Tullgren funnel to extract the wireworms (Box C, pages 40–44). They are identified to species, counted and measured. On the farm, the pot contents can be sorted by hand (directly in the pot saucer) and specimens picked out for counting and preservation. Samples can be identified by comparing them to species descriptions in this guide, magnification from a hand lens can be enough to spot the important features. However, for more certainty, samples can be sent to an entomologist for identification (Resources, page 65).

For further reading on wireworm monitoring methods, see Vernon and van Herk (2013b).

Adult click beetle trapping

Besides monitoring wireworm populations, trapping click beetles (adult form of wireworms) can be used to estimate risk of wireworm damage. The recently developed Vernon Pitfall Trap (VPT) (Figure 9) is an inexpensive and easy to use tool for monitoring beetle populations and predict future wireworm severity. While the traps are effective for capturing beetles passively, they become very highly effective monitoring tools when baited with the female beetle sex pheromone.

Pheromones are available for some click beetle species introduced to Canada from Europe (e.g. *Agriotes lineatus*, *A. obscurus*, *A. sputator*), and are in development for select Prairie species (e.g. *Limonius californicus*, Gries et al. 2021). For example, in British Columbia, pheromone-baited VPT traps can collect more than 100 male *A. obscurus* (dusky wireworm) or *A. lineatus* (lined click beetle) per day during peak swarming season, and in Prince Edward Island, they can collected more than 1000 male *A. sputator* (no common name) beetles per day (van Herk et al. 2018a). When deployed in spring, as beetles are emerging from the soil, these traps are the easiest ways to detect click beetle (wireworm) species compared to any of the above wireworm (larval) baiting methods.

While it is difficult to establish a direct connection between the number of beetles collected in a pheromone trap with the number of wireworms in the field (due in part to their patchy distributions, long life histories, and the effect of previous crops grown in rotation on wireworm populations), the relative number of beetles collected by such traps can be used to develop a field risk-rating system. This has been done in Canada for the three *Agriotes* species introduced from Europe (Vernon and van Herk, unpublished) and several other *Agriotes* species in Europe (Furlan et al. 2020b). This type of monitoring would require several years, as beetles in a current year represent damaging larval populations in the subsequent years (Furlan et al. 2020b). When sex pheromones for key Prairie pest species become available, it is hoped such a field risk-rating system can be developed for the Prairie provinces as well.

As with wireworm (larval) monitoring, however, low numbers of beetles caught in traps is not a reliable indication of low risk to the crops. Other factors that need to be considered when assessing risk include previous cropping history, past history of wireworm damage in the field, and proximity to areas known to have wireworm injury. For example, a field may be at higher risk if it has been planted to crops that favour wireworm survival and egg laying in previous years (e.g. cereals and grasses) than if it was planted to crops that require a lot of cultivation (e.g. potatoes) and/or if an effective insecticide (e.g. Thimet 20G, in potatoes) has been applied.

BOX C: Making a Vernon bait trap

Vernon bait traps, developed by Dr. Bob Vernon and modified from Chabert and Blot (1992), is a standardized way to bait for wireworms. The traps consist of a 10-centimetre (4-inch) plastic pot with 8 holes at the base (Figure C1) filled with a mixture of wheat seed and vermiculite [see Figure C2 for the final product and Figure C3 for detailed instructions]. The trap is soaked before placement in the soil (Figures C4–C7), and the germinating seeds produce carbon dioxide that attract wireworms. After 10–14 days, remove the trap (Figure C8). Researchers extract the wireworms using specialized extraction funnels (Figure C9), but on the farm, the samples can be hand sorted for wireworms.

Figure C1. Bait trap container: 10-centimeter plastic pot (left) with eight drainage holes (right). Photos: Ted Labun, Syngenta Canada Inc.

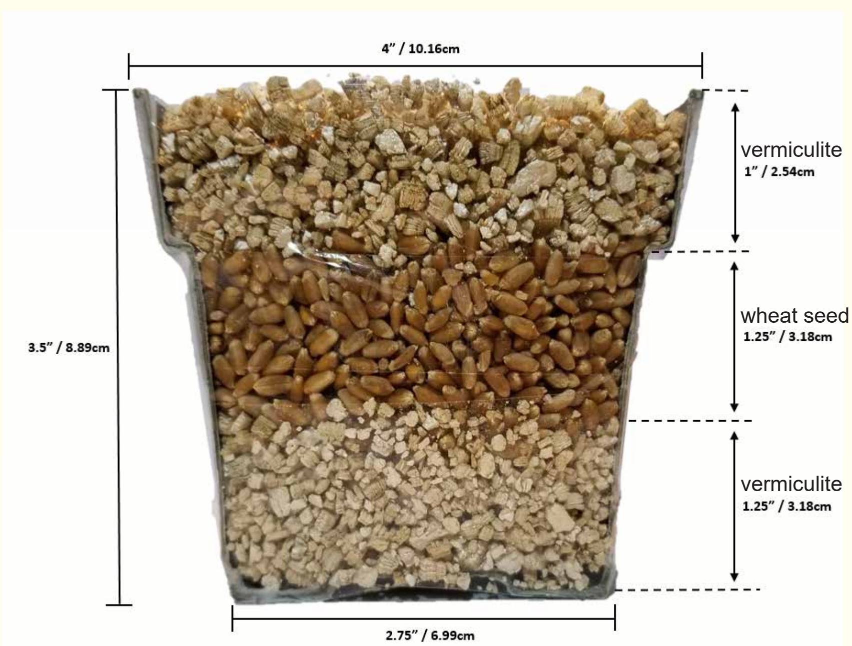

Figure C2. A side view of a completed Vernon bait trap. Photo: David Shack, AAFC-Lethbridge

