

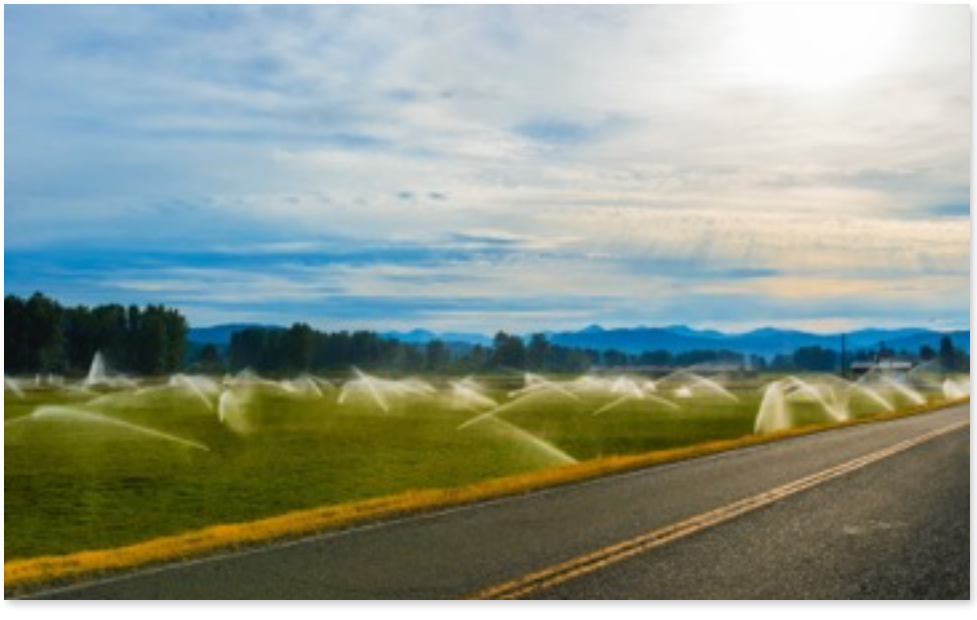



INTEGRATED PEST MANAGEMENT FOR CRANBERRIES IN WESTERN CANADA

2nd Edition 2015

By Sheila Fitzpatrick, Warren Wong, Miranda Elsby & Heidi van Dokkumburg





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Disclaimer

No product endorsement is implied by any of the information in this guide. Agriculture and Agri-Food Canada and the authors of this guide accept no responsibility for crop damage, personal injury, or property damage sustained as a result of using techniques or products described herein.

FOREWORD

Why a second edition?

In the years since production of the original Integrated Pest Management Guide for Cranberries in Western Canada, the pest community has become more diverse, the chemistries of registered pesticides have changed, new cranberry varieties have been introduced and cranberry culture has expanded from peat soils to former pasture “upland” sites. Global issues such as climate change and honey bee decline have had an impact on cranberry horticulture and pest management.

In cranberry, as in many other horticultural crops, one of the most formative changes in pest management has been deregistration and phase-out of several broad-spectrum organophosphate insecticides. Currently-registered insecticides have more specific modes of action (and lower mammalian toxicity) than the organophosphates. More detailed knowledge of pest identity and development is needed to maximize the efficiency of these newer insecticides.

What is Integrated Pest Management?

Integrated Pest Management, abbreviated IPM, is a decision-making risk-management process involving coordinated use of multiple suppressive tactics to manage pests that would otherwise cause economically significant damage. Pests are detected, identified and regularly monitored by growers and/or IPM practitioners in consultation with research and/or extension professionals.

IPM takes into account that cranberry growing is a business, and that cranberry growers, like all farmers, exercise stewardship of the land they farm. IPM provides growers with decision-making tools to assess pest problems over time and apply management tactics only when economically significant damage is likely to occur.

Features of this IPM Guide

- Full colour, high resolution photographs of pests and their damage.
- Full colour, high resolution photographs of the most common beneficial predatory or parasitic insects.
- Science-based descriptions of insect life cycles and feeding habits.
- General, science-based information on how to detect and manage the pests.

Because the identity of registered insecticides changes frequently, this Guide does not specify the insecticides registered for each insect pest. Growers can obtain a list of registered insecticides on-line from BC Berries Production Guide, BC Cranberry Marketing Committee, or Cranberry Institute.

Blackheaded Fireworm larva
emerges from tent of leaves and silk

Blackheaded Fireworm eggs

Blackheaded Fireworm early stage larva

BLACKHEADED FIREWORM

Rhopobota naevana

Pest Status: This insect is one of the major pests of cranberry in British Columbia.

Life cycle and feeding habits: This insect overwinters in the egg stage. Overwintering eggs are yellow, about 0.5 mm (less than 1/16 inch) in diameter, and are found on the underside of cranberry leaves. Hatching of the first generation usually begins in late April, reaches a peak in early May and is completed by early June.

Newly hatched larvae burrow into the leaf near the egg, then move up to the growing tip of uprights or runners. Larvae may tunnel into unopened buds or web together the terminal leaves of uprights with silk and feed inside this shelter or “tent”. Each larva may make five or six tents before it pupates. After a feeding period of 3 - 5 weeks, fully grown larvae, which are about 8 mm (1/3 inch) long with a shiny black head, go into the pupal stage in the trash layer or within their tents. The first adults usually appear in late May or early June. This first flight of moths lasts until July. During this time, the male and female moths (6 mm [1/4 inch] long) can be seen flying among the vines. Most mating occurs in late afternoon and early evening. Eggs are laid on the underside of cranberry leaves. These second-generation eggs begin hatching in late June or early July. In addition to making tents, larvae feed on uprights and runners directly and may burrow into the developing fruit.

Blackheaded Fireworm adult

Blackheaded Fireworm late stage larva

Blackheaded Fireworm tent conceals larva within

When the larval population is high and injury is severe, damaged plant tissue dries out and appears scorched as if by fire. Following pupation, moths of the second generation are present from late July through September. Although most eggs laid by second-generation moths will not hatch until the next spring, a third generation of larvae may be seen in August and September if temperatures remain warm. These third-generation larvae are injurious to fruit. In warm years, moths of the third generation may be seen flying as late as December on dry-pick farms.

Detection: Monitoring for this pest begins by looking for larvae in late April. Look closely at runner tips and buds along warm edges of beds for small tents and frass made by newly hatched larvae (about 1.5 mm [1/16 inch] long). One to two weeks after larvae are first seen, extensive monitoring can be done by completing “visual sweeps”: crouching to examine areas of about 0.18 metres (2 square feet). Pheromone traps for monitoring moth flight should be placed in fields in mid-May. About three weeks after first catch, being checking for larvae.

Management: An insecticide treatment is recommended if an average of 1 larva/visual sweep is found. During bloom, do not apply insecticides that are toxic to bees. A parasitic wasp, *Trichogramma sibericum*, is sometimes found in beds not treated with insecticides. These wasps are well-adapted to parasitize fireworm eggs. Three species of parasitic insects are known to attack blackheaded fireworm larvae on farms where insecticide use is minimal. These three are: *Hemisturmia tortricis*; *Sympiesis bimaculatipennis*; and *Microplitis* sp. A granulosis virus is also known to infect blackheaded fireworm larvae on unmanaged cranberry farms.


Sparganothis adult


Sparganothis tenting


Sparganothis larva

SPARGANOTHIS FRUITWORM

Sparganothis sulfureana

Pest Status: When present and not controlled, this insect can be a major pest of cranberry.

Life cycle and feeding habits: Sparganothis fruitworm overwinters as a first instar larva in the trash layer of the cranberry bed or webbed into leaves on the cranberry plant. In spring, as plants come out of dormancy, the tiny larvae move onto the foliage to feed.

Very young larvae are yellowish with black heads and can be confused with blackheaded fireworm larvae. Older larvae are yellowish green with brownish yellow heads, and reach 10 - 15 mm (half an inch) long when fully grown. Sparganothis larvae feed within tents similar to but looser than those made by blackheaded fireworm larvae. In June, first generation Sparganothis larvae finish feeding and web uprights together to form a pupation site.

