
International Institute of Biological Control
An Institute of CAB International

European Station

Final report

Chamaesphecia crassicornis Bartel 1912 (Lepidopterea; Sesiidae), a suitable agent for the biological control of leafy spurge (*Euphorbia esula* L.) (Euphorbiaceae) in North America

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March 1994

CAB International is an intergovernmental organization providing services worldwide to agriculture, forestry, human health and the management of natural resources

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Abstract:

Leafy spurge is a herbaceous perennial of Eurasian origin that has become a serious weed on the prairies and non crop areas in North America. There are currently no satisfactory means of control with the result that it is often left to spread and displace native range species.

The most effective biocontrol agents reducing weed density are those attacking the root system. In 1991 the European root-boring moth *Chamaesphecia hungarica* was first released in Canada in moist habitats, and *Ch. astatiformis* in mesic habitats in 1993. *Ch. crassicornis* is a species adapted to drier habitats in the steppe biome. Larval transfer tests with *Ch. crassicornis* were made on 28 plant species including 18 *Euphorbia* species from four subgenera, five native U.S. spurges, six plant species in other genera of Euphorbiaceae, and four *Chamaesphecia* host plants from another 2 families. The larval host range of *Ch. crassicornis* is restricted to a few spurges in the subgenus Esula. Its climatic and habitat requirements, as well as its narrow host range will restrict it to the target spurge in North America. It would be best suited for release in mesic-dry habitats on the prairies.

Introduction

Leafy spurge (*Euphorbia esula* L. sensu lato) (Crompton *et al*. 1990) is a toxic herbaceous perennial of Eurasian origin that forms dense stands in North America, particularly on the prairies but it is also found along roadsides, river banks, flood plains and mountain slopes. The infested area approximately doubles every ten years and direct costs and losses could reach $144 million annually by 1995 in Montana, North Dakota, South Dakota and Wyoming (Bangsund and Leistritz 1991). The weed also displaces scarce native plants of which one has threatened status. Cultural and chemical methods are expensive, largely ineffective on the long term and ecologically undesirable (Alley and Messersmith 1985; Anonymous 1989).

Classical biocontrol is the most economic and environmentally satisfactory means of saving the habitat of native species and increasing forage for cattle . The target of the Canadian programme for the biocontrol of spurge is to reduce the weed to a 5% cover on 95% of the infestation. At this density cattle graze around the stems and there is little or no loss of native plant diversity. This goal should be attainable as most stands on the steppes of Central Europe are small, scattered and generally have a spurge cover of 5% or less.

In Central Europe, spurge is attacked by a large complex of specialized insects and pathogens (Harris *et al*. 1985) of which the most damaging to the plant are those attacking the root system and reducing the water and nutrient uptake. In specific Canadian and northern U.S. sites leafy spurge is being reduced by five species of chrysomelid beetles in

the genus *Aphthona* that feed on the outside of the roots: *A. nigriscutis* Foudras on open sites at the dry end of the spurge range, *A. cyparissiae* (Koch) on slightly moister sites, *A. flava* Guill. on dry partially shaded sites with a high water table and a long growing season, *A. lacertosa* (Rosh.) and *A. czwalinai* (Weise) on loam to clay soils. The inside of the larger roots in Eurasia is attacked by equally site specific moths in the genus *Chamaesphecia. Ch. crassicornis* Bartel is a species of mesic-dry steppic habitats that supplements the impact of the chrysomelid beetles on the larger and more vigorous spurge plants. The genus is not represented in North America, so there should be no native specialized natural enemies to attack it in North America.

2.0. Purpose and need

2.1. Significance of action

In North America, leafy spurge forms stands with up to 100% cover on pastures, range land and non-crop areas. The most serious infestations are on the prairies where its deep root system allows it to become the competitive dominant on open sandy soils, but the plant also survives on heavy moist soils and at shaded sites. It is recorded from 26 States (Dunn 1979) and all Canadian provinces except Newfoundland (Frankton and Mulligan 1987). Most introductions appear to have been in grain and brome grass seed brought by settlers from the Ukraine to the prairies between 1870-1880, but it was first recorded in 1827 on the east coast where it was probably introduced in ballast from western Europe (Dunn 1985). The most serious Canadian infestations in Manitoba were estimated 3,238 ha in 1952, and spread to 46,000 ha by 1982 with estimated costs and losses of $600,000/year. This is small compared to the problem in North Dakota where it was first reported in 1907, infested 91,000 ha by 1962, almost 192,000 by 1973 and 390,000 by 1983 (Thompson *et al*. 1990). The economic losses for North Dakota, South Dakota, Montana and Wyoming were estimated over $100 million (Anonymous 1992) in 1990 and could reach $144 million annually by 1995 (Bangsund and Leistritz 1991). Spurge is clearly a major economic problem and continued spread is alarming.