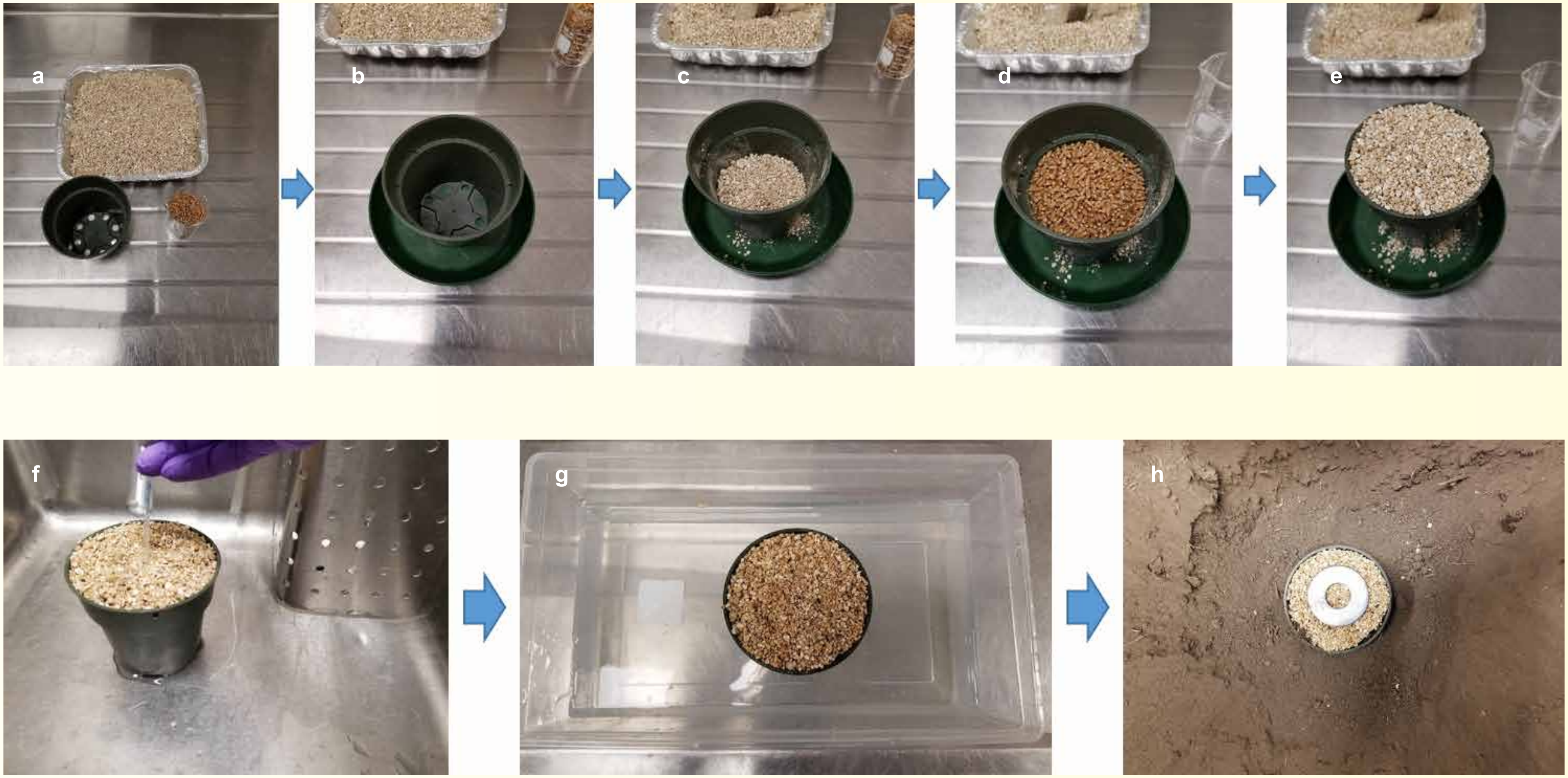

Figure C3. Assembling a Vernon bait trap: a) assemble materials - 10-centimetre (4-inch) pot, vermiculite, wheat seed; b) place pot in a tray (helps catch any spillage; c) fill first third of pot with vermiculite; d) fill next third with wheat seed; e) fill last third with vermiculite; f) saturate pot with water until water runs out of bottom of the pot - do this two times; g) place pot in a bin with several inches of water and allow pot to soak for 24 hours; h) dig a hole 5 to15 centimetres (2 to 6 inches) deeper than the height of your pot, place the baitball at the bottom of the hole, bury the pot. Important: ensure soil is snug around the trap so there are no air pockets. Optional: add metal washer if using a metal detector to find the trap again. Leave for 1-2 weeks. Photos and descriptions: David Shack, AAFC-Lethbridge

BOX C: Cont'd

Figure C4. Step 3: Digging the 15 cm deep hole for the trap. A coring tool (left) or a shovel works fine too. Disturb as little soil as possible and check depth (right) before placing trap. Photos: Ted Labun, Syngenta Canada Inc.

Figure C5. Step 4: The Vernon bait trap in the hole, with the top of the trap 5 cm below the soil surface. Photos: Ted Labun, Syngenta Canada Inc.

Figure C6. Step 5: The Vernon baitball trap and hole covered with soil. Ensure soil is compacted against the sides of the traps and there are no air pockets by wiggling the trowel around the flower pot. Photos: Ted Labun, Syngenta Canada Inc.

Figure C7. Step 6 [optional]: Cover the Vernon baitball trap and soil with a 20-centimetre (8-inch) plastic lid if possible, to keep soil moist and retain heat. Photos: Ted Labun, Syngenta Canada Inc.

BOX C: Cont'd

Figure C8. Step 7: Carefully removing the Vernon bait trap after 14 days (left). Note that seeds have germinated (centre). The contents of a bait trap ripped apart and ready for sorting (right). Photos: left, centre: Ted Labun, Syngenta Canada Inc.; right: Haley Catton, AAFC-Lethbridge

Figure C9. An example of the Tullgren funnels used by researchers to extract wireworms. Hot lights drive wireworms down the funnels into collection cups. Photo: Haley Catton, AAFC-Letbridge

Integrated pest management options

Integrated pest management (IPM) is a strategy that combines cultural, biological and, when necessary, chemical pest control methods. This strategy leads to the most sustainable control, but requires knowledge about the pest, monitoring methods, and, when available, economic thresholds (i.e. the point where the cost of control is equal to potential yield loss caused by a pest). [Note: AAFC's Guide to Field Crop and Forage Pests and their Natural Enemies in Western Canada (Philip et al. 2018) has a nice summary of IPM principles and methods.]

Different management methods target specific wireworm life stages, and provide within-season (fast) or long-term (usually slow) control. Resident wireworms are the stage most directly damaging to crops, and immediate within-season control means subduing these residents. However, since they live and move around in the soil, wireworms are difficult to target effectively. Over the longer term, the number of resident wireworms can be reduced by targeting other life stages. Possibilities include targeting egg-laying click beetles (killing adults, or reducing their egg-laying capacity) and reducing egg, neonate wireworm, and pupa survival. The reproductive stage is the only above-ground stage of the life cycle and makes the adult stage a good target for population reduction over the longer term [Table 3, page 62 for how management options impact the different life stages].

While we have a reasonably solid foundation of knowledge on the main pest wireworm life cycles on the Prairies, there are knowledge gaps about how they respond to different management options and for predicting wireworm damage based on monitoring results. In addition, there are no economic thresholds available for wireworm in Canada, and these are difficult to determine.

The following cultural, biological and chemical control options should to be considered in balance with other agronomic concerns and constraints in a farming system.

Cultural control

Cultural control involves manipulating the cropping environment to be unfavourable for pests. For wireworms, the goals of cultural control are to decrease egg laying by adult female click beetles or to reduce wireworm survival (Vernon and van Herk 2013b).

Crop rotation

In general, crop rotation is not a simple fix for wireworm like in crop-specific and short generation pests like wheat stem sawfly or orange blossom wheat midge. In theory, there are two ways that crop rotation could be helpful for reducing wireworm populations: 1) reducing the number of eggs laid in a field or 2) reducing wireworm survival.

In regards to reducing the number of eggs laid in a field, little is known about egg-laying preferences of Prairie click beetles in regards to common Prairie crops. However, it is likely that many female beetles lay their eggs in the same field where they emerge from hibernation, regardless of the crop planted, especially the less mobile species like *S. a. destructor* that do not fly readily (Doane 1963a).

In terms of impacts of rotation on wireworm survival, resident wireworms are quite resilient: they can eat a variety of crops and can take a year off feeding entirely if conditions are poor (Strickland 1935). In contrast, neonate (newly hatched) wireworms require suitable food to survive their first season. This is an important vulnerability in the wireworm life cycle. Strickland (1939) tested survival of *S. a. destructor* (Prairie grain wireworm) neonates on various crops and found highest survival on perennial grasses, intermediate survival in spring wheat and barley, and low or no survival on broadleaf crops and weeds. Perennial cultivated grasses provide more food in the shoulder seasons (spring and fall), which allowed young wireworms to grow quickly. There have also been some mixed research results. Strickland (1939) reported that neonate *S. a. destructor* (Prairie grain wireworm) survival was poor on alfalfa and flax, raising their potential as rotational crops for controlling wireworm populations. However, a subsequent study with *S. a. destructor* (Prairie grain wireworm) neonates found high survival on flax (Davis 1958), and studies with other wireworm species have shown alfalfa to not be effective in controlling wireworm populations (Thomas 1940, Noronha 2011). This variation in results is likely from the differences (e.g. geographic locations, wireworm species, soil conditions) among the studies conducted (Vernon and van Herk 2013b).

A few rotational crops apparently showing potential for wireworm control are buckwheat (*Fagopyrum esculentum*) and various mustards (yellow mustard, *Sinapis alba*; brown mustard, *Brassica juncea*). Recent research in Atlantic Canada with European wireworms (*Agriotes* spp.) showed reductions in wireworm damage to potatoes or carrots following brown mustard (MacKenzie et al. 2010, Noronha 2011) or buckwheat (Noronha 2011) compared to alfalfa or cereals (Figures 26, 27). Mustard and buckwheat may be inhospitable to wireworms due to the chemicals they produce. For example, mustards produce glucosinolates which break down into compounds that are toxic or repulsive to wireworms, including *L. californicus* (sugarbeet wireworm), a native Prairie species (Williams et al. 1993). However, toxic concentrations for this species may difficult to achieve in the field (Elberson et al. 1996). Buckwheat produces different chemicals (phenols and flavonoids) that may act to discourage wireworm feeding (Bohorquez Ruiz et al. 2019). Strickland (1939) reported zero survival of neonate *S. a. destructor* (Prairie grain wireworm) on buckwheat, but research is needed to determine if the crop has any effect on *S. a. destructor* and other Prairie wireworm populations in the field.

