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Biological Control of Leafy Spurge In Alberta: Progress And Prospects

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Biological control of leafy spurge in Alberta: Progress and prospects

Abstract:

This report describes the nature and extent of the leafy spurge problem in Alberta and summarizes the biological control efforts which have been undertaken in the province against this weed from 1978 to 1994. Leafy spurge is a herbaceous perennial weed, native to Europe, which spreads both by means of its creeping root system and by seed. It is unpalatable to cattle and can form dense stands on uncultivated land. Leafy spurge is estimated to infest around 6,000 hectares throughout Alberta in a wide range of soil and habitat types, particularly along river systems in the southern part of the province. Biological control efforts have been conducted since 1982 by the Alberta Environmental Centre, Alberta Agriculture, and Agriculture and Agri-Food Canada, in cooperation with the International Institute of Biological Control in Delémont, Switzerland. Eleven insect species have been released as biological control agents against leafy spurge in Alberta.

The most successful agent to date is the root-feeding beetle *Aphthona nigrescutis*, originally introduced from Hungary. This insect has been released at over 120 research sites; in addition, over 140,000 beetles have been redistributed to users through a program of redistribution clinics. *Aphthona nigrescutis* is giving excellent control of leafy spurge on dry, open sites such as hilltops or south-facing slopes, particularly on lighter soils. At one experimental site, leafy spurge above-ground biomass was over 100 gm⁻² when *A. nigrescutis* was released, and was reduced to less than 1 gm⁻² five years later. *Aphthona nigrescutis* has either failed to establish or has had no significant impact on leafy spurge in moister, more sheltered sites and on heavier soils. The related species *Aphthona flava* is also established and has been redistributed to 44 research sites. Its site requirements appear to be similar to those of *A. nigrescutis*, but it appears to be adapted to warmer summer temperatures than those normally experienced in Alberta. It has so far not reached high population densities at any except the original release site.

The main need now is for biological control agents which will be successful in moister and lower-lying sites such as riverbanks, flood plains and mesic pastures. Agents which are currently being tested in these environments include the stem-mining fly *Pegomya curticornis*, the defoliating moth *Minoa murinata*, and the root-feeding beetles *Aphthona cyparissiae* and *Aphthona lacertosa*. *Pegomya curticornis* and *M. murinata* are established in caged release sites, while *A. cyparissiae* and *A. lacertosa* are established at some open release sites.

Introduction

1.1 The leafy spurge problem

Leafy spurge (*Euphorbia esula* L. Euphorbiaceae) (Plate 1) is a herbaceous, perennial weed native to Europe and Asia. It was introduced to North America, probably from eastern Europe, in the late 19th or early 20th century (Dunn 1985). It has since spread widely in the northern U.S. states and Canada, becoming a serious weed problem in many areas. The largest infestations occur in the northern Great Plains in the U.S. and the Canadian prairie provinces. Leafy spurge is highly competitive in uncultivated land. New shoots develop from numerous buds on the underground stems and creeping roots, enabling it to spread through established vegetation. It also produces large amounts of fertile seed, which is scattered up to 4.6 m from the parent plant by an explosively-opening seed capsule (Watson 1985). All parts of the plant contain a milky latex which is irritating to cattle, horses, and some humans. The latex is unpalatable, and reportedly toxic, to cattle. In a study in Montana, forage utilization by cattle was significantly reduced where leafy spurge cover exceeded 10% (Hein and Miller 1992). Sheep and goats can apparently graze leafy spurge without ill effects. It occurs occasionally in cultivated land in Alberta, but is not usually a serious problem in such sites.

In Alberta leafy spurge occurs throughout most of the agricultural areas of the province, although there have been few reports from the Peace River region. The most extensive infestations occur in the southern and east-central parts of the province. Leafy spurge in Alberta appears to be strongly linked to river systems, as can be seen in Fig. 1, which shows the distribution of all biocontrol releases against leafy spurge in Alberta from 1978 to 1983. As biocontrol agents have now been released in most areas with significant leafy spurge infestations, this map gives a good indication of the general distribution of leafy spurge in the province. Major infestations occur along the St. Mary's, Oldman, South Saskatchewan, Bow and Red Deer Rivers, and the weed is also present along the Battle and North Saskatchewan rivers. Habitats close to rivers range from dry, gravelly or sandy river banks to moist flood plains with heavy soils.

In southern Alberta, spread of leafy spurge away from the rivers may be limited by moisture stress in open, dry, prairie habitats. In the more mesic conditions of central Alberta, flourishing stands of leafy spurge are found at some sites remote from rivers. The association with river systems in this area may indicate that the weed has been dispersed along watercourses, rather than a lack of suitable habitats away from rivers.

Leafy spurge is found on a wide range of soil types. Vigorous stands have been found in Alberta on soils with sand contents ranging from 10 to 100%, clay contents from 0 to 54%, and pH between 6.0 and 8.7. It is usually found in open areas, but can spread into partial shade.

1.2 Control measures

In Alberta the only chemical control measure recommended for leafy spurge in oilseeds is crop desiccation with diquat. In forage legumes, spot treatment with the non-selective herbicide amitrole or crop desiccation with diquat are the only chemical control measures recommended (Alberta Agriculture 1994). In cereals and forage grasses 2,4-D and MCPA can be used but will give top growth control only. In hay and grazing land 2,4-D, dicamba+2,4-D, MCPA and picloram can be used. All these treatments will kill legumes and other broad-leaved forage plants, and with the exception of picloram, will give top growth control only. Grazing restrictions apply to all these treatments. Picloram is a persistent compound which will prevent the growth of broad-leaved species for several years after application. It is water-soluble and will leach out of sandy or low organic matter soils. Its use along rivers therefore poses risks of water contamination and of killing trees and other native vegetation.

Fig. 1. Distribution of all release sites of biocontrol agents against leafy spurge in Alberta, 1978-1993.

1.3 Biological control

Classical biological control is the introduction of host-specific natural enemies from the native range of a weed for the long-term depression and regulation of weed populations. It is an appropriate method for control of many exotic weeds, particularly perennial species in uncultivated land which have become much more abundant than in their areas of origin. These agents, which are often plant-feeding insects, can develop high population densities in the area of introduction and reduce the weed population to an acceptable level (Harley and Forno 1992). Before introduction, candidate biological control agents must be extensively studied and tested to ensure that they will accept the target weed as a host plant and that they are specific enough that they will not cause significant damage to non-target plants. In Canada, approval for release of introduced weed biocontrol agents must be obtained under the Plant Protection Act (Harris 1991), and depends on review of each species by an advisory panel of Agriculture and Agri-Food Canada.

1.4 Leafy spurge as a target for biological control

The possibilities for biological control of leafy spurge in North America were reviewed by Harris *et al.* (1985), who also provided a list of insects and fungi associated with the plant in Europe and identified possible candidate biological control agents. Potential biological control agents have also been surveyed in China (Pemberton and Wang 1989). In a study aimed at selecting the most suitable target weeds for classical biological control in Alberta (McClay 1989), leafy spurge was identified as the fourth most suitable target of 138 weed species reviewed, with a score of 91 out of a possible 113. Features making it a good prospect for biological control include its non-native status, its occurrence in undisturbed habitats, its perennial life cycle, its lack of beneficial attributes, and its taxonomic distance from economic or native plants in Alberta. Factors tending to reduce its suitability for biological control are its genetic complexity and variability.

1.5 Agencies involved in biological control of leafy spurge

Research on biological control of leafy spurge in Alberta has been part of a larger program involving several agencies inside and outside Canada. Surveying and screening of new candidate biocontrol agents for leafy spurge has been undertaken in Europe mainly by staff of the International Institute of Biological Control (IIBC), European Station, at Delémont, Switzerland, while some agents have also been screened at the United States Department of Agriculture Biological Control of Weeds Laboratory at Rome, Italy and subsequently at Montpellier, France. Some agents have also been screened in the quarantine facility at the Regina Research Station of Agriculture and Agri-Food Canada. Funding for screening of biocontrol agents has been provided by Agriculture and Agri-Food Canada, Alberta Environmental Centre, Alberta Agriculture, and several other provinces, federal agencies, the United States Department of Agriculture, and U.S. states. The primary centres for importation of leafy spurge biocontrol agents in Canada have been the quarantine facilities located until 1992 at the Regina Research Station, and since 1992 at the Lethbridge Research Centre. Agents released in Alberta have been obtained by importation from Europe via these facilities, and from field populations established in other provinces and states through cooperation with biocontrol workers in those jurisdictions.

2 Biology of agents released in Alberta

This section describes the biology and effects on the host plant of each of the biocontrol agents which has been released to date against leafy spurge in Alberta.

2.1 *Aphthona cyparissiae* (Koch) (Coleoptera: Chrysomelidae)

Biology (Maw 1981, Sommer and Maw 1982): *Aphthona cyparissiae* (Plate 2) occurs in Spain, France, Italy, Germany, Switzerland, Austria, Hungary, Czechoslovakia, southern Poland and Russia, Yugoslavia and Bulgaria. It was found mainly in well drained sandy or rocky sun-exposed ruderal sites in the southern Rhine Valley, the Swiss Valais,

eastern Austria and on sheep pastures in western Hungary. In the Rhine Valley, adult beetles appear in late May to early June and live for about three months. Mean fecundity is 285 eggs per female. Eggs are laid in the soil; larvae after hatching move down into the soil and begin feeding on the filamentous roots of leafy spurge. As the larvae grow they also mine the yearling and perennial roots. There are three larval instars. Larvae overwinter in the soil in the third instar, and pupate in the spring. Host range tests showed that *A. cyparissiae* is able to feed and develop exclusively on a few *Euphorbia* spp., mostly in the subgenus *Esula*. Under field conditions in Europe its host range is restricted to *Euphorbia cyparissias*, *E. esula*, *Euphorbia virgata* and *Euphorbia* × *pseudovirgata*.

2.2 *Aphthona czwalinai* Weise (Coleoptera: Chrysomelidae)

Biology (Gassmann 1984): The biology of *A. czwalinai* (Plate 3) is similar to that of other *Aphthona* spp. developing on leafy spurge. In Europe and Asia it is found from northeastern Germany, eastern Austria, Czechoslovakia, Poland, Russia and the lower Danube region to central Asia and eastern Siberia. It was most often found at mesic, loamy sites where the host plant was growing mixed with other vegetation. It was not found at most of the open, dry sites inspected. In the field it was found primarily on *E. esula*. In the laboratory it completed development on *E. virgata* and Canadian leafy spurge, although these appeared less suitable hosts.