The latex in the spurge gives cattle scours, mouth blisters and in large amounts can cause death with the result that cattle avoid grazing in areas with moderate to high spurge densities, although it is eaten in hay (Lym and Kirby 1987). The latex of other spurge species with similar diterpenoids is a cocarcinogen (Hecker 1978), and in man it produces dermatitis, blisters and can cause blindness (Kingsbury 1964) so that widespread occurrence of leafy spurge in recreational areas is undesirable.

Leafy spurge displaces native plants. The most noteworthy is the western prairie fringed orchid, *Platanthera praeclara* Steviak & Bowles. Most of the remaining orchid populations are on North Dakota prairie with spurge or vulnerable to spurge invasion. The difficulty for conservation is that the orchid is killed by the herbicides and other treatments used for spurge control. It received threatened status in the U.S.A. in 1989 (U.S. Federal Register, Fish and Wildlife Service, 1989). Also, western spiderwort (*Tradescantia occidentalis* (Britt.) Smyth) in its northern enclave in Manitoba is being displaced by leafy spurge. One site was lost in 1993 and threatened status is being recommended (S.L. Hohn, personal communication).

2.2. Alternatives to proposed action

2.2. 1. Chemical control of spurge

In non-arable land picloram is the most persistent and effective herbicide available and at 2.24 kg/ha retreatment may not be necessary for 3-5 years (Alley and Messersmith 1985). Picloram is expensive, extremely persistent, mobile and kills a broad spectrum of forbs. On coarse soils in Saskatchewan it was found 22 months after application at a depth of 90-120 cm and in the top 30 cm at approximatively 1 km away (Smith *et al*. 1988). Thus, large uses of picloram are ecologically undesirable. As a result, its use is prohibited in the largest Canadian spurge infestations such as Shilo, MB and discouraged in Saskatchewan by the removal of the provincial subsidy for spurge control. The best chemical options remaining are 2,4-D, and dicamba. However, they do not kill the roots of established plants and have to be reapplied in 1-2 years (Alley and Messersmith 1985). Spurge can be controlled by a combination of cultivation and treatment with 2,4-D but survives either one with the result that about 3% of the infestation is on land cropped to cereals on which herbicides are not used.

There is an urgent need to find an alternative to picloram for spurge control as its use is increasingly being restricted. Also, there is an economic and environmental need to reduce the total amount of herbicide applied for the control of spurge on non-arable land. Classical biological control offers a more economic and environmentally acceptable solution.

2.2.2. Non-chemical means of control

Sheep will graze young spurge and in a five-year Alberta trial, reduced its basal area by 98% (Johnston and Peake 1960); but the weed returns to its former dominance in 2-3 years after the sheep are removed. Sheep avoid grazing the mature stems which can cause losses from poisoning (Johnston and Peake 1960). Thus, sheep are an effective control as long as the grazing is done early, while the spurge shoots are young. The desirability of using sheep depends on the economics of the relatively small North American market for mutton and at best sheep can only be used in certain areas. For example, they are unsuitable in conservation areas dedicated to the protection of the native prairie flora which evolved with bison (cattle) grazing.

2.3. Goal and reasons for the choice of *Ch. crassicornis*

In total 16 species of insects have been approved for release of which 11 have been established. The most effective of those feeding on the feeder-roots and the root reserves. All the root-feeders are habitat specific with the result that a series will be necessary to achieve the programme goal.

Studies on the life history and host specificity of *Ch. crassicornis* were conducted between 1984 and 1988 at the USDA-ARS Biological Control Laboratory in Rome, Italy, now at Montpelier, France (Pecora *et al*. 1990). Based on the work done in Europe, an

Environmental Assessment of *Ch. crassicornis* was published in 1992 and the species was recommended for release in the United States (Spencer and Prevost 1992). The screening tests included four biotypes of North American leafy spurge and eight test plant species including seven species in genus *Euphorbia* and *Ricinus communis* (see Appendix).