Another reason to rotate crops may be to grow something tolerant to wireworm feeding, rather than trying to control population numbers. Among cereals, oat is more tolerant than other cereals to wireworm feeding (King et al. 1933), and barley may be more tolerant to wireworm feeding than wheat (Rashed et al. 2017, Milosavljević et al. 2019).

Figure 26. Brown mustard has been an effective rotational crop before potatoes to reduce wireworm damage in PEI. Photo: C. Noronha, AAFC-Charlottetown

Figure 27. Buckwheat has been an effective rotational crop before potatoes to reduce wireworm damage in PEI. Photo: C. Noronha, AAFC-Charlottetown

Soil amendments

A more effective management strategy than growing glucosinolate-producing crops is perhaps incorporating a glucosinolate-rich soil amendment. In the presence of water, the glucosinolates are rapidly converted into volatile insecticidal compounds that serve as a biofumigant in the soil. Research in Italy showed that broadcasting defatted seed meal of a specialized line of *Brassica carinata* (carinata, Ethiopian mustard) controlled *Agriotes* spp. wireworms as effectively as chemical insecticides when applied under certain conditions (Furlan et al. 2010) (Figure 28):

- High enough glucosinolate concentration in the seed meal: 160 µmoles of glucosinolates per litre (quart) of soil, or 2.16 metric tonnes per hectare (0.96 US tons per acre) of defatted seed meal per hectare if incorporated 20 centimetres (8 inches) deep.
- Even broadcast of the seed meal.
- Immediate incorporation of the seed meal into the top 20 centimetres (8 inches) of the soil (to ensure biofumigants are released in the soil).
- Suitable soil temperature (10.5–16°C) and moisture (as close to field capacity as possible). Irrigation may be necessary.
- Wireworm presence near the soil surface at the time of incorporation (e.g. spring) to ensure directly exposure to the volatile biofumigants before they evaporate.

Figure 28. Trials in Italy incorporating de-fatted *Brassica carinata* seed meal into the soil have shown promise for reducing wireworm damage. Photo: L. Furlan, Veneto Agricoltura

While these requirements preclude its use in large-scale minimum till crop operations on the Prairies, this method could be useful in small-scale organic production systems (Vernon and van Herk 2013b).

Starvation

Early recommendations for wireworm control on the Canadian Prairies were to employ summer fallow every three years, keeping fields clean of weeds through shallow tillage (King et al. 1933, Glen and King 1938). This technique starved neonate wireworms, reducing the year's cohort of new wireworms. However, since resident larvae can go a one or more years without food, summer fallow in one year can even cause worse damage the following year from resident wireworms as they resume feeding with gusto (King 1928, Glen and King 1938, Burrage 1964). Recent research in Washington state demonstrated that *L. californicus* (sugarbeet wireworm) populations were lower in a summer fallow-winter wheat rotation compared to continuous spring wheat (Esser et al. 2015). However, summer fallow is no longer recommended on the Canadian Prairies due to moisture loss and soil erosion concerns.

Just as young wireworms can be killed by starvation, wireworm populations may benefit when food is provided continuously throughout the year (e.g. Strickland 1939, Furlan et al. 2009, Furlan et al. 2017), especially in the shoulder seasons of fall and winter. This food can be provided in the form of winter crops, cover crops, perennial crops or even weeds (Stone 1951, Furlan et al. 2017, Burrage 1964). For example, Stone (1951) found that winter cover cropping of barley, and sometimes sweet clover and mustard, increased *L. californicus* (sugarbeet wireworm) infestations compared to summer fallow in California (Stone 1951). He attributed this increase to the shelter the crops provided for adult beetles during the egg-laying period, while the effect of extra food for larvae is unknown. A 29-year survey in Italy found that corn fields that had forages or a double crop (two consecutive crops in a season) within the past two years had increased wireworm damage from *Agriotes* species (Furlan et al. 2017). The authors suggested the longer feeding season for wireworms in these fields helped boost survival of young larvae. Therefore, producers on the Prairies with heavy wireworm infestations should consider the possible effects of cover crops and winter crops on wireworm populations in balance with the agronomic benefits from using these practices.

Tillage

Many growers on the Prairies have adopted minimum- or zero-tillage in recent decades. When summer fallow was a common practice, shallow tillage (< 8 centimetre / < 3 inches) was used to kill weeds that would support wireworms (Glen and King 1938). However, deep tillage (12–15 centimetres / 4.75–6 inches) favours wireworms (King et al. 1933, Glen and King 1938). Tillage could make soil conditions more favourable for survival of eggs (see section on *Adult click beetles and eggs*, page 17). Female *S. a. destructor* (Prairie grain wireworm) beetles (adult) are not strong diggers but prefer to lay their eggs at a depth of 12–15 centimetres (4.75–6 inches) into moist soil. Tillage loosens the soil allowing them to reach better conditions to lay their eggs (Strickland 1927). Tillage is probably not very effective at harming larval wireworms as they are mobile in the soil and can move back into the soil after being disrupted by tillage. However, the pupal stage may be vulnerable to tillage, as they are fragile and immobile at this stage of their life. King et al. (1933) recommended shallow tillage during the last ten days of July to disrupt click beetle pupae. However, soil health degradation from erosion or moisture loss likely outweighs any beneficial effects of reducing wireworm populations using this method.

Resistant or tolerant crop varieties

This powerful method of cultural control is one of the most effective tools against insect pests (e.g. wheat midge, wheat stem sawfly). However, there are no varieties of any crop that are resistant to wireworm damage. It is known that genetic differences in tolerance to wireworm feeding do exist (Strickland 1931, Higginbotham et al. 2014), but breeding efforts have not focused on this trait. Strickland (1931) described field experiments in Alberta that showed that Garnet wheat suffered more than Marquis or Reward wheat from *S. a. destructor* (Prairie grain wireworm) wireworm feeding. More recently, Higginbotham et al. (2014) in Washington state, identified a group of genotypes tolerant to *Limonius infuscatus* (western field wireworm) and *L. californicus* (sugarbeet wireworm) feeding. Similar differences in wireworm susceptibility have been noted in potato cultivars in Europe, Asia, and USA (Langdon and Abney 2017, reviewed by Vernon and van Herk 2013b), but more research is needed to pursue developing tolerant cultivars. Unfortunately, while resistant cultivars may provide crop protection, they are not likely to reduce wireworm populations in a field given the pest's broad host range, long life spans and ability to tolerate starvation.

Trap crops

Trap cropping is an emerging method to reduce wireworm damage. This strategy is used to pull wireworms away from a valued target crop. Its efficacy depends on (1) the trap crop being more attractive than the target crop, and (2) syncing planting time with wireworm activity. Trap cropping can be used alone or combined with insecticide to create an "attract and kill" strategy. This strategy was used in British Columbia and Ontario, growing wheat as the trap crop in potatoes to manage non-Prairie wireworm species (*Agriotes obscurus* in British Columbia, *Melanotus* spp. in Ontario). It gave effective control with much lower amounts of insecticide than conventional in-furrow insecticide application (Vernon et al. 2016). Wheat has also been used with some promise as a trap crop for *A. obscurus* in strawberry production or in fallow fields in British Columbia (Vernon et al. 2000, Vernon 2005).

When the main crop is wheat, pulses may be effective trap crops. Recent research in

Montana demonstrated that intercropping spring wheat with pea or lentil trap crops protected the wheat from *L. californicus* (sugarbeet wireworm), *H. bicolor* and *A. mellillus* (flat wireworm) damage [note: these three wireworm species are found in Alberta] (Adhikari and Reddy 2017, Sharma et al. 2019) (Figure 29). Field experiments indicated that wheat seedlings were damaged less often when intercropped with pea and lentil seedlings, with the pulse trap crops attracting 2–3 times more wireworms than wheat seedlings (Adhikari and Reddy 2017). European research shows that pea may also have some potential as an inter-row trap crop in potatoes (Landl and Glauninger 2013).