2.3 *Aphthona flava* Guill. (Coleoptera: Chrysomelidae)

Biology (Maw 1981, Sommer and Maw 1982): The biology of *A. flava* (Plate 4) is similar to that of other *Aphthona* spp. developing on leafy spurge. In Europe it is found in Italy, Austria, Czechoslovakia, southern Poland and Russia, Yugoslavia, Bulgaria and Rumania. In studies by IIBC it was commonest in Italy, where it was found predominantly on dry and sun-exposed sites with a high water table, and in Hungary, where it occurs on heavily grazed sheep pastures. Mean fecundity was 224 eggs per female. Its host range is similar to that of *A. cyparissiae*. *Aphthona flava* has been released and established in Montana (Pemberton and Rees 1990).

2.4 *Aphthona lacertosa* (Rosh) (Coleoptera: Chrysomelidae)

Biology (Gassmann 1990a): The biology of *A. lacertosa* (Plate 5) is similar to that of other *Aphthona* species feeding on leafy spurge. It is found in Austria, Yugoslavia, and southeast Hungary, mainly in association with *E. virgata* and *E. cyparissias*. It occurs at mesic-dry to wet sites, often on loamy soils and at sites with a well-developed herbaceous vegetation; it thus has distinctly different habitat preferences to those of *A. nigriscutis*. The host range of *A. lacertosa* is restricted to a few species in the subgenus *Esula*.

2.5 *Aphthona nigriscutis* Foudras (Coleoptera: Chrysomelidae)

Biology (Maw 1981, Gassmann 1985): The biology of *A. nigriscutis* (Plate 6) is similar to that of other *Aphthona* species developing on leafy spurge. In Europe it is found in

Hungary. It is strongly associated with dry sites and occurs on both fine and coarse soils but less commonly on soils of intermediate textures. In studies at AEC mean fecundity was 153 eggs per female, and the maximum observed was 440 eggs per female. *Aphthona nigricutis* is now established at numerous sites throughout Alberta. Detailed information on the establishment, redistribution and effects of *A. nigricutis* in Alberta can be found in section 4.5 below.

2.6 *Hyles euphorbiae* (L.) (Lepidoptera: Sphingidae)

Biology (Harris 1984, Harris and Alex 1971): This species, known as the spurge hawkmoth, is a large moth native to southern and central Europe, northern India and central Asia. Females lay up to 110 eggs on the leaves of many *Euphorbia* species. The large and brightly coloured caterpillars (Plate 7) feed on the foliage, consuming up to 2.7 g dry weight per larva (New 1971). *Hyles euphorbiae* overwinters as a pupa under rocks or below the soil surface.

2.7 *Lobesia euphorbiana* (Freyer) (Lepidoptera: Tortricidae)

Biology (Harris and Soroka 1982): This small moth lays its eggs on the undersides of the leaves of leafy spurge. On hatching, larvae move towards the shoot tips, where they feed in a 'bundle of terminal leaves tied together by silk (Plate 8). Pupation occurs in a silk cocoon in the same leaf bundle, and there may be two or more generations per year. *Lobesia euphorbiana* overwinters as pupae in the leaf tips or off the plant.

2.8 *Minoa murinata* (Scop.) (Lepidoptera: geometridae)

Biology (Harris 1985): This small moth is widely distributed in Europe and Asia between approximately 40°N and 54°N, from Britain to Siberia. It occurs in a wide range of habitats, from dry steppes and plains to moist woods. In the southern part of its range it is found mainly in mountainous areas, suggesting an intolerance for high temperatures. The eggs are laid in lines on the lower leaf surface. The larvae (Plate 9) feed on leafy spurge foliage and pupation occurs in the soil. Its main host in Europe is cypress spurge, *E. cyparissias*, but it is also reported from *Euphorbia amygdaloides*. In host-range tests it accepted several *Euphorbia* spp. in the subsections Galarrhaei and Esulae, including leafy spurge. Mean fecundity in the laboratory was 57 eggs per female.

2.9 *Oberea erythrocephala* (Schrank) (Coleoptera: Cerambycidae)

Biology (Schroeder 1980): This stem-boring beetle occurs throughout central and southern Europe, Asia Minor, the Caucasus and in southwestern Siberia. Females girdle the upper parts of stems by cutting grooves around them, and eggs are then laid into the stems just above the girdle. Larvae (Plate 10) mine the stems, root crowns and upper parts of the roots. Pupation and adult emergence take place in the spring. In the field in Europe, it has been recorded breeding on *E. cyparissias*, *E. esula*, *Euphorbia seguieriana*, *E. virgata*, *Euphorbia palustris* and *Euphorbia lucida*.

2.10 *Pegomya curticornis* (Stein) and *P. euphorbiae* (Kieffer) (Diptera: Anthomyiidae)

Biology (Gassmann 1987, Michelsen 1988, Gassmann and Shorthouse 1990): Until these two stem-mining fly species were studied in detail as potential biological control agents for leafy spurge, they were considered to belong to a single species, *P. argyrocephala* (Meigen). The biology of both species is similar. Eggs are laid early in spring in the young shoot tips of spurges. The larva mines down through the stem, causing it to wilt or die (Plate 11), and continues to feed in the stem-base near its junction with the root, where it pupates in mid summer. A gall is formed around the feeding site in the stem base.

The exact host preferences of these *Pegomya* species have been unclear because of taxonomic revisions and difficulty in identifying the European members of the *E. esula/virgata* complex, although there is no doubt that they have narrow host ranges within the subgenus *Esula*. According to Michelsen (1988), the primary host of *P. euphorbiae* is *Euphorbia cyparissias*, but it is also occasionally reared from *E. lucida*, *Euphorbia waldsteinii* (= *E. virgata*), and *E. seguieriana*. Michelsen (1988) states that the only host of *P. curticornis* is *E. waldsteinii* (= *E. virgata*). For the time being the nomenclature of Michelsen (1988) will be used here, for consistency with previously published information. However, more recent collections and host range testing suggest that *P. curticornis* is specific to European *E. esula* s. str. and will not develop on *E. virgata* or North American leafy spurge (Gassmann and Tosevski 1993). Further studies are desirable to confirm the identity of the species established in Alberta.

2.11 *Spurgia esulae* Gagné (Diptera: Cecidomyiidae)

Biology (Gagné 1990): This gall midge, native to Italy, forms galls in the terminal buds of *E. esula* (Plate 12). Larvae feed gregariously in the gall, which is composed of expanded and overlapping leaves. They pupate in cocoons among the leaves of the gall. *Spurgia esulae* is reported only from *E. esula*, although related species form similar galls on other European *Euphorbia* species.

3 Releases of biocontrol agents in Alberta

Initial releases of biocontrol agents against leafy spurge in Alberta were made using material imported from Europe, from laboratory cultures, or from colonies established in other provinces or states, as available. Both open and field cage releases were made; when field cages were used, these were usually 1.8 × 3.6 × 1.8 m cages of 8 mesh per cm saran screening. Agents introduced from outside Canada were imported via the quarantine facilities at the Regina or Lethbridge Research Centres of Agriculture and Agri-Food Canada. When agents became established in Alberta, the initial field colonies were used as sources for redistribution releases within the province. A complete listing of releases of biocontrol agents for research purposes against leafy spurge in Alberta from 1978 to 1993 is given in Appendix 1.

At the time of each release, relevant information was recorded on a release form and later transferred to a personal computer database (Appendix 2). Each release was assigned a unique identifying code of the form *AB-yy-nnnn*, where *yy* is the year of release and *nnnn* is a serial number, which was then used to track all data collected from that release site. Details recorded included the agent species released, life history stage, number released, source from which the agent was obtained, date and time of release, weather data, and whether the release was an open or cage release. Release site characteristics recorded included location, topography, slope, aspect, shade, moisture status, and soil characteristics. Characteristics of the vegetation were recorded, including percentage ground cover of leafy spurge, grasses, forbs, and woody vegetation, density of flowering and vegetative stems of leafy spurge, and weed canopy height. Vegetation parameters were mostly estimated from quadrats placed along one or two straight-line transects through the release site at 1-m intervals. If two transects were used, they were placed at 90° to each other in a cross pattern. Until 1989, 10 0.25 m² quadrats were used; from 1990 onwards 20 0.1 m² samples were taken to increase the precision of estimates of density and cover. At most sites soil samples (upper 15 cm) were collected for analysis and photographs were taken from several different viewpoints.

Sites were monitored by returning annually to each site at a time of year suitable to detect evidence of establishment. Agents were searched for visually to detect the insects or evidence of their feeding, or by using a sweep net. Vegetation characteristics were recorded in the same way as at the initial release; at a few sites quadrats were also clipped, and the vegetation sorted, dried and weighed to follow changes over time in the biomass and composition of the plant community. Monitoring data were also recorded on a field data sheet and later transferred to a database. Details of all items recorded during field release and monitoring are given in Appendix 2.

When sufficient data was available for an agent species, the monitoring results were analysed to determine which site characteristics were favourable for establishment and population increase of that species, and to detect changes in leafy spurge populations and other plant communities as a result of the biocontrol agent introduction. Results on a species-by-species basis are given below.

The protocol described above was followed for releases made for research purposes. In addition to these documented releases, some agents were distributed directly to users through redistribution clinics or field days. At these clinics, agents were provided to users such as Agriculture Fieldmen, private landowners, city and park weed control staff, and native bands. Users were advised of correct site requirements, release methods and monitoring techniques. These sites did not receive identifying codes, and monitoring was the responsibility of the users.

3.1 *Aphthona cyparissiae*

This agent was first released in Alberta in 1982 at two sites near Cardston. It established at both sites but has not increased sufficiently to have an impact on the leafy spurge population or to provide a source of beetles for redistribution. A third release near Hardisty in 1986 of beetles from Switzerland failed to establish. Between 1989 and 1992, six additional releases of *A. cyparissiae* were made using material from the field colony

at Maxim, Saskatchewan. It has been recovered at four of these sites; however, at one of these, near Hardisty, it was recovered only in the first two years after release and appears now to have died out. A further eight releases were made in 1993 and seven in 1994; data on establishment at most of these sites is not yet available. One release made in 1993 near Pincher Creek is known to have established well on a site where *A. nigriscutis* had previously failed to establish. Location of release sites: Fig. 2.

3.2 *Aphthona czwalinai*

A small release of *A. czwalinai* (32 adults) was made on an island in the St. Mary's River near Spring Coulee in 1985; it was never recovered at this site. Two releases were made in 1993; data on establishment from these releases is not yet available. *Aphthona czwalinai* is surviving well in caged experimental plots at the Lethbridge Research Centre. Location of release sites: Fig. 3.

Fig. 2. Distribution of releases of *Aphthona cyparissiae* in Alberta, 1982-1994.

Fig. 3. Distribution of releases of *Aphthona czwalinai* and *Aphthona lacertosa* in Alberta, 1985-1993.