Our tests extend the range of plants tested to approximatively the same range of those tested for *Ch. hungarica* and *Ch. astatiformis*, two species previously approved for release in North America (Gassmann and Tosevski 1994).

Ch. crassicornis supplements the impact of the chrysomelid beetles in mesic-dry habitats, particularly in stands with large vigorous spurges. It is a more vigorous disperser than the beetles and in European sites it kills plants and reduces stand vigour. *Ch. crassicornis* is a root-borer and so fills a niche that is presently vacant in North America.

The genus *Chamaesphecia* and the guild of spurge root borers is not represented in North America, so there should be no specialized natural enemies present. Consequently the moth should increase to the high population densities necessary for a biocontrol agent.

3.0. Description of leafy spurge

3.1. Taxonomy

Order:	Geraniales
Family:	Euphorbiaceae
Genus:	*Euphorbia*
Subgenus:	Esula Pers.
Section:	Esula (Roeper) Koch
Subsection:	Esulae Boiss.
Species:	*E. esula* L. (sensu lato) (2n=60); leafy spurge.

The genus *Euphorbia* contains about 1,600 species with species native to Africa, Asia, Europe and North America and includes annuals, herbaceous perennials, trees and succulents. Webster (1967) recognized 5 subgenera that occur in North America either as natives or introductions: Esula, Agaloma, Chamaesyce, Poinsettia, Euphorbium. This is the classification followed in this study, although Webster (1975) suggested that the Chamaesyce are sufficiently different to warrant their own genus. The importance of this is that restriction of an insect species to development on a taxon within the *Euphorbia* s.str., decreases the possibility that it can develop on the Chamaesyce.

The subgenus Esula is largely old world in origin but includes 21 native North American species. These species are:

- Annuals: *E. commutata*, *E. crenulata*, *E. helleri*, *E. longicruris*, *E. obtusata*, *E. piplidion*, *E. roemerana*, *E. spatulata*, *E. tetrapora*;

- Subtropical (humid) perennials: *E. inundata*, *E. telephiodes*, *E. trichomata*;

- Arid, semi-arid and mediterranean perennials: *E. alta*, *E. brachycera*, *E. chamaesula*, *E. florida*, *E. incisa*, *E. lurida*, *E. palmeri*;

- Continental and temperate perennials: *E. purpurea*, *E. robusta*.

The subgenus Agaloma (Raf.) House is a new world group with 26 North American species.

The subgenus Chamaesyce Raf. has diversified in North America and contains 58 native species.

The subgenus Poinsettia (Graham) House contains 3 North American species.

The subgenus Euphorbium L. is largely African, but a few species are grown in North America as ornamentals.

Leafy spurge is morphologically variable, and there is controversy as to whether it is a single variable species or an aggregate of two or more species (see for example Radcliff-Smith 1985; Stahevitch *et al*. 1988; Crompton *et al*. 1990 and references therein). Furthermore, there remains uncertainty about the relationship of North American leafy spurge and European taxa. European populations showed greater variability in the number of triterpenoids present in the latex than has been detected in North American collections of leafy spurge (Holden & Mahlberg 1992). Although Smith & Tutin (1968) demote *E. virgata* Waldst. & Kit. to subspecific status within *E. esula*, most European botanists maintain *E. esula* and *E. virgata* as separate species. In this report, we follow the recommendation by Crompton *et al*. (1990) that North American leafy spurge should be named *E. esula* (sensu lato). For European accessions we discriminate between *E. esula* (sensu stricto) and *E. virgata* (= *E. esula* subsp. *tommasiniana* (Bertol.) Nyman), in Smith & Tutin (1968)). When this is not the case, the European *E. esula* group is also referred to *E. esula* (s.l.).

3.2. Distribution

The center of origin of *E. esula* (s.l.) is apparently the Caucasian region (Croizat 1945, Kuzmanov 1964). The plant occurs throughout Europe from the Atlantic to the Urals except for the extreme north and south. It also extends eastwards in southern Siberia and has been introduced into northern China (Prokhanov 1949).

Dunn (1979) mapped the U.S. distribution of leafy spurge on a county basis. It is virtually absent south of 40 N latitude and almost no infestations of “economic” or “potentially economic” density occur east of the Mississippi River. The most widespread infestation occurs in Minnesota, but the weed problem is most severe in North Dakota, followed closely by Montana (Noble *et al*. 1979).