Figure 29. A trap crop trial in Montana, with wheat as the cash crop and pea as the trap crop. Photo: A. Sharma, Montana State University.

While not a live trap crop, green manure can function in a similar way. Furlan et al. (2020a) found that incorporating fresh meadow (e.g. green manure or cover crop) into soil just before seeding corn protected the crop from damage. This effect was likely because wireworms were distracted from the seeds by feeding on the live grass remnants in the soil.

Seeding rates and timing

General recommendations to reduce damage in wireworm-infested fields is to both increase seeding rates and delay seeding. A higher seed rate can mean that more plants survive after wireworm damage. King et al. (1933) recommended to seed when seeds will germinate and grow at the fastest rate with sufficient moisture. In other words, shallow and late seeding. If seeded into dry soil, wireworms may partially eat and destroy many seeds whereas when seeded in moist soil, one seed or plant may occupy each wireworm for a prolonged time (King et al. 1933). In addition, late seeding may provide a food shortage that leads to more wireworm cannibalism (Strickland 1939).

Flooding

Flooding fields has been investigated as a control method in in field experiments in Washington state with *Limonius californicus* and *L. canus* (Lane and Jones 1936), and California with *L. californicus* (Campbell and Stone 1938) with mixed results. Successful drowning of wireworms required a high soil temperature and sufficient flooding time. At temperatures of 18–20°C (64–68°F) in the top 12 inches (30.5 centimetres) of flooded soil, 24–67% of *L. californicus* and *L. canus* wireworms survived 10–36 days (Lane and Jones 1936). When soil was 12°C (54°F), 74% survived 210 days of flooding (Land and Jones 1936). If soil was at least 21°C at a 10-centimetre (4-inch) depth, more than 90% of *L. californicus* wireworms died in laboratory and field experiments in California (Campbell and Stone 1938). Flooding has also been investigated and shown some promise for several non-Prairie species in laboratory experiments (van Herk and Vernon 2006 and references therein). However, *S. a. destructor* (Prairie grain wireworm) may be quite tolerant to flooding. Strickland (1927) submerged neonate *S. a. destructor* (Prairie grain wireworm) in the lab and noted that the wireworms could live, feed, and moult underwater. Not a single wireworm died during the 6-week experiment, although temperature of the water was not reported.

In most cases, deliberate summer flooding is not feasible in large Prairie fields. Flooding could also have unwanted effects on non-target organisms such as beneficial insects (e.g. reduced wireworm predators in Fox 1959) and soil health. Therefore, flooding should not be considered as an effective control option on the Prairies.

Reducing egg-laying

An ongoing wireworm infestation means that female click beetles have been able to lay their eggs in the vicinity. It follows than that if female beetles could be intercepted or prevented from laying eggs for several years, wireworm problem could be reduced in a field. However, very little is known about the egg-laying preferences of females. Those that do not fly readily (*S. a. destructor* / Prairie grain wireworm) are likely to lay their eggs in the same field where they have emerged, regardless of the crop present. Those that fly could travel to preferred crops (e.g. cereals) to lay their eggs, but the extent to which this happens is unknown. For some European wireworm species, many adults colonize crop fields from "permanent" wireworm population reservoirs like ditches, grassy headlands or field edges, or pivot corners. Vernon and van Herk (2013a) used a creative solution to this problem by using trenches to physically exclude European click beetles from walking into the field to lay eggs (flight was rare). For the Prairies, it is unknown if the bulk of Prairie female click beetles emerge within-field or travel from reservoirs to lay their eggs in crop fields. Even so, this method would only be useful in small fields next to heavy wireworm reservoirs.

Some wireworm species need to mate to reproduce (e.g. *S. a. destructor* / Prairie grain wireworm), therefore egg laying could be reduced by disrupting mating somehow. Mass trapping males with a sex pheromone has been used in other parts of the world to disrupt mating or time spraying to control click beetles (reviewed in Vernon and van Herk 2013b). Pheromones have been isolated and commercially synthesized for several wireworm species in Canada (e.g. *Agriotes* species, Vernon and van Herk 2013b), but this work is still in development for Prairie species. A sex pheromone for *L. californicus* has recently been identified (Gries et al. 2021).

However, mating disruption as a single strategy will not be effective on the Prairies as two of the main Prairie species do not always mate to reproduce (e.g. *H. bicolor* and *A. mellillus*). This means that there are few or no males to attract away from the females. Secondly, it would be difficult to trap enough males to reduce female mating. For *S. a. destructor* (Prairie grain wireworm), the sex ratio of adults is approximately 1:1, and females only need to mate once to fertilize their 100s of eggs.

Kabaluk et al. (2015) discuss an interesting attract and kill possibility in a European wireworm species – using pheromones to attract males to infections of the disease-causing (pathogenic) fungus *Metarhizium brunneum* (see Biological control, page 51). Infected males could infect females when mating, causing females to have a shorter lifespan and reduced egg-laying period. Perhaps this strategy could be used against *S. a. destructor* (Prairie grain wireworm) since adult males emerge before females (Doane 1961). Research on Prairie species under Prairie conditions would be necessary to investigate this possibility.

It must be noted however, that reducing egg laying of any one species would not necessarily be an easy solution to the Prairie wireworm problem — it is unknown how the pest complex would respond. In theory, reducing one of the wireworm species in a field or even a region could lead to replacement with another, especially if species are similar and are active in the same time and space (though this can get complicated, Kaplan and Denno 2007). This may be the case on the Prairies as many fields have more than one pest wireworm species, usually *H. bicolor* and *S. a. destructor* (Prairie grain wireworm). In addition, because cannibalism seems to be important in some species (e.g. *S. a. destructor* / Prairie grain wireworm), reduced egg-laying could also lead to similar numbers of larger wireworms per area, regardless if they start out crowded or not. This "self-thinning" or "density dependence" effect is widely known in weed management, where seed production can sometimes be reduced by 90%, and still result in the same biomass of pest plants (e.g. Buckley et al. 2001). Research is needed into the multi-species interactions and density-dependence of Prairie wireworms.

Biological control

Biological control involves using or encouraging living organisms to manage a pest. This strategy has been studied extensively in wireworms, mostly in non-Prairie species, and has some promising avenues (reviewed in la Forgia and Verheggen 2019).

Pathogens (Diseases)

A number of fungal and bacterial pathogens have been investigated for their ability to control wireworms. The most promising agent is *Metarhizium brunneum* (formerly known as *M. anisopliae*), a naturally-occurring fungus found in the soil (Kabaluk et al. 2017) (Figure 30). This fungus killed the main Prairie wireworm species tested in laboratory experiments (Zacharuk and Tinline 1968, Ensafi et al. 2018), and showed continued potential to protect spring wheat from Prairie wireworms in field experiments in Montana (Reddy et al. 2014, Antwi et al. 2018). For example, Reddy et al. (2014) found that *Metarhizium brunneum* F52, *Metarhizium robertsii* DWR 346, or *Beauvaria bassiana* GHA applied as a soil drench protected wheat from *H. bicolor* and *L. californicus* (sugarbeet) wireworms similarly as imidacloprid seed treatment. However, this equivalency to chemical treatment was not seen in a follow-up study in the same region with the same pathogens applied in-furrow on granular carriers (Sharma et al. 2020).

Figure 30. Wireworms (*Agriotes* spp.) infected by the fungus *Metarhizium brunneum*, a promising biological control agent. Photo: T. Kabaluk, AAFC-Agassiz

Most of the research into *M. brunneum* has been conducted on European wireworm species (Kabaluk 2014). Seed treatment with the fungus improved corn yields in British Columbia, where *Agriotes obscurus* (dusky wireworm) was abundant (Kabaluk and Ericsson 2007b), and application near potatoes decreased tuber damage (Brandl et al. 2017). Novel ideas such as combining the fungus with other biopesticides (Ericsson et al. 2007), carbon dioxide-producing attractants (Brandl et al. 2017) or sex pheromones to attract and kill wireworms or click beetles also have potential (Kabaluk et al. 2015). Kabaluk et al. (2015) propose using the fungus on adult click beetles through an innovative attract-and-kill strategy. Adult male click beetles (*Agriotes obscurus* / dusky wireworm) were lured to fungal inoculum using pheromones. Infection was eventually fatal to the males, but females could be infected by diseased males through mating, possibly reducing female survival and egg-laying.