First-generation Sparganothis adults are moths that mate and lay colourless or pale yellow eggs in masses on the upper surface of cranberry leaves in June and July. The moths' wings are usually bright sulfur yellow with a pattern of reddish scales that forms a cross when the wings are folded across the body. Second-generation larvae feed on foliage and berries in July and August.

Path between berries

Sparganothis feeding larva

Sparganothis fruit damage appearance

Second-generation moths mate and lay eggs on foliage in late summer and early fall. Larvae that hatch from these eggs overwinter. Berry feeding by second-generation larvae can cause economic damage to cranberry crops. Each larva can feed on and in 3 - 5 berries, often damaging the outer surface of others surrounding the feeding area. These wounds decrease the aesthetic value of the crop and are an entryway for fruit disease. Pupation can occur in the berries.

Detection: The most effective way to monitor for Sparganothis is through visual inspection. Sweep net monitoring is often unreliable and ineffective. Overwintered larvae usually become active during bud break and are continually present throughout the season. In spring, larvae make tents by webbing together several leaves, very similar to blackheaded fireworm, but generally more loosely woven.

Berry damage can be confused with that of blackheaded fireworm or cranberry fruitworm. Berries damaged by Sparganothis larvae are usually clean inside, not filled with frass as is characteristic of berries damaged by cranberry fruitworm larvae. Adult male moths can be detected using pheromone traps.

Management: Use of insecticides registered for control of Sparganothis fruitworm, applied according to label directions, are effective management tools. In other cranberry growing regions, it is believed that Sparganothis becomes a problem when natural enemies, such as egg parasites (*Trichogramma spp.*) and the parasitic tachinid fly, *Erynnia tortricis*, are killed by insecticides.

Cranberry Fruitworm exit hole

Photographed by Jim Troubridge

Cranberry Fruitworm adult

CRANBERRY FRUITWORM

Acrobasis vaccinii

Pest Status: Cranberry fruitworm is potentially a major pest in British Columbia.

Life cycle and feeding habits: The cranberry fruitworm spends the winter in the larval stage, wrapped in a hibernaculum made of old leaves, sand, soil and other material under vines on the bed floor. Pupation occurs in spring and the moths typically begin to appear in the middle of June.

Generally, peak flight occurs about the same time cranberries are in full bloom and may continue through much of July. The moths are dark brown with very noticeable white bands on the forewings and have a wingspan of about 1.5 cm (2/3 inch). They rest under the vines during the day, particularly during bright sunshine. When disturbed, they fly 15 - 17 metres (50 - 55 feet) before coming to rest on the vines. Moths are strong fliers, moving readily between cranberry beds and alternate hosts such as highbush blueberries. The eggs are generally laid on the calyx end of the cranberry. When the larva hatches, it usually crawls to the stem end, chews into the berry, and seals its entrance hole with a white silken web. Only very close inspection will reveal that the berry has been attacked. The larva is pale green with a yellowish head. Larvae have three pairs of front legs and five pairs of hind legs. When fully grown, a larva is 1.3 cm (1/2 inch)

Cranberry Fruitworm larva

Cranberry Fruitworm frass within berry

Cranberry Fruitworm larva in berry

long. It rarely leaves a berry until it has eaten all the pulp and seeds, and filled the berry with frass. Usually it leaves the berry by boring through the side and into an adjoining berry. One larva may eat three to six berries before going into diapause (a dormant, hibernation-like state) in the trash for the winter. Infested green fruits redden, and then shrivel up like raisins.

Detection: Male moths are attracted to traps baited with cranberry fruitworm pheromone. In Massachusetts, egg-laying begins when berries have just begun to grow, and may continue to late August. Females prefer to lay eggs on berries larger than pinhead stage. Studies in Massachusetts demonstrated that female moths wait for the fruit to expand before they began laying eggs. The phenology of the cranberry plant gives a good estimate of the time of egg-laying. Work in Massachusetts showed that most eggs are found at the calyx end of berries from edges of beds and ditches, in weedy areas, and on berries that stick up above the vine canopy. If possible, 25 – 50 berries from these areas should be examined under a magnifier or microscope to look for eggs.

Management: If eggs are found during monitoring, a registered insecticide should be applied. Insecticides should not be applied during bloom or against fruitworm larvae, which are protected in the berries.


Photographed by Jim Troubridge

Bruce Spanworm adult


Photographed by Jim Troubridge

Winter Moth adult

Bruce Spanworm adult

Bruce Spanworm hind wing spot

BRUCE SPANWORM
Operophtera bruceata

WINTER MOTH
Operophtera brumata

Pest Status: Both species are polyphagous (feed on many host plants). Periodic outbreaks of winter moth have occurred on shade trees, apples and blueberries in Victoria, Vancouver, Richmond and Delta. Both species are found throughout the Fraser Valley and may be seen in cranberries.

Life cycle and feeding habits: Overwintered winter moth and spanworm eggs hatch in March or early April. Larvae begin feeding on leaves, flowers and buds of deciduous ornamental and fruit trees, and do so throughout the entire spring. Larvae may be seen in early April through mid-May as they hang down on silken threads from the trees. The wind will blow them to neighbouring trees and larvae will also fall on cranberry beds located close to trees. Larvae of both species are pale green with a light whitish stripe along the side. They vary in length from less than 2 mm (1/16 inch) upon hatching to over 13 mm (1/2 inch) at maturity. Larvae have a pale green head, three pairs of front legs, and two pairs of hind legs. The number of hind legs distinguishes these larvae from leafrollers. Fully grown larvae are 2 cm (7/8 inch) long and have three white stripes on each side.

Photographed by Jim Troubridge

Bruce Spanworm or Winter Moth larva

Winter Moth hind wing spot absent

Winter Moth adult

When larvae have finished feeding they drop to the ground and pupate in the soil. Male moths fly during winter in November, December and sometimes January. Although the female moths are flightless, larvae may be carried by the wind and eggs and larvae can be inadvertently transported in or on vehicles or containers. Spanworm adults generally emerge one to two weeks later in the fall than winter moths. There is one generation per year of both species.

Detection: Spanworm males can be separated from winter moth males by the presence of a small dot on the hind wing of the spanworm that is not seen on the winter moth. Since the same pheromone attracts males of both species, it is possible to trap them from November to January. However, the pheromone is difficult to synthesize and rarely available.

Winter moth or spanworm larvae can be detected during monitoring for blackheaded fireworm. Winter moth/spanworm larvae make tents similar to those made by fireworm larvae. Winter moth/spanworm larvae are most often found near infested deciduous trees or blueberries. The larvae can look similar to blackheaded fireworm in early stages.

Management: Chemical control is usually not necessary but, if high populations are found, insecticides recommended for fireworm can also provide control of winter moth/spanworm larvae. Larvae and pupae of both species are subject to attack by parasitic and predatory insects. Pupae may or may not be killed by flooding at harvest.

Straw-coloured Tortrix adult

Straw-coloured Tortrix larva

STRAW-COLOURED TORTRIX

Clepsis spectrana

Pest Status: This leafroller, which attacks other fruit crops such as raspberry, strawberry and currant as well as white spruce and white cedar in the Pacific Northwest, is found occasionally in cranberries in British Columbia.

Life cycle and feeding habits: Larvae are dark chocolate-brown with tiny yellowish dots on segments along the side. Mature larvae are 12 - 15 mm (1/2 - 2/3 inch) long. Larvae have three pairs of front legs and five pairs of hind legs. Adults are nocturnal and readily attracted to lights. They fly from late March until early August.

Larvae have been seen feeding on tips of hardhack (spirea) on dikes. They roll and tie terminal leaves together and feed within this protected site. Larvae found in March have apparently overwintered from the fall generation of the previous year. Those found from May to August represent the current year's generations. There are two to three generations a year in British Columbia.