In Canada the most severe infestations occur in southern Manitoba with 46,000 ha in 1982, Saskatchewan with approximately 20,000 ha, Alberta north to the Peace River with approximately 10,000 ha; but previously small and supposedly stable stands have recently started to spread rapidly (Harris 1984). There are also some stands in eastern Canada such as near Guelph, ON, which are apparently associated with Ukrainian Mennonite settlement.

In summary, the North American distribution is primarily the Northern Great Plains. Noble *et al*. (1979) estimate that about 90% of it may be found within 1000 km of Wolf Point in northeastern Montana. This distribution still reflects an historical origin and the weed has not reached its limit of spread either within or outside this region.

3.3. Life history

The life history of leafy spurge in North America has been described by Best *et al*. (1980). It is a perennial hemicryptophyte that is a competitive dominant on dry prairie soils in North America. The features leading to this competitive dominance are that stems are erect and 0.3 to 1.0 m tall which makes them taller than most other herbaceous prairie plants. Also, established plant communities are invaded by horizontal spurge roots, with the result that stands often consist of a series of clones 1 or 2 m in diameter. Vertical spurge roots usually penetrate to a depth of 1.2 m and may go as deep as 2.5 m (Coupland and Alex 1954). This enables the spurge to continue growing for longer on dry coarse prairie soils than most native herbaceous species. The roots are also a storage organ with an oven-dry weight of 9,518 kg/ha (Messersmith *et al*. 1985) that enables the plant to regrow rapidly after defoliation whether this is done by herbicides, mowing, sheep, goats or biocontrol agents.

About two-thirds of the North American leafy spurge infestation is on coarse dry soils; however, it survives equally well at moist sites, heavy clay soils and in light to moderate shade. Its relative scarcity on the moist and heavy soils relates to that most of these are under arable agriculture and are subjected to annual cultivation and herbicide treatments. The spurge can often survive either one of these treatments but not both. The result is that on the moister and heavier soils, leafy spurge is mostly found along field margins and other uncultivated areas.

Leafy spurge reproduces both vegetatively by roots and root fragments and by seed. The seed is mainly important for long distant spread and as it is viable for up to 8 years (Bowes and Thomas 1978), leafy spurge is able to reinvade after picloram and other persistent herbicides have dissipated. However, seedling survival in established plant communities is poor, so new infestations tend to become established on disturbed sites such as gravel pits and along graded roadsides. This has resulted on the Canadian prairies in a vigorous and continuing municipal programme for the chemical control of roadside patches even though stands in adjacent fields are ignored.

A characteristic feature of the family Euphorbiaceae is the presence of latex which may comprise 4-5% of plant dry weight (Nemethy *et al*. 1979). The lactiferous cells are laid down in the embryo and ramify through the aerial and underground parts of the plant except for the short roots, primary root cortex, woody root tissue (Raju 1985) and the

stem pith. The latex is rich in starch but this is not part of the plant's reserves (Biesboer and Mahlberg 1978) and its primary function seems to be defensive. Parasitic and predatory organisms must either be able to handle it or to avoid it. In either case, this usually requires a high degree of specialization which is enhanced by wide differences in the triterpenoid and other toxic, irritant and cocarcinogenic compounds between closely related taxa.

To summarize, there are five important features of leafy spurge biology that relate to its biocontrol: 1. The variation in the toxic components of the latex appear to have resulted in the specialization of many organisms at the subspecific level of leafy spurge for which there are no good morphological features. 2. The ability of spurge to recover from defoliation by rapid mobilization of its root reserves. 3. The ability of spurge to persist and spread in the absence of seed production by horizontal roots and regeneration from root fragments. 4. The ability of spurge to survive water shortage by virtue of its deep root system. 5. The ability of spurge to invade a wide variety of habitats; coarse dry soils, moist heavy soils and shaded sites.

3.4. Related economic and native plants

3.4. 1. Economic species

The economically most important *Euphorbia* in North America is *E. pulcherrima* Willd. (subgenus Poinsettia). It is a perennial which is propagated from cuttings as a Christmas pot plant. This trade has an annual value of $54 million (Harris 1984). *E. antysyphilitica* Zuccar. (subgenus Agaloma) is a perennial that produces a high quality wax. It is the basis of a small industry in northern Mexico with an annual value of $1 million. The plant is a tough xerophyte that produces only a few scale-like ephemeral leaves. It does not survive in regions with winter frost and so occurs south of the distribution of leafy spurge.

