Aplocera plagiata (L.)

INVASIVE SPECIES ATTACKED: St. John's wort (*Hypericum perforatum* L.)

PREVIOUSLY KNOWN AS: *Anaitis plagiata*

TYPE OF AGENT: Foliar feeding moth

COLLECTABILITY: Limited

ORIGIN: France, Germany and Switzerland

DESCRIPTION AND LIFE CYCLE

Adult:

The moths are overall light grey coloured with three darker gray bands that run parallel across the fore wings (Harris 2003). They are referred to as 'treble-bar moths' and their wingspan is between 2.7 and 4.0 cm (UK Moths 2003). When at rest, the wings are triangular in shape (Winston et al. 2012).

A. plagiata has two generations per year in B.C., however, they can exist with a single generation per year such as seen in northern England and Scotland (UKMoths 2003). The first generation adults emerge in May and June in fewer numbers than the summer generation, potentially as a result of winter mortality (Perigo 2013). Mating and oviposition begins shortly after the adults emerge. The second generation adults appear when the host plants are flowering, usually from August to September. Females lay up to 300 eggs during their lifetime singly or clumped into small groups onto leaves and flowers (Rees 1996).

Fig. 1. *A. plagiata* adult (credit Powell et al. 1994)

Egg:

The eggs are oval-shaped and pearl white. They will incubate on the plants for 5-7 days (Perigo 2013).

Larva:

The 'inch worm-like' larvae develop through various stages and change from their initial light brown/tan and green colour to reddish-brown with deep shading along their upper back and darker stripes along their body (Washington State University 2013). When they are fully mature the larvae will measure 2.2 cm in length. The first generation of larvae begin to show up at the end of June and are present to mid-July while the second generation larvae are present from mid-August into September (see the Life Cycle Summary below). First generation larvae feed on the leaves and second generation larvae additionally feed on the flowers (Perigo 2013).

Fig. 2. *A. plagiata* larva

A. plagiata larvae are able to recognize their host St. John's wort from the presence of a chemical recognition token and, therefore, do not bite other non-host plants (Harris 1967). St. John's wort contains the toxin quinone hypericin which is contained in the plant's glands along the leaf margin, in the stem and even in the flower. Hypericin is an oxygen-dependent phototoxin (activated by sunlight) which can be toxic to insects as well as mammals. Insects that feed on St. John's wort have developed a number of mechanisms to prevail such as metabolizing the toxin. It has been suggested that the insects may also use biochemical and physiological mechanisms (Fields 1990). However, *A. plagiata* larvae do not appear to have a negative reaction to an increase in light intensity. Early instar larvae stay on the plants night and day and the fourth instar even stays in full sunlight. However, the fifth instar larvae feed mainly during the night and spend the day burrowed in the soil. The abdominal cuticle of this fifth instar *A. plagiata* allows much less light to pass through it than does *Chrysolina* larvae's cuticle. *Chrysolina* larvae's cuticle transmits significant light and they protect themselves by feeding at dawn and then spending the day burrowed into the soil while the toxin is metabolized. *A. plagiata*'s action of burrowing in the soil during the day has been speculated to avoid predation as these larvae have reached significant size and its typical stick mimic may not suffice (Fields 1990).

When temperatures decrease in the fall, *A. plagiata* larvae become lethargic and stop feeding. In October into November in Britain larvae are found on dead flower stems. The larvae leave the plants after they experience the first hard frost

and burrow into the soil or under litter to overwinter and then pupate late the following spring (Harris 1967; Washington State University 2013). The larvae can withstand high and low temperatures, but harsh winters, high elevations, and northern locations may affect the overwintering generation if they do not develop sufficiently before winter (Powell et al 1994). The larvae emerge the following spring and continue to feed. This is the only inch worm found on St. John's wort. (Harris 2003).

Pupa:

Pupae are slender and light greenish-golden brown. Pupation takes 15-17 days to complete and takes place in the litter or soil (Rees 1996; Perigo 2013).

Overwintering stage:

Immature larvae overwinter in the soil and resume feeding on St. John's wort foliage the following spring.

