OPERATIONAL FIELD GUIDE

TO THE PROPAGATION AND ESTABLISHMENT OF THE BIOCONTROL AGENT *RHINUSA ANTIRRHINI* (TOADFLAX SEED-FEEDER)

May 2008

BRITISH COLUMBIA
The Best Place on Earth

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May 2008

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1. PURPOSE

This document summarizes information for the biocontrol agent *Rhinusa antirrhini* while it was classified as 'primary' and the responsibility of the Forest Practices Branch. The information is a combination of scientific facts and field observations. Intended as a 'field guide' for those unfamiliar with *R. antirrhini,* a seed-feeding weevil of Dalmatian and yellow toadflax (*Linaria dalmatica* (L.) P. Mill spp. *dalmatica* and *Linaria vulgaris*, respectively), the summary contains pertinent information for field propagation and establishment of the biocontrol agent as well as a historical background of its introduction into British Columbia (B.C.).

2. INTRODUCTION

The goal of the Ministry of Forests and Range (MFR) is to reduce target invasive plant populations to ecologically and economically acceptable levels and to prevent their encroachment into new areas. MFR Range Branch's Invasive Plant Program is responsible for ecology, inventory, early detection/ rapid response and treatments of invasive plants using mechanical, chemical and biological control treatment methods. The Forest Practices Branch's, Biocontrol Development Program is responsible for enabling the screening research and carrying out the development of new (or rare in the province) biocontrol agents for B.C.

Implicit in the use of biocontrol methods is the acknowledgment that invasive plant eradication is not achievable. Rather, biocontrol agent species and host invasive plant species exist in predator-prey relationships where the invasive plants are intended to be held at acceptable population levels with self-sustaining agent populations.

The Biocontrol Development Program is a cooperative venture between the Ministry of Forests and Range (MFR) (acting on behalf of: the Ministries of Agriculture and Lands and its Integrated Land Management Bureau; Energy, Mines and Petroleum Resources and its Oil and Gas Commission; Environment; Transportation and Infrastructure; and, Tourism, Culture and the Arts), Agriculture and Agri-Food Canada (AAFC), Commonwealth Agricultural Bureau International (CABI-Europe) in Switzerland, as well as numerous other provincial and state agencies across western North America.

Current taxonomy lists all eleven *Linaria* species in Canada and the United States as exotic (Wilson et al. 2005). There are two invasive exotic *Linaria* species of concern in B.C., Dalmatian toadflax (*Linaria dalmatica* (L.) P. Mill spp. *dalmatica*) and yellow toadflax (*L. vulgaris* P. Mill). Often considered as a separate species, narrow-leaved Dalmatian toadflax, or broomleaf toadflax, (*L. genistifolia* or *L. genistifolia* (P.) Mill. ssp. *dalmatica*) may be a biotype of Dalmatian toadflax (Wilson et al. 2005) and will be

considered the same species as *L. dalmatica* for the purposes of this report. Of these, Dalmatian toadflax is, to date, the most widespread in the province. Both perennial species were introduced from Europe as ornamentals and have since naturalized in North America (Groppe 1992). For example, Dalmatian toadflax was introduced as an ornamental in the USA in 1894 (Robocker 1974). Dalmatian toadflax occupies uncultivated, summer dry, coarse soils while yellow toadflax occupies loamy soils in areas where summer conditions are relatively moist (Gassmann et al. 2001). Both toadflaxes, as with other *Linaria* species, are toxic to livestock and wildlife, but, stands are generally avoided. There is a resulting loss of forage, biodiversity and other ecosystem values and a hinderance to some crops such as strawberries, alfalfa, hay and raspberries and to maintenance of orchards (Groppe 1992). These toadflax species are difficult to control manually and with herbicide due to the creeping root systems and waxy cuticles, respectively. Biological control, therefore, was sought to control these species.

3. BIOLOGICAL CONTROL AGENTS FOR DALMATIAN TOADFLAX IN BRITISH COLUMBIA

Efforts to acquire biological control agents for B.C. Dalmatian and yellow toadflaxes began in the 1960s (Mason and Huber 2002). Most agents attack both yellow and Dalmatian toadflaxes, but, the agents generally have host plant preferences dependent on which plant species they were originally harvested from in Europe (i.e., they have formed 'host races'). Assessment of whether these insect host races are true species or subspecies is ongoing and may change the nomenclature used for these biocontrol agents on toadflax. Since the 1960's, several insect agents have been released:

- *Calophasia lunula* (defoliating moth) – 1965;
- *Brachypterolus pulicarius* (adventive flower-feeding beetle) – 1989;
- *Rhinusa neta* (seed-feeding weevil, previously *Gymnaetron netum*) – adventive;
- *Mecinus janthinus* (stem-boring weevil) – 1991;
- *Eteobalea intermediella* (root-feeding moth) – 1991;
- *Eteobalea serratella* (root-feeding moth) – 1992;
- *Rhinusa antirrhini* (seed-feeding weevil, previously *Gymnaetron antirrhini*) – Dalmatian toadflax strain was released in 1993, yellow toadflax strain is adventive; and,
- *Rhinusa linariae* (root-galling weevil) – 1996.

Although *B. pulicarius* and *R. neta* were not screened for host specificity and petitioned for importation, subsequent research has been conducted on both these insects following their arrival to North America and B.C., respectively. *M. janthinus*, *R. antirrhini* (Dalmatian toadflax strain) and *R. linariae* are actively being spread, by collection and release, across the province while the remaining agents are either spreading of their own accord with minimal assistance (*C. lunula*, *B. pulicarius*, and *R. neta*) or have been

unsuccessful to date in the tented conditions previously attempted in Kamloops, B.C. (*E. intermediella* and *E. serratella*).

There are two strains of *Rhinusa antirrhini* in B.C. One strain of weevil shows a preference for yellow toadflax and another for Dalmatian toadflax (Powell et al. 1994). Molecular studies have suggested that these two strains are separate *Rhinusa* species and both strains have been found to feed on both plant species (Wilson et al. 2005). The yellow toadflax strain is adventive to North America (Gassmann and DeClerck-Floate 2001). *R. antirrhini* specific to yellow toadflax were first collected in Canada near Montreal in 1917, were found in B. C. in the 1950s, and were collected from Ontario and introduced into Saskatchewan and Alberta in 1957 (Harris 1961). They were also reported to be present on yellow toadflax in all Canadian provinces except Manitoba, Saskatchewan and Alberta (prior to the 1957 releases) and in the northeastern and northwestern United States (Smith 1959). Due to the host-specificity of the yellow toadflax weevil, it was decided that a smaller scale screening program would be appropriate for the Dalmatian toadflax weevil which resulted in the testing of a few critical native plant species (Groppe 1992). Screening of the Dalmatian toadflax *R. antirrhini* weevil began in 1989 and concluded in 1992 with weevils from Yugoslavian Dalmatian toadflax (Agric. Can. 1990). The Yugoslavian weevils were first released in Canada in B. C. in 1993 (De Clerck-Floate, R.A. and P. Harris. 2002). The weevils have established and readily increased in various populations on Dalmatian toadflax in B.C. This report focuses mainly on the Dalmatian toadflax strain of *R. antirrhini*.

4. *RHINUSA ANTIRRHINI*

Coleoptera: **Curculionidae**
Common name: Toadflax seed-feeding weevil

BIOLOGY

GENERATIONS PER YEAR: one per year

ADULT STAGE: Adults are oval, black and 3-5 mm long. The rostrum (nose) is distinctly curved and pointed looking from the side but from an aerial view it appears straight, thick and abruptly tapered ((Hoffman 1958). Pubescence covers the rostrum (but it is bare at the tip) and body and appears yellowish to brown (Hoffman 1958). The prothorax is narrowly rounded at the front while the rear corners are blunty angled (Figure 1).

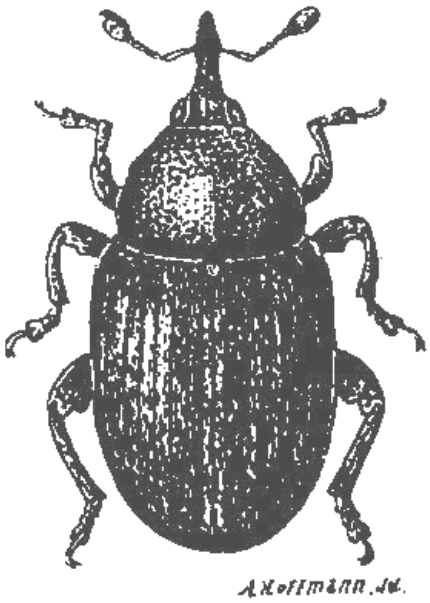

FIGURE 1. *Rhinusa antirrhini*.

Adults emerge from hibernation in the soil or from seed capsules as early as mid April in low elevation bunchgrass areas. Generally, they appear in May when the plants are 20-30 cm tall. They feed first on tender new growth which initiates branching lateral plant growth. The weevils then move to the flowers to feed on pollen and young seeds (Figure 2 Powell et al. 1994) (Harris and Gassmann 2003). Several adults can be found within a single bloom.

R. antirrhini normally lay eggs from June through September, often having to delay oviposition until *Brachypterolus pulicarius* damage has subsided (Harris and Gassmann 2003). When flowers have developed to almost full size, females prepare oviposition sites by chewing into the carpel (Paetel 1997). Female weevils will lay into the green pods, between 10 to 132 eggs with an average of 54 (Harris and Gassmann 2003). Oviposition by spring-emerged females will continue as along as suitable flowers are available, despite the potential for development within the given season (Gassmann and Paetel 1998). Eggs laid late in the season would not be expected to develop since they would probably not overwinter in the dry, dead, seed pods (Paetel 1997). *R. neta* females die following oviposition (Paetel 1997) and as with other *Rhinusa* species, *R. antirrhini* are presumed to have the same biology (Harris and Gassmann 2003).

EGG STAGE: The oval, creamy yellow eggs (Paetel 1997) are inserted singly into each cavity. Up to eight eggs are laid in each pod and are covered with a yellow excrement to seal the hole. Within a week, “an external and internal protuberance or spur “(Wilson et al. 2005) can be observed just above the oviposition hole (Paetel, 1997). Thereafter, the “spur pushes the egg deep among the developing seeds, triggering the formation of a gall that causes the 8-12 seeds surrounding the egg to grow up to 10 times their normal size” (Wilson et al. 2005). The seeds “become mushy and soft and lose their greenish colour” (Paetel 1997), perhaps as a result of a biochemical reaction to the eggs, but, this is not confirmed (Wilson et al. 2005).

LARVAL STAGE: Several larvae can occupy a single seed pod chamber as observed at Campbell Mountain in B.C. The first larval instars feed on the pale enlarged seeds (Groppe 1992). The final instar larvae may feed on regular developing seeds. Full grown larvae are white with clear dark brown heads (Harris and Gassmann 2003). Typical to weevils, their distinct ‘c’ shape can easily be identified in the pod. Mature larvae build an oval cell or cocoon in preparation for pupation (Groppe 1992).

PUPAL STAGE: Pupation occurs within the seed pod. This stage takes between 10 to 15 days. The literature describes the pupae as having two pointed horns at the top of their thorax (Gassmann and Paetel 1998). Mature pupae have been observed to closely resemble their adult form and, hence, may be distinguished from *R. neta*. See section 5, the Interaction with Other Biological Control Agents, for more information.

F1 ADULTS: In August and September, adults emerge from their pupal cases through the upper opening of dried seed capsules or from a hole the adult may chew in the pod wall (DeClerck-Floate pers comm. 1993). They do not mate nor oviposit but instead overwinter. Weevils will feed following emergence and have been observed as late as November before overwintering, however, their movements are quite slow in cool temperatures. Adults overwinter in the soil duff but can also overwinter inside dried seed capsules (Harris and Gassmann 2003).

DISPERSAL METHOD: The adult weevil both walks and flies to reach its mate and host plants.

FIGURE 2. *Rhinusa antirrhini* (adult).

RANGE

Native (European) Distribution

The native distribution of the *R. antirrhini* weevil is recorded as throughout "central and southern Central Europe, the Mediterranean region and the Caucasus" as well as Algeria (Groppe 1992). Harris and Gassmann (2003) report that *R. antirrhini* "extends from North Africa to the northern limit of yellow toadflax, but it is scarce in southwest Europe", as well as occurring in the cool moist locations of Europe.

The *Linaria* plant genus is spread completely around the globe but has the biggest diversity in the Mediterranean. Yellow toadflax originates from southwestern Asia, western Europe and the steppes of south-eastern Europe (Groppe 1992). Dalmatian toadflax originates from the Mediterranean region from Yugoslavia to Iran and was cultivated as an ornamental in Europe in the 1500's (Robocker 1974). Dalmatian toadflax and narrow-leaved toadflax "belong to a group of species with a largely central-eastern Mediterranean distribution" (Groppe 1992). The European distribution of Dalmatian and narrow-leaved toadflax are shown in Figure 3 (Groppe 1992).

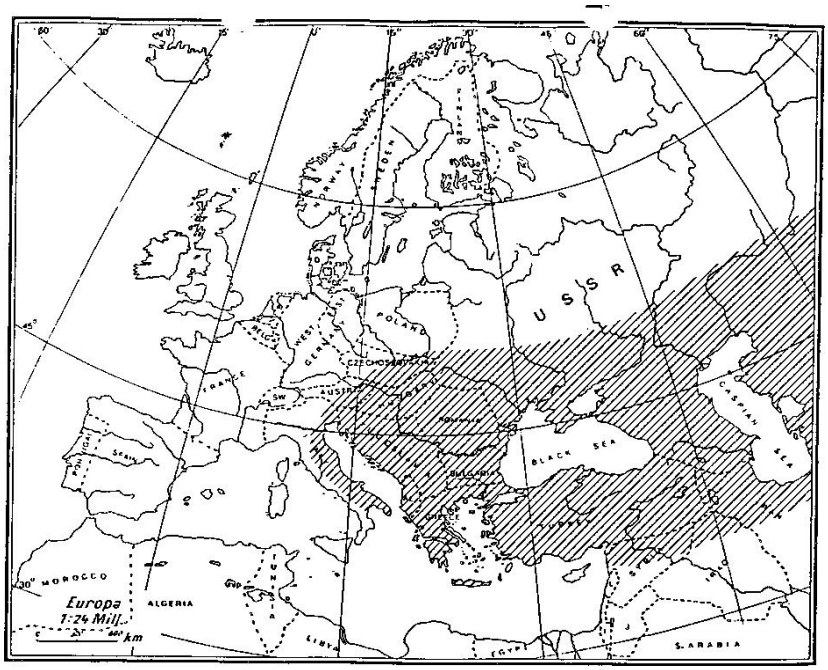

FIGURE 3. Native geographic distribution of *L. dalmatica* and *L. genistifolia* in Europe (after Tutin et al. 1972).

See Appendix A and B for detailed information on Dalmatian toadflax (*Linaria dalmatica* (L.) P. Mill spp. *dalmatica*) and yellow (common) toadflax (*Linaria vulgaris*), respectively.

Predicted North American Distribution

Very little information is available on the predicted distribution of *R. antirrhini*. Instead, information has been inferred from existing locations of the weevil strains. The adventive yellow toadflax strain of *R. antirrhini* has been reported to have limited abundance in North America (Gassmann et al. 2001). It has been recorded in the north and southeastern States, from California and the northwest and in various provinces in Canada, including B.C. (Smith 1959). The Dalmatian toadflax strain of *R. antirrhini* originates from Yugloslavia, more specifically, from Macedonia (Gassmann and Paetel 1998). Harris and Gassmann (2003) describe the areas occupied in Europe as cool and moist. It has also been stated by Powell et al. (1994) that the weevil does not do well in locations with extreme cold winter temperatures. Figures 4 (Groppe 1992) and 5 (Vujnovic and Wein 1996) depict the North American distribution of the host plants for comparison.

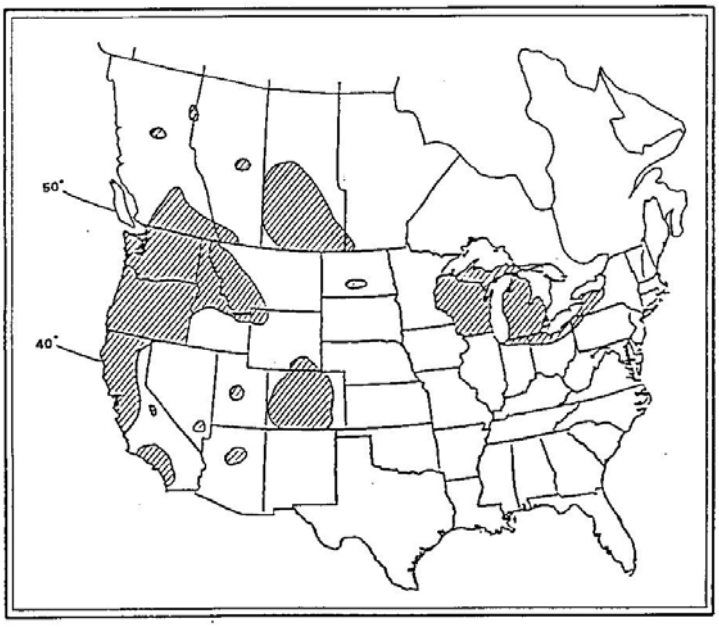

FIGURE 4. Distribution of *L. dalmatica* and *L. genistifolia* in North America and Canada (after Alex 1962 and USDA Agriculture Handbook 1970).

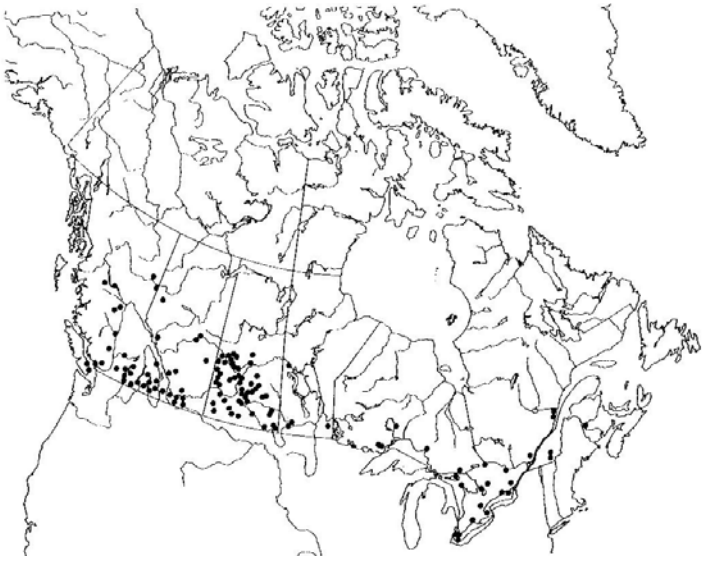

FIGURE 5. Distribution of *Linaria dalmatica* (L.) Mill. In Canada based on specimens in ALTA, CAN, DAO, MT, NFLD, OAC, QFA, SASK, UBC, and WIN Herbaria.

BRITISH COLUMBIA HABITAT

R. antirrhini strains attack both Dalmatian and yellow toadflax. To date, however, the focus has been on the distribution of the Dalmatian toadflax strain of *R. antirrhini* as this invasive plant has been of greater concern than yellow toadflax for the majority of the province. However, some work in B.C. has been done on recording the weevil's dispersal on yellow toadflax populations as indicated in Table 2.

Since little was known about the habitat requirements of *R. antirrhini* while selecting sites in B.C.'s multitude of habitat types, efforts have been made to release *R. antirrhini* into temperate to mild habitat conditions, with the hope of promoting survival, where *M. janthinus* does not already exist. The *R. antirrhini* releases were then monitored to determine whether the agent has been able to establish and its habitat preferences. As mentioned previously, *R. antirrhini* is reported to not do well in habitats with extreme cold winter temperatures. However, *R. antirrhini* has been found to establish on Dalmatian toadflax in all Biogeoclimatic Ecosystem Classification (BEC) zones it was released into to date, including Bunchgrass (BG), Ponderosa pine (PP), Interior Douglas-fir (IDF), Interior cedar-hemlock (ICH) and Montane spruce (MS) with the lowest and highest recorded elevations as 290 m (BGxh1 at Osoyoos Ecological Reserve) and 1205 m (MSdm1 at KVR/Chute Lake Road), respectively (Table 1). The Biogeoclimatic Ecosystem Classification (BEC) system is an ecological classification grouping similar landscapes called ecosystems into hierarchical classifications. The BEC in B.C. is defined as a particular plant community and its associated physiography, soil and climate that occupy a segment of the landscape (Meidinger and Pojar 1991). For more information on BEC, go to http://www.for.gov.bc.ca/hre/becweb/.

To date, the most extreme sites occur at Juliet Creek along the Coquihalla Highway, which has a fairly high elevation but good snow insulation, and near Clinton which is cooler than most sites, has a shorter summer (i.e. less heat units) and is very windy. Although *Rhinusa* spp. have been observed at these locations, they have been identified as *R. neta*. Since the literature describes *R. antirrhini* as capable of completing development in habitats with shorter growing seasons than *R. neta* (Paetel 1997), it is speculated that *R. antirrhini* will establish at these sites as well and, therefore, a subsequent quantity of agents were released at Juliet Creek (see Interaction with Other Biological Control Agents Section).

Establishment, increase in weevil numbers and dispersal have typically been found quicker, higher and more extensive, respectively, at sites in the Bunchgrass, Ponderosa pine and Interior Douglas-fir BEC zones. Figures 6 and 7 show typical habitat for *R. antirrhini* establishment.

	Treatments			
BEC	Total treatment sites[a]	Established	Unknown	Dispersal sites on Lina dal
BG xh 1	5	5		
BG xh 2	2	2		2
BG xw 1				3
ICH dw	1	1		
IDF dk 2	2	2		1
IDF dk 3	1		1	
IDF dm 1	3	3		
IDF mw 2	1	1		3
IDF xh 1	5	4	1	
IDF xh 1a	3	3		1
IDF xh 2	2	2		6
IDF xh 4	1	1		
MS dm 1	1	1		
MS dm 2	1		1	
PP dh 1	1			
PP xh 1	1	1		
PP xh 2	2	2		9

a) Treatments do not include 2007 releases as monitoring typically is not conducted on same year releases.

TABLE 1. *R. antirrhini* field sites on Dalmatian toadflax by BEC zone 1996 to 2007.

FIGURE 6. China Creek.

FIGURE 7. Midway.

The adventive strain of *R. antirrhini* on yellow toadflax has recently been recorded in a few BEC zones as shown in Table 2. The lowest and highest recorded elevations are 360 m (PPxh2 at Chase, along Hwy #1) and 1108 m (IDFdk2 at Shovelnose Mountain), respectively.

BEC	Dispersal Sites on Yellow Toadflax
IDF dk 1	1
IDF dk 2	4
IDF mw 2	2
IDF xh 2	3
PP xh 2	1
SBS dh 1	1

TABLE 2. Recorded adventive *R. antirrhini* field sites on yellow toadflax by BEC zone 2006 to 2007.

5. INTERACTION WITH OTHER BIOLOGICAL CONTROL AGENTS

BRACHYPTEROLUS PULICARIUS

B. pulicarius are small (1 to 2 mm) black, elongate to oval, seed-feeding beetles (Figure 8 Powell et al. 1994). They are beetles and, hence, do not have the long snout of weevils. The most common biotype of *B. pulicarius* in North America prefers yellow toadflax, however, a biotype that prefers Dalmatian toadflax is also present (Wilson et al. 2005).

B. pulicarius beetles feed on toadflax shoot tips and developing flowers while the larvae feed on the pollen in the flowers (McClay 1992), floral tissues and developing seeds in the flowers (Wilson et al. 2005). Adult feeding can delay and suppress early-season flowering while larvae feeding can reduce seed production by 75% or more (Wilson et al. 2005).

Powell et al. (1994) states the *B. pulicarius* larvae will feed on *Rhinusa* larvae through early summer to August and advises to avoid releasing *Rhinusa* in areas where *Brachypterolus* are abundant. Wilson et al. (2005) adds that *B. pulicarius* will consume *Rhinusa* eggs as well as the young larvae. However, Groppe (1992) reports that *B. pulicarius* and *R. antirrhini* coexist well together on yellow toadflax and results in high rates of seed reduction. It is expected that the same would occur on Dalmatian toadflax. This expectation is reflected by Harris (1989) as he mentions that *R. antirrhini* “destroys much of the seed escaping the attack of *B. pulicarius*” so they appear to not conflict. On yellow toadflax, the combination of *B. pulicarius* and the yellow toadflax *R. antirrhini* strain are reported to reduce toadflax seed production by 90% (Harris 1988). Even though *B. pulicarius* can affect the abundance, and therefore, impact of *Rhinusa* weevils, this complementary feature results in the greatest impact on seed production occurring when *B. pulicarius* and *Rhinusa* coexist (Wilson et al. 2005).

FIGURE 8. *Brachypterolus pulicarius*.

CALOPHASIA LUNULA

C. lunula are pale to dark brown defoliating moths that are distinguished by a white crescent marking, along with other white markings, on the central part of their wing (Figure 9 Powell et al. 1994). The adult moth ranges from 12 to 14 mm and has a wingspan of 27 to 30 mm. The larvae are very distinct and easy to find on their host plants (Figure 10). They are pearl-coloured with five yellow stripes and black markings along their sides and back (Powell et al. 1994).

Although *C. lunula* can cause significant defoliation, it appears to have minimal impact, if any, on toadflax populations (Gassmann et al. 2001). It has been observed in B.C. that with extreme defoliation flower production can be hindered which would affect *R. antirrhini*'s ability to oviposit but this does not occur uniformly on a single site.

FIGURE 9. *Calophasia lunula* adult.

FIGURE 10. *Calophasia lunula* larvae.

C. lunula feeding should be distinguished from feeding of the native Checkerspot butterfly (*Euphydryas anicia* in the Family Nymphalidae) which also defoliates Dalmatian toadflax. The adult (Figure 11) and pupa (Figure 12) of the Checkerspot

butterfly are easily identified by their spotted markings. The pupae also create webbing on the plants unlike *C. lunula*.

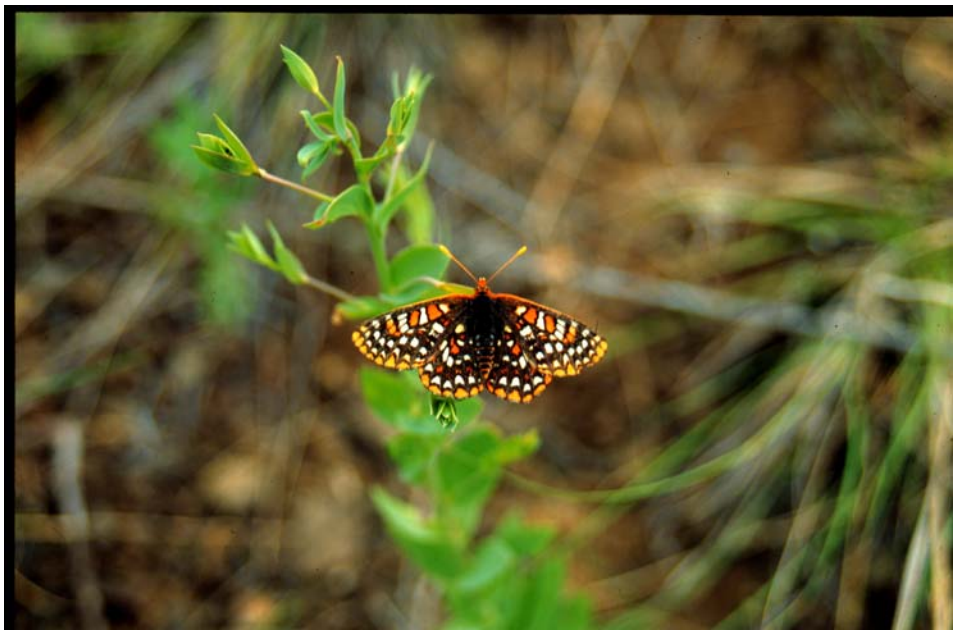

FIGURE 11. Checkerspot butterfly.

FIGURE 12. Checkerspot butterfly pupae and webbing.

ETEOBALEA INTERMEDIELLA AND SERRATELLA

The two *Eteobalea* root-feeding moths are very similar in appearance. Both are black with yellow heads and silver to gold, lightly metallic appearing markings on their wings (Figure 13 Powell et al. 1994). They both have a wingspan of 16 to18 mm (Powell et al. 1994).

E. intermediella attacks Dalmatian and yellow toadflaxes while *E. serratella* prefers yellow toadflax (Saner 1990). *E. serratella* is reported to prefer areas with sandy soil and very dry conditions (Powell et al. 1994).

Both these species have been introduced into tents at one time in Kamloops, B.C. Although they have been recorded to exist for more than one generation and more than one year, to date they have not been found to have established. Their interaction with *R. antirrhini* is, therefore, not an issue at this time.

FIGURE 13. *Eteobalea intermediella*.

MECINUS JANTHINUS

M. janthinus are black weevils that, when lit by sunlight, often show a greenish-blue metallic sheen on their elytra. They are on average 5 mm long and are elongate in shape (Figure 14 Powell et al. 1994).

FIGURE 14. *Mecinus janthinus*.

M. janthinus larvae hatch, tunnel, and feed in toadflax stems, causing a disruption in the flow of nutrients. One to over 100 larvae can occur per stem (De Clerck-Floate and Harris 2002). With the disruption in nutrient flow, flowering can be prevented (Figure 15). Larval feeding takes place in spring, from May to the beginning of June. With increased populations of *M. janthinus* in B.C., infestations of Dalmatian toadflax are noticeably affected as seen in the Lac du Bois grassland park near Kamloops, B.C. where the weevil was released in 1997 (Figure 16).

FIGURE 15. Prevention of flowering of Dalmatian toadflax (*Linaria dalmatica*) by *Mecinus janthinus*.

(A)

(B)

FIGURE 16. *Mecinus janthinus* trial in the Lac du Bois grassland park near Kamloops, B.C., 2004 (a) and 2006 (b).

As mentioned, adult *R. antirrhini* weevils lay their eggs into the flower carpel in June. The prevention of flowering caused by *M. janthinus*, therefore, poses a difficulty for establishing and developing *R. antirrhini* as a biological control agent. It is necessary then to release *R. antirrhini* into locations either free of or with low *M. janthinus* numbers. With multiple agencies moving this latter biological control agent around the provinc, coupled with the agent readily dispersing itself from its release sites to new toadflax infestations, this becomes no easy task. However, it has been observed, for example on Campbell Mountain, Naramata, that Dalmation toadflax will react to *M. janthinus* attack by sending out additional shoots and flowers later in the season. These will be used for delayed oviposition by the *R. antirrhini*. When this occurs early enough in the summer there is still sufficient time for development and emergence of F1 adults prior to winter.

RHINUSA NETA

The *R. neta* weevil's colour ranges from ash grey to olive brown and has a different rostrum shape than *R. antirrhini* (Harris and Gassmann 2003). The rostrum "is not tapered or pointed and barely curved (more strongly curved in the female than the male" (Harris and Gassmann 2003). Additionally, where the two species co-exist in Europe, *R. neta* has been noted to be at least 50% bigger than *R. antirrhini* (Harris and Gassmann 2003). *R. antirrhini* can be distinguished from *R. neta* generally by the colour and size but more effectively by the the body shape where *R. antirrhini* are oval and *R. neta* are fairly square. *R. antirrhini* can also be distinguished from *R. neta* by the size and colour, and later by the pattern and colour, of the larval head capsules and the shape of the pupae as shown in Figures 17 (Gassmann and Paetel 1998) and 18 (Gassmann and Paetel 1998). The head capsules of first and second instar *R. antirrhini* larvae are smaller and slightly darker brown that *R. neta* while the third instar larvae have clear dark brown head capsules compared to *R. neta*'s light brown head capsules that display an indistinct pattern (Gassmann and Paetel 1998). The pupae "of both species can be distinguished by the shape of the two humps on the first dorsal thoracic segment" (Gassmann and Paetel 1998).

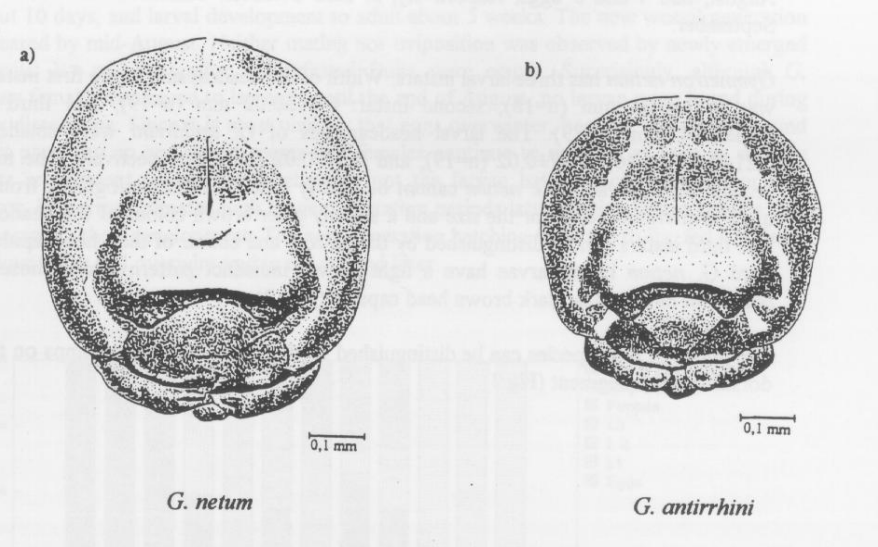

FIGURE 17. Headcapsule of the third instar larva of *G. netum* and *G. antirrhini*.

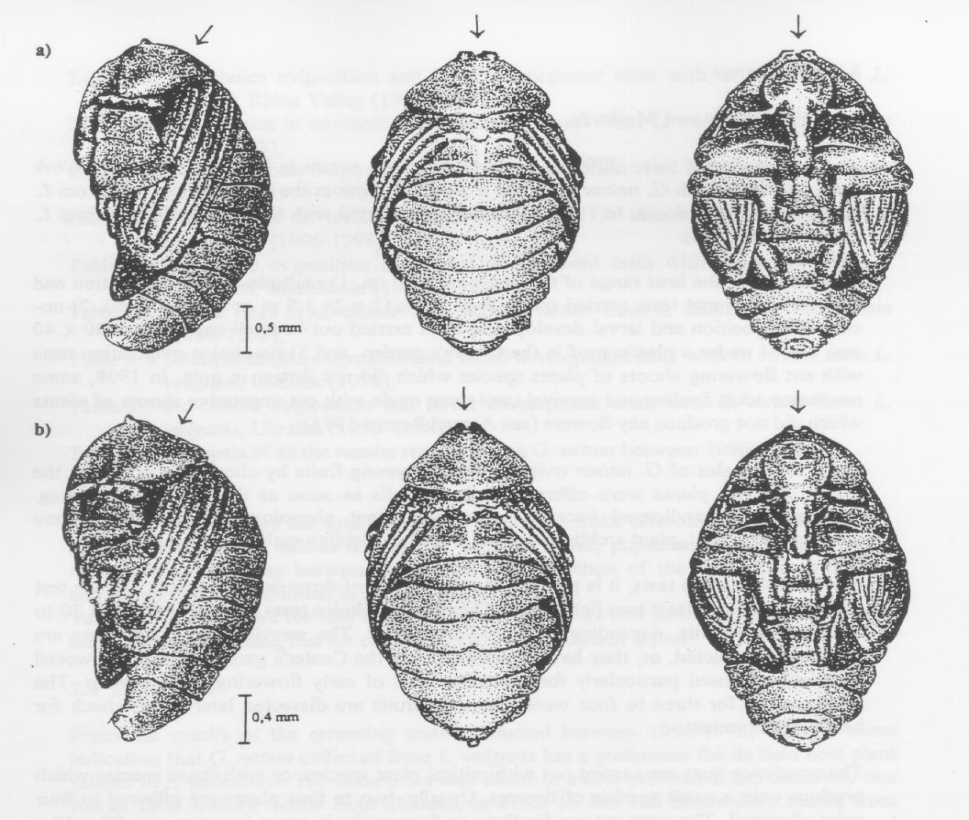

FIGURE 18. Lateral, dorsal and ventral view of the pupa of: a) *G. netum* b) *G. antirrhini*.

R. neta do not cause the seeds to turn to mush (Paetel 1997) and are not gall formers. *R. neta* larvae feed and can destroy a high proportion of the seeds in the capsule that they occupy. With high numbers of weevils where larvae densities could reach to greater than two larvae per capsule, all viable seeds may be destroyed in occupied capsules (Wilson et al. 2005).

The life cycle timing of the two *Rhinusa* species is basically the same (Wilson et al. 2005). However, in the spring, the comparative emergence dates of *R. antirrhini* and *R. neta* appears to be site dependent. At one site investigated (with yellow toadflax) *R. antirrhini* emerged first from hibernation while at another site *R. neta* was first (Paetel 1997). Following mating and ovipositing, egg development begins. The *R. neta* eggs take approximately 10 days to develop, the larvae take about 3 weeks to reach the pupal stage and the pupae take about 2 weeks to become adults (Gassmann and Paetel 1998). However, it was found that *R. antirrhini* develop a little faster than *R. neta* (Paetel 1997).This would appear to give *R. antirrhini* the competitive edge to not only be able to complete development of the F1 generation in cooler climates with shorter vegetation periods but also to have more larvae complete development in warmer climates with late oviposition.

As with several other toadflax biocontrol agents, *R. neta* has separate biotypes that prefer either yellow or Dalmation toadflax and exist in scattered populations in Western US and Canada (Wilson et al. 2005). It was reported that on yellow toadflax the *R. neta* "species appears to be displaced by *R. antirrhini* in Canada and to be of little biocontrol value" (Harris 1989). However, *R. antirrhini* and *R. neta* co-exist in Europe and will co-exist in B.C. When trying to establish a new location with either agent it would be best to check first to see if the plants are not inundated with an existing agent to ensure competition for resources is not excessive.

RHINUSA LINARIAE

R. linariae are black, convex-shaped weevils that are rounded in the front and rear and are covered with short, dense, grey hairs. The rostrum is strongly arched and gradually tapered with fine hairs near the top. The feet and antennae also have hairs but they are darker coloured than the rest of the body (Figure 19 Hoffman 1958). This root-galling weevil ranges from 2.5 to 3.0 mm in length (DeClerck-Floate et al. 1994).

Different strains of *R. linariae* readily attack both Dalmatian and yellow toadflax, however, they do not prevent flowering of either species. The biological control agent *R. linariae*, therefore, does not directly conflict with *R. antirrhini,* but, the indirect effects from high densities of *R. linariae* is currently unknown.

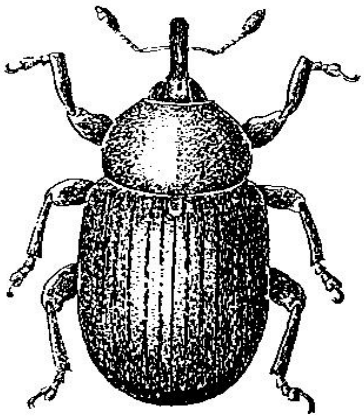

FIGURE 19. *Rhinusa linariae*.

4. HISTORY OF INTRODUCTION

R. antirrhini was approved for release in North America in 1992 and the first shipment from CABI to B.C. occurred in July 1993. The original shipment of *R. antirrhini* contained 300 weevils which were placed inside a tent at the MFR Propagation Facility (MFRPF) in Kamloops, B.C. (Figure 20). The tent was monitored for the weevils' presence but none were found for several years. In 1995, the tent was removed and the plants were left uncontained.

FIGURE 20. MFRPF *Rhinusa antirrhini* propagation tent.

In July 1994, an additional 200 weevils were received and placed inside a second tent. Two sizes of weevils had been discovered in this shipment as they went through quarantine in AAFC's laboratory in Lethbridge, AB, and were apparent when they were placed inside the tent. Weevils were sent to a taxonomist in Ottawa for identification. Two species of *Rhinusa* were found, *R. antirrhini* and *R. neta*. Since *R. neta* from Europe was not approved for release in Canada at that time (although the weevil was already adventive in the country), 104 F1 *Rhinusa* weevils from the 1994 shipment were collected and returned to AAFC in the fall of 1994. The *R. antirrhini* and the *R. neta* were separated and overwintered in the lab facilities. The few surviving *R. antirrhini* were sent back to the MFRPF in the spring of 1995 and placed into a third tented plot. The single plot occupied by the 1994 release was sprayed with insecticide in the spring of 1995 to ensure no *R. neta* remained in Kamloops. Additionally, the seedheads were clipped and placed in small cages to observe any latent emergence of weevils. The European *R. neta* population was, thereafter, tested for host specificity as a precaution.

In 1996, an additional 332 *R. antirrhini* weevils were received from CABI and placed into three new tents and a single field release.

The plants from all releases were continually checked for any sign of *R. antirrhini* and in 1997 several seed pods from the original 1993 plot were found with the characteristic chewed exit holes. Additionally in 1997, many weevils were observed in the 1996 tents. At this time there was a concern that the original releases did not establish quickly because of a high aphid population in the 1993 tent and the continued requirement for pollination. According to DeClerck-Floate and Richards (1994), "Dalmatian toadflax must be cross-pollinated to produce seed". "Bumble bees are the major pollinators of Dalmatian toadflax, and their presence or absence will affect the availability of food for the seed weevil, *Gymnetron antirrhini*, or any seed-feeding insect released for biocontrol of Dalmatian toadflax" (DeClerck-Floate and Richards 1994). Although it is general practice to put bees into tents containing seed-feeding agents, it was thought prudent to establish uncontained plots of Dalmatian toadflax to raise large numbers of *R. antirrhini* weevils more quickly. Over 1000 weevils were collected from the existing tents and placed into an open area infested with Dalmatian toadflax approximately 930 square meters in size. Further agents and infested seed pods were added to this area in 1998.

Collection for field release of *R. antirrhini* from the MFRPF tents began in 1999. In 2001, following the realization that the tented releases were continuing to yield good volumes of weevils for field release and a necessity to consolidate land used for propagation and observations at the MFRPF, the open area plot was dismantled. In the years following, the number of tented plots were decreased as monitoring of the field releases showed good establishment and dispersal from the original sites (see Table 1 in the Habitat section). Efforts were concentrated in August and September of 2007 to collect as many weevils as possible from the single remaining tented plot. This plot will be dismantled in the spring of 2008.

Weevils have not been collected from the field for re-distribution because the MFRPF has yielded sufficient weevils to achieve the objective of establishing the biocontrol agent in varying habitat types. However, the field collection method is the same as that used at the MFRPF and is described in the Redistribution section. Field collection rates have ranged from 19 to 29 weevils in five minutes or 228 to 348 weevils per hour. The total number of weevils collected from the MFRPF and the number of releases they generated are summarized in Figure 21.

Year	1996*	1999	2000	2001	2002	2003	2004	2005	2006	2007	Total
# of Releases	1	3	2	4	7	7	6	2	3	14	49
# of Weevils Released	80	1316	531	793	2607	3796	2208	307	773	2805	15,216

*These weevils came from CABI, Switzerland.

FIGURE 21. *Rhinusa antirrhini* collected from the MFR Propagation Facility and distributed in field releases in B.C.

The weevils are readily dispersing from these collection sites as noted in Table 1. They have been found to disperse approximately 18 km away from a release site in seven years.

5. REDISTRIBUTION

Redistribution of agents is a critical part of a biocontrol program. To ensure efficient distribution throughout *R. antirrhini's* potential provincial range, invasive plant managers should endeavour to recollect from established field sites and make releases into new sites. First, however, Dalmatian toadflax infestations should be investigated for the presence of other agents not only to decrease competition for resources but also to determine if a release of *R. antirrhini* is necessary. For example, if *M. janthinus* is controlling the invasive plant population, it may be deemed unnecessary to expend the effort to release another agent. For general information regarding redistribution of biological control agents, please refer to Module 1.9 Biological Treatment & Monitoring of the IAP Reference Guide which is located at http://www.for.gov.bc.ca/hfp/invasive/index.htm.

FIELD COLLECTION

How to collect

Field collection of *R. antirrhini* typically involves aspirating the weevils from the plants or visually locating adult weevils in a Dalmatian toadflax infestation and hand

picking them from plants. Dalmatian toadflax plants can be swept for the weevils but this can be damaging to the plants. The stems of Dalmatian toadflax plants are relatively stiff and when hit with a sweep net can either snap off or catapult the small weevils away from the sweep net opening. This latter was determined to be the case when large numbers of *M. janthinus* weevils were seen on stems prior to sweeping but low numbers of weevils ended up in the sweep nets. Sweeping is also not very effective when the weevils are in the flowers.

R. antirrhini weevils can be observed in flowers, on plant stems, lateral stems, floral parts, leaf axils and on leaves. Weather conditions have some effect on locating the weevils and they are generally easier to find when it is warmer. Aspirators with plenty of suction are required to aspirate from flowers. Squeezing the rear of the toadflax blossom will cause the flower to open and expose the adults for collection. Each blossom can only be squeezed a couple times before the tissue breaks down and it no longer opens in this manner. As well, old flowers do not open as readily when squeezed as the tissue is not firm. Disturbing the plants by brushing the tops and irritating the inflorescences often cause the adults to move to the outer lip of the blossoms and eventually outside. Aspirating weevils directly from the plants works well as seeds, plant parts and other insects can be left at the site and the weevils are not jeopardized by storing them with spiders and other predators. Plants need to be approached with care when using these methods. If the weevils notice movement**,** shadows or the plant is shaken, they will either fly off or more commonly drop to the ground and lie motionless in the soil where they are difficult to see due to their small size. Additionally, sorting the collections may be necessary to avoid unintentional *R. neta* transfers.

R. antirrhini may also be collected in August by harvesting small lengths of stems with infested seedheads attached, prior to adult emergence. Do not pull up plants when collecting if the intent is to maintain the infestation as a collection site. Cut the stems with enough length to tie them in small bundles to be delivered to a release site. The stems should be propped upright to prevent the pods from molding in moist ground conditions. This method is more time consuming and there is a high potential to spread seeds and possibly *R. neta* from site to site. Exact numbers of weevils can only be extrapolated by opening several pods and estimating the average number of weevils per pod. In order to determine whether the weevils found inside the pods are alive, they must be observed long enough to revive. This can happen within a few minutes if the temperature is high enough, which is generally the case in August. However, if weevils are extracted from pods in cooler temperatures, placing the weevils in the palm of one hand, cupping the other over top and blowing gently on the agent will be suffice to revive them.

Where to collect

The following are suggested collection site criteria:

- **Site size:** *R. antirrhini* readily disperse, therefore, if sites are very large the agent may be difficult to monitor or collect efficiently. However, if a site is small, although establishment of the agent can be readily assessed, the plant population may not be able to sustain a continual population of *R. antirrhini*, particularly if the seed bank dwindles or another agent such as *M. janthinus* heavily infests the site. A good size for a collection site ranges between 0.5 and 1.5 ha.
- **Plant density:** The average estimated Dalmatian toadflax density of typical established sites suitable for collection range from 6 to 10+ plants/m^2 although 2 to 5 plants/m^2 are also collectable but not as efficient.
- **Ground cover:** Although ground cover is often lacking or minimal, this feature varies and has even involved sites with moss, though this is not typical.
- **Competing vegetation:** Agents are usually found in areas that either have little competing vegetation (e.g., road edges or loose slopes), but, also on plants growing within an area where the native vegetation is reclaiming.
- **Shade:** Sites should not be shaded, however, the plant usually does not grow in these conditions anyway.
- **Slope:** *R. antirrhini* has not shown a preference for slope as it has been found on level and sloped locations. For efficient collection, flat or gentle slopes are best while steep slopes can be reserved strictly for biocontrol.
- **Aspect:** Dalmatian toadflax has been observed in B.C. to typically be absent from steep north aspects, therefore, would not be conducive for *R. antirrhini* establishment. There appears to be no preference for any other aspects.
- **Elevation:** *R. antirrhini* can be found in a range of elevations. To date, the lowest to highest elevations are 290 m to 1205 m, respectively.
- **Moisture regime**: Dalmatian toadflax generally does not grow in moist conditions and *R. antirrhini* appears to inhabit all of its host plant's growing conditions.
- **Temperature**: *R. antirrhini* has not yet been found established in the cooler climates of B.C. (northwest of Clinton or near the Coquihalla toll booth). Generally, for initial establishment, sites receiving cold air drainage may be poor choices, especially if they are relatively flat or depressed, allowing cold air to pool.
- **Soil texture:** Soils may be coarse to fine and uniformly textured but preferably well-drained. Where litter is absent, the soil should not be compact to allow the agent to burrow for winter protection.
- **Soil moisture:** Dalmatian toadflax plants normally are established on loose soils that retain very little moisture. It is assumed that spring flooding would have an adverse affect on the dormant adults over-wintering in the soil.
- **Snow cover:** Generally snow cover is preferable to provide protection against extreme cold and fluctuating temperatures.

Sites that to date have been found collectable are: Palmer Forsythe (IAPP Site ID 215914); Louis Creek (IAPP Site ID 116721); and North side of McQueen Creek (IAPP Site ID 223729). Other sites thought to be promising for future collection are: Spencer Hill (IAPP Site ID 114457); and Midway (IAPP Site ID 113312).

When to collect

Time of Year

The collection period occurs either in spring (May and June) or in summer (August and September). DeClerck-Floate and Richards (1994) recommend that *R. antirrhini* is best released in the spring and at lower elevations to better coincide with bee pollination of toadflax flowers, and, thus, ensure establishment and population increase of the seed-feeding weevil on its food resource. However, Powell (1994) suggests collection of *R. antirrhini* should take place from July to August.

In the spring, there have been large numbers of adult *R. antirrhini* found between May and June at the same time as the population peak of the stem-boring weevil *M. janthinus*. At the MFRPF in Kamloops, located on the valley floor (345 m in BGxh2), *R. antirrhini* have been observed mating in May and June. The weevils have also been observed to not congregate in the spring flowers as much as in late summer. Since Dalmatian toadflax is in full bloom in spring, it is necessary to search many blooms to find the weevils residing within and which are dispersed throughout the site. Of interest, just prior to mating, the weevils have been observed to be the most active in flight. Throughout the collection periods, the *R. antirrhini* females will be in various stages of oviposition and may be ovipositing into the plants at the collection site and/or onto the walls of a collection container. Spring collection, which should occur late enough for sufficient weevils to have come out of hibernation to make the effort worthwhile, should also occur early enough for the females to still be gravid.

During summer collection, it has been found easier to locate *R. antirrhini* adults. By mid August, some mature adults will still be present and some gravid females will still be laying eggs into available flowers while newly emerging F1 adults will be contributing to the population. This F1 generation will be exponentially larger (barring major mortality or predation) than the spring population as each spring female will have laid on average 54 eggs (Harris and Gassmann 2003). Since spring-emerged adults that have oviposited die, it is best not to collect early in August to avoid soon-to-perish weevils. Additionally, if the collection contains spring-emerged adults that are ovipositing late, there may not be enough time for the subsequent larvae to develop before fall frosts, especially at higher elevations. The pollination and

development of seeds for the larvae to feed upon also tapers off in late summer (DeClerck-Floate pers comm. 2007).

During August and September, most flowers will be gone except for the delayed blooms within which the adults of both generations will congregate (as well as on the stems of flowering plants). Few flowers on a site will require more movement between plants to collect the weevils, but, usually the flowers that are present will yield several adults each. Up to six adults have been found in a single flower. If no flowers are present, the weevils are not as apparent as they will reside in leaf axils, on small leaves and terminal buds, under leaves, or on/in the soil, making it much more difficult to find them. Additionally, since the F1 generation are not seeking other weevils with which to mate and then available plants for oviposition, but, instead are preparing for hibernation, they are likely less apt to disperse from the site. As well, if collection occurs into September, temperatures are often lower and the weevils would be less prone to flight. The collection end date is weather dependant. Consecutive hot days promote continuous adult emergence in August and September. However, once cooler fall temperatures have arrived, it is much harder to find the adults as they begin to prepare for hibernation.

At the Kamloops MFRPF, collection of F1 adults generally was done in late August and into September. This was in part due to the availability of staff to address this agent with respect to time constraints around managing other biocontrol agent species. Additionally, releases made from summer collections readily established in BC. Figure 22 depicts the weevil population numbers over several years as a result of observation and collection activities.

It does not appear from collections done in the German Rhine Valley that either sex proportionately emerges nor disappears from the population before the other (Paetel 1997). It is possible to identify male and female *R. antirrhini* weevils to check these proportions and ensure equal releases, but, it has not been practiced in B.C. as it appears not to be necessary and the size of the insect does not make this a practical field exercise.

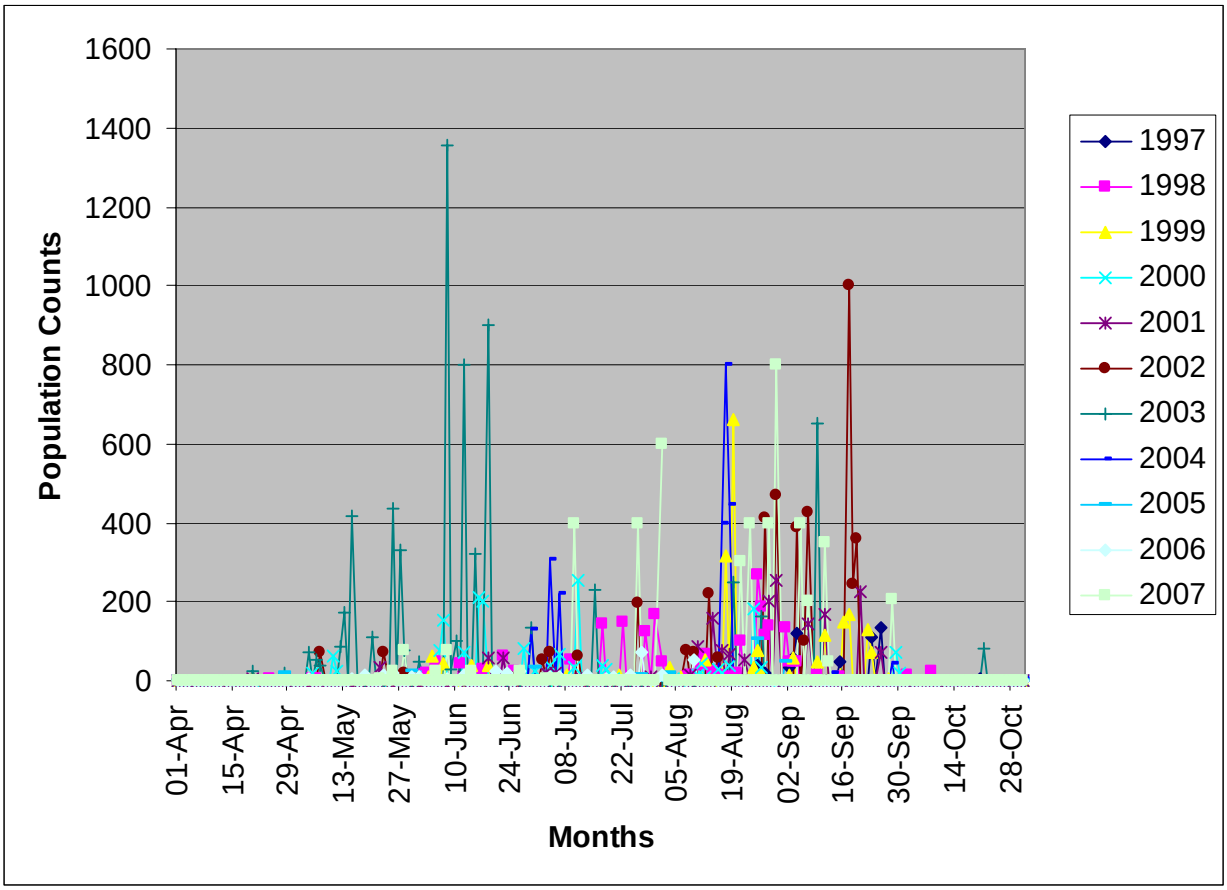

FIGURE 22. *R. antirrhini* annual combined observation and collection numbers.

Time of Day

Warm days have been found to be better for collecting than cooler days. Bright days have also been found good for collection, even when temperatures are slightly cooler as is the case in September. As well, the latter part of the day has been found best for collection as the weevils have been observed to reside in leaf nodes and on the soil surface in the morning, but, become much more active and readily visible on all plant parts as the day progresses. However, early collection times may take place on hot days with clear skies to avoid working in extreme heat. Adults can be found on the upper parts of the plants, leaf axils, on the stems, on flower parts, floral spikes, and, in particular, within flowers. *R. antirrhini* are still present on rainy days but are less active and are more likely to be found on the underside of a leaf, in a leaf node, in a flower, or dug into the upper soil surface than on more easily viewed surfaces. Use a hand lens to properly identify the adults if there is a question of its species.

When the temperatures are high and/or bright light, the agents are more active and more apt to fly away, yet, they are also more visible, therefore, it is potentially faster to obtain large numbers and more weevils in these conditions. The observed period just before mating when the weevils are more prone to flight also makes collection more difficult.

SHIPPING

Shipping instructions can be found within Module 1.9 Biological Treatment & Monitoring of the IAP Reference Guide which is located at http://www.for.gov.bc.ca/hfp/invasive/index.htm.

Additionally, up to 200 *R. antirrhini* weevils can be packaged into 1 litre bulk food containers. These should be released as soon as possible, particularly when the females are actively ovipositing in the spring. Transport the weevils with sufficient foliage for feeding. Dalmatian toadflax is quite succulent and water transpiration can be heavy, creating measurable water beading and pooling when held for several hours, even when packed with freezer packs or in an electric cooler. Recent practices have been to place a blue shop towel into the container, forming a 'vase shape', the clipped vegetative plant parts are then placed into the 'vase' before adding the adults. Do not ship any flowers or pods which may encourage oviposition during transport or can carry other biological control agents or parasites.

FIELD RELEASE

Prior to any releases, check for previous *R. antirrhini* or other biocontrol agent releases or dispersal in the Invasive Alien Plant Program (IAPP) Application found at http://www.for.gov.bc.ca/hfp/invasive/index.htm as well as in the field prior to opening the containers. *R. antirrhini* is readily distributing itself on toadflax. The potential for natural dispersal is particularly important when *M. janthinus* is present. Release sites should be large enough to contain enough toadflax to support a viable insect population with corridors of Dalmatian toadflax available for movement to other locations.

A potential release site needs to meet certain criteria to ensure success and longevity. It must meet program needs from a logistic standpoint i.e. travel distance, land tenure and accessibility. It must also be conducive to agent survival and establishment. Criteria for release sites are the same as those of collection sites (see Where to collect section)

Additional consideration

Late season releases should not be made into areas where temperatures are considerably lower than the original collection area. An extreme drop in temperature may cause immediate mortality but it may also prevent the weevils from reaching a suitable overwintering location and, therefore, mortality, resulting in wasted efforts. Late season release sites should have similar habitat criteria to the collection area.

6. MONITORING

For general information regarding monitoring of biological control agents, please refer to Module 1.9 Biological Treatment & Monitoring of the IAP Reference Guide which is located at http://www.for.gov.bc.ca/hfp/invasive/index.htm.

AGENT

Sites can be monitored for the presence of *R. antirrhini* adults in May through September, however, better monitoring results occur in August and September. This is due to the same reasons outlined in the Field Collection Time of Year section.

Seed pods can be checked for the presence of larvae and pupae in mid to late July and early August at ideal locations such as the Okanagan, Kamloops, lower North Thompson and Similkimeen, however, in more extreme habitats such as Juliet Creek and Meadow Lake, larvae and pupae observations can continue into September.

Although *R. antirrhini* and *R. neta* larvae can be distinguished from one another (see Interaction with Other Biological Control Agents section), this practice may be too time consuming or detailed for regular field practices. On the other hand, pupae can be distinguished using a hand lens to observe the thoracic humps (see Interaction with Other Biological Control Agents section). Also, mature *R. neta* pupae have been observed to closely resemble their adult shape and, therefore, may be distinguished from *R. antirrhini*.

Adults can be found on the upper parts of the plants, leaf axils, stems, on flower parts, floral spikes, and in particular within the flowers. To look inside the flowers, squeeze the base so they open and weevils within can be observed. Again, use a hand lens, or the naked eye, to properly distinguish between *R. antirrhini* and *R. neta* weevils. Although the two *Rhinusa* species differ in shape, *R. neta*'s size and color can vary and it has occasionally been found smaller than normal and at times quite dark. *R. neta*'s shape, however, remains the same. The species can also be distinguished from the shape of the rostrum as described in the Interaction with

Other Biological control Agents section. It may be necessary to aspirate the weevils into a collection container for easier viewing. It has been observed that *R. antirrhini* weevils leave the flower much more readily than *R. neta* when the flower is manipulated, however, both readily fly once out of the flowerhead. *R. antirrhini* also will reside inside the flower with *B. pulicarius.*

Where toadflax is heavily attacked by *M. janthinus*, spring blooms can be prevented, resulting in less efficient monitoring when searching in fewer flowers, on other plant parts and mixed among the *M. janthinus* weevils. Searching for *R. antirrhini* after *M. janthinus*'s spring attack and within late season toadflax blooms has proven to be more efficient.

Additional considerations:
If monitoring is done in the early part of the day or in poor weather when temperatures are low, the agent will be inactive. Checking flowers will usually produce adults, but they will not be easily identified if they are not active enough to show their rostrums. Again, a cold and inactive adult can be encouraged to become mobile by cupping the insect in the palm of your hand and carefully breathing warm air onto it. The weevils can be handled and identified more easily in cooler temperatures as the adults are not as quick to fly away as in warm, hot and bright conditions.

PLANT

Harris and Gassmann (2003) note a plant response to spring activity of *R. antirrhini*. The spring feeding "releases lateral shoots so the plants become bushy with delayed flowering".

Seed pods can be checked for the oviposition marks and gall spurs from May through September. The darkened area on the outside of the pod in Figure 23 indicates the oviposition mark. Spurs can be seen just above the oviposition point (Harris and Gassman 2003) (Figure 24). The presence of pod damage, larvae or pupae presence can indicate the timing required for future collection.

FIGURE 23. Oviposition mark on Dalmatian toadflax pod.

FIGURE 24. "Spur" on dried pod caused by oviposition.

It has also been observed in B.C. that when attacked pods are viewed from the top as in Figure 25, they will appear to have either pale contents or be empty. When the pods with pale contents are opened, a weevil can be found below a powdery mass which is packed above the agent (until such time as the weevil prepares to emerge). Once the weevil emerges from the pod, it can be seen that the pod is empty. However, this has been observed at sites where both *R. antirrhini* and *R. neta* are present, so it is not an indication of a specific species. Unattacked pods will have have a smaller opening than attacked pods and will have maturing seeds visible within. Figure 25 shows an attacked pod with its pale contents toward the top of the photo and an unattacked pod beneath. The unattacked pod exhibits the typical small, uniform opening for seed dispersal which can be discerned from the larger, non-uniform opening resulting from exiting *Rhinusa* weevils.

FIGURE 25. Attacked (top) vs unattacked pod (bottom) showing contents.

Exit holes typically can be seen in August and September, however, the weevil does not always create these and instead exits the pod out of the top opening. The exit holes sometimes created in the side or base of the pods by newly emerging adults are visible (Figure 26).

FIGURE 26. *R. antirrhini* exit hole in the side of the seedpod.

Fewer seeds result from attacked pods. Figure 27 shows the number of seeds left within a seed pod following attack by a *Rhinusa* species (left) while the pod on the right has not been attacked and has its full compliment of seed.

FIGURE 27. Seed produced in pod chambers as a result of *Rhinusa* attack (left) and no attack (right).

Additional considerations:

Monitoring the year immediately after the release has proven effective to determine establishment status. Waiting too long between making the release and monitoring may allow the agent too much time to disperse and become sparse. As well, frequent monitoring will provide knowledge of additional biological control agent populations on the site and provide insight into a potential change in the plant community.

7. SUMMARY

R. antirrhini is one of eight biological control agents present in B.C. to control toadflax. To date, there has been no significant conflict documented or observed between the various agents. Instead, the agents' activities have generally proven to complement one another in the control of toadflax. However, the presence of the various agents at a site should be investigated prior to release of *R. antirrhini* to increase the weevil's chances of establishment and population increase. Attention should also be given to determining the necessity of releasing the seed-feeding weevil as the agent may have already dispersed to the site or *M. janthinus* may be effectively controlling the target plant. *R. antirrhini*'s ability to reduce seed production is a significant factor in the long term management of toadflax in the province. Less seed development will reduce seed bank deposits and transfers to new sites.

Appendix A - DALMATIAN TOADFLAX

Common Name: Dalmatian toadflax
Scientific Name: *Linaria dalmatica* (L.) P. Mill spp. *dalmatica*
Synonym: Linaria genistifolia (P.) Mill. spp. dalmatica (Wilson et al. 2005)
Family: Scrophulariaceae (Figwort)

The plant
A short-lived perennial herb, introduced as an ornamental in the USA in 1894. Originates from the Mediterranean region from Yugoslavia to Iran and was cultivated as an ornamental in Europe in the 1500's (Robocker 1974). Spreads by seed and creeping root stock. The root system consists of a large, rough-surfaced tap root which may be up to or longer than 180 cm and possibly branched, and the long, (up to 3 m or longer) branching lateral roots whose buds produce new vegetative growth. Mature plants are 60 to 120 cm tall. The stems, several per plant, are smooth and light-green (Figure 28). Leaves are also light green and are heart-shaped, dense, alternate and individually clasp the stem. The flowers are 'snapdragon' shaped: double-lipped, bright yellow and tinged with orange on the inner lip. The flowers have long spurs projecting from their bases and the entire structure can reach 4 cm in length. Up to 500,000 seeds have been recorded from a single plant under good growing conditions. Seeds, sharply angular and 1-2 mm long, remain viable up to 10 years and are dispersed mainly by wind and browsing animals. The plant, like all *Linaria* spp., is toxic to livestock, however, cattle tend to avoid grazing in toadflax infested stands (DeClerck-Floate and Harris 2002).

Habitat

Widespread throughout B.C. including the Skeena, Nechako, Cariboo, Thompson, Okanagan, Similkameen, Fraser Canyon, East Kootenay and Boundary areas. It has also been observed on Galeano Island, one of the Gulf Islands.

Growing conditions

- Stress tolerant plant able to grow in conditions of low temperatures, coarse textured soils and summer drought. Soil types range from sand to gravelly loam and silt loam. Possibly extremely competitive with annual vegetation, other perennial herbs and even its own species. Living Dalmatian toadflax roots have a possible allelopathic effect (Robocker 1974). Found to outcompete other vegetation mainly by its ability to attain soil water from limited supplies. Toadflax seedlings do not compete effectively for soil moisture with fast maturing winter annuals and established perennials (Robocker 1974). Dalmatian toadflax, therefore, seldom becomes established in healthy, closed plant communities but

is located in disturbed soils, cultivated fields, waste areas, gardens, open grassland and transitional forest-grassland. Dalmatian toadflax is known to exist in the B.C. BEC zones of Bunchgrass, Ponderosa pine, Interior Douglas-fir, Interior cedar-hemlock, Coastal Douglas-fir, Coastal Western hemlock, Montane spruce and the Sub-boreal spruce.

FIGURE 28. Dalmatian toadflax (*Linaria dalmatica*).

Appendix B - YELLOW TOADFLAX

Common Name: Yellow toadflax
Scientific Name: *Linaria vulgaris*
Family: Scrophulariaceae (Figwort)

The plant

- A short-lived perennial herb, introduced into New England before 1672. Originates from south-western Asia, western Europe and the steppes of south-eastern Europe (Saner et al. 1994). Spreads by seed and creeping root stock. The root system consists of a tap root, which may extend more than 1 m, and lateral roots. Mature plants are 20 to 30 cm and sometimes up to 80 cm tall. The stems, several per plant, are generally unbranched, hairless and green (Figure 29). Leaves are also hairless and green and are numerous, narrow, pointed, alternate and attach one per node to the stem (Powell et al. 1994). They range in size from 25 to 75 mm long but are 40 mm on average. The flowers are 'snapdragon' shaped: double-lipped, bright yellow with an orange (rarely whitish) center. The flowers have long spurs projecting from their bases and the entire structure can reach 25 mm in length. Seeds are black or dark brown, winged and 2 mm in diameter. Seed production and viability are variable. They are dispersed mainly by wind, water, birds, rodents and other wildlife. However, it has been observed that during a growing season over 80% of the mature seeds fell within a 0.5 radius of the parent plant. Yellow toadflax, like all *Linaria* spp., is toxic to livestock, however, cattle tend to avoid grazing in toadflax infested stands (DeClerck-Floate and Harris 2002).

Habitat

- Found in the Thompson, Okanagan, Similkameen, Boundary, East Kootenay, Cariboo, Peace River, Skeena and Bulkley areas. The North American latitude range extends as far north as 55 to 65^{o} and elevation range extends from sea level up to 2200 to 2800 m (Saner et al. 1994).

Growing conditions

- Able to quickly colonize open sites, it is found in cultivated fields, waste areas, gardens, open grassland and transitional forest-grassland (Figure 30) (Powell et al. 1994). The vegetative reproduction allows yellow toadflax to take advantage of less hospitable sites such as subarctic areas or pastures or orchards where regular herbicide application or fire occur. Preferred soils include coarse, fertile and relatively summer moist grassland soils and it is limited by wet or dark

conditions. Mainly occurs in the biogeoclimatic zones of Bunchgrass, Ponderosa pine and Interior Douglas-fir (Powell et al. 1994).

FIGURE 29. Yellow toadflax (*Linaria vulgaris*).

FIGURE 30. Yellow toadflax (*Linaria vulgaris*) infestation.

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