While *Metarhizium brunneum* shows strong potential for biological wireworm control, more research is needed before it can be used efficiently and effectively in large-scale production on the Prairies. Effectiveness varies with many factors:

- Wireworm species (Zacharuk and Tinline 1968)
- Size within species (Zacharuk and Tinline 1968, van Herk and Vernon 2011)
- Fungal strain (Ansari et al. 2009, Eckard et al. 2014)
- Concentration (Kabaluk et al. 2007)
- Temperature and exposure time (Kabaluk and Ericsson 2007a)
- Combinations with other pesticides (Ericsson et al. 2007)
- Soil type (Ensafi et al. 2018)
- Soil moisture (Ensafi et al. 2018)
- Resident soil microbes (Kabaluk et al. 2017)

In addition, the fungus may have non-target effects (de Azevedo et al. 2019) that require investigation.

Bacterial control of wireworms is in the early exploration stage, and potential agents would require substantial research before they could be used in the field (la Forgia and Verheggen 2019).

Nematodes

Pathogenic nematodes have been investigated for controlling wireworm species with mixed results. Ansari et al. (2009) found a nematode that killed 67% of European *Agriotes lineatus* (lined click beetle) wireworms in lab experiments. Morton and Garcia-del-Pino (2017) found up to 76% mortality of the European *Agriotes obscurus* (dusky wireworm) in lab experiments, and 48% mortality in the field. Several studies exist with the prairie species *Limonius californicus* (sugarbeet wireworm). Toba et al. (1983) found only 28–29% mortality in field experiments, while Sandhi et al. (2020) found highly variable results with mortality up to 56% in a greenhouse experiment with one strain of nematodes. The bottom line, though, is that nematodes have not been shown to be reliably effective or economic for wireworm biocontrol (la Forgia and Verheggen 2019). This lack of efficiency may be because it is very difficult for nematodes to enter inside wireworms. Sandhi et al. (2020) found that no matter the concentration of nematodes applied, no more than a third penetrated their *L. californicus* (sugarbeet wireworm) hosts. Reasons for poor nematode penetration into wireworms include the host's hard bodies, and protective filters of thick hairs in their mouths and breathing holes (spiracles) (Eidt and Thurston 1995).

Predators

Wireworm predators have been noted several times in the literature, but their impact on wireworm populations has not been quantified. Predacious insects are beneficial to the farm as they provide free pest control (see www.fieldheroes.ca for more information about beneficial insects).

The most important group of insect predators of wireworms is probably the ground beetle (Carabidae, carabid) (Thomas 1940) (see Box B). Strickland (1927, 1935, 1939) noted that carabids in their adult (above ground, beetle) and larval (below ground, immature) stages were important *S. a. destructor* (Prairie grain wireworm) wireworm predators, but that the wireworms could eat the carabid larvae too. Graf (1914) found carabid larvae in the soil next to damaged *L. californicus* (sugarbeet wireworm) wireworms in California. In lab experiments, Stone (1941) found carabids would eat 1–19 *L. californicus* (sugarbeet wireworm) click beetles or 20 wireworms per day. Lemke and Catton (unpublished data) observed *Pterostichus melanarius* (no common name) beetles eating and digging into soil for wireworm prey in the lab (Figure 31).

Figure 31. The predacious adult ground beetle *Pterostichus melanarius* kills, eats and even digs in the soil for wireworms in lab experiments. Photo: H. Catton, AAFC-Lethbridge.

Another major insect predator of wireworms may be stiletto fly larvae (Stone 1941) (Figure 32). In lab experiments, Stone (1941) found 21 stiletto fly larvae killed 70 *L. californicus* (sugarbeet wireworm) wireworms in 50 days, with one stiletto fly killing nine wireworms. Interestingly, soil-dwelling larvae of a European stiletto fly (*Thereva nobilitata*) has been observed feeding on European wireworms in British Columbia in the field and in laboratory experiments (van Herk et al. 2015a).

Not to be overlooked, one of the main predators of wireworms may be wireworms themselves, as they are known to be extremely cannibalistic (Strickland 1939).

Other wireworm and click beetle predators that have been noted in other areas include birds, amphibians and rodents (Graf 1914, Strickland 1935, Thomas 1940, Zacharuk 1962a, Dobrovolsky 1970). Birds especially are important predators of wireworms in cultivated soil (Graf 1914, Thomas 1940).

Figure 32. Stiletto fly larvae (Therevidae) are predators of wireworm. Photo: J. Gavloski, Manitoba Agriculture and Resource Development

Parasites

Several parasites have been noted on wireworms (mostly non-Prairie species), but infestation rates were usually low (e.g. usually <6% infestation, Dobrovolsky 1970, Traugott et al. 2015). Zacharuk (1962a) found mites on up to 95% of *S. a. destructor* (Prairie grain wireworm) wireworms in some years, but noted that the mites did not appear to affect the wireworms. Parasitoids of wireworms have rarely been documented, and have not been found to make an impact on wireworm populations (Thomas 1940, Traugott et al. 2015, la Forgia and Verheggen 2019).

Chemical control

Chemical control is the main option used on the Prairies for reducing wireworm damage. Registered chemical control in cereals and pulses is in the form of seed treatments, which target actively feeding wireworms in the soil. Other treatments such as in-furrow applications are registered for potatoes (see Root crops section, page 56). Since lindane was de-registered in Canada in 2004, most available seed treatments for cereals have been neonicotinoids (Group 4). Unfortunately, while these, as well as diamides (Group 28) and pyrethroids (Group 3), may offer within-season plant protection, they are generally not effective in killing wireworms. Published scientific studies indicate that chemicals in these groups temporarily immobilize and/or repel wireworms but do not consistently reduce populations (details below). The lack of population control can allow wireworm numbers in a favourable field to continue increasing over time, to the point they eventually reduce (or overcome) a chemical's ability to provide within-season crop protection (e.g. van Herk et al. 2018b). A chemical treatment that kills wireworms would provide a significant improvement in multi-year management of this pest (i.e., it may reduce or eliminate the need for applying insecticides for 1–2 subsequent years). Most of the published research on the toxicity of available insecticides report on non-Prairie wireworms, usually *Agriotes* species. Different wireworm species can be more or less susceptible to insecticides (e.g. van Herk et al. 2007, Esser et al. 2015). It is reasonable to assume that the broad patterns from the research studies largely apply to the Prairie wireworm situation as well, but the details may vary species to species. Check your provincial crop production manuals for current chemical options for wireworm crop protection (See Resources, page 65).

Considerations

Approaches to managing wireworms with chemical controls depend on the crop to be protected and an understanding of wireworm seasonal movements (i.e. feeding periods). Equally important is understanding how an insecticide affects wireworms: whether they repel, temporarily immobilize, and/or kill; how long the chemical persists in the soil; and how the chemical affects resident wireworms (those hatched in the years prior to insecticide application) and neonates (those hatched in the year of application).

For example, the decrease in wireworm problems in Canada (and worldwide) after World War II is commonly attributed to the introduction and wide-scale, repeated use of organochlorine insecticides, some of which (e.g. heptachlor) were highly persistent and killed wireworms more than ten years after a single application (Wilkinson et al. 1964, 1976). According to this theory, the current resurgence in wireworm populations can be attributed (at least in part) to the gradual decline of organochlorine residues in the soil (see further discussion in Vernon and van Herk 2013b).