Life Cycle Summary

Biocontrol Agent ↓	Activity of interest	Jan to Apr	May		Jun		Jul		Aug		Sep		Oct		Nov to Dec
			1 – 15	16-31	1 – 15	16-30	1 – 15	16-31	1 – 15	16-31	1 – 15	16 - 30	1 – 15	16-31	
Aplocera plagiata	lifecycle	2nd gen larva	pupa		adult	adult / larva		pupa		adult /2nd gen larva				2nd gen larva overwinter	
	Monitor						larva			larva					
	Collect						larva			larva					

EFFECTIVENESS ON HOST PLANT

The spring generation feeds on leaves and is capable of substantially defoliating plants. This feeding is considered to be most damaging as it occurs when the host plant is most vulnerable (Harris 1967). The summer generation feeds on flowers. Defoliation inhibits the host plant but does not kill it, although it may help to prevent reestablishment of St. John's wort and competing vegetation may be able to suppress the weakened plants (Harris 2003; Harris 1967). They are active fliers which enables them to easily seek scattered patches of their host plant (Harris and Maw 1984). Additionally, *A. plagiata*'s ability to produce two generations per year was considered beneficial as a biocontrol agent as it would allow for a rapid population increase (Harris 1967). In large quantities, *A. plagiata* can decrease the amount of flower and therefore seed production (Winston 2012). However, Jensen, Harris and Sampson (2002) reported the populations of *A. plagiata* had not increased to high numbers so their effect on their host plant was minimal. On the other hand, this assumption dismisses the potential for *A. plagiata* to have cumulative effects on its host along with other biocontrol herbivores. Cappuccino (2000) includes examples where non-dominant species load (insect mass per unit of host plant) positively correlates with the load of a dominant species; therefore, supporting the practice of releasing several biocontrol agents on a host plant rather than just one.

HABITAT AND DISTRIBUTION

Native:

A. plagiata is native to central France to the northern limit of St. John's wort in Sweden (Harris et al 1969). It is listed as a common moth, found frequently over the better portion of the British Isles and is also found as far as West India and Japan (UKMoths 2003).

North America:

The first releases of *A. plagiata* in North America took place in B.C. in 1967, 1977 and 1980. It is established in this province. Scott (2013) mentions the moth is also established in Ontario (Ottawa (Dunrobin)) and although Winston et al. (2014) reports on releases in 1977 in New Brunswick, in 1984-1985 in Nova Scotia and in 1981 in Saskatchewan, establishment was not mentioned. In the Pacific Northwest U.S., *A. plagiata* was first released in 1989 in Oregon (Montana Field Guides 2014) where it has established. Oregon further reports that the moth has been released in 19 counties and has established in 14 (Oregon Department of Agriculture 2013). However, it does remain limited as it is only further established in northern Idaho, eastern Washington (WSU 2013), and is also reported established in Montana (Stevens County 2006).

Known Preferences in British Columbia:

A.plagiata exists in most locations of its target plant St. John's wort in B.C.

BRITISH COLUMBIA RECORD

Origin:

The source of agents for B.C. has been France, Germany and Switzerland (Harris 2003).

History:

St. John's wort was first noticed in B.C. in the early 1940's (Harris and Peschken 1971). Difficulties to control this invasive plant led to investment into Canada's first biological control program, initiated in 1951 (Jensen et al 2002). Prior to *A. plagiata*'s introduction into B.C., five species of biological control agents had been released in attempts to control this target plant. *Chrysolina guadrigemina* and *C. hyperici* (foliar-feeding beetles) were first imported into B.C. from the U.S. in 1951 and 1952, respectively (Harris 1962). By 1953, St. John's wort had increased considerably due to favourable weather conditions and in 1955 *Agrilis hyperici* (root-feeding beetle) and *Zeuxidiplosis giardia* (gall-forming midge) were imported (Smith 1956). *Chrysolina varians*, another foliar-feeding beetle, was introduced in 1957. *A. hyperici*, *Z. giardia* and *C. varians* were thought not to have survived at that time. The two *Chrysolina* beetles spread and were having an effect on St. John's wort in various moisture zones (corresponding primarily at that time to the Interior Douglas-fir and Ponderosa pine BEC zones), however, neither were effective in the drier range of the plant, particularly on the steppic grasslands in the southern interior (Harris et al 1969; Harris 1967). It was also considered that the moth would not interfere with the *Chrysolina* beetles on the moister sites (Harris 1967), therefore, *A.plagiata* was imported into B.C. in 1967 (Harris et al 1969). At a later date, in 1979, *Aphis chloris* (sap-sucking aphid) was also imported and both this agent and *A. hyperici* have subsequently been found to have established.