3.4.2. Native species

The main cause for concern over the introduction of agents for the biocontrol of leafy spurge is the native *Euphorbia* species (Pemberton 1985). The U.S. Endangered Species Act (1973) requires that the survival of species listed in the Federal Register as endangered (LE) or threatened (LT) should not be compromised by release of a biocontrol agent. The Federal Register also includes other listings that are not covered by the Endangered Species Act. Category 2 is an entry level for species that on investigation are moved to category 1 (for which there is substantial data to support biological vulnerability) or to category 3 (not threatened or endangered). Testing rare species is difficult because because they are often not available or only in small numbers. However, lack of risk can be demonstrated if the plant occurs in a taxon unacceptable to the insect, if they have different geographic ranges or different habitats.

There are no endangered or threatened native spurges in Canada and only three in the United States. These are *E. deltoidea* spp. *deltoidea* Engelm. ex Chapm. (endangered), *E. garberi* Engelm. ex Chapm. (threatened) and *E. skottsbergi* var. *kalaeloana* (endangered) which are all annual species in subgenus Chamaesyce. The former two species are restricted to dune habitats in southern Florida and the latter occurs in Hawaii and hence are not a risk from agents released on the mainland. There are no endangered or threatened North American spurges in the subgenera Esula, Poinsettia, or Agaloma.

The Federal Register (1985) lists 21 catagory 1 spurges in Hawaii, which are not discussed further since they are not at risk from biocontrol agents released on the mainland. There is also one continental species in category 1, i.e. *E. hooveri* L.C. Wheeler, that is an annual Chamaesyce species restricted to California. There are seven species in category 2: two in subgenus Esula (*E. telephioides* Chapm. and *E. purpurea* (Raf.) Fernald) and five in subgenus Chamaesyce. Both *E. telephioides* and *E. purpurea* occur south of the southern 40º N limit of the moth. Finally there are nine species in category 3: one in subgenus Esula, six in subgenus Agaloma, and two in subgenus Chamaesyce. *E. roemerana* Scheele (subgenus Esula) is outside the eco-climatic zone of the moth. Futhermore, it is an annual species and thus it is unsuitable for larval development of *Ch. crassicornis*.

4.0. *Chamaesphecia crassicornis*

4.1. Taxonomy

Order:	Lepidoptera
Family:	Sesiidae
Subfamily:	Sesiinae Boisduval 1828
Tribe:	Aegeriini Stephens 1829
Genus:	*Chamaesphecia* Spuler 1910
Species:	*Chamaesphecia crassicornis* Bartel 1912

Ch. crassicornis has been identified by I. Tosevski. Voucher specimen are in the IIBC collection at Delémont, Switzerland and the CNC Ottawa, Canada.

The Sesiidae is a cosmopolitan family of 1,063 described species (Heppner & Duckworth 1981). Morphologically they belong to a well defined group of insects with characteristically transparent wings and bright coloured rings on the abdomen (for a detailed account on the morphology of the Sesiidae, see Naumann 1971 and Fibiger & Kristensen 1974).

The genus *Chamaesphecia* Spuler, 1910, occurs only in the Paleartic and includes 78 species. The host plants are mainly in the families Lamiaceae, Euphorbiaceae, Scrophulariaceae and Hypericaceae. The Euphorbiaceae-group consists of 10 species (Tosevski *et al*. 1994). Most of the *Chamaesphecia* species, the host plants of which are known, are associated with one plant species (strictly monophagous) or to a few very closely related

species (oligophagous within one genus). According to Eichlin & Duckworth (1988), there are no species of Sesiidae on native North American spurge species.

4.2. Materials and methods

Work was started in 1992 with a survey in Hungary and establishing a breeding colony of *Ch. crassicornis* at Delémont. The screening tests were conducted in 1993.

Life history. *Ch. crassicornis* was collected as larvae in late spring and infested roots were kept in a greenhouse in emergence cages. After mating, oviposition was obtained on cut shoots of the field host plant kept in transparent plastic cylinders in the greenhouse.

Screening tests. Five newly hatched larvae were transferred onto the stem bases of potted plants in usually 4-5 replicates. Larval transfer tests were made with 28 plant species including 18 *Euphorbia* species from four subgenera, five native U.S. spurges, six plant species in other genera of Euphorbiaceae, and four *Chamaesphecia* host plants from another two families. The infested plants were kept in the greenhouse and dissected at the end of October-early November.

4.3. Results

Adult morphology: Alar expanse between 16-22 mm. Fore wing of male dark brown with all hyaline areas well developped. Discal spot dark brown to black, ETA oval elongated divided into 3-4 cells. Apical area brown, with golden-yellow spots between the veins. Abdomen dark brown, distal margin of 2, 4, and 6th (sometimes also 7th) tergites white bordered, with pale brown broken line medially. Anal tuft brown, externally and in the middle whitish-brown. Female similar to male, fore wing with less distinct hyline areas.

Egg morphology: The eggs are brown to dark brown, pear-shaped, with a pruinose surface (0.91±0.02mm × 0.67±0.01 mm, n=30). The front pole is narrower, crateriform, with short catkin-like protrusions, so that the rosette is open and visible at the bottom of the crater. The average number of aeropyles is 8.8±2.0 (n = 15, range 6-15) (see also Tosevski *et al.* 1994).

Habitat: On mesic-dry to dry habitats with loamy soil and on coarse soil where spurge is intermixed with a dense and tall vegetation. The moth frequently occurs on roadsides and embankments.

Distribution: *Ch. crassicornis* is known from southeastern Austria, southern Slovakia, Hungary, Serbia, Romania, Bulgaria, southern Russia, Kazakhstan and Kirgizia (Fig. 1). It is a rare species in Central Europe.

Field host range: The host-plant is *E. virgata*. The moth has never been reared from other perennial spurges like *E. esula* (s.str.), *E. cyparissias*, *E. seguieriana*, *E. lucida*, *E. polychroma*, *E. amygdaloides*, *E. myrsinites* and *E. palustris* although two of these, *E. cyparissias* and *E. polychroma*, support larval development in the laboratory.

Bionomics: The adults fly in July. The eggs are laid singly on the stem or into the leaf axil. Neonate larvae drop to the ground and bore directly into the root. In spring, the larvae mine into the central part of the root where development continues. The larvae, which have an annual or biennial development, pupate in early June at the top of the exit tunnel. There is no cocoon.

Laboratory rearing: A total of 33 adults emerged from the material collected in Hungary in 1993 and four larvae (11%) were still alive in mid September. 80% of these adults emerged between July 26 and August 7, the last one on August 30. From the 77 L1 transferred on *E. virgata* in 1992, 10 larvae (13%) completed their development and the adults emerged in 1993. Another two large larvae (2.6%) were found alive in mid September. Thus, the percentage of *Ch. crassicornis* with a biennal cycle is similar to that observed by Pecora *et al*. (1990) who found that about 80% of the adults emerged during the first year.

Copulation occurred late in the morning, 1-4 days after eclosion. *Ch. crassicornis* copulated readily in captivity. Mated females produced on average 80 eggs (range 15-146; n = 9). The potential fecundity was 163 eggs (range 83-178). Egg development took about two weeks at 20º C. When transferred during the second half of August, the larvae reached the L3/L4 instar in early November.

Mortality factors. Parasitism is an important mortality factor of *Ch. crassicornis*. Parasitism by three yet undetermined parasitoids (in the families Ichneumonidae, Braconidae and Tachinidae) reached 54% in 1992 but only 21% in 1993 in the main collection site. Another important mortality factor is the failure of newly hatched larvae to penetrate into a spurge root.

Laboratory host range. Larval survival was restricted to species in subgenus Esula, i.e. *E. virgata* (33.3%), North American leafy spurge (27.8%), *E. cyparissias* (15.0%), E. polychroma (5.0%), *E. lathyris* (5.0%) and *E. incisa* (28.0%) (Table 1). The rate of larval development was nearly the same on all plant species except on *E. incisa* on which it was slightly slower for the majority of the larvae. The second instar larvae which were found on *E. virgata* and North American leafy spurge were due to late larval transfers. Larval weight of the three L4 instar larvae on *E. virgata* was less than 5.0 mg and reached 1-2,5 mg for the second and third instar larvae on all plant species. Thus, in contrast to *Ch. hungarica* and *Ch. astatiformis* in which most of the larval growth occurs in late summer and fall, most of the larval growth of *Ch. crassicornis* occurs in the following spring.

5. Discussion

The host range of *Ch. crassicornis is* restricted to some species in subgenus Esula. *E. incisa*, *E. cyparissias* and to a lesser extend *E. lathyris* support *Ch. crassicornis* development in confinment. This is similar to the results obtained by Pecora *et al*. (1990) (see Appendix).

Spurges in the other three subgenera tested do not support larval development in the laboratory and this is a reliable indication that they will not be hosts in nature. This means that the economic species *E. pulcherrima* (subgenus Poinsettia) and *E. antisyphilitica* (subgenus Agaloma) are not vulnerable. No species in subgenus Chamaesyce were tested as the risk to them is small. The subgenus is different from the rest of the *Euphorbia* and is placed in its own

genus, *Chamaesyce*, by Webster (1975), thus it is unlikely to be attacked by an insect restricted to the subgenus Esula. Furthermore, most of the North American species are annuals and so unsuitable for a moth that requires a perennial to complete its life cycle. There are 49 species in Wheeler's (1941) monograph on North American continental *Chamaesyce.* Of these, 12 of the perennials are restricted to a region considerably south of the southern limit of the moth (Fig. 2). The remaining species, *E. fendleri* Torr. & Gray has a range that extends from Texas to Nebraska, Oklahoma and Wyoming and so slightly overlaps that of the moth. It is not rare except for *E. fendleri* var. *triligulata* Wheeler which is only known from the type collected in Texas.

The two endangered or threatened native spurges in continental North America are not at risk: *E. deltoidea* spp*. deltoidea is* a perennial Chamaesyce restricted to Florida) and *E. garberi is* an annual Chamaesyce restricted to Florida as well. There is one continental species in Category 1 (*E. hooveri*) that is not a risk because it is an annual Chamaesyce restricted to California. There are seven species in Category 2 and nine in Category 3 of which only two are perennials in the subgenus Esula (*E. telephioides* (Florida) and *E. purpurea* (a mid eastern species of swampy woods). The northern limit of *E. purpurea* in Maryland and Virginia is south of the southern 40ºN limit of the moth, and furthermore its swampy habitat is unsuitable. The only native spurge that might support development in the laboratory and occurs within the distribution range of the moth is *E. robusta* (Engelm.) Small; however, its dry rocky outcrop habitat is not utilized by the moth in Europe.

It is concluded that no native North American spurges are at risk for one or more of the following reasons: they occur outside the subgenus Esula to which the moth is restricted, they occur south of the distribution range of the moth, they are annuals, or they do not occur in the moth habitat. Of the three European *Chamaesphecia* spp. that develop on North American leafy spurge, *Ch. crassicornis* is the best candidate in terms of its ability to develop on leafy spurge. Feeding by a single larva is very detrimental to its host in Europe. The scarcity of the moth in Europe is probably due to high level of parasitism and the scarcity and patchy distribution of its host plant, *E. virgata.* Thus, *Ch. crassicornis* is expected to build up quickly high populations in North America when released from these major constraints.

6.0. Environmental consequences

6. 1. General

Leafy spurge is a herbaceous perennial of Eurasian origin that has become a serious weed on the prairies and non crop areas in North America. The control cost and losses from leafy spurge are estimated to be over 100 million dollars a year. The still more alarming fact is that inspite of large control programmes with herbicides, the weed continues to spread. Thus, chemical control methods have proved expensive, largely ineffective and ecologically undesirable.

The direct effects of weed biocontrol agents is to reduce the density of the weed and allow the return of a mixed community of native and forage herbaceous plants, faunal diversity and food chains. Therefore, biocontrol has a positive economic effect on land by increasing the forage value and hence cattle production. The main indirect effects are a reduced use of herbicides for spurge control.

6.2. Physical environment

1. Air. The establishment of *Ch. crassicornis* will have no effect on air quality.
2. Water. The establishment of *Ch. crassicornis* will have no detrimental effects on water quality. Indeed, some indirect beneficial effects may be expected if the moth is effective enough to reduce the use of herbicides for spurge control.
3. Land. Soil quality will not be adversely affected by the establishment of *Ch. crassicornis*. The value of spurge infested land should increase as biocontrol takes effect.

6.3. Human health risks

Ch. crassicornis will have no detrimental human health effects. However, spurge is a human health risk in its own right. Spurge latex has the potential to cause blindness and dermatitis and it is a cocarcinogen. Thus, any reduction in the prevalence of spurge particularly in parks and recreation