3.3 *Aphthona flava*

The first release of *A. flava* in Alberta was made in 1982 at a site near Cardston, where 100 beetles were released. In 1983, a further 25 beetles were released at this site and 247 beetles were released at a second site, also near Cardston. At the first site two shoots with possible feeding marks were found in 1984; other than this there was no evidence of establishment until 1986, when adults were found in very small numbers. From 1987 to 1990, numbers increased steadily; by 1990 *A. flava* had spread about 100 m from the release point to cover over 10,000 m², and sweep net sampling collected 14.2 adults per sweep with heavy feeding damage on the plants. Spurge density has declined at this site since the population of *A. flava* reached high levels. However, the site has been grazed for several years by sheep, and *A. nigriscutis* is also present. It is therefore not possible to attribute the reduced spurge density to the effects of *A. flava* alone. At the second site, adults emerged from soil samples collected in May 1984; a few adult beetles were also found by sweeping at this site in July 1984. The population at this site increased steadily but less dramatically, and was not monitored closely after 1988 because of access problems.

Between 1986 and 1990, 1,303 beetles from the first site at Cardston were redistributed to 10 sites around Alberta. Only two of these releases, one made in 1989 on a river bank near Medicine Hat and one made in 1990 in a pasture near Millet, resulted in temporary establishment. At the Medicine Hat site beetles were recovered each year until 1992 but not in 1993 or 1994, while at Millet beetles were recovered only in the year after the release. Redistribution of *A. flava* was stepped up in 1991, and in 1991 and 1992 a total of 14,747 beetles were released at 34 sites. Beetles were recovered in subsequent years at 20 of these sites. At none of these redistribution sites, however, has *A. flava* reached high population densities comparable to those achieved by *A. nigriscutis*, and to date there is no clear sign of an impact on the leafy spurge density. Emergence of *A. flava* appears to be strongly dependent on temperature conditions; at most sites recovery rates declined and emergence was later in the cool wet summer of 1993, while in the warmer conditions experienced in 1994 numbers of adults increased. Location of release sites: Fig. 4.

Fig. 4. Distribution of releases of *Aphthona flava* in Alberta, 1982-1992.

3.4 *Aphthona lacertosa*

The first release of *A. lacertosa* in Alberta consisted of 320 beetles from Hungary released in a hay field on a silt loam soil with 7% organic matter near Spruce Grove in 1990. A second release of 195 beetles was made in a pasture on a sandy loam soil with 5% organic matter near Millet in 1991. Beetles were recovered in small numbers by sweeping (maximum 0.45 beetles/sweep), or by visual search, at both sites up to 1994. The population appears to be increasing more at Spruce Grove, which has the heavier soil of the two sites. There has been no obvious impact yet on leafy spurge density at either site. Both these releases are adjacent to sites where both *A. nigriscutis* and *A. flava* had failed to establish, consistent with the observations in Europe that *A. lacertosa* prefers more mesic and loamy sites than the latter two species. Two further releases were made near Cardston in 1992 and Lethbridge in 1993, and adults were recovered at both these sites in 1994.

Two adult *A. lacertosa* collected at Spruce Grove in 1993 laid numerous eggs in the laboratory at Vegreville; these were placed on the soil surface in pots containing leafy spurge plants. The pots were left in the greenhouse until late autumn and then overwintered in a cool growth chamber. A total of 40 adult *A. lacertosa* emerged from the pots in spring 1994, suggesting that this species can be easily multiplied on potted leafy spurge plants. Rearing is currently under way to provide further material for field releases in 1995. There is also a strong population in experimental plots at the Lethbridge Research Centre. Location of release sites: Fig. 3.

3.5 *Aphthona nigriscutis*

Aphthona nigriscutis was first released in Alberta in 1983 at Cardston, using material from Hungary. A second importation of *A. nigriscutis* from Hungary was released at Hardisty in 1986, but failed to establish. Establishment at the Cardston site was confirmed in 1986. Beetles were first collected from this site for redistribution in 1987, and between 1988 and 1990, a total of 24,860 *A. nigriscutis* were released at 122 documented sites throughout Alberta.

In addition, over 140,000 beetles were supplied for over 260 releases by individual landowners, Agriculture Fieldmen, and other users, through a series of seven redistribution clinics conducted in 1991-1994. The clinics provided users with beetles and training in release methods, site selection and monitoring. The importance of releasing the beetles in suitable habitats was stressed. A pamphlet on biological control of leafy spurge (Alberta Agriculture 1991) was produced to provide this information to potential users and the general public. Approximately 50,000 beetles were also supplied to users in other provinces and the U.S. Most beetles used in the primary redistribution were taken from the original site at Cardston, but many of those supplied to redistribution clinics and users outside the province came from the very successful 1988 and 1989 releases at sites in Edmonton.

At the most successful sites, *A. nigriscutis* causes stress on the spurge plants which is visible in the form of reduced flowering within one to two years after release. Within three to four years its population increases to densities which cause extensive defoliation

through adult feeding, accompanied by reduction of the spurge shoot density and cover in the vicinity of the release site. Dispersal is relatively slow for the first few years, with beetles and damage evident within a 5 to 10 m radius of the original release point. When populations reach a density which causes serious defoliation, dispersal becomes more rapid, and beetles may have spread up to 100 m by four to five years after release. At the most highly favourable sites, adult beetles disperse in the form of a "solitary population wave" (Kovalev 1990), in which an advancing front of beetles moves into a new area of relatively untouched spurge, leaving an area of totally defoliated plants behind them. Such areas produce little spurge regrowth in the following year, leaving them open to the increase of competing vegetation. Plants on the edge of the advancing front are heavily loaded with adult *A. nigriscutis*; a single stroke of a sweep-net can sometimes capture thousands of beetles.

Further details on the effects of *A. nigriscutis* on leafy spurge and on the site characteristics favourable to establishment are given in section 5.1. Location of release sites: Fig. 5.

Fig. 5. Distribution of releases of *Aphthona nigriscutis* in Alberta, 1983-1992.

Fig. 6. Distribution of releases of *Lobesia euphorbiana* and *Minoa murinata* in Alberta, 1990-1994.

3.6 *Hyles euphorbiae*

A release of 224 *H. euphorbiae* larvae was made near Cardston in July 1978. No recoveries have been made, and there have been no further releases.

3.7 *Lobesia euphorbiana*

A release of 150 pupae of *L. euphorbiana* was made in a field cage at Cardston in July 1990. Some webbed shoot tips were seen at this site later in the season, but no sign of overwinter survival or establishment has been seen subsequently. A second release was made in a field cage near Millet in September 1991. On this occasion infested plants containing an estimated 400 cocoons, from a rearing cage at Vegreville, were transplanted to a caged field site. Adults and eggs were seen in the cage in late May 1992, and by the end of July some larvae had pupated. In early September very young second-generation larvae were abundant. The second generation appears not to have overwintered successfully, as there were no indications of survival of *L. euphorbiana* in 1993 or 1994. Successful adaptation of *L. euphorbiana* to Alberta climatic conditions will depend on selection of a univoltine strain. This appears to have occurred in Manitoba, where *L. euphorbiana* is well established, and material from this population was released at Cardston in 1994. Location of release sites: Fig. 6.

3.8 *Minoa murinata*

Between 1991 and 1994, one caged and ten open releases of *M. murinata* were made using approximately 6,500 larvae and 500 adults. Releases were made in the City of Edmonton, in the Counties of Wetaskiwin, Ponoka, Flagstaff and Mountain View, and in the Municipal Districts of Cardston and Pincher Creek. To date there have been no recoveries at any of the open release sites. The caged release site is located on a dense stand of leafy spurge which grows to over 1 m in height. At this site, adults and larvae have been recovered every year since the release was made in July 1991. In 1992 adults were seen in late June and larvae were present from early July to August. Newly oviposited eggs were seen in September, suggesting that a second generation had started, but it is unlikely that this could have been completed. In 1993 adults were again observed in mid June and larval feeding was seen in July and August. In 1994 emergence was earlier, the first adults being seen in late May, and numerous adults and eggs were present in late June. By early September, plants in this cage had been totally defoliated, suggesting that an abundant second generation had been completed. These results indicate that *M. murinata* is well adapted to the climatic conditions of central Alberta, and suggest that its failure to date to establish from open releases may be related to biological factors such as predation or dispersal. Location of release sites: Fig. 6.

3.9 *Oberea erythrocephala*

A release of 123 adults of *O. erythrocephala* from Switzerland was made at Cardston in June 1980. The site was later burned and sprayed and no recoveries were made in 1981 (Harris 1984). During mass collections of *A. nigriscutis* near this site by USDA-APHIS

staff, single adults of *O. erythrocephala* were reportedly collected in 1989 and 1990 (R. Richard, USDA-APHIS, personal communication). Thus it is possible that the species may still be present in low numbers. A second, caged release of 20 adults was made on an island in the South Saskatchewan River near Redcliff in 1986. This site was monitored in 1987, 1989, and 1992, and no signs of establishment were seen.

3.10 *Pegomya* spp.

The *Pegomya* species released in Alberta will be referred to here by the names used in Michelsen (1988), as these were the names considered applicable at the time when they were shipped and released. However, in the light of more recent observations in Europe (see section 2.10 above), further studies should be made to confirm the identity of the population which is now present in Alberta.

In 1988, two caged releases were made with 23 adult *P. euphorbiae* near Cardston and 9 adult *P. curticornis* near Millet. The flies may have been in poor condition by the time they were released, and no signs of attack or establishment were ever observed at either of these sites.

In autumn 1989, further material of both species was received as pupae in galls from Hungary. These were stored over winter at -4°C, and placed at 10°C in late March 1990. In April 1990, 128 adults emerged from galls shipped as *P. euphorbiae* and 24 adults from those shipped as *P. curticornis*. Emergence of *P. euphorbiae* began approximately ten days earlier than that of *P. curticornis*.

After emergence, the adult *P. euphorbiae* were held for mating in cages about 40 × 40 × 80 cm and provided with diluted honey and yeast extract solutions for feeding. They were then placed in oviposition cages consisting of a 30 × 10 cm Plexiglas tube placed over a potted leafy spurge plant with young shoots up to about 15 cm tall. Two pairs of flies were placed in each oviposition cage and the plants were changed after two days. A total of 59 plants were exposed to oviposition in this way. All surviving flies were then released at an open site at Edmonton. By early May, many attacked shoots were seen in the potted plants. These plants were overwintered outdoors under microfoam sheeting and a field cage was placed over them in spring 1991. Very few adult flies emerged from the pots in 1991 and no attacked shoots were seen in that year. No signs of damage or establishment were seen in 1990 or subsequent years at the open release site. By mid-1991, therefore, there were no survivors from the material received as *P. euphorbiae*.