Releases of European, Switzerland and France imported *A. plagiata* moths occurred between 1967 and 1987. The first BC field collection was made in 1992 from a 1967 release site near Grand Forks. No further field collections occurred until 2008. Dispersal sampling done in 2008 indicated the moth is freely distributing itself throughout the southern interior, confirming a report by Jensen, Harris and Sampson (2002) that the agent had "established over a 300 km^2 area of south-central B.C. from releases made in the late 1970s." To date there have been 10 field releases of *A. plagiata*, seven of which have established and 23 recorded dispersal sites in B.C.

Biogeoclimatic Ecosystem Classification Zones:

In B.C., *A. plagiata* releases have been made and found established in several biogeoclimatic (BEC) zones (Figure 1). The subzones and variants (i.e. further defined locations within each BEC zone) in which the moth has established following release or dispersed to on its own, largely reflect the predicted requirement of dry sites. Further, sites that fall within moist subzone/variant descriptions typically consist of microsites with very good drainage such as gravelly soils. Examples of this are the dispersal site at Robert's Bank in the CDFmm (see Soil Texture and Compactness section for a site image) and the release site south of the Nanaimo airport on Vancouver Island. However, establishment has not been confirmed at the 1987 Sub-boreal spruce (SBS) site near Quesnel, although this site is also very gravelly.

Figure 1. *Aplocera plagiata* establishment in Biogeoclimatic Zones from 1967 to 2014 (Invasive Alien Plant Program 2014)

BEC	Subzone/ Variant	Subzone/Variant Description	Releases Established	Releases Not Established	Dispersal Sites
CDF	mm	Moist maritime	1		1
CWH	dm	Dry maritime	1		1
ESSF	dk1	Elk dry cool		1 unk	
ICH	dw1	West Kootenay dry warm			4
ICH	mk4	Kootenay moist cool			2
ICH	xw	Very dry warm	1		5
IDF	dm1	Kettle dry mild			1
IDF	dm2	Kootenay dry mild	1		1
IDF	mw2	Thompson moist warm			1
IDF	xh2	Thompson very dry hot		1	
IDF	xh4	Boundary very dry hot	2		3
MS	dm1	Okanagan dry mild	1		
PP	dh2	Kootenay dry hot			1
PP	xh1	Okanagan very dry hot			2
PP	xh3	Kettle very dry hot			1
SBS	mh	Moist hot		1	

SITE CRITERIA

Site criteria have been summarized from the literature and for existing sites *A. plagiata* has been released onto (10, seven of which have established) or self-dispersed to (23) within B.C (Invasive Alien Plant Program 2014). The summarized sites do not depict all ranges of these criteria the agent may currently or eventually occupy.

Growing Season:

Larvae require early spring foliage to complete development (Harris 2003). *A. plagiata* requires a growing season that is long enough for the insect to complete two generations (Washington State University 2013) (see the Life Cycle Summary section above). If autumn temperatures drop too quickly, the second generation of larvae are not able to survive through the winter (Winston 2012).

Site Size:
The range of site sizes of releases is 0.25 to 13.00 ha. Seventy percent of releases made onto sites in this range established. *A. plagiata* dispersed on its own onto sites in the range of 0.0001 to 5.00 ha with areas of 0.01-0.05 and 0.1-0.5 ha having the largest concentrations of survival at 22% and 30%, respectively (Invasive Alien Plant Program 2014).