Detection: Larvae can usually be detected during blackheaded fireworm monitoring.

Management: There are no insecticides registered for this insect on cranberry. Insecticides against blackheaded fireworm will likely provide some control.

Photographed by Jim Troubridge

Fall Fruitworm adult

Photographed by Kim Patten

Fall Fruitworm larvae, pupa covered with cranberry seeds, and adult

FALL FRUITWORM

Lotisma trigonana

Pest Status: Fall fruitworm is rarely a pest in British Columbia.

Life cycle and feeding habits: This moth has been considered a serious pest of cranberry in Washington and Oregon since 2000, and has been detected in small numbers in British Columbia. Adult moths lay 0.5 mm eggs on the calyx of the fruit in mid-late summer. When larvae hatch from these eggs, they tunnel into the berries and feed on the seeds and pulp, exploiting 2 - 3 berries.

Larvae have also been observed to feed on foliage when travelling between berries. Older larvae have an amber head, light beige body and rows of dots behind the head. Once finished feeding, larvae pupate within the fruit or drop to the soil. Infested berries turn black on the outside and brown inside.

Detection: There are currently no monitoring protocols for this moth. Feeding larvae are usually detected during harvest.

Management: There are several reported parasitoid species throughout the U.S., but currently none for British Columbia. It is likely that insecticide recommendations for blackheaded fireworm would also provide control for the fall fruitworm.

Photographed by Jim Troubridge

Alfalfa Looper adult

Oregon State University, Ken Gray Collection #G58-3

Alfalfa Looper larva

ALFALFA LOOPER

Autographa californica

Pest Status: The alfalfa looper has many host plants and larvae are often found on dry-pick farms.

Life cycle and feeding habits: This insect is primarily an alfalfa pest but can be found in garden crops, horticultural crops, ornamental trees and tree fruits. The damage is caused by the larvae, which move like spanworms by arching their backs. Alfalfa looper larvae have three pairs of front legs and three pairs of hind legs. Larvae may be seen in cranberry in June and July. Larvae are light green with a narrow light stripe on each side of the body, two light stripes along the back and a pale head. Mature larvae are about 2.5 cm (1 inch) long. The moth's forewings are grey with a distinct silver, sickle-shaped spot near the middle of each wing. The body and hind wings are dull grey or brown. These moths appear all summer long due to overlapping generations.

Detection: Areas of infestation may be characterized by defoliation and discolouration. Infestations would likely be detected when scouting for blackheaded fireworm.

Management: Chemical control is usually not necessary, but if many larvae are detected, a registered insecticide for climbing cutworms is recommended. Consider spot-spraying if the infested area can be defined. Damage will be minimized if larvae are detected soon after hatching and insecticide is applied in the evening. Insecticides are most effective on small larvae.

Ochropleura adult

Ochropleura larva

Ochropleura implecta

(no common name)

Pest Status: This pest has caused economic damage on dry-pick farms in Richmond, British Columbia.

Life cycle and feeding habits: Moths fly, mate, and lay eggs from mid-May until late June, and again from late July until late August. Eggs are laid singly or in small groups on cranberry foliage, and hatch in about 10 days. Young larvae are dark chocolate-brown with a white lateral stripe and mature larvae are paler brown with a beige lateral stripe. Mature larvae are 2.5 cm (1 inch) long. Larvae have three pairs of front legs and five pairs of hind legs.

Larvae feed at night and are particularly fond of berries. They partially consume unripe and ripe berries in July and August.

Detection: Sweep at night for larvae in early June. Moths are attracted to pheromone traps for blackheaded fireworm and to light traps.

Management: If many larvae are detected, a registered insecticide for climbing cutworms is recommended. Consider spot-spraying if the infested area can be defined. Damage will be minimized if larvae are detected soon after hatching and if insecticide is applied in the evening. Insecticides are most effective when larvae are small.

Photographed by Jim Troubridge

False Armyworm adult

Photographed by Jim Troubridge

False Armyworm larva

FALSE ARMYWORM

Xylena nupera

Pest Status: This pest is not common on cranberries in British Columbia.

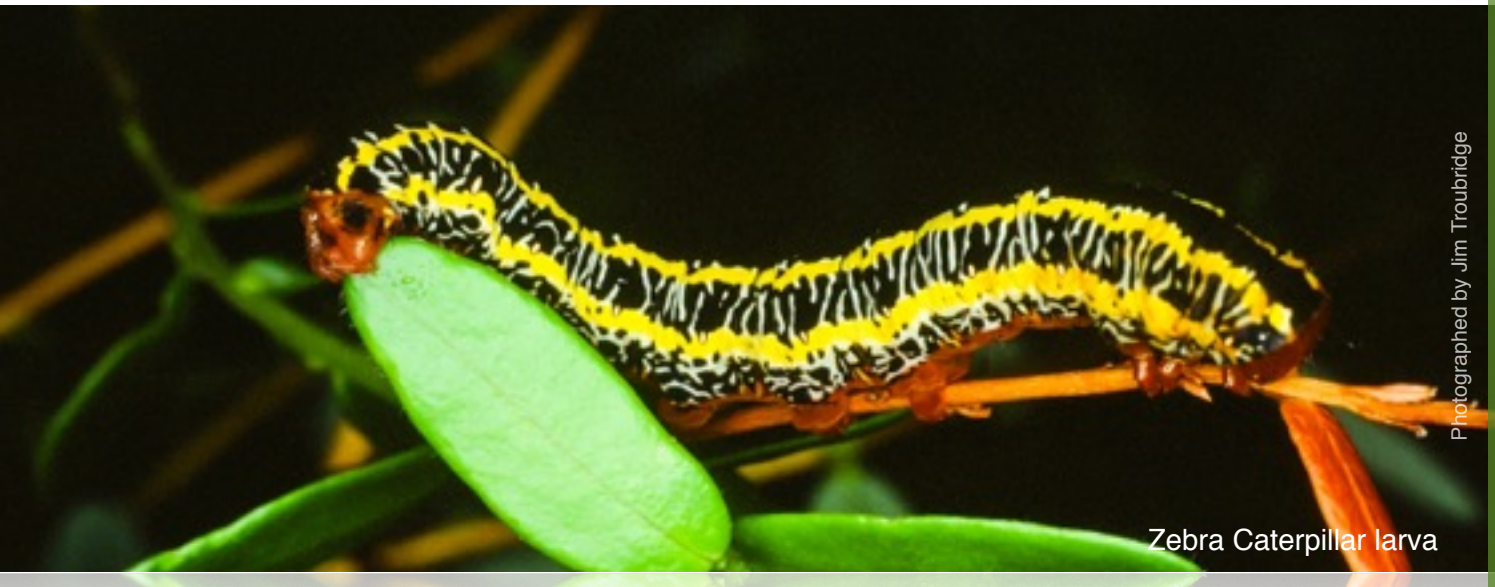
Life cycle and feeding habits: False armyworm moths emerge in September, overwinter and fly again in spring. Females lay their eggs in late April or early May, and eggs hatch during the second and third week of May. Newly hatched larvae are whitish with many black spots. Young larvae feed freely during the daytime. Larvae have three pairs of front legs and five pairs of hind legs. Larvae feed nocturnally as they mature in late June. They vary in colour from green with whitish lines along the back and sides when young to grass green to dark brown or black when mature. At maturity, they are 5.1 cm (2 inches) long. Mature larvae remain dormant in the ground for 2 - 6 weeks before pupating. There is only one generation of false armyworms per year. They are voracious feeders, consuming all new growth. Other host plants include apple, wild cherry and many weeds.

Detection: Young larvae may be detected feeding on terminal buds during monitoring for fireworms. As larvae mature, sweeping at night is the most effective monitoring technique.

Management: Chemical control is usually not necessary, but if many larvae are detected, a registered insecticide for climbing cutworms is recommended. Consider spot-spraying if the infested area can be defined. Damage will be minimized if larvae are detected soon after hatching and insecticide is applied in the evening. Sprays are most effective when larvae are small.