On April 30, 1990, the 24 adult *P. curticornis* were placed on potted leafy spurge plants with shoots up to 20 cm tall in a field cage, and by late May twenty attacked shoots were visible. The pots were overwintered in the same way as for *P. euphorbiae*, and by mid-May 1991 49 attacked shoots were visible on 22 plants. All plants with attacked shoots were transplanted to a site at Millet in mid July, by which time the larvae would either have been feeding in the galls below ground level or would have pupated. A field cage was placed over this site in March 1992 to confine emerging adults. On April 28, 10 adult flies were seen in the cage, and on May 6 an estimated 300 attacked shoots were visible. All attacked shoots were withered or severely stunted by July 1992. The cage

cover has been replaced each spring since then and adults have continued to emerge in late April or early May until 1994. Adult emergence occurs when the leafy spurge shoots are about 15 cm tall, and attacked shoots remain stunted at or below this height.

Beginning in 1993, attempts were made to redistribute *P. curticornis* from the field cage population at Millet to other sites. Adult flies were released in a field cage near Spruce Grove, and infested plants were transplanted to a caged site near Olds. The field cage release of adult flies resulted in some attacked shoots in 1993, but there was no evidence of subsequent overwinter survival. Attacked shoots were found in the Olds cage in summer 1994, indicating that *P. curticornis* had successfully overwintered and bred there.

None of the four releases of adult *Pegomya* flies (two caged and two open) were successful, whereas both releases made by transplanting infested plants to the field in mid- or late-summer, and caging the release site the following spring, resulted in establishment. Although labour-intensive, this method therefore appears to be the most reliable way of establishing *Pegomya*. The advantage of this method may be that flies emerge in the spring properly synchronized with the growth of leafy spurge at the site, and find stems at the correct stage of development for successful attack. This is suggested by observations made in 1993 at the Spruce Grove site, where several stems showed signs of early attack and later regrowth. Dissection of these stems always showed a dead larva which had failed to reach the stem base. Possibly if eggs are laid into stems that are already too tall or elongating too rapidly, the larva is unable to reach the stem base and is therefore unable to complete development. Location of release sites: Fig. 7.

3.11 *Spurgia esulae*

Three releases of *S. esulae* have been made in Alberta, only one of which has so far led to temporary establishment in the field. Seventy-five galls from North Dakota were placed in a leafy spurge patch at Edmonton on July 1, 1989. One month later, 26 galls were found over a 100 m² area around the release site. In June 1990, six fresh galls were found near the release point, indicating that at least a few individuals had overwintered successfully. No sign of further breeding has been seen since at the site, and leafy spurge there has now been largely eliminated by *A. nigriscutis*. Location of release sites: Fig. 7.

Fig. 7. Distribution of releases of *Pegomya* spp. and *Spurgia esulae* in Alberta, 1988-1993.

4 Establishment and impact of *Aphthona* spp.

4.1 *Aphthona nigriscutis*

A total of 132 documented releases of *A. nigriscutis* were made on leafy spurge in Alberta between 1983 and 1992. Fourteen of these sites were not monitored for various reasons (sites destroyed, unable to locate, etc.). Of the 118 sites monitored, establishment has occurred at 82, an establishment rate of 69.5%. Numbers of beetles recovered varied widely between sites, ranging from a few individuals at the least successful sites to dense populations causing total defoliation and significant reductions in spurge density at the most successful sites. Some of the factors affecting success of establishment of *A. nigriscutis* are illustrated in Figs. 8-13. In these graphs, the success of establishment of each site is estimated by the maximum capture rate of adult beetles in sweep net samples (in beetles per sweep). Soil texture was clearly correlated with success of establishment, with few releases being successful at sites where the soil contained less than 40% sand, or more than about 30% clay (Fig. 8). Sites where the soil pH was below 7.2, or organic matter was above about 8%, were unsuccessful with a few exceptions (Fig. 9). Release site topography was also important; releases made at sloped or convex sites were generally more successful than those made at flat or concave sites (Fig. 10). This applied over all scales of relief, from the micro scale (10 m around the release point) to the macro scale (1000 m around the release point). For releases on sloping sites, a southern or western aspect was the most favourable for establishment (Fig. 11). There was no clear relationship between success of establishment and characteristics of the leafy spurge stand such as height, density, or percentage of flowering stems (Figs. 12 - 13).

Fig. 8. Effects of soil texture on recoveries of *Aphthona nigriscutis* in Alberta.

Fig. 9. Effects of soil pH and organic matter on recoveries of *Aphthona nigriscutis* in Alberta.

These relationships do not necessarily imply a direct response of the insects to the various site factors mentioned. It is possible, for example, that the insects perform poorly at sites which are cool or poorly drained, and that such sites also tend to develop more acid soils or higher levels of organic matter. This does not necessarily imply that the insects respond directly to pH or organic matter.

Numbers of beetles released do not appear to be critical for establishment; successful establishment was obtained with releases of 50 to 500 beetles. *Aphthona nigriscutis* has also been observed at the release sites of other agents such as *A. flava*, where it was never released deliberately. We suspect that it may have been introduced to these sites as stray individuals resting on clothing, equipment or vehicles of staff who had previously visited *A. nigriscutis* release sites. This suggests that *A. nigriscutis* can establish successfully from quite small numbers of individuals.

Fig. 11. Effects of release site aspect on recoveries of *Aphthona nigriscutis* in Alberta. Thick lines: mean maximum capture rate (adults per sweep). Thin lines: standard error.

Fig. 10. Effects of release site topography on recoveries of *Aphthona nigriscutis* in Alberta. Bars show mean maximum capture rate of *A. nigriscutis* (adults per sweep) at sites in each relief category at each scale. Numbers above bars indicate the number of sites in that category.

Fig. 12. Effects of leafy spurge shoot density and flowering status on recoveries of *Aphthona nigriscutis* in Alberta.

Aphthona nigriscutis disperses relatively slowly from release points (Fig. 14); one year after release, the mean maximum distance from the release point at which adults or feeding damage were observed was 6.5 m. The mean dispersal distances 2, 3 and 4 years after release were 14 m, 66 m and 124 m, respectively. The observed increase in rate of dispersal in the third and fourth years may partly reflect the greater ease of finding beetles as the population density increases. It may also indicate, however, that *A. nigriscutis* responds to crowding by increasing its rate of dispersal.

The most detailed data on the effects of *A. nigriscutis* on leafy spurge populations were obtained from a series of six releases made on a south-facing railway bank in the City of Edmonton. Release sites were spaced at intervals of 45 to 100 m along the bank. Three of these releases (AB-88-0021, AB-88-0026, AB-88-0033) were made using 200 adults each in early, mid-and late July 1988 respectively. Three more releases (AB-89-0012, AB-89-0014, AB-89-0015) were made on July 12, 1989, using 50, 200 and 500 adults, respectively. Percentage cover, shoot densities, and bio-mass were determined from twenty 0.1 m² quadrants at the time of release, and annually in early August from 1990 onwards. Beetle numbers were estimated annually using sweep net samples, except in 1990 when 30-minute visual counts were used. Sites were also photographed annually in early July from standard viewpoints.

All releases resulted in establishment, and a patch of depression of spurge density or flowering was evident around each of the sites within one to two years after release. By 1992 populations from all release sites had spread and coalesced, so that *A. nigriscutis* was present along a 650 m length of the railway bank. Populations have continued to disperse since then.

Between two and three years after release, reduction in leafy spurge abundance was evident from the biomass and cover measurements. Spurge abundance continued to de-

Fig. 13. Effects of leafy spurge canopy height and shoot density on recoveries of *Aphthona nigriscutis* in Alberta.

Fig. 14. Distances of dispersal of *Aphthona nigriscutis* from release sites in Alberta. Solid triangles: maximum distance at which adults or feeding damage were observed from release point. Open circles: means.

cline until five years after release, by which time it had virtually disappeared from the sampled areas (mean percentage cover less than 1% and biomass less than 1 gm⁻²). The abundance of other vegetation categories (grasses, forbs and woody species) increased as the leafy spurge density declined (Figs. 15-16).

Fig. 15. Aboveground biomass (mean $\pm$ standard deviation) of leafy spurge and other vegetation types at six Edmonton release sites after release of *Aphthona nigriscutis*.

Fig. 16. Percentage cover (mean $\pm$ standard deviation) of leafy spurge and other vegetation types at six Edmonton release sites after release of *Aphthona nigriscutis*.

A series of annual views of one of these release sites, showing the decline in leafy spurge infestations, is shown in Plates 13-18.

4.2 *Aphthona flava*

Aphthona flava has not been released as extensively in Alberta as *A. nigriscutis*, and has been recovered in much smaller numbers. It is therefore more difficult to assess its habitat requirements. There appears to be a trend towards better establishment at sites with high sand content (Fig. 17), and most successful establishments have been at sites with soil pH between 7 and 8 (Fig. 18).

Aphthona flava does not appear to perform well at sites with well-developed grass cover or with very sparse leafy spurge cover; most successful establishments occurred at sites with less than 20% grass cover and more than 30% leafy spurge cover (Fig. 19). There appears to be considerable over-

Fig. 17. Effects of soil pH and organic matter on recoveries of *Aphthona flava* in Alberta.

lap between its requirements and those of *A. nigriscutis*, as shown by the fact that *A. nigriscutis* has become established at many *A. flava* sites through accidental release. However, the general field appearance of successful *A. flava* sites tends to be somewhat more sheltered and mesic than that of good *A. nigriscutis* sites.

The establishment of *A. flava* in most parts of Alberta may be limited by its slower postdiapause development. Its peak adult emergence often does not occur until late July or August, while in favourable sites *A. nigriscutis* can emerge by early June. This suggests that *A. flava* may be adapted to a warmer climate, which would be consistent with the origin of this population from northern Italy.

5 Discussion

5.1 Potential of agents currently available

Aphthona nigriscutis has proven effective in controlling leafy spurge infestations in Alberta on drier sites, lighter soils, and south-facing slopes. Other agents will be required for heavier soils, low-lying and moister sites, such as flood plains, river banks, and fertile pasture sites in central Alberta. Other *Aphthona* species (*A. flava*, *A. cyparissiae*) have successfully controlled leafy spurge at sites in Montana and Saskatchewan. It thus appears likely that any of this group of species can potentially be effective against leafy spurge, provided that they are released in habitats which meet their requirements. The

Fig. 18. Effects of soil texture on recoveries of *Aphthona flava* in Alberta.

Fig. 19. Effects of vegetation cover on recoveries of *Aphthona flava* in Alberta.

matching of *Aphthona* species to suitable habitat types is thus the key to effective use of this group of agents. From our experience to date with *A. flava*, it appears to perform best at sandy but not too dry sites without a well-developed grass cover. Combined with its late emergence, which presumably limits the potential rate of population increase, this suggests that it is likely to be suitable for a very limited range of sites in Alberta. We suggest that it is at present not worthwhile to continue extensive distribution of *A. flava*. However, selected sites where it is now established should continue to be monitored to evaluate its longer-term population development and impact. *Aphthona cyparissiae* has not yet developed significant populations at most sites where it has been released in Alberta. Further monitoring will be necessary to determine whether it can be effective under Alberta conditions. The potential of *A. lacertosa* merits further investigation. This species occurs in a wide range of habitat types in Europe, including mesic sites and loamy soils, and it has survived in Alberta at two sites where *A. nigriscutis* and *A. flava* have consistently failed to establish. Further releases of this species should be made in Alberta to evaluate its suitability and impact.

Of the other species currently available, the potential of *Pegomya* deserves further investigation. This insect attacks young leafy spurge shoots very early in the season and stunts or kills them before they can become competitive. Heavy attack by *Pegomya* on a leafy spurge stand should therefore reduce its ability to displace grasses and other vegetation. *Pegomya* has proved well able to survive under Alberta climatic conditions, and as the larvae are never in direct contact with the soil it may be less sensitive than the *Aphthona* species to soil characteristics. The emergence of adults early in the spring, when few other insects are active, and the internal feeding site may also favour this species by protecting it to some extent from native predators and parasitoids. *Minoa murinata* has also shown itself in outdoor cages to be well adapted to the Alberta climate. Controlled-environment studies with *M. murinata* have shown that it is sensitive to high temperatures; it therefore seems most promising for use in cooler or shaded sites. Further field studies in 1995 will focus mainly on evaluation of *Aphthona lacertosa*, *Pegomya* and *Minoa murinata*.

Another group of potential agents consists of the root-boring moths *Chamaesphecia astatifformis* Herrich-Schäffer, *Chamaesphecia hungarica* (Tomala) and *Chamaesphecia crassicornis* (Bartel) (Lepidoptera: Sesiidae). These have not been discussed here as no field data from Alberta are available yet; however, some of these species may have potential in moister or mesic situations (Gassmann 1990b). Field cage rearing is under way at the Lethbridge Research Centre.

5.2 Implementation and technology transfer

The two basic requirements for successful implementation of biological control are the identification of effective agents adapted to environmental conditions in the area where they are to be used, and a system to supply those agents in sufficient numbers to the sites where they are required. Some agents which have been successful against weeds have dispersed so rapidly throughout the area of infestation that little intervention was needed beyond the initial release to bring about successful control. This will not, how-

ever, be the case with *Aphthona* species against leafy spurge, which will require considerable logistic effort to make use of their potential.

At present the only effective agent available in large numbers within Alberta is *A. nigriscutis*. The supply of the agent is not a limiting factor, as a successful site produces the beetles in far larger numbers than are needed to maintain control once the spurge has been reduced to a low density. A number of such sites exist in Alberta. They have, however, a limited useful life as a source of beetles, as leafy spurge is likely to be reduced to low densities within four to five years after establishment. To make the most effective use of the agent, therefore, surplus beetles should be collected intensively for redistribution from these sites during the outbreak phase.

The main limitations on the use of biological control against leafy spurge are the logistic constraints on collecting, packaging and transporting the insects from the collection sites to scattered release sites. Because of the relatively slow dispersal of *Aphthona* species, large numbers of releases are needed to obtain full coverage of large leafy spurge infestations. For the insects to spread throughout an area of leafy spurge within three to four years in suitable habitat, releases should ideally be spaced 50 m apart or less. If redistribution releases are made sparsely or haphazardly, spurge will continue to spread in habitats where it could be controlled, while surplus beetles from productive established sites will go to waste.

Currently, redistribution of *A. nigriscutis* is done by Alberta Agriculture, Food and Rural Development or by municipalities through the Agriculture Service Boards as a public service, without charge to users. The current level of resources available to these agencies does not allow full use of the available supply of *A. nigriscutis*. More effective use of these agents would therefore require additional funding for the current system of free redistribution, a fee for service, or private sector involvement in redistribution. At present, no private sector companies are involved in redistribution of weed biocontrol agents in Alberta.

A second limitation on the implementation of biological control is that potential users may be unaware of its possibilities, may lack the skills and information needed to use it effectively, or may be unfamiliar with the sources of supply of the biocontrol agents. Many producers and land managers in Alberta are skilled and knowledgeable in chemical and cultural methods of weed control, but, for most, biological control is a new technique requiring unfamiliar skills. Continued extension and technology transfer efforts will be needed to ensure that potential users are aware of the possibilities of biological control, understand its effects, and are able to select suitable biocontrol agents and release them in environments in which they will be effective.

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Appendix 1: List of releases of agents against leafy spurge in Alberta 1978-1994

The list is sorted first by agent species and then by release date.

Release identifier	Agent	No.	Release date	Lat. (°N)	Long. (°W)	Municipality
AB-82-0001	<i>Aphthona cyparissiae</i>	190	Jul 21 1982	49.2	113.3	Cardston
AB-83-0006	<i>Aphthona cyparissiae</i>	450	Jul 14 1983	49.2	113.3	Cardston
AB-86-0002	<i>Aphthona cyparissiae</i>	174	Jul 10 1986	52.7	111.6	Flagstaff
AB-89-0034	<i>Aphthona cyparissiae</i>	975	Jul 26 1989	52.7	111.3	Flagstaff
AB-91-0103	<i>Aphthona cyparissiae</i>	510	Jul 3 1991	49.6	112.9	Blood Indian Reserve
AB-92-0006	<i>Aphthona cyparissiae</i>	500	Jun 30 1992	49.8	110.9	Cypress
AB-92-0014	<i>Aphthona cyparissiae</i>	500	Jul 1 1992	50.9	114.0	City of Calgary
AB-92-0011	<i>Aphthona cyparisside</i>	500	Jul 3 1992	53.0	113.2	Wetaskiwin
AB-92-0005	<i>Aphthona cyparissiae</i>	500	Jul 9 1992	52.7	111.1	Provost
AB-93-0016	<i>Aphthona cyparissiae</i>	200	Jul 6 1993	49.5	114.2	Pincher Creek
AB-93-0017	<i>Aphthona cyparissiae</i>	200	Jul 6 1993	49.5	114.2	Pincher Creek
AB-93-0018	<i>Aphthona cyparissiae</i>	200	Jul 6 1993	49.5	114.2	Pincher Creek
AB-93-0014	<i>Aphthona cyparissiae</i>	200	Jul 20 1993	49.2	113.3	Cardston
AB-93-0015	<i>Aphthona cyparissiae</i>	200	Jul 20 1993	49.2	113.3	Cardston
AB-93-0013	<i>Aphthona cyparissiae</i>	250	Aug 5 1993	49.0	113.4	Cardston
AB-93-0026	<i>Aphthona cyparissiae</i>	500	Aug 5 1993	49.8	112.3	Taber
AB-93-0005	<i>Aphthona cyparissiae</i>	250	Aug 6 1993	49.8	113.1	Willow Creek
AB-94-0006	<i>Aphthona cyparissiae</i>	400	Jun 22 1994	50.1	110.6	Cypress
AB-94-0009	<i>Aphthona cyparissiae</i>	250	Jun 22 1994	49.8	112.4	Taber
AB-94-0007	<i>Aphthona cyparissiae</i>	400	Jun 23 1994	50.9	111.0	Special Area #2
AB-94-0008	<i>Aphthona cyparissiae</i>	800	Jun 23 1994	52.6	111.3	Flagstaff
AB-94-0010	<i>Aphthona cyparissiae</i>	250	Jun 23 1994	49.4	113.1	Cardston
AB-94-0011	<i>Aphthona cyparissiae</i>	250	Jun 23 1994	49.4	113.1	Cardston
AB-94-0012	<i>Aphthona cyparissiae</i>	200	Jun 23 1994	49.4	113.1	Cardston
AB-85-0002	<i>Aphthona czwalinai</i>	32	Jul 2 1985	49.4	113.1	Cardston
AB-93-0019	<i>Aphthona czwalinai</i>	200	Jul 6 1993	49.7	114.1	Pincher Creek
AB-93-0020	<i>Aphthona czwalinai</i>	300	Aug 19 1993	49.2	113.3	Cardston
AB-82-0002	<i>Aphthonaflava</i>	100	Jul 21 1982	49.2	113.3	Cardston
AB-83-0001	<i>Aphthonaflava</i>	25	Jun 2 1983	49.2	113.3	Cardston
AB-83-0004	<i>Aphthonaflava</i>	247	Jun 30 1983	49.2	113.3	Cardston
AB-86-0004	<i>Aphthonaflava</i>	40	Jul 31 1986	52.6	113.7	Ponoka
AB-86-0005	<i>Aphthonaflava</i>	78	Aug 14 1986	50.9	114.1	City of Calgary
AB-87-0003	<i>Aphthonaflava</i>	85	Jul 23 1987	53.5	113.0	Strathcona
AB-87-0005	<i>Aphthonaflava</i>	100	Aug 5 1987	52.7	111.3	Flagstaff
AB-87-0008	<i>Aphthonaflava</i>	50	Aug 18 1987	49.2	113.3	Cardston
AB-88-0005	<i>Aphthonaflava</i>		Jun 29 1988	50.1	110.8	Cypress
AB-88-0020	<i>Aphthonaflava</i>	100	Jul 1 1988	53.5	113.8	Parkland
AB-89-0041	<i>Aphthonaflava</i>	200	Aug 2 1989	50.1	110.6	Cypress
AB-90-0023	<i>Aphthonaflava</i>	200	Jul 12 1990	53.1	113.5	Wetaskiwin
AB-90-0028	<i>Aphthonaflava</i>	200	Jul 12 1990	52.7	111.3	Flagstaff
AB-90-0055	<i>Aphthonaflava</i>	200	Jul 19 1990	51.2	114.8	Rocky View
AB-91-0101	<i>Aphthonaflava</i>	447	Jul 4 1991	49.0	111.3	Forty Mile
AB-91-0023	<i>Aphthonaflava</i>	200	Jul 25 1991	52.8	111.1	Wainwright
AB-91-0026	<i>Aphthonaflava</i>	200	Jul 25 1991	53.6	113.4	City of Edmonton
AB-91-0027	<i>Aphthonaflava</i>	200	Jul 25 1991	53.6	113.4	City of Edmonton
AB-91-0051	<i>Aphthonaflava</i>	200	Jul 25 1991	52.6	113.7	Ponoka
AB-91-0052	<i>Aphthonaflava</i>	200	Jul 25 1991	52.8	113.1	Wetaskiwin

Release identifier	Agent	No.	Release date	Lat. (°N)	Long. (°W)	Municipality
AB-91-0054	<i>Aphthona flava</i>	200	Jul 26 1991	52.7	111.3	Flagstaff
AB-91-0055	<i>Aphthona flava</i>	200	Jul 26 1991	52.7	111.3	Flagstaff
AB-91-0056	<i>Aphthona flava</i>	200	Jul 26 1991	52.6	111.3	Flagstaff
AB-91-0057	<i>Aphthona flava</i>	200	Jul 26 1991	52.6	111.3	Flagstaff
AB-91-0102	<i>Aphthona flava</i>	1000	Aug 1 1991	49.8	112.2	Taber
AB-91-0015	<i>Aphthona flava</i>	500	Aug 22 1991	50.8	111.0	Special Area #2
AB-91-0016	<i>Aphthona flava</i>	500	Aug 22 1991	50.9	111.0	Special Area #3
AB-91-0017	<i>Aphthona flava</i>	500	Aug 22 1991	50.9	111.0	Special Area #3
AB-91-0018	<i>Aphthona flava</i>	500	Aug 22 1991	50.9	111.0	Special Area #3
AB-91-0019	<i>Aphthona flava</i>	500	Aug 22 1991	50.9	111.0	Special Area #3
AB-91-0020	<i>Aphthona flava</i>	500	Aug 22 1991	50.9	111.0	Special Area #3
AB-91-0021	<i>Aphthona flava</i>	500	Aug 22 1991	51.2	110.2	Acadia
AB-91-0058	<i>Aphthona flava</i>	500	Aug 22 1991	50.9	114.0	Foothills
AB-91-0059	<i>Aphthona flava</i>	500	Aug 22 1991	50.9	114.0	City of Calgary
AB-91-0060	<i>Aphthona flava</i>	500	Aug 22 1991	51.1	114.6	Rocky View
AB-91-0061	<i>Aphthona flava</i>	500	Aug 22 1991	51.9	114.3	Mountain View
AB-91-0062	<i>Aphthona flava</i>	500	Aug 22 1991	53.1	113.5	Wetaskiwin
AB-92-0019	<i>Aphthona flava</i>	500	Jul 28 1992	49.7	114.1	Pincher Creek
AB-92-0026	<i>Aphthona flava</i>	500	Jul 28 1992	49.2	113.4	Cardston
AB-92-0027	<i>Aphthona flava</i>	500	Jul 28 1992	49.2	113.3	Cardston
AB-92-0020	<i>Aphthona flava</i>	500	Jul 29 1992	49.7	113.2	Willow Creek
AB-92-0021	<i>Aphthona flava</i>	500	Jul 29 1992	51.1	114.2	City of Calgary
AB-92-0022	<i>Aphthona flava</i>	500	Jul 29 1992	50.9	114.0	City of Calgary
AB-92-0028	<i>Aphthona flava</i>	500	Jul 29 1992	49.7	112.9	City of Lethbridge
AB-92-0029	<i>Aphthona flava</i>	500	Jul 29 1992	49.7	112.9	Lethbridge
AB-92-0030	<i>Aphthona flava</i>	500	Jul 29 1992	49.9	111.4	Cypress
AB-92-0023	<i>Aphthona flava</i>	500	Jul 30 1992	52.6	113.7	Ponoka
AB-92-0031	<i>Aphthona flava</i>	500	Jul 30 1992	50.0	110.9	Cypress
AB-90-0007	<i>Aphthona lacertosa</i>	95	Jul 5 1990	53.5	113.8	Parkland
AB-90-0012	<i>Aphthona lacertosa</i>	230	Jul 17 1990	53.5	113.8	Parkland
AB-91-0002	<i>Aphthona lacertosa</i>	195	Jun 14 1991	53.1	113.5	Wetaskiwin
AB-92-0012	<i>Aphthona lacertosa</i>	404	Jun 26 1992	49.2	113.3	Cardston
AB-93-0021	<i>Aphthona lacertosa</i>	100	Jun 16 1993	49.7	112.9	Lethbridge
AB-83-0005	<i>Aphthona nigriscutis</i>	557	Jun 30 1983	49.2	113.3	Cardston
AB-86-0003	<i>Aphthona nigriscutis</i>	179	Jul 10 1986	52.7	111.3	Flagstaff
AB-87-0001	<i>Aphthona nigriscutis</i>	200	Jul 15 1987	51.9	113.8	Red Deer
AB-87-0002	<i>Aphthona nigriscutis</i>	100	Jul 15 1987	49.6	112.8	Lethbridge
AB-87-0004	<i>Aphthona nigriscutis</i>	300	Aug 5 1987	52.7	111.3	Flagstaff
AB-87-0006	<i>Aphthona nigriscutis</i>	300	Aug 6 1987	50.0	110.6	City of Medicine Hat
AB-87-0007	<i>Aphthona nigriscutis</i>	300	Aug 6 1987	50.9	114.1	City of Calgary
AB-88-0003	<i>Aphthona nigriscutis</i>	200	Jun 26 1988	49.6	112.9	Blood Indian Reserve
AB-88-0004	<i>Aphthona nigriscutis</i>	200	Jun 28 1988	49.7	114.1	Pincher Creek
AB-88-0006	<i>Aphthona nigriscutis</i>	200	Jun 29 1988	50.2	112.7	Vulcan
AB-88-0007	<i>Aphthona nigriscutis</i>	200	Jun 29 1988	50.1	110.8	Cypress
AB-88-0008	<i>Aphthona nigriscutis</i>	200	Jun 29 1988	50.0	110.6	City of Medicine Hat
AB-88-0009	<i>Aphthona nigriscutis</i>	200	Jun 29 1988	50.9	111.0	Special Area #2
AB-88-0010	<i>Aphthona nigriscutis</i>	200	Jun 29 1988	51.9	114.3	Mountain View
AB-88-0011	<i>Aphthona nigriscutis</i>	200	Jun 29 1988	50.1	110.7	Cypress
AB-88-0012	<i>Aphthona nigriscutis</i>	200	Jun 30 1988	51.2	110.2	Acadia
AB-88-0013	<i>Aphthona nigriscutis</i>	200	Jun 30 1988	51.2	114.8	Stoney Indian Reserve
AB-88-0014	<i>Aphthona nigriscutis</i>	200	Jun 30 1988	51.2	114.9	Stoney Indian Reserve
AB-88-0015	<i>Aphthona nigriscutis</i>	200	Jun 30 1988	52.7	111.1	Provost

Release identifier	Agent	No.	Release date	Lat. (°N)	Long. (°W)	Municipality
AB-88-0016	<i>Aphthona nigriscutis</i>	200	Jun 30 1988	51.5	114.1	Mountain View
AB-88-0017	<i>Aphthona nigriscutis</i>	200	Jun 30 1988	52.6	113.7	Ponoka
AB-88-0018	<i>Aphthona nigriscutis</i>	200	Jun 30 1988	53.1	113.5	Wetaskiwin
AB-88-0019	<i>Aphthona nigriscutis</i>	200	Jul 1 1988	53.5	113.8	Parkland
AB-88-0021	<i>Aphthona nigriscutis</i>	200	Jul 4 1988	53.6	113.4	City of Edmonton
AB-88-0022	<i>Aphthona nigriscutis</i>	200	Jul 13 1988	49.6	112.9	Blood Indian Reserve
AB-88-0023	<i>Aphthona nigriscutis</i>	200	Jul 14 1988	51.2	114.8	Stoney Indian Reserve
AB-88-0024	<i>Aphthona nigriscutis</i>	200	Jul 14 1988	53.1	113.5	Wetaskiwin
AB-88-0025	<i>Aphthona nigriscutis</i>	200	Jul 14 1988	51.2	114.9	Stoney Indian Reserve
AB-88-0026	<i>Aphthona nigriscutis</i>	200	Jul 15 1988	53.6	113.4	City of Edmonton
AB-88-0027	<i>Aphthona nigriscutis</i>	200	Jul 15 1988	53.5	113.8	Parkland
AB-88-0028	<i>Aphthona nigriscutis</i>	200	Jul 26 1988	49.6	112.9	Blood Indian Reserve
AB-88-0029	<i>Aphthona nigriscutis</i>	200	Jul 26 1988	51.2	110.8	Stoney Indian Reserve
AB-88-0030	<i>Aphthona nigriscutis</i>	200	Jul 26 1988	51.2	110.9	Stoney Indian Reserve
AB-88-0031	<i>Aphthona nigriscutis</i>	200	Jul 26 1988	53.1	113.5	Wetaskiwin
AB-88-0032	<i>Aphthona nigriscutis</i>	200	Jul 27 1988	53.5	113.8	Parkland
AB-88-0033	<i>Aphthona nigriscutis</i>	200	Jul 29 1988	53.6	113.4	City of Edmonton
AB-89-0003	<i>Aphthona nigriscutis</i>	210	Jul 11 1989	49.2	113.4	Cardston
AB-89-0004	<i>Aphthona nigriscutis</i>	200	Jul 12 1989	49.7	112.9	City of Lethbridge
AB-89-0005	<i>Aphthona nigriscutis</i>	200	Jul 12 1989	51.8	110.1	Special Area #4
AB-89-0006	<i>Aphthona nigriscutis</i>	200	Jul 12 1989	49.7	112.9	City of Lethbridge
AB-89-0007	<i>Aphthona nigriscutis</i>	500	Jul 12 1989	52.7	110.2	Wainwright
AB-89-0008	<i>Aphthona nigriscutis</i>	50	Jul 12 1989	52.7	110.2	Wainwright
AB-89-0009	<i>Aphthona nigriscutis</i>	50	Jul 12 1989	49.8	112.4	Taber
AB-89-0010	<i>Aphthona nigriscutis</i>	200	Jul 12 1989	52.7	110.2	Wainwright
AB-89-0011	<i>Aphthona nigriscutis</i>	200	Jul 12 1989	49.8	112.4	Taber
AB-89-0012	<i>Aphthona nigriscutis</i>	50	Jul 12 1989	53.6	113.4	City of Edmonton
AB-89-0013	<i>Aphthona nigriscutis</i>	500	Jul 12 1989	49.8	112.4	Taber
AB-89-0014	<i>Aphthona nigriscutis</i>	200	Jul 12 1989	53.6	113.4	City of Edmonton
AB-89-0015	<i>Aphthona nigriscutis</i>	500	Jul 12 1989	53.6	113.4	City of Edmonton
AB-89-0016	<i>Aphthona nigriscutis</i>	200	Jul 13 1989	52.7	111.3	Flagstaff
AB-89-0017	<i>Aphthona nigriscutis</i>	200	Jul 13 1989	52.7	111.3	Flagstaff
AB-89-0018	<i>Aphthona nigriscutis</i>	500	Jul 13 1989	52.7	111.3	Flagstaff
AB-89-0019	<i>Aphthona nigriscutis</i>	50	Jul 13 1989	52.7	111.3	Flagstaff
AB-89-0020	<i>Aphthona nigriscutis</i>	200	Jul 13 1989	53.4	113.5	Leduc
AB-89-0022	<i>Aphthona nigriscutis</i>	200	Jul 20 1989	50.0	111.3	Forty Mile
AB-89-0023	<i>Aphthona nigriscutis</i>	200	Jul 20 1989	50.1	111.2	Forty Mile
AB-89-0024	<i>Aphthona nigriscutis</i>	200	Jul 20 1989	50.1	111.2	Forty Mile
AB-89-0025	<i>Aphthona nigriscutis</i>	200	Jul 21 1989	50.1	111.2	Forty Mile
AB-89-0026	<i>Aphthona nigriscutis</i>	200	Jul 21 1989	50.1	111.2	Forty Mile
AB-89-0027	<i>Aphthona nigriscutis</i>	200	Jul 25 1989	49.7	113.2	Willow Creek
AB-89-0028	<i>Aphthona nigriscutis</i>	200	Jul 25 1989	49.7	113.2	Willow Creek
AB-89-0029	<i>Aphthona nigriscutis</i>	200	Jul 25 1989	49.7	113.2	Willow Creek
AB-89-0030	<i>Aphthona nigriscutis</i>	200	Jul 25 1989	49.7	113.3	Willow Creek
AB-89-0031	<i>Aphthona nigriscutis</i>	200	Jul 25 1989	49.6	113.3	Willow Creek
AB-89-0032	<i>Aphthona nigriscutis</i>	200	Jul 25 1989	49.6	113.3	Willow Creek
AB-89-0033	<i>Aphthona nigriscutis</i>	200	Jul 26 1989	49.7	113.3	Willow Creek
AB-89-0035	<i>Aphthona nigriscutis</i>	200	Jul 26 1989	49.7	113.2	Willow Creek
AB-89-0036	<i>Aphthona nigriscutis</i>	200	Jul 26 1989	49.7	113.3	Willow Creek
AB-89-0037	<i>Aphthona nigriscutis</i>	200	Jul 28 1989	50.9	114.0	City of Calgary
AB-89-0038	<i>Aphthona nigriscutis</i>	200	Jul 28 1989	51.1	114.6	Rocky View
AB-89-0039	<i>Aphthona nigriscutis</i>	200	Aug 1 1989	49.8	112.2	Taber

Release identifier	Agent	No.	Release date	Lat. (°N)	Long. (°W)	Municipality
AB-89-0040	<i>Aphthona nigriscutis</i>	200	Aug 2 1989	50.1	110.6	Cypress
AB-89-0042	<i>Aphthona nigriscutis</i>	200	Aug 2 1989	50.0	110.9	Cypress
AB-89-0043	<i>Aphthona nigriscutis</i>	200	Aug 2 1989	50.0	111.0	Cypress
AB-89-0044	<i>Aphthona nigriscutis</i>	200	Aug 2 1989	50.1	110.8	Cypress
AB-89-0045	<i>Aphthona nigriscutis</i>	200	Aug 2 1989	49.8	110.9	Cypress
AB-89-0046	<i>Aphthona nigriscutis</i>	200	Aug 3 1989	49.0	111.3	Forty Mile
AB-89-0047	<i>Aphthona nigriscutis</i>	500	Aug 3 1989	49.0	111.3	Forty Mile
AB-89-0048	<i>Aphthona nigriscutis</i>	200	Aug 3 1989	49.0	111.3	Forty Mile
AB-89-0049	<i>Aphthona nigriscutis</i>	50	Aug 3 1989	49.0	111.3	Forty Mile
AB-89-0050	<i>Aphthona nigriscutis</i>	200	Aug 4 1989	50.9	114.0	Foothills
AB-89-0051	<i>Aphthona nigriscutis</i>	200	Aug 4 1989	50.9	114.1	City of Calgary
AB-89-0052	<i>Aphthona nigriscutis</i>	200	Aug 9 1989	49.6	112.9	Lethbridge
AB-90-0020	<i>Aphthona nigriscutis</i>	2400	Jul 11 1990	51.9	114.3	Mountain View
AB-90-0021	<i>Aphthona nigriscutis</i>	200	Jul 12 1990	53.1	113.5	Wetaskiwin
AB-90-0022	<i>Aphthona nigriscutis</i>	200	Jul 12 1990	53.1	113.5	Wetaskiwin
AB-90-0024	<i>Aphthona nigriscutis</i>	100	Jul 12 1990	53.0	113.4	Wetaskiwin
AB-90-0025	<i>Aphthona nigriscutis</i>	200	Jul 12 1990	53.0	113.2	Wetaskiwin
AB-90-0026	<i>Aphthona nigriscutis</i>	200	Jul 12 1990	52.6	111.3	Flagstaff
AB-90-0027	<i>Aphthona nigriscutis</i>	200	Jul 12 1990	52.7	111.3	Flagstaff
AB-90-0029	<i>Aphthona nigriscutis</i>	200	Jul 12 1990	52.7	111.3	Flagstaff
AB-90-0030	<i>Aphthona nigriscutis</i>	200	Jul 12 1990	52.7	111.3	Flagstaff
AB-90-0031	<i>Aphthona nigriscutis</i>	200	Jul 12 1990	52.7	111.3	Flagstaff
AB-90-0032	<i>Aphthona nigriscutis</i>	200	Jul 12 1990	52.6	111.4	Flagstaff
AB-90-0033	<i>Aphthona nigriscutis</i>	200	Jul 13 1990	54.0	114.4	Barrhead
AB-90-0051	<i>Aphthona nigriscutis</i>	200	Jul 13 1990	49.7	112.9	City of Lethbridge
AB-90-0052	<i>Aphthona nigriscutis</i>	200	Jul 13 1990	49.7	112.9	City of Lethbridge
AB-90-0069	<i>Aphthona nigriscutis</i>	200	Jul 15 1990	50.9	114.0	City of Calgary
AB-90-0070	<i>Aphthona nigriscutis</i>	200	Jul 16 1990	49.8	112.8	Lethbridge
AB-90-0013	<i>Aphthona nigriscutis</i>	200	Jul 18 1990	52.8	111.1	Wainwright
AB-90-0014	<i>Aphthona nigriscutis</i>	200	Jul 18 1990	52.7	111.1	Wainwright
AB-90-0053	<i>Aphthona nigriscutis</i>	200	Jul 19 1990	51.2	114.8	Bighorn
AB-90-0054	<i>Aphthona nigriscutis</i>	200	Jul 19 1990	51.2	114.8	Bighorn
AB-90-0081	<i>Aphthona nigriscutis</i>	200	Jul 20 1990	49.9	112.5	Lethbridge
AB-90-0082	<i>Aphthona nigriscutis</i>	200	Jul 20 1990	49.9	112.5	Lethbridge
AB-90-0083	<i>Aphthona nigriscutis</i>	200	Jul 20 1990	49.8	112.8	Lethbridge
AB-90-0084	<i>Aphthona nigriscutis</i>	200	Jul 20 1990	49.8	112.8	Lethbridge
AB-90-0085	<i>Aphthona nigriscutis</i>	200	Jul 20 1990	49.8	112.8	Lethbridge
AB-90-0056	<i>Aphthona nigriscutis</i>	200	Jul 23 1990	49.9	111.8	Taber
AB-90-0057	<i>Aphthona nigriscutis</i>	200	Jul 24 1990	49.9	111.7	Taber
AB-90-0058	<i>Aphthona nigriscutis</i>	200	Jul 24 1990	49.8	112.3	Taber
AB-90-0059	<i>Aphthona nigriscutis</i>	200	Jul 25 1990	50.8	111.0	Special Area #2
AB-90-0060	<i>Aphthona nigriscutis</i>	200	Jul 25 1990	50.8	112.8	Wheatland
AB-90-0061	<i>Aphthona nigriscutis</i>	200	Jul 25 1990	50.8	112.8	Wheatland
AB-90-0062	<i>Aphthona nigriscutis</i>	200	Jul 25 1990	50.8	112.8	Wheatland
AB-90-0063	<i>Aphthona nigriscutis</i>	200	Jul 25 1990	50.8	112.8	Wheatland
AB-90-0064	<i>Aphthona nigriscutis</i>	200	Jul 25 1990	50.8	112.8	Wheatland
AB-90-0065	<i>Aphthona nigriscutis</i>	200	Jul 25 1990	50.8	112.8	Wheatland
AB-90-0066	<i>Aphthona nigriscutis</i>	200	Jul 27 1990	51.6	113.2	Kneehill
AB-90-0067	<i>Aphthona nigriscutis</i>	200	Aug 2 1990	49.7	114.1	Pincher Creek
AB-90-0071	<i>Aphthona nigriscutis</i>	200	Aug 16 1990	49.7	113.3	Willow Creek
AB-90-0072	<i>Aphthona nigriscutis</i>	200	Aug 20 1990	49.7	114.1	Pincher Creek
AB-90-0073	<i>Aphthona nigriscutis</i>	200	Aug 20 1990	49.6	113.9	Pincher Creek

Release identifier	Agent	No.	Release date	Lat. (°N)	Long. (°W)	Municipality
AB-90-0074	<i>Aphthona nigriscutis</i>	200	Aug 21 1990	51.7	114.5	Mountain View
AB-90-0075	<i>Aphthona nigriscutis</i>	200	Aug 22 1990	49.0	111.3	Forty Mile
AB-90-0076	<i>Aphthona nigriscutis</i>	200	Aug 27 1990	49.9	111.4	Cypress
AB-90-0077	<i>Aphthona nigriscutis</i>	200	Aug 27 1990	49.8	110.9	Cypress
AB-90-0078	<i>Aphthona nigriscutis</i>	200	Aug 28 1990	50.0	111.3	Cypress
AB-90-0079	<i>Aphthona nigriscutis</i>	200	Aug 28 1990	50.2	110.6	Cypress
AB-90-0080	<i>Aphthona nigriscutis</i>	200	Aug 28 1990	50.0	111.3	Forty Mile
AB-91-0024	<i>Aphthona nigriscutis</i>	500	Jul 25 1991	52.8	111.1	Wainwright
AB-91-0025	<i>Aphthona nigriscutis</i>	500	Jul 25 1991	52.8	111.1	Wainwright
AB-91-0053	<i>Aphthona nigriscutis</i>	500	Jul 25 1991	52.9	113.3	Wetaskiwin
AB-92-0024	<i>Aphthona nigriscutis</i>	500	Jul 15 1992	53.4	113.7	Parkland
AB-78-0002	<i>Hyles euphorbiae</i>	109	Jul 19 1978			Cardston
AB-78-0003	<i>Hyles euphorbiae</i>	115	Jul 19 1978			Cardston
AB-90-0006	<i>Lobesia euphorbiana</i>	150	Jul 4 1990	49.2	113.3	Cardston
AB-91-0030	<i>Lobesia euphorbiana</i>	400	Sep 4 1991	53.1	113.5	Wetaskiwin
AB-91-0006	<i>Minoa murinata</i>	375	Jul 19 1991	53.1	113.5	Wetaskiwin
AB-91-0012	<i>Minoa murinata</i>	359	Jul 24 1991	49.2	113.3	Cardston
AB-92-0007	<i>Minoa murinata</i>	500	Jun 30 1992	53.0	113.4	Wetaskiwin
AB-92-0010	<i>Minoa murinata</i>	500	Jul 3 1992	53.0	113.3	Wetaskiwin
AB-92-0015	<i>Minoa murinata</i>	1000	Jul 8 1992	49.7	114.2	Pincher Creek
AB-92-0016	<i>Minoa murinata</i>	500	Jul 10 1992	53.6	113.4	City of Edmonton
AB-92-0025	<i>Minoa murinata</i>	300	Jul 23 1992	52.6	113.7	Ponoka
AB-94-0013	<i>Minoa murinata</i>	1000	Jul 14 1994	51.9	114.3	Mountain View
AB-94-0015	<i>Minoa murinata</i>	235	Aug 4 1994	52.7	111.3	Flagstaff
AB-94-0016	<i>Minoa murinata</i>	151	Aug 10 1994	52.6	113.7	Ponoka
AB-94-0017	<i>Minoa murinata</i>	106	Aug 10 1994	53.0	113.4	Wetaskiwin
AB-94-0015	<i>Minoa murinata</i>	2000	Sep 12 1994	52.7	111.3	Flagstaff
AB-80-0001	<i>Oberea erythrocephala</i>	123	Jul 3 1980	49.2	113.3	Cardston
AB-86-0001	<i>Oberea erythrocephala</i>	20	Jul 7 1986	50.1	110.8	Cypress
AB-88-0002	<i>Pegomya curticornis</i>	9	May 6 1988	53.1	113.5	Wetaskiwin
AB-91-0007	<i>Pegomya curticornis</i>	50	Jul 19 1991	53.1	113.5	Wetaskiwin
AB-93-0001	<i>Pegomya curticornis</i>	28	May 10 1993	53.5	113.8	Parkland
AB-93-0008	<i>Pegomya curticornis</i>	56	Aug 25 1993	51.9	114.3	Mountain View
AB-88-0001	<i>Pegomya euphorbiae</i>	23	May 2 1988	49.1	113.3	Cardston
AB-90-0001	<i>Pegomya euphorbiae</i>	108	Apr 24 1990	53.6	113.4	City of Edmonton
AB-89-0002	<i>Spurgia esulae</i>	75	Jul 1 1989	53.6	113.4	City of Edmonton
AB-90-0011	<i>Spurgia esulae</i>	150	Jul 16 1990	53.6	113.4	City of Edmonton
AB-93-0023	<i>Spurgia esulae</i>	1380	Jun 18 1993	49.7	112.9	City of Lethbridge

Appendix 2: Data recording system for release sites

These instruction sheets were provided to field staff involved in making releases of biocontrol agents or monitoring release sites. They are included here to provide details on the types of data collected at the field release sites.

Release and monitoring records for weed biocontrol agent

Instructions for completing forms

Many of the items on the release form are self-explanatory. These notes explain some of those which are less obvious.

Item	Explanation	Example
Release identifier	Consists of two letters for the province, 2 digits for the year and a 4-digit serial number. Each release should have a separate serial number which is used to track all data or material from that release site. You may be assigned a block of serial numbers to use for your own releases, e.g. 101-0200.	AB-91-0112
Target weed	The weed which the biocontrol agent is intended to control.	Leafy spurge
Biocontrol agent	Scientific or common name of the insect released.	Copper spurge beetle
Immediate source	Location of the colony from which the insects released were taken.	Cardston
Original source	Where this population of the insect originated. Leave blank if you do not know.	Italy
Area of release	Area over which you spread the insects when making the release, in square metres.	
Soil sample	Circle Y if soil sample was collected. Sample should be from the top 6 inches, not including any litter or debris from the soil surface. Collect enough to fill a standard Alberta Agriculture soil sample box.	Y
Cage/Open/Both	Circle one alternative to indicate whether insects were released in a field cage, in the open, or both. Indicate, 25%, 50%, 75 % or 100%.	O
Cloud cover		
Wind speed	Circle one letter to indicate <u>C</u> alm, <u>L</u> ight, <u>M</u> oderate or <u>S</u> trong.	
Latitude, longitude Ecoregion, Classification system	May be left blank if the legal land description has been entered. May be left blank.	M

Item	Explanation	Example
Treelayer, shrub layer, herb layer	List the main species of trees, shrubs and herbs (including grasses) growing at the release site. Collect herbarium specimens if you are not able to identify them to species at the site. Tag all specimens with the release identifier.	
Altitude	Altitude above sea level, in metres. Use altimeter or get from topographic map.	
Slope	Slope of ground at the point of release (use clinometer). If site is flat enter .	
Aspect	Direction in which the slope faces at the point of release. If release site is flat (slope=0) leave blank.	SE
Relief: Micro, Meso, Macro	These items describe the relief around the release site. "Micro" refers to the local relief, up to 10 metres out from the release point. "Meso" is medium scale, up to 100 metres out, and "Macro" is large scale relief, up to 1 kilometre out from the release point. Looking out to each of these distances in turn, decide if the release point is generally below the level of the surrounding land (concaVe), above the level of the surrounding land (conveX), at the same level (Flat), or above it on one side and below it on the other (Sloped).	Micro: S Meso: X Macro: V
Shade	Circle one letter to indicate <u>N</u> one, <u>L</u> ight (e.g. shaded during part of the day by nearby bushes), <u>M</u> oderate (e.g. a site among scattered trees with open spaces between the tree canopies) or <u>F</u> ull (e.g. under a continuous tree canopy).	N
Moisture regime	Circle one letter to indicate <u>X</u> eric (dry sites, soil dry for most of the growing season, vegetation typical of dry areas, e.g. cactus, sagebrush), <u>M</u> esic (moderate, neither very dry nor very wet) or <u>H</u> ygic (soil moist for most of the growing season, plant species typical of wet sites, e.g. rushes).	M
Land use surface cover	pasture, summerfallow, roadside, railway bank, park, etc. Describe any layers covering the soil surface, e.g. leaf litter, dead grass, lichens, etc. If soil surface is exposed, write "bare".	Pasture Mostly bare, some dead grass
Soil texture, sand, silt, clay, organic, soil pH	Leave blank: These values will be obtained from the soil sample you collect.	
Previous herbicide use	Note any known herbicide use at the site: what product was used, rate, when.	Tordon 22K, 3.6 litre/acre, in 1989.

Item	Explanation Example	
Natural enemies	Note any potential predators on the biocontrol agents seen at the release site, if especially abundant.	Ants
PERCENT COVER (Target weed, Grasses, Forbs, Woody)	Place the .1 m ² quadrat on the ground and look down on it from vertically above. Estimate what <u>percentage of the area</u> of the quadrat is covered by <u>live vegetation</u> in each of the four groups: the target weed, grasses, forbs (i.e. broadleaved herbs) and woody plants (e.g. wild rose, buckbrush). As a rough guide, use the size of your fist held out at arm's length to estimate 10% of the quadrat's area. Repeat at 1-metre intervals along the staked-out lines. Remember that these figures refer to the <u>area covered</u> by these types of growth, <u>not</u> to the number of plants. The four values will add up to less than 100% if some bare ground or dead vegetation is visible inside the quadrat.	
TARGET WEED SHOOT COUNTS (Vegetative, Flowering, Total)	After doing the cover estimate for each quadrat, count the <u>number</u> of vegetative (non-flowering) and flowering shoots of the <u>target weed only</u> . Add these together and enter the total on the next line, marked "Total."	
BIOMASS (Target weed, Grasses, Forbs, Woody)	Not required at most sites. If required, clip all vegetation from each of the .1 m ² quadrats after doing the cover estimates and shoot counts, sort into the same 4 groups (target weed, grasses, forbs, woody), oven dry and record dry weights in the appropriate spaces.	

Monitoring form:

Many of the entries on this form are the same as on the release form. The following ones are additional:

Item	Explanation	Example
Area of insect spread	Area in square metres over which insects or definite signs of insect activity (feeding damage, etc.) were found.	
Insect numbers	For spurge beetles, record the number of adults found in 5, 10 or 20 sweeps (do 10 or 5 sweeps at sites at which beetles are very abundant, otherwise 20). Record the number of sweeps in the OTHER NOTES area. For other insects record the numbers found and describe the sampling method (e.g. "visual search, 30 minutes") in the OTHER NOTES area.	(5 sweeps)
Greatest distance of insect spread	Greatest distance from the release point (in metres) at which insects or definite signs of their presence were found.	
Direction of insect spread	Geographic direction in which insects have spread furthest from the release point	NW
Direction of spread in relation to topography	Same as previous, but in relation to local topography or land-marks instead of compass direction	up slope

Please return all completed forms for Alberta release sites to me at the address below and keep copies for your own records. The original forms filled out by hand in the field should be used; to avoid possible errors as well as to save time, please do not recopy data onto clean forms later or get the forms typed.

Plate 1. Leafy spurge in a river valley in southern Alberta.

Plate 2. Adult *Aphthona cyparissiae* on leafy spurge.

Plate 3. Adult *Aphthona czwalinai* on leafy spurge.

Plate 4. Adult *Aphthona flava* on leafy spurge (Photo: A. Gassmann).

Plate 5. Adult *Aphthona lacertosa* on leafy spurge.

Plate 6. Adult *Aphthona nigriscutis* on leafy spurge (Photo: A. Gassmann)

Plate 7. Larva of *Hyles euphorbiae* on leafy spurge.

Plate 8. Adult *Lobesia euphorbiana* on leafy spurge.

Plate 9. Larvae of *Minoa murinata* feeding on leafy spurge.

Plate 10. Larva of *Oberea erythrocephala* in leafy spurge stem.

Plate 11. Leafy spurge shoot showing stunting due to larval feeding of *Pegomya curitcornis*.

Plate 12. Gall formed by *Spurgia esulae* in shoot tip of leafy spurge.

Plate 13. Site AB-88-0021 in July 1989, one year after release of 200 *Aphthona nigriscutis*.

Plate 14. Site AB-88-0021 in July 1990, two years after release of 200 *Aphthona nigriscutis*.

Plate 15. Site AB-88-0021 in July 1991, three years after release of 200 *Aphthona nigriscutis*.

Plate 16. Site AB-88-0021 in July 1992, four years after release of 200 *Aphthona nigriscutis*.

Plate 17. Site AB-88-0021 in July 1992, five years after release of 200 *Aphthona nigriscutis*.

Plate 18. Site AB-88-0021 in July 1992, six years after release of 200 *Aphthona nigriscutis*.