Plant Density:
This agent can be used in low density St. John's wort infestations as it is a strong flier and adept at finding scattered plants (Harris 2003). *A. plagiata* has established on sites in B.C. with a plant density range of >/+ 1 plant/m^2 to > 10 plants/m^2. Lack of establishment has occurred at sites within this range as well: 50% of releases at sites with 2-5 plants/m^2 established, while 100% and 50% of releases established at sites with each of 6-10 and >10 plants/m^2, respectively. Forty-eight percent of the locations *A. plagiata* dispersed to in this range were recorded on sites with 2-5 plants/m^2 while 8% were recorded on >/+ 1 plant/m2 and 22% were recorded on each of sites with 6-10 and >10 plants/m^2, respectively (Invasive Alien Plant Program 2014). Density can also be described by Distribution Codes which combine density and cover and have a range of codes from 1 to 9 where 1 is a single occurrence of a plant and 9 is a continuous dense occurrence of a species (British Columbia Ministries of Environment and Forests 1990). The moth has established at sites with a distribution range of 2 to 9. While the release treatments have been placed at sites with a distribution code of 5 or higher, the moth's self-dispersal has occurred relatively consistently across all sites from 2 to 9 with the highest percent (26%) occurring with a distribution code of 5 which describes a few patches or clumps of a species (Invasive Alien Plant Program 2014).

Ground Cover:
No data on ground cover has been collected.

Competing Vegetation:
No data on competing vegetation has been collected; however, the effectiveness of biocontrol agents is enhanced with the pressures of competing vegetation.

Shade:
A.plagiata is described as doing well in open sites, without shade (Mangold 2009).

Slope:
The range of slopes of both established release sites and subsequent sites the moth has dispersed to on its own is 0 to 58% slope. Seventy percent of the releases made onto sites in this range established. However, although the 30% of releases that did not establish were all on 0% slope, 43% of all established dispersal sites were on 0% slope. The moth has not been found nor tested above 58% (Invasive Alien Plant Program 2014).

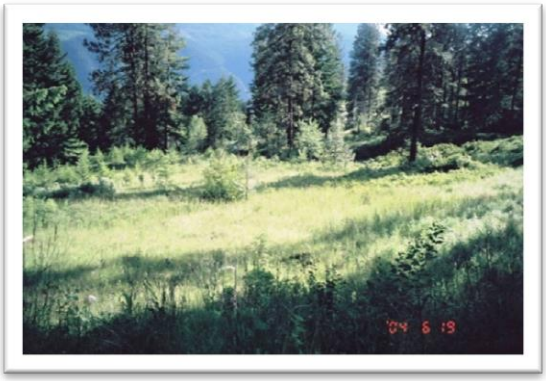

Fig. 3. *Chyrsolina spp*. dispersal area near Grand Forks (Ponderosa pine zone)

Fig. 4. *A. plagiata* site near Christina Lake (Interior cedar hemlock zone)

Fig. 5. *A. plagiata* dispersal location near Agassiz (Coastal western hemlock zone)

Aspect:
The aspect range of both currently established release sites and subsequent sites the moth has dispersed to on its own is 0 to 270°. Seventy percent of the releases made onto sites in this range established. However, while the 30% of releases that did not establish were all on sites of 0°/360°, 43% of the sites onto which the moth self-dispersed were also at 0°/360° (Invasive Alien Plant Program 2014).

Elevation:
The elevation range of both established release sites and subsequent sites the moth has dispersed to on its own is 1 to 969 m. The moth has not been found nor tested above this elevation range although as of September 2014 St. John's wort has been recorded up to 1757 m in B.C. Seventy percent of releases made onto sites in this elevation range

established, while the agent self-dispersed to sites across this range, with the largest concentration of dispersal (27%) is on sites of 651 to 700 m (Invasive Alien Plant Program 2014).

Fig. 6. *A. plagiata* dispersal location near Rock Creek (Interior Douglas-fir zone)

Elevation, Slope and Aspect:

The highest elevations with established *A. plagiata*, occupied by moths that have dispersed to these sites, are at 966 and 969 m. Both these sites have south-facing slopes. Conversely, one release did not establish at a site at 954 m with no slope. Additionally, there are three and four sites each of established release and dispersal records, respectively, that occur on sites between 700 and 900 m with south-facing slopes and one record of a dispersal site at these elevations (869 m) that has no slope. Positive establishment occurs on a north-facing slope at a release site at 646 m (Invasive Alien Plant Program 2014). This may be a reflection of the agent's preference for slope at various elevations but conversely may reflect other factors, such as where the host plant inhabits.