In the Prairies, the increased use of the organochlorine lindane as a seed-treatment for cereal and corn between 1954 and 1961 coincided with a decrease in wireworm damage (Burrage 1964). In early work, William Fox and others demonstrated that wireworm damage to wheat could be eliminated with lindane applied at 70 grams active ingredient/hectare (1 ounce active ingredient/acre), and that it reduced populations of *S. a. destructor* (Prairie grain wireworm) and *H. bicolor* by approximately 70% (Arnason and Fox 1948; Harding 1986). Mortality of other economic non-Prairie species (e.g. *Agriotes obscurus* / dusky wireworm) was similar (Vernon et al. 2009). Most importantly, lindane (while not as persistent as other organochlorides) had sufficient residual action to kill up to 85% of neonate wireworms (*A. obscurus* / dusky wireworm) that hatched a month or two after treated wheat seed was planted (Vernon et al. 2009, 2013b). As a result, a single lindane application could provide several years of wireworm control. However, lindane was de-registered in Canada in 2004 due to its persistence as an organic pollutant.

An insecticide capable of killing both resident and neonate wireworms in high numbers would provide growers with several management options. Use of the chemical in one year should reduce populations sufficiently so that there would be low wireworm numbers in the subsequent 1–2 years (provided the treatment is applied when wireworms are feeding and will contact the chemical). Planting treated wheat seed in one year would then allow a high value crop like potatoes to be grown in the subsequent year with low economic risk of wireworm injury (Vernon and van Herk 2013b). The cereal crop bearing the insecticide treatment would function as a clean-up, rotational crop. However, this would require seed treatments that are at least as effective as lindane at reducing wireworm populations (e.g. fipronil, Group 2B, not registered in Canada, or an equivalent product such as broflanilide, see below, van Herk et al. 2021a).

Current insecticides (2021)

The recent market standard for protection from wireworms in cereals and pulses in Canada have been neonicotinoid seed treatments (e.g. thiamethoxam, imidacloprid, clothianidin, Group 4A). These systemic insecticides provide within-season crop protection by temporarily intoxicating and immobilizing wireworms, allowing seedlings to establish. However, both field and lab studies have shown that many or most wireworms exposed to these chemicals do not die, rather their intoxication lasts for days or weeks, after which they recover to resume feeding (Prairie species: van Herk et al. 2007, Morales-Rodriguez and Wanner 2015; non-Prairie species: van Herk et al. 2008, 2015b, Cherry et al. 2017). The low mortality caused to resident wireworms, combined with no effect on neonates (which hatch from beetle eggs several months after seeding) means that neonicotinoids do not provide multi-year control of this pest in the field (Prairie species: Esser et al. 2015, Morales-Rodriguez and Wanner 2015, van Herk et al. 2018b, 2021a, Milosavljević et al. 2019; non-Prairie species: Vernon et al. 2009, 2013a,b). Thus, while neonicotinoids can offer “wireworm suppression” (within-season plant stand protection), they must be applied each year for crop protection. The level of crop protection provided by neonicotinoids can drop under high wireworm pressure (e.g. Prairie species: van Herk et al. 2018b; non-Prairie species: Vernon et al. 2013b).

High wireworm pressure may still cause substantial damage to treated crops as each wireworm needs to chew on a plant to ingest the pesticide – the more wireworms there are, the more chewing damage there will be. Finally, neonicotinoids are currently under re-evaluation by Health Canada and could be phased out in coming years (Health Canada Pest Management Regulator Agency 2020a). Therefore the search for newer and more effective management options for wireworm must continue.

Like neonicotinoids, many other newer insecticides temporarily immobilize wireworms after exposure, after which the insects recover completely and resume feeding. These insecticide groups include pyrethroids (e.g. tefluthrin, bifenthrin, Group 3A), diamides (e.g. chlorantraniliprole, cyantraniliprole, Group 28), spinosyns (Group 5), and spirotetramat (Group 23) (van Herk et al. 2015b, 2018b, 2021a; Vernon et al. 2009, 2013a, Cherry et al. 2017). While chemicals in these groups can offer “wireworm suppression” (within-season plant stand protection), they can also fail under high wireworm pressure (Prairie species: van Herk et al. 2018b) and have not been shown to significantly reduce field populations of wireworms in the peer-reviewed scientific literature. Note that while research with diamides (chlorantraniliprole, cyantraniliprole, Group 28) has shown mixed results for crop protection and no significant wireworm mortality (Arrington et al. 2015, Cherry et al. 2017, van Herk et al. 2015b, 2018b, 2021a, Larsen et al. 2016, Vernon et al. 2013a), no published study on wireworms has included the currently registered seed treatment formulation of chlorantraniliprole for cereals, peas and lentils on Prairie wireworm species. Further research is needed, to determine the level of wireworm protection provided by this formulation on the Prairies.

In late 2020, a new non-systemic insecticide called broflanilide (meta-diamide, Group 30) was registered in Canada for wireworm control in cereals, potato, and corn (Health Canada Pest Management Regulatory Agency 2020b). So far, there is one study published on broflanilide and wireworms (van Herk et al. 2021a). This study described 7 years of field trials in British Columbia with *Agriotes obscurus* (a non-Prairie wireworm species) comparing wheat plant stand protection 20–26 days after planting and wireworm catches the fall or spring after harvest. Seed treatments tested were a registered thiamethoxam (neonicotinoid, Group 4) product, several rates of broflanilide, and several other seed treatments not currently registered in wheat in Canada including cyantraniliprole (Group 28, diamide). All treatments resulted in significant crop stand protection 20–26 days after planting, except in one year when no treatment was different than the untreated control. However, broflanilide plots at 5 grams active ingredient per 100 kilograms of wheat seed had significant reductions the number of neonate wireworms (2 of 7 years) and resident wireworms (4 of 7 years), particularly in years with higher wireworm pressure. The neonicotoinoid and diamide plots did not show wireworm population reductions (van Herk et al. 2021a). The study indicated that broflanilide provided similar within-season crop protection to the recent market standard neonicotinoid thiamethoxam and similar wireworm mortality to the de-registered lindane, but at far lower dosages than either of those alternatives. A chemical with these effects can provide multi-year control of wireworm populations. However, since broflanilide is non-systemic, it does not control above-ground pests of cereals (e.g. some cutworm species) when applied as a seed treatment, and may need to be paired with another, systemic insecticide to address those additional concerns.

Future pesticides

There are few effective wireworm insecticides available to growers, but it is anticipated new chemistries will continue to be researched. Longer term, chemical control of wireworms may involve molecular gene silencing techniques like interference-RNA (RNAi). This highly targeted technique is species specific, quickly biodegradable and has been used successful in other pests (e.g. corn rootworms

Diabrotica spp.) in Canada and the USA. Research into RNAi for *Agriotes sputator* (no common name) wireworms is underway at Dalhousie University, but is still in the early stages (King 2018).

Root crops

Chemical control of wireworms in potatoes (and other root crops harvested late in season) is different than in cereals and other crops that need protection at the time of planting. To be effective, wireworms either need to access the chemical:

1. When they feed on the treated mother tuber,
2. When they come into contact with the in-furrow application of the insecticide (applied as sprays of granulars) in spring, or,
3. The insecticide needs to be present long enough to actually kill wireworms when they come for their fall feeding on the daughter tubers

Vernon et al. (2013a) has shown that very good blemish control and wireworm reduction can be obtained with phorate (Group 1B), chlorpyrifos (Group 1B) and fipronil (Group 2B, but not registered in Canada for wireworms), as well as wheat seed treated with very low rates of fipronil sprinkled in furrow at the time of planting (Vernon et al. 2016). The latter works by the germinating wheat seedlings producing carbon dioxide which attracts the wireworms to the insecticide (i.e. attract and kill). This strategy can greatly reduce the amount of chemical applied per acre, but its efficacy will be dependent on the wireworm feeding periods. Planting late in the spring (after wireworms have moved down into the soil profile) may be less effective than planting at the time of wireworm feeding. For a further review of chemical and non-chemical management of wireworms in potatoes, see Vernon and van Herk (2013b, 2018).

In late 2020, broflanilide (a new Group 30 insecticide) obtained registration from Health Canada for use in cereals, corn, and potatoes. In potato, it is registered as an in-furrow spray. While there are currently no published studies on its efficacy as an in-furrow application, several field studies demonstrating its effectiveness in protecting tubers from wireworm damage have been conducted (Vernon and van Herk, unpublished), and broflanilide has shown effective wireworm population control as a seed treatment for wheat (van Herk et al. 2021a).