Photographed by Jim Troubridge

Zebra Caterpillar adult



Photographed by Jim Troubridge

Zebra Caterpillar larva

ZEBRA CATERPILLAR

Melanchra picta

Pest Status: Larvae are occasionally found on cranberries but prefer to feed on weeds, especially blackberry.

Life cycle and feeding habits: This cutworm spends the winter as a partially grown larva. The adults emerge in spring and lay eggs in clumps on leaves. There is only one generation per year. Larvae have very conspicuous yellow stripes running along each side of the body separated by alternating black and white stripes running around the body. Larvae have three pairs of front legs and five pairs of hind legs. Larvae can reach more than 3 cm (1.25 inches) in length. They feed on foliage.

Detection: Larvae may be found during monitoring for blackheaded fireworm larvae.

Management: Chemical control is usually not necessary. If many larvae are detected feeding on cranberry plants, a registered insecticide for climbing cutworms is recommended. Consider spot-spraying if the infested area can be defined. Damage will be minimized if larvae are detected soon after hatching and insecticide is applied in the evening. Insecticides are most effective when larvae are small. The tachinid *Winthemia quadripustulata*, a beneficial insect, is known to parasitize zebra caterpillar larvae.

Rusty Tussock Moth larva

RUSTY TUSSOCK MOTH

Orgyia antigua

Pest Status: When present, rusty tussock moth can damage large patches of cranberry vines.

Life cycle and feeding habits: Young larvae hatching in the spring are 4 - 7 mm (1/4 - 3/8 inch) long, while mature larvae are around 3 cm (1.25 inches) long. The larvae are very colourful and distinctive with tufts of bristle like hairs along the back. Larvae have three pairs of front legs and five pairs of hind legs. Larvae feed on blossoms and upright tips for several weeks in the spring. The female moth does not fly, but emits a strong pheromone that is very attractive to male moths. Moths emerge in mid-summer, then mate and lay eggs that overwinter. There is only one generation per year. Infested fields may become increasingly populated if females are left to "call" in males from adjacent fields or forested areas. Cranberry beds become infested by windborne young larvae which disperse on long silk threads from adjacent forests. The long fine body hairs allow larvae to be carried by air currents for as much as 500 metres (1600 feet). Infestations in cranberry beds are patchy and may occur in the same area year after year.

Detection: Larvae are usually detected during monitoring for second-generation blackheaded fireworm. Headlands and ditch vegetation may be a source of crawling larvae. It is recommended to watch for outbreaks in surrounding forests or tree stands. Early detection is important, because most damage is done by mature larvae. Feeding is usually observed in patches, which may appear darker in colour than surrounding foliage and have fewer blossoms.

Management: Insecticides applied to target second-generation blackheaded fireworm larvae may also reduce the numbers of rusty tussock moth larvae.

Rusty Tussock Moth pupa

Photographed by Jim Troubridge

Rusty Tussock Moth adult male

Photographed by Jim Troubridge

Rusty Tussock Moth adult female

Dearness Scale female aggregation

DEARNESS SCALE

Rhizaspidiotus dearnessi

Pest Status: When it is present, Dearness scale can become a serious pest.

Life cycle and feeding habits: Scales are soft-bodied orange insects, covered by a beige or white scale resembling a clam shell. Females are more rotund and globular than the longer and flatter males, because females are usually filled with eggs. The protected males and females overwinter on the vines, with crawlers (first stage mobile immatures) usually beginning to hatch from eggs in June. Crawlers are bright orange to yellow and very small, not usually visible to the naked eye. They can be observed with a dissecting microscope, and are approximately 0.3 mm long. As the crawlers mature within the female, they emerge sequentially from a slit in the protective shell over about four weeks. They then begin wandering along vines, or are dispersed by wind, and settle to begin feeding on a plant stem within one to three days. Once stationary,

Dearness Scale

Dearness Scale female adult

Photographed by Miranda Elsby

Crawlers emerging

Photographed by Miranda Elsby

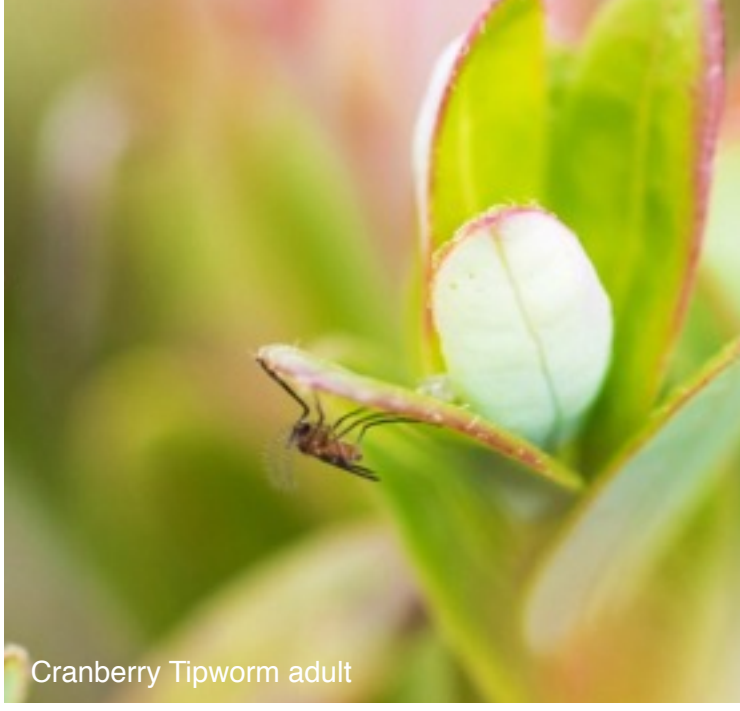
Crawlers emerging

crawlers form their own thin protective shell. They settle singly or in clusters along the vine and, sometimes, on ripening fruit. Crawlers insert needle-like mouthparts and feed continuously. Adult male scales are winged and mobile, and seek out the stationary females for matings.

Detection: When scale infestations are heavy, vines can turn red and become brittle. Patches of red/brown dying vines or a thin canopy can indicate an infestation, but close inspection of the vines is a more reliable diagnostic measure. The white/beige clamshells should be easily observed against the dark colour of the vine, and will be found singularly or clustered. The white scale can be pulled away to reveal the orange/yellow insect within. The colour contrast between scale and vine is especially evident when plants are wet.

Management: Naturally occurring biological controls of dearness scale are usually present in the field, including the parasitic wasp *Coccidencyrtus dearnessi.* A scale from which a parasitoid has emerged will have a small pinhole on the outer shell. Insecticide applications during the flight period of this natural enemy likely increase scale outbreak severity.

Cupped shoot contains larvae



Cranberry Tipworm adult

Cranberry Tipworm eggs

CRANBERRY TIPWORM

Dasineura oxycoccana

Pest Status: Cranberry tipworm has become a major pest since it was first observed in British Columbia in 1998.

Life cycle and feeding habits: The adult cranberry tipworm is a small midge, with a body length of approximately 1 - 2 mm (1/32 - 1/16 inch). The tipworm adult emerges from overwintered pupal stages in the debris litter of fields throughout the growing season, and the female lays its tiny eggs in the tips of cranberry upright shoots.

The life cycle of this insect includes egg, three larval instars, a pupal stage, and adult, with several overlapping generations in a growing season, making it difficult to predict population peaks and patterns. Individuals take several weeks to develop from egg to adult. As the tipworm larvae develop from small whitish first and second instars to orange third instars, they use their mouthparts to feed on the tender meristem tissue of the cranberry bud. The pupa forms a silken cocoon on the inside of the damaged cranberry leaf, and emerges as an adult tipworm. Some larvae drop to the soil to pupate, overwinter, and emerge in the following year.

Most of the damage caused by tipworm infestation is done during the second and third larval stages, when the immatures are aggressively feeding on the bud of the upright shoot. As the tipworm larvae feed, leaf and bud

Cranberry Tipworm pupa

Cranberry Tipworm 3rd instar

Cranberry Tipworm 2nd instars

tissues are damaged, causing stunting, distortion, and sometimes death. Damage to apical buds stimulates lateral vegetative shoots, thereby reducing the number of flowering shoots in the field. This extra lateral shoot growth is especially damaging if done late in the growing season, as the plant has no time to regenerate flowering shoots to bear fruit for the subsequent year's harvest.

Detection: Cranberry tipworm can be a difficult pest to monitor because symptoms are often not observed until after damage has occurred. Cupped, puckered, silvery leaves at the tips of cranberry shoots indicate that a second or third instar larva is feeding within. Collect cranberry shoots from the field and open them on the stage of a microscope (10 to 20 x magnification) to see eggs, larvae, and pupae.

Management: Insecticide sprays have historically targeted adults flying around to mate and lay eggs, rather than the larval stages which are protected within the cupped cranberry shoot. However, chemical management tools have progressed to include systemic options which target feeding larval stages. Used according to label instructions, after pollinators have left the field, registered systemic insecticide provides effective control of cranberry tipworm. There are several known natural enemies of cranberry tipworm, including four parasitoids known by their species' names *Aprostocetus*, *Platygaster, Ceraphron,* and *Inostemma*. Although they are not available commercially as a means of control and little is known about their ability to suppress tipworm populations, they should nonetheless be treated as an important component in bog diversity.

Rodent path

Rodent tunnel

RODENTS

Pest Status: Rodents, usually voles, are present in and around most cranberry fields. The majority of rodent damage and tunnelling in cranberry vines is believed to be caused by the Townsend's vole (*Microtus townsendii*).

Life cycle and feeding habits: Townsend's voles are common in wetland and grassland meadows. They can be up to 24 cm (9 inches) in length, with dark brown/black-tipped fur, grey underbellies, and small ears. They can reproduce frequently between the months of April and October, and will maintain high populations when environmental conditions are optimal. Lowest population densities are usually observed in winter and spring, with a rapid increase in summer and fall during times of peak reproduction. They can establish a large network of overlapping tunnels and burrows, using them for protection, feeding, storage, travelling, and nesting. Examination of the burrows and runways will often show fecal droppings, and evidence of feeding on old berries and clipped plants. Perennial crops like cranberries may show continual increases in vole populations as well as crop damage because burrow networks are left undisturbed by tillage practices such as plowing.

Voles may feed on leftover cranberries that have fallen beneath the vines post-harvest, and on other herbaceous plants, grasses, seeds, tubers, and rhizomes. They may also occasionally

Partly consumed cranberries in rodent tunnel

eat snails, insects, or animal remains. Their feeding habits are mainly determined by seasonal food availability, with herbaceous plants and grasses being favoured in spring and summer, seeds in late summer and fall, and woody plants in winter. Winter feeding on the woody vines may not be immediately detected until next season once stem girdling is more apparent.

Detection: Vole trails beneath cranberry vines are a good indicator that the rodents are frequenting the area, possibly gnawing on vines and injuring plants. Patches of dying vines could be indicative of feeding, and could easily be mistaken for cranberry girdler damage. Looking for chewing marks and other indicators such as girdler frass or larvae will help distinguish between vole and girdler damage. Vole feeding marks are usually non-uniform with various angles, dispersed in random patches. These patches may look similar to those caused by girdler or weevil larvae.

Management: Large population fluctuations make pest pressures difficult to predict. Many voles are active during the day and night, and do not hibernate. They are usually strong swimmers and sometimes good climbers, and serve as prey for other wildlife such as snakes, predatory birds, and coyotes. Mowing dikes and ditch areas can help to destroy vole and other rodent habitat, while exposing the rodents to predatory birds and mammals.

Rodent chewing on crown of cranberry plant

Cranberry Girdler larva, chewing damage, and frass

CRANBERRY GIRDLER

Chrysoteuchia topiaria

Pest Status: Cranberry girdler is a serious pest in cranberry beds, and in turf, lawns and young conifer plantings

Life cycle and feeding habits: Young larvae feed on soft tissues such as crowns, leaves and roots of grasses. Mature larvae feed on the bark of cranberry roots and crowns, girdling or severing the roots in the process. They do most of their damage in late August to early September. This pest is reported to overwinter as a mature larva wrapped in a silk cocoon covered with soil. Evidence suggests that in British Columbia, pupation may occur in fall and pupae may overwinter. There is usually only one generation of per year but, in warm years, a second flight of girdler moths may occur in late summer. Most moths emerge from the soil and take flight from early June until mid-July. They are about 1.3 cm (1/2 inch) long with straw-coloured forewings fringed with silver, and showing three dots along the outer edge. Eggs are scattered on the trash of the cranberry beds during the flight period. The larvae emerge after 4 - 14 days, depending on temperature. Newly hatched larvae are about 1.5 mm (1/16 inch) long. Larvae mature to 1.3 cm (1/2 inch) after several weeks, and chew on the bark of roots and underground stems, girdling and severing vines.

Cranberry Girdler eggs


Photographed by Jim Troubridge
Cranberry Girdler pupa


Cranberry Girdler adult

Detection: Patches of many dead or dying uprights in late summer and early fall may indicate girdler damage. Damaged roots and larvae can be found by peeling back dying vines on a warm afternoon and digging carefully in the upper 5 cm (2 inches) of soil and trash. Girdler larvae leave characteristic brown to orange sawdust-like frass. Pheromone traps and walking counts are typically used to detect and monitor moths. Adults are most likely to be active on warm days (above 16°C) with low wind speeds (0 - 6km/hr in the bed), and can be observed flying up when walking through beds.

Management: Nematodes can be applied 2 - 4 weeks after peak flight to control young larvae. The recommended rate varies from 1 - 3 billion per acre (2.5 - 7.5 per hectare). Larvae can be drowned by flooding beds in August, but this flooding greatly increases the risk of fruit rot on producing beds. Flood water should be deep enough to cover the highest weeds, because larvae crawl up them to escape, and should be left on the beds for 24 - 48 hour. Flood-harvesting in early September may kill larvae that have not yet spun their cocoons and become impervious to flooding.

Older beds with a thick trash layer and little sand tend to have the most serious infestations. Regularly sanded beds tend to have fewer girdler problems, probably because the sand covers fungi, moss and small plants on which young larvae feed. Sand may also be abrasive and damaging to larvae. Observe dikes and grass areas surrounding the beds as a possible source of infestation.

Black Vine Weevil adult

BLACK VINE WEEVIL

Otiorhynchus sulcatus

Pest Status: This is the most common weevil pest in cranberry beds.

Life cycle and feeding habits: The adult black vine weevil is a black snout beetle about 8 - 9 mm (1/3 inch) long. Adults emerge from pupal cells in the soil from mid-June to the end of June; some adults may live through the winter. Adults feed on foliage for 4 - 6 weeks before egg-laying begins. Black vine weevils are all flightless females so there is no mating before egg-laying. Eggs are laid at the soil surface during the summer beginning in July and hatch within 2 - 3 weeks. The newly emerged larvae descend to feed on rootlets and, later, on the larger roots and root bark. The larvae are white, legless, have brown heads, and often curl their bodies into the shape of the letter C. They feed from the time of emergence until pupation the next spring. They may be inactive during very cold spells in winter. There is only one generation per year.

Detection: In spring and fall, the larval population of black vine weevils can be monitored by rolling back damaged vines and looking through the top 5 cm (2 inches) of soil for girdled vines and larvae. Mature larvae are about 8 - 9 mm (1/3 inch) long in spring. In fall, they are younger, smaller and harder to see. Larvae can completely girdle roots up to the crown of the plants. Damaged vines look similar to cranberry girdler or rodent-damaged vines, but lack the frass left by girdler larvae at feeding sites. Symptoms of damage (wilting, weakening, browning, death) begin to appear in

Photographed by Wes McDiarmid

Black Vine Weevil larva

May or June and intensify through the season. Monitoring for weevil adults is done using a sweep net. On warm, still nights after dusk in early July, sweep beds once or twice a week until eggs begin to mature within the adult weevil and egg-laying begins. To determine the presence and maturity of eggs within an adult weevil, pinch the abdomen of about 10 weevils and look for spherical white eggs. When the weevil is ready to lay eggs, its entire abdomen contains eggs and little else. Weevil detection can also be done by observing alternate vegetation in the vicinity of the cranberry bed. If present, characteristic leaf-notching caused by feeding adults will be readily seen on plants such as salal. Notching on cranberry can be difficult to see.

Management: When flood water is used during harvest, most weevil larvae will be drowned. On dry-pick farms or young, unharvested beds, weevil larvae and pupae can be drowned by flooding beds in winter. Hold water on the bed for 2 - 4 weeks, if the plants can safely sustain water for that long. Re-infestation can occur by recycling flood water containing weevils from one bed to another.

Entomophilic nematodes, which are biological control agents, can be applied in spring (May) and in fall (September) to target black vine weevil larvae in the soil. Soil temperatures should be at least 13°C and lots of irrigation applied to the bed before and after nematode application.

Black Vine Weevil root damage

Strawberry Root Weevil

Root Damage

Strawberry Root Weevil adult

STRAWBERRY ROOT WEEVIL

Otiorhynchus ovatus

Pest Status: This weevil is often found with black vine weevil and causes damage if populations are high.

Life cycle and feeding habits: Adults are about 4 - 5 mm (1/5 inch) long (half the size of the black vine weevil). Adults are shiny black with thinly scattered yellowish short hairs, reddish-brown antennae and legs, and coarse, deep, punctures on the wing covers. Like the black vine weevil, the wings are fused making the weevils flightless. No males have been found. Strawberry root weevils have a life cycle similar to black vine weevils. Larvae feed on small roots and on bark of larger roots in a manner similar to the larvae of black vine weevil. Like the black vine weevil, other hosts include some small fruits, fruit trees, shrubs, and many conifers in nurseries and plantations.

Detection: Adults are usually detected during night sweeping.

Management: Techniques used for black vine weevil will also help to manage strawberry root weevil. Mature larvae may be suppressed in spring and summer with nematode applications. Spot treatments can be applied if cost savings are a consideration. For spring applications, a cold-tolerant nematode should be applied. Weevils are not usually a problem in water-harvested beds, and can typically be suppressed by holding the flood waters for at least 7 days after harvest.

Photographed by Jim Troubridge

Clay-coloured Weevil adult

CLAY-COLOURED WEEVIL

Otiorhynchus singularis

Pest Status: This weevil is not as common as black vine or strawberry root weevils. It has only been found on beds not flooded at harvest or during dormancy. If numerous, clay-coloured weevils could cause damage.

Life cycle and feeding habits: Clay-coloured weevils are intermediate in size between strawberry and black vine weevils, and have a mottled, clay-coloured exterior that may look black when wet.

Adults emerge very early in spring, when the other two species are still larvae or pupae; egg-laying by clay coloured weevils also precedes the other two species. Larvae feed on cranberry roots. Adults feed on the foliage of cranberries and other plants. There is one generation per year.

Detection: Clay-coloured weevil adults can be detected very early in the spring because they overwinter as nonfeeding, soft-bodied adults while the other two species are still larvae and pupae. Sweep from the middle of April through June to detect clay-coloured weevil adults.

Management: To control clay-coloured weevil larvae, nematodes would need to be applied approximately 4 - 6 weeks after mature eggs are found in adults.

Cranefly larva

CRANE FLY

European *Tipula paludosa*
Marsh *Tipula oleracea*

Pest Status: These insects are potential pests of cranberry. Larvae are commonly called leatherjackets.

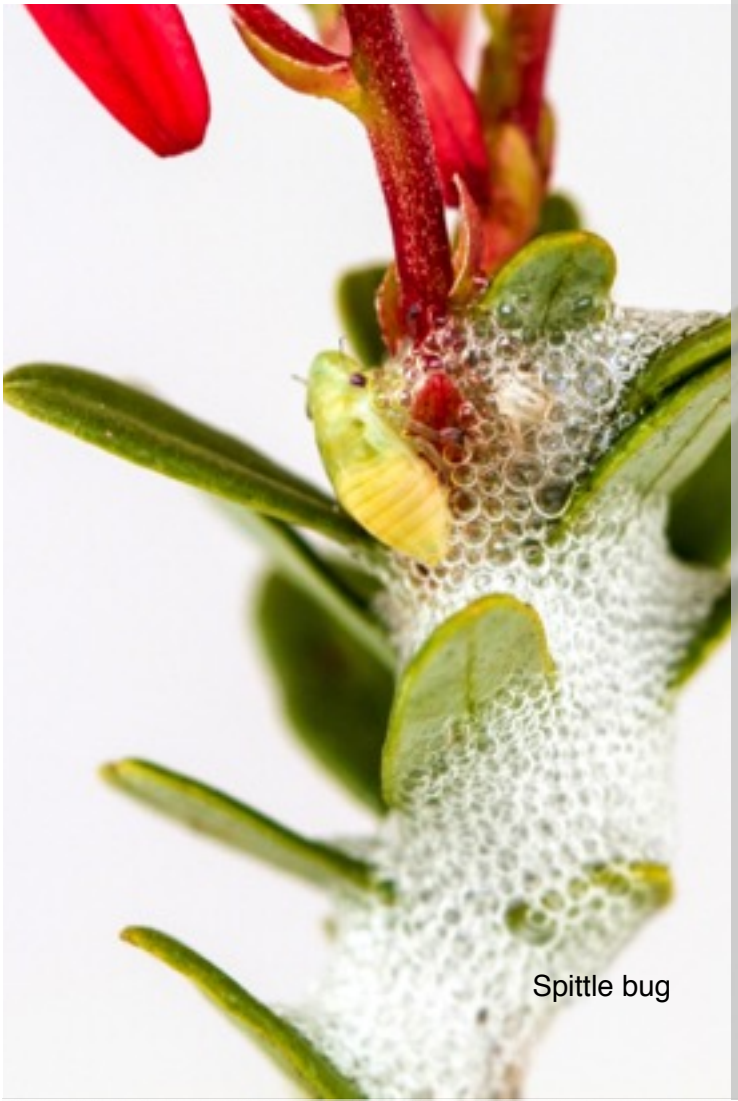
Life cycle feeding habits, and detection: European crane fly adults emerge, mate and lay eggs in late August through September. Eggs hatch during the fall and larvae begin feeding on the roots and crowns of turf. Larvae overwinter and continue to feed in spring. In about mid-May, depending on weather, they stop feeding and pupate, staying underground in a non-feeding stage until they emerge as adults in August and September. Marsh crane flies emerge in April as well as in the fall. Following the emergence of marsh crane flies, egg-laying and larval development occurs. Larvae of both species have a tough, grey/brown skin and a cylindrical body tapered at both ends. Larvae chew and feed on the roots and crowns of grasses. Marsh crane flies may be seen flying over the vines in spring, early summer, and fall whereas European crane flies are only seen in late summer or fall. Larvae are usually found in the roots of grasses and sedges.

MEADOW SPITTLE BUG

Philaenus spumarius

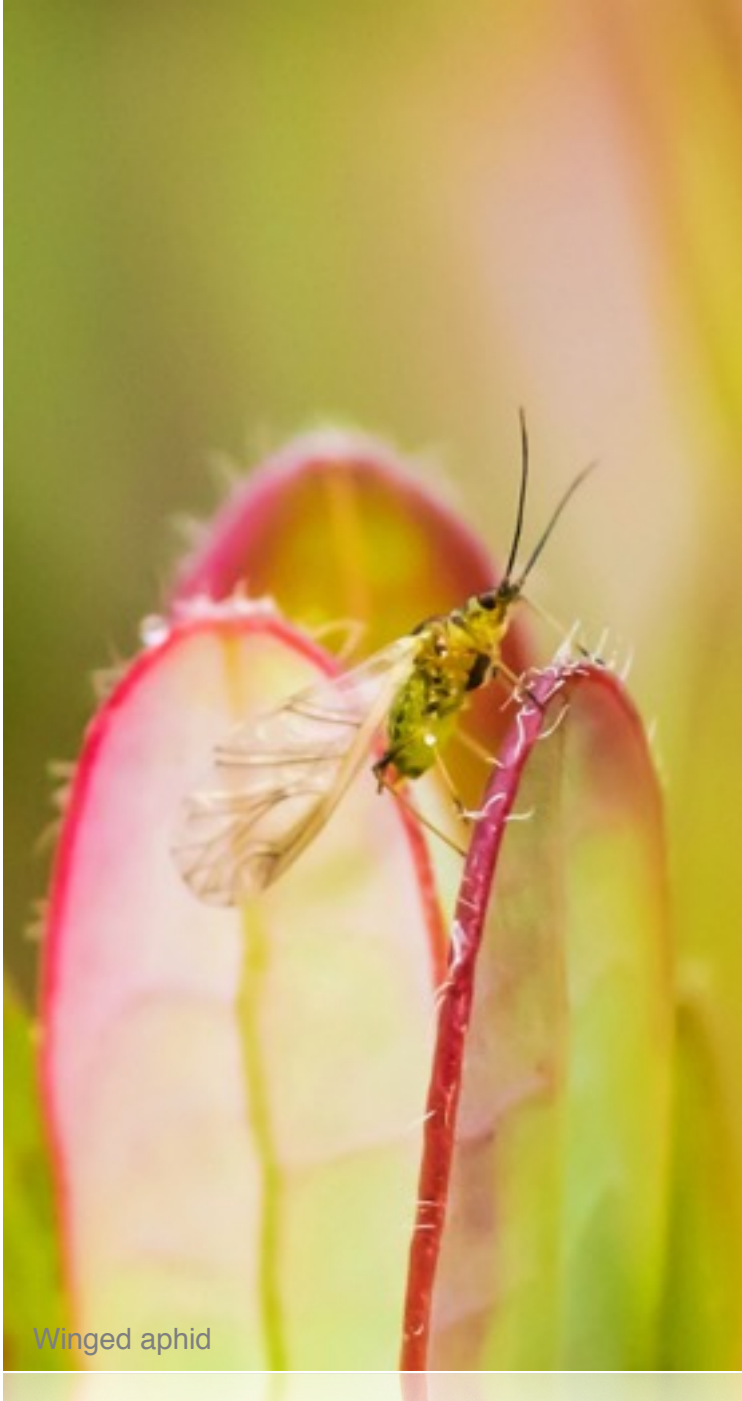
Pest Status: This insect is sometimes observed but is not known to cause serious damage to cranberries in British Columbia.

Life cycle, feeding habits, and detection: The nymphs live in white masses of spittle which they form around themselves on the plant stem. When fully grown, spittle bug nymphs are about 6 mm (1/4 inch) long and are yellow to orange. They suck sap from cranberry shoots. The adults, which do not form froth shelters, feed on the vines in a similar manner. There is only one generation per year. These insects overwinter as eggs in the bark of cranberry vines. Eggs hatch in early spring and the first spittle masses, containing the nymphs, occur in late April to May. Adults appear in late May and are present until late fall. Eggs are laid from July until the first frost. The adults are wedged-shaped, greyish brown insects with short, blunt heads and large eyes. Adults measure about 6 - 10 mm (1/4 - 3/8 inch) long. They jump and fly readily.



Spittle bug


Aphid immatures


Winged aphid

APHID

Ericaphis fimbriata

Pest Status: This species of aphid is observed on cranberry but is not a pest at this time.

Life cycle and feeding habits: In spring, first instar female aphids hatch from overwintered eggs. First and subsequent instars insert their mouthparts into succulent leaf and bud tissue, and feed by sucking up plant sap. Aphids develop through four wingless instars and then emerge as adults, which can be winged or wingless. Generally, winged adults are more likely to develop from dense clusters, whereas wingless adults develop from sparser populations. During spring and summer, all aphids are females that reproduce without mating. The aphids can be green or coral pink in colour.

In fall, winged male adults, as well as winged and wingless female adults, are produced. Mating occurs and shiny black eggs are laid. These eggs overwinter. Feeding by aphids on cranberry does not cause noticeable damage. On highbush blueberry, *Ericaphis fimbriata* is a known vector of Blueberry Scorch Virus, but this virus is not a current problem in cranberry.

Detection: Aphids are usually seen during spring monitoring for blackheaded fireworm and other foliar pests.

Management: Targeted management strategies are not needed because aphids have many natural enemies. Ladybird beetles, lacewings, harvestmen and larvae of syrphids feed on all stages of aphid. A number of species of parasitoids, notably the wasp *Praon unicum*, lay eggs within aphids and develop by feeding on aphid body tissue.

Parasitic wasp adult

Round “mummy” contains a developing wasp

Parasitic wasp adult

PARASITIC WASPS

Parasitic wasps, also called parasitoids, are naturally present on cranberry farms. Four types of wasp are described here.

Adult ichneumonid wasps are slender insects with long abdomens. They almost always have a permanently protruding ovipositor that can be several times longer than the body. Ichneumonids use the ovipositor to deposit one or more eggs on or inside the host. Ichneumonids range from 5 - 36 mm (1/4 - 1.5 inches) long and vary in coloration. Ichneumonids are mostly parasitic on the eggs and immature stages of a variety of insects and spiders. The growing larvae devour the host from within and emerge either when ready to pupate or as adults.

Trichogramma wasps are very tiny insects, 0.3 - 1.0 mm (1/16 inch) long. They use their ovipositor to insert one or more eggs inside a host egg, which develop and emerge as adults.

Braconid wasps range from 2 - 15 mm (1/8 -5/8 inch) long. The adults are similar in appearance to ichneumonid wasps but their bodies are stouter, usually black and the ovipositor is seldom carried outside the body until it is needed for oviposition. They are important control agents and parasitize a number of different insects like aphids, caterpillars, weevil larvae, flies, true bugs, sawflies and other wasp-like larvae. Aphids parasitized by braconids are recognizable by their golden/silvery or black colour and its parchment-like texture, often referred to as a “mummy”.

Eulophids belong to a group of tiny insects 1 - 3 mm (1/16 - 1/8 inch) long. They parasitize a number of crop pests. This is a biologically diverse group, with some species attacking mites (as predators), spider egg cases, scale insects, and thrips, but most attack beetle or moth larvae or pupae, flies, other wasps, and sometimes leafrollers.

Ladybird Beetle adult

Ladybird Beetle larva

LADYBIRD BEETLE

Ladybird beetles are among the most familiar beetles occurring in British Columbia. Their often bright colourings — red or orange with black spots — advertise their “bitter” taste to possible predators. The female beetle deposits her yellow-orange eggs in clusters of 10 – 50 on foliage near a food supply. The emerging larvae are elongated and spindle-shaped. They often are brightly banded in patterns that identify the species.

Larvae do not resemble adults and are easily seen on cranberry foliage or on weeds in the beds. A full-grown larva can consume about 50 aphids in one day. An adult female needs up to 100 aphids before reproducing and will feed on approximately 2000 aphids in her lifetime, which can last 1-2 months during warmer seasons.

Adult beetles are very mobile and actively search for food. They are attracted by large numbers of aphids and increase their reproductive rates accordingly — up to 100 eggs per female. It takes 20 - 35 days for an egg to develop into an adult.

Ladybird beetles are predaceous both as adults and larvae. They prey mostly on aphids and on young scale insects. The larvae have also been observed to feed on small caterpillars like blackheaded fireworm as well as on each other. In cranberry beds, ladybird beetle larvae have been seen attempting to pry open fireworm tents using their legs and mandibles. Ladybird beetles are often found overwintering in large swarms of adults under leaves and debris or in buildings.

Syrphid larva

Syrphid adult

SYRPHID

Adult syrphids, also called hover flies, mimic the movements and colourings of bees and wasps. These colours warn potential predators away from bees and wasps, and accomplish the same effect for the harmless syrphid flies that possess no stinger. Adult syrphids feed on pollen, nectar and the sugary secretion called “honey dew” produced by aphids. The adult female moves up and down a plant, searching for aphids while hovering in one spot. After the female has located a colony, she deposits the eggs in small batches among the aphids. Depending on the species, the female lays between 400 - 1000 oblong, white eggs that hatch after a few days. Larvae are very efficient predators. They hunt for aphids by raising the front part of their bodies and swinging back and forth until they bump into their victim.

On contact with an aphid, the larva uses its mouthparts to pierce the aphid and suck it dry. One syrphid larva can destroy up to 400 aphids in its 7 - 10 days of life. Larvae pupate in the soil or rolled-up leaves. Metamorphosis takes about 7 - 8 days, after which the adult flies emerge. Depending on the climate, 3 - 7 generations a year are possible. Syrphids also play an important role as pollinators and can often be observed in and around cranberry beds.

Syrphid fly larvae can be easily mistaken for caterpillar pests. A key difference between syrphid larvae and other pest larvae (such as Sparganothis fruitworm or blackheaded fireworm) is the absence of a brown or black head capsule, and the signature swaying movement as the syrphid larva makes its way up and down the cranberry shoot.

Bee Pollination

BEE POLLINATORS

Bees are the primary pollinators of cranberry. For fruit set to occur, cranberry flowers require a small amount of pollen to be deposited on the stigma. When more pollen is deposited on the stigma, more seeds will result. The more seeds a berry has, the larger the fruit will be. Poor pollination has a negative effect on fruit size and crop yield. Bumble bees and honey bees are the main pollinators of cranberry.

Bumble bees are the most important native pollinators of cranberries in British Columbia. Bumble bees are robust, hairy bees with black, white and yellow and/or orange markings. Bumble bees forage for both nectar and pollen on cranberry, usually simultaneously. To collect pollen, they hold onto the flower with their legs and vibrate their wing muscles, causing the release of a cloud of pollen that sticks to the bees' ventral surface. When the stigma of a flower touches pollen on the bee's body, transfer occurs. Bumble bees are social insects and build their nests in the ground, where the mated queen overwinters in the soil while the rest of the colony dies at the onset of cold weather.

Apis mellifera, the only honey bee species in North America, is valued for the honey it produces. Honey bees forage on cranberry mostly for nectar. They harvest pollen by drumming the anthers of cranberry blossoms with their forelegs which causes pollen to be released. Like bumble bees, honey bees are social insects. They build nests in which both workers and the queen overwinter. When a colony gets too large, a swarm consisting of the old queen and many workers will leave the hive to find a new home. Due to their complicated communication system, honey bees are able to inform their sister workers of the exact locations of food sources. Honey bees prefer other forage to cranberries. Blackberries, false dandelion and clover are very attractive to honey bees and thus compete with cranberries for honey bee pollination.

Calligrapha californica adult

BEETLES

The two most commonly occurring ground beetle species in British Columbia cranberry beds are the common black ground beetle (*Pterostichus* spp.) and the European ground beetle (*Carabus nemoralis*). The beetles range in size from 3 - 36 mm (1/8 - 1.5 inches) and are often dark and shiny or brightly coloured and iridescent with striated or grooved wing covers. Ground beetles are mostly nocturnal hunters. They are predaceous as both adults and larvae and feed mostly on soft-bodied insects like caterpillars and weevil larvae.

Two species of herbivorous beetles in the family Chrysomelidae have been observed feeding on weeds in cranberry fields in British Columbia: *Calligrapha californica* and *Altica sp.*

DRAGONFLY

Dragonflies are usually colourfully patterned with two pairs of long, membranous wings with numerous cross-veins. Dragonflies are very strong fliers, making them exceptional aerial predators. They prey on a wide range of flying insects, usually captured mid-flight. Their prey includes mosquitoes, moths, gnats, flies, and any other flying insect they are able to capture. Females lay their eggs on plants near or in the water. Immature stages are aquatic, and feed on mosquitoes, tadpoles, and even small fish. Males can be territorial when searching for potential mates.

Dragonfly adult

HARVESTMAN

Harvestmen, also called daddy long-legs, are arachnids like spiders. Spiders have two body parts, two fangs, and produce silk. Harvestmen have one oval body part, no fangs, do not produce silk and have eight extremely slender legs. Harvestmen are rarely found indoors, preferring moist areas outside. They feed on plant juices or dead insects, but some species could feed on living insects.

All spiders are predacious and feed mainly on insects. They play an important role in restraining insect populations. Spiders are mostly generalist predators. They prey on any kind of insect they are able to catch. In crops like cranberries, both webspinners and hunting spiders contribute to the reduction of aphids, flies, gnats, caterpillars and other harmful insects.

Harvestman adult

Green Lacewing adult

LACEWING

Green lacewings are often seen on cranberries and on trees, shrubs and other low growing plants in the vicinity of cranberry beds. They are active predators at night and give off a disagreeable odour when threatened. The brownish larvae have enormous curved pincers with which they seize their prey and suck it dry. Larvae are called “aphid lions” because of their ferocious appetite for aphids. They can consume a few hundred aphids in one day. They will also attack mites, leafhoppers, small caterpillars, and thrips. Commercially raised green lacewings are available.

Brown lacewings are nocturnal like the green lacewings, but are smaller in size. The females deposit their eggs on foliage near a food source. Brown lacewings are predaceous in their adult and larval stages with several generations per year and feed on spider mites, aphids and other soft-bodied insects.

GLOSSARY

Generation: One complete cycle of life stages. For example, a generation of blackheaded fireworm includes the progression of life stages from egg through larva to pupa and finally adult.

Larva (plural: larvae): The immature stage of an insect that undergoes metamorphosis. The larva hatches from the egg. Some synonyms are maggot, grub, or caterpillar, depending on the order to which the insect belongs.

Instar: The period or stage between molts in the larva, numbered to indicate the various periods (e.g., the first instar is the stage between the egg and first molt).

Pupa (plural: pupae): The resting inactive instar that is intermediate between larva and adult.

Pupal cell: A protective casing in which the pupa develops, usually formed by the layering of detritus.

Pupation: The act of becoming a pupa.

Trash layer: The layer of dead leaves and other plant debris beneath the cranberry vines that sits on top of the soil. It can serve as an area of protection, egg deposition, or hibernation for many insect pests.

Adult: The fully grown sexually mature insect (e.g., moth, beetle, weevil, midge).

Frass: Solid, larval insect excrement.

Pheromone: A substance secreted by an animal that triggers certain behaviour (e.g., mating behaviour) or reactions in a receiving individual of the same species.

Pheromone trap: A trap baited with insect pheromone to attract, monitor, or disrupt populations in the field.

Parasitic insect: One that lives on or in another insect or host in a way that derives all nourishment from the tissue.

Parasitoid: A transition condition in parasitism in which the larva is parasitic in the early stages, and then goes on to kill its host.

Entomophilic: Insect-loving. Used here to describe nematodes that seek insect larvae.

Diapause: A condition of suspended animation in insects in which they slow or shut down metabolic processes.

Hibernaculum: A tent or sheath made out of a leaf or other material, in which a larva hides or hibernates.

Ovipositor: The structure on the insect body by which eggs are placed; usually concealed, but sometimes extends beyond the end of the body.

Calling behaviour: Insect behaviour which initiates mating usually involving pheromone release or body movements.

Tachinid: Insects belonging to the large family of true flies, often important natural enemies of insect pests and sometimes used in biological control programs.