Temperature:

As witnessed from its extensive native range, *A. plagiata* can withstand high and low temperatures in dry locations (Harris and Peschken 1971).

Moisture Regime:

Assessment of *A.plagiata* in its native range describes it as adapted to and ecologically restricted to dry habitats and its subsequent dispersal in new habitats will be defined by the dryness of the sites (Harris 1967). Two years following the moth's original releases in B.C. and investigation into its establishment, the moth was proposed suitable for sites with a Thornthwaite's moisture index below -10 (Harris et al 1969). In this respect, the moth may not do well in years with high precipitation levels or in areas with consistently high rainfall such as coastal B.C. (Harris 1967; Mangold 2009). However, the moth has been found established at two sites in the CDF mm: on the lower mainland; and on Vancouver Island. Both these sites have well-drained gravelly soils.

Soil Moisture:

The moth requires well-drained soil (Harris 2003). Generally dry sites that have a microsite feature of moist soils are not suitable to *A. plagiata*. The overwintering larvae may experience fungal infections in moist soils and may explain its lack of colonization of moist sites (Harris 1967).

Fig. 7. *A. plagiata* dispersal location at Robert's Bank (Coastal Douglas-fir zone)

Soil Texture and Compactness:

The moth prefers rocky, sandy-based or limestone soils (Harris 2003).

Snow Cover:

No data on snow cover has been collected.

Salt Water Influence:

Dispersal sampling in 2012 shows *A. plagiata* can, at least at one site, tolerate areas near salt water after being found dispersed on a spit in Delta.

Disturbance:

A. plagiata is susceptible to a few types of disturbance:

- Mowing disturbs the agent directly when the life stage occurs on the plant (May to September) or it will remove the majority of the moth's food source.
- *A.plagiata* larvae are vulnerable to fungal infections, particularly in moist soils. An infection may be detected by the early symptom of colour concentration around the infection area (Harris 1967).
- Larvae are susceptible to ants and wasps (Stevens County 2013).

When disturbed the larvae will mimic dead twigs. Adults make frequent erratic flight patterns when disturbed and land a short distance away before taking flight again.

AGENT HANDLING:

Collecting:

This biocontrol agent is collected as larvae during the summer. The larvae may be hand-picked off the plants to minimize rough handling or they may be collected using sweep nets. The larvae should not be kept in overcrowded

containers and should be provided with some foliage, preferably attached to stiff St. John's wort stems to provide food and the ability to cling and decrease contact with one another as they are held or transported to minimize stress. Containers should be kept in cool locations and, when transported, within coolers also housing ice packs wrapped in paper towel to absorb unwanted moisture.

Releasing:

Five hundred larvae are adequate for release (Harris 2003). Releases made with 285 larvae or more established (70%) while those made with 169 larvae or less have not established (30%) to date in B.C. The larvae should be spread around the site on various host plants (one to two larvae per plant) to ensure all are able to obtain sufficient food (Perigo 2013).

Monitoring:

Foliar feeding is usually observed before the larvae are located. As noted previously, unlike the *Chrysolina* species larvae, *A. plagiata* larvae can feed in full sunlight so may be observed on the plant during daytime hours. The larvae's colouring allows it to blend well with the colours of its host plant so they may not be immediately obvious, especially the smaller larvae. However, with a small amount of practice, the larvae may be readily observed. The larvae can easily be located during rain showers.

Fig. 8. *A. plagiata* larva mimicking a motionless "stick"

Fig. 9. *A. plagiata* feeding evidence on St. John's wort plant stem

NOTES

- As this agent feeds on foliage also required by the *Chrysolina* species, it is recommended to not release this moth at the same location as the beetles or at least where the beetle numbers have not yet risen to ensure the moth's population has sufficient foliage for the larvae stage to increase in number and disperse to new locations.

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