Adult control

Spraying for adult click beetles is not a viable strategy, as there are no chemicals registered for controlling click beetles on the Prairies. A spray program to control click beetles would be difficult as it would require precise, real-time monitoring of female beetle numbers, and would likely need to be repeated several times per year for several years to significantly reduce wireworm populations in the soil. Multiple sprays within a season are necessary as female emergence is quite difficult to predict with beetles emerging over multiple weeks in the spring (mid-April to mid-June, Doane 1961). Furthermore, beetles can reinvade fields from adjacent fields and headland areas after spraying. Multiple years of adult control would be required, as killing them before they lay their eggs only prevents the formation of a new generation of wireworms, but does not impact the resident larvae already present in the soil. Sprays applied after females have laid their eggs will be ineffective. Studies with field sprays of click beetles have been conducted in Europe (Ester and van Rozen 2005) and in Prince Edward Island (Vernon and van Herk, unpublished), and significantly reduced adult numbers of various *Agriotes* species in both. However, neither study reported on reduction of wireworm numbers in the soil, though further studies into this are ongoing (van Herk, unpublished). Unfortunately, it is likely the repeated field-scale insecticide applications may negatively impact non-target organisms (e.g. beneficial insects like pollinators and predators).

RESEARCH NEEDS

In reviewing all the information available for wireworms on the Prairies, a few research needs have become evident.

Biological information

Thanks to extensive, high quality work from earlier researchers, we have a solid knowledge on the life cycle of *S. a. destructor* (Prairie grain wireworm) which was the most abundant wireworm pest at the time. This knowledge has been critical to understanding the challenges of the wireworm problem. However, *S. a. destructor* (Prairie grain wireworm) is just one in a complex of wireworm species.

In recent decades, population abundances seem to have changed. *H. bicolor* is now the most abundant wireworm in many fields (van Herk et al. 2021b). While we have some information on this species, we do not have a full understanding of its behaviours. *H. bicolor* is a smaller wireworm than *S. a. destructor* (Prairie grain wireworm) with some key differences. For example, adult *H. bicolor* beetles fly, and the species is known to have both sexual and parthenogenetic (all female) populations on the Prairies. These differences could have implications in monitoring and behaviour.

For other species, we have very little knowledge of either their life history or behaviour. For example, our life history knowledge on another main species, *L. californicus* (sugarbeet wireworm) comes from work done in California almost 100 years ago. Surveys have shown that this species is more abundant on irrigated land and therefore may be a bigger pest in potato. As a result, we need more information on the biology of these other wireworm species, and how they and *S. a. destructor* (Prairie grain wireworm) interact in the fields they co-habit. For example, if we were to develop a species-specific control method (e.g. using pheromones), would one or more of the other species replace the original species being controlled in terms of numbers? Does cannibalism in wireworms mean that decreasing egg-laying would not reduce the number of resulting resident wireworms in a field?

Decision support tools

The good news is that new chemical options for wireworm control have come on the market. However, what is needed next are decision support tools to help producers decide when to use these insecticides. All pest control methods have pros and cons (e.g. pros: reduced damage, provide peace of mind and a sense of “taking action”; cons: expense, labour, non-target effects), and producers need more information to decide when a chemical application is in their best interest. For example, any treatment that harms beneficial insects may have a hidden cost, since these insects provide value in pest control of wireworm and other unrelated pests (see www.fieldheroes.ca for more information on beneficial insects).

Easier and more accurate monitoring methods coupled with validated economic thresholds for wireworm in cereals are needed. This is especially important since wireworms are usually the only reason to treat cereal seed with insecticide on the Prairies. An economic threshold based on data from the previous year would be most helpful, as it would give producers enough time to decide whether to treat seed the following spring. The data could be from plant damage observed (e.g. the threshold of 15% corn plants damaged in Europe, Furlan et al. 2017), or from the wireworm or click beetle trapping monitoring methods (see Monitoring section). The advantage of the trapping methods is getting species-specific information, which is important in wireworm management.

Integrated pest management methods and their effects

There are several methods to approach wireworm population control. Research is needed on these methods specific for the Prairies, especially on how the various methods interact with each other to achieve sustainable control.

Research from other parts of the world show potential in biological control for wireworms, especially with *Metarhizium* fungus. This method could be especially helpful in small scale or organic production systems.

The isolation of sex pheromones for Prairie species would help with click beetle monitoring efforts, and could possibly be used in combination with *Metarhizium* for population control.

Creative IPM methods are needed, and research is needed to evaluate their impacts at the field, population and even landscape levels of the insects. The research must take a holistic approach by considering wireworm species complexes together (in combination with species-specific information), and by considering IPM methods in balance with other agronomic and operational factors in the farming system. For example, recommending tillage to control wireworm pupae is not in line with the soil and moisture conservation benefits of no-till operations on the Prairies.

In general, the wireworm problem on the Prairies is complex, with many factors to consider. Research must continue to seek the most sustainable and efficient ways to mitigate damage from these pests with the least expense and non-target effects possible. Fortunately, wireworm research is ongoing around the world and we can look to other areas for ideas, as well as forging our own leadership path here on the Canadian Prairies.

Tables

Table 1. Summary of wireworm life stages for *H. bicolor* (no common name), *S. a. destructor* (Prairie grain wireworm), and *Limonius californicus* (sugarbeet wireworm). The life cycle of *Aeolus mellillus* (flat wireworm) is different as it has a 1–2-year life cycle, and can pupate in the spring.

	Click beetle	Egg	Neonate (1st year) wireworm	Resident wireworm (2nd year or later)	Pupa
When?	Overwinter in the soil (inactive). Active for mating and egg-laying for several weeks in the spring.	Several weeks in the spring.	After eggs hatch each year, July to fall.	Occur all year round. Active in early spring to late fall.	Several weeks in late summer.
Where?	On the soil surface, in soil cracks, in soil in overwintering (pupal) chamber.	Near the soil surface, deeper if soil cracks are available.	Most in top 70 cm (27.5 in.) of soil, some found 70–105 cm (27.5–41 in.) deep (Milosavljević et al. 2017).	Most in top 70 cm (27.5 in.) of soil, but some found 70–105 cm (27.5–41 in.) deep (Milosavljević et al. 2017).	In the soil, 5–8 cm (2–3 in.) deep (Zacharuk 1962a).
Description	Mobile: can walk or sometimes fly. Some species need to mate, other do not. Easiest life stage to monitor during their active season. Main job is to lay eggs. Most species are not damaging to crops.	Immobile. Vulnerable to desiccation, predation.	1st year wireworms hatched in spring. Not typically damaging at this stage, feed on root hairs in summer. Can damage root crops in the fall. Vulnerable to starvation, desiccation, cannibalism. Somewhat mobile in soil to escape unfavourable conditions.	Wireworms in 2nd year and later. Resilient. Mobile in soil. Most damaging and long-lived stage of the pest. Actively feed in the spring when field crops are most vulnerable. Can withstand starvation and less than ideal soil conditions if there is food.	Immobile and fragile. Vulnerable to disturbance.
Directly damaging to this year's crop?	No.	No.	No, except to root crops in the fall.	Yes.	No.
How would controlling this life stage help wireworm control?	Longer term population control.	Longer term population control.	Longer term population control (but within-year protection from fall feeding on root crops).	Within-year crop protection and longer term population control.	Longer term population control.

Table 2a. Larval stage: Summary and comparison of the 4 main pest wireworm species in the Canadian Prairies.

Common name	No common name	Prairie grain wireworm	Flat wireworm	Sugarbeet wireworm
Latin name	*Hypnoidus bicolor*	*Selatosomus aeripennis destructor*	*Aeolus mellillus*	*Limonius californicus*
Years in soil	2–3	3–4 (up to 11)	1–2 (probably)	3–4 (probably)
Mature larval size (from Glen et al. 1943)	10–12 mm (0.4–0.5 in.)	17–23 mm (0.7–0.9 in.)	12–15 mm (0.5–0.6 in.)	17–22 mm (0.7–0.9 in.)
Larval appearance	Pale yellow body. U-shaped caudal notch. Outer prongs are short and face upward.	Shiny, hard-bodied, yellow-ish-orange colour, often a stout build. Has eyespots. Caudal notch is wide and shallow. Prongs are fleshy and not erect as in *H. bicolor*.	Brown or reddish-brown head and prothorax, rest of body is pale yellow or whitish, and soft. Caudal notch is pointy.	Hard-bodied, yellow to deep yellow colour. No eyes. Caudal notch is a nearly closed, making a “keyhole” shape.
Larval feeding	Shredding and boring.	Shredding and boring.	Active. Predacious. Boring and cutting of plants.	Shredding and boring.
Notes	Most abundant pest wireworm on the Prairies. More active and aggregated in fields than *S. a. destructor*. May not respond to bait traps as well as *S. a. destructor* (Prairie grain wireworm).	The most destructive wireworm per capita.	The most active wireworm, also predacious.	Often found in irrigated fields and fields with higher soil moisture.

Table 2b. Adult stage: Summary and comparison of the 4 main pest wireworm species in the Canadian Prairies.

Common name	No common name	Prairie grain wireworm	Flat wireworm	Sugarbeet wireworm
Latin name	*Hypnoidus bicolor*	*Selatosomus aeripennis destructor*	*Aeolus mellillus*	*Limonius californicus*
Adult length	4.5–6 mm (0.2 in.) (Brooks 1960).	Females: 10.7–13.2 mm (0.4–0.5 in.) Males: 7.75–11.5 mm (0.3–0.5 in.) (Strickland 1927).	5.5–8 mm (0.2–0.3 in.) (Brooks 1960).	8.5–11 mm (0.3–0.4 in.) (Brooks 1960).
Adult appearance	Pronotum black. Antennae, hind angles, legs, and elytra (wing covers) dark brown with a reddish tinge. Covered in short fine hair.	Black, sometimes with bluish-greenish metallic sheen. Hairless. Long distinct hind angles. Body shape is robust.	Reddish yellow with dark brown spots on pronotum and elytra. Long sharp hind angles. Has very short fine, hair.	Pronotum is black, elytra are reddish brown, both are covered in dense white or yellow hair. Hind angles are very short. Body shape is slender.
Adult sex ratio	Some populations are all female, some have both sexes.	1:1 male:female	All females in Canada	Biased toward males in early emergence, and females later in emergence (Stone 1941)
Eggs per female	Unknown	>200 but estimates range from 264–946	Average of 18–51, but up to 151	~250
Adult flight	Yes	No	Probably	Yes
Adult mating	Yes and no: some populations are all female	Yes: mate only once	No: all female	Yes
Sex pheromone	Unknown	Yes, identified (unpublished)	No	Yes, identified (Gries et al. 2021)

Table 3. Summary of potential Prairie wireworm management options in field crops and their effects on survival or egg-laying.

	Click beetles & egg laying	Egg survival	Neonate wireworms	Resident wireworms	Pupae
Tillage	No effect or even counter-effective. Can help females lay eggs deeper in soil.	Potential.	Unlikely.	Unlikely.	Yes, shallow tillage in late July.
Crop rotation	Possible effect on egg laying, unknown.	Unlikely.	Potential, cereal crops provide greater survival than broadleaves (Strickland 1939).	No.	No.
Summer fallow	Adults are mobile, but may prefer to lay eggs in fields with cover.	Unknown.	Likely, if kept weed-free, neonates are vulnerable to starvation.	Maybe, if kept weed-free. But for some, does not kill & makes them more voracious the following year.	Unlikely unless tilled in late July.
Soil amendments	No.	Unknown.	Maybe with defatted *Brassica* seed meal, (Furlan et al. 2010), not tested on the Prairies.	Maybe with defatted *Brassica* seed meal, (Furlan et al. 2010), not tested on the Prairies.	Unknown.
Insecticide seed treatments in the following groups: — Neonicotinoids (Group 4A) — Diamides (Group 28) (Confers crop protection but not wireworm population reduction)	Not tested, but unlikely to come into contact.	Not tested, but unlikely to come into contact.	Research has shown no effect. Chemicals may break down before neonates are present.	Systemic insecticide, can be ingested from seed or plant. Immobilizes resident wireworms long enough to protect crop (especially under low-moderate pressure) and cause some death, but have not been shown to significantly reduce populations.	Not tested, but unlikely to come into contact.

Table 3. Cont'd.

	Click beetles & egg laying	Egg survival	Neonate wire-worms	Resident wireworms	Pupae
Insecticide seed treatment in Group 30 (broflanilide) **(Confers crop protection and wireworm population reduction)**	Not tested, but unlikely to come into contact.	Not tested, but unlikely to come into contact.	Yes — through residual (van Herk et al. 2021a). Chemical is not systemic.	Yes — through feeding or contact (van Herk et al 2021a). Chemical is not systemic.	Not tested.
Adult mass trapping	Not feasible at present, but has some potential. Would require multiple years to significantly reduce wireworm numbers in soil.	No.	No.	No.	No.
Pheromone traps	Possibly. Pheromones for Prairie wireworms are in development. They trap males only, but useful for monitoring, potentially developing thresholds and risk assessments. Potential to use for mating disruption or combine with other tools like pathogens to affect females.	N/A	N/A	N/A	N/A
Insecticide sprays (not registered)	Difficult to implement, effectiveness unknown.	No.	No.	No.	No.
Trap cropping	Unknown.	No.	Unknown.	Can distract but not kill unless combined with another tool for "attract and kill" (e.g. insecticide, pathogen).	No

Resources

Crop Protection Guides (provincial), updated annually

Alberta Blue Book (Crop Protection Manual): www.alberta.ca/crop-protection-manual.aspx

Saskatchewan Guide to Crop Protection: www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/crop-guides-and-publications/guide-to-crop-protection

Manitoba Guide to Field Crop Protection: www.gov.mb.ca/agriculture/crops/guides-and-publications

Diagnostic labs
(contact first to determine how to send samples and if fees apply)

Alberta

Alberta Plant Health Lab
Crop Diversification Centre North
17507 Fort Road NW
Edmonton Alberta T5Y 6H3
780-638-3999
planthealthlab@gov.ab.ca

Saskatchewan

Crop Protection Laboratory
1610 Park Street
Regina, SK S4N 2G1
306-787-8130
cpl@gov.sk.ca

Manitoba

Contact/drop off samples at your local MB ARD office or
Crop Diagnostic Services
Primary Agriculture Branch
201-545 University Crescent
Winnipeg, Manitoba R3T 5S6
204-945-7707
www.gov.mb.ca/agriculture/crops/crop-diagnostic-services/

Agriculture and Agri-Food Canada (wireworm identification only)

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Field Guides

Field Crop and Forage Pests and their Natural Enemies in Western Canada: Identification and Management Field Guide (Philip et al. 2018)

http://publications.gc.ca/site/eng/9.852934/publication.html

Cutworm Pests of Crops on the Canadian Prairies: Identification and Management Field Guide (Floate 2017)

http://publications.gc.ca/collections/collection_2017/aac-aafc/A59-42-2017-eng.pdf

Field Guide for wireworms in Québec (in French only, great photos) (Saguez 2017)

https://cerom.qc.ca/vffqc/documents/Saguez_2017-Guide-d-identification-VFF-ISBN_978-2-9813604-5-8.pdf

Websites

Prairie Pest Monitoring Network

www.prairiepest.ca

Beneficial Insects in Crop Fields

www.fieldheroes.ca

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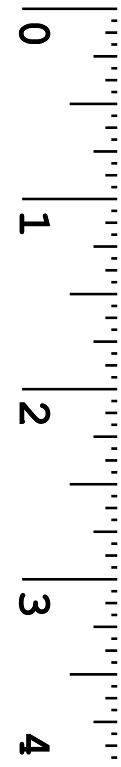
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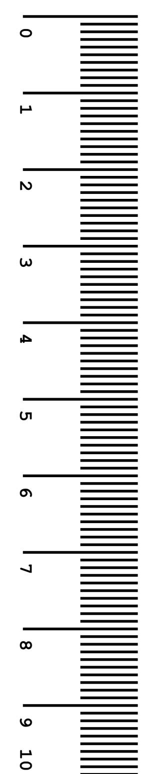
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Guide to Pest Wireworms in Canadian Prairie Field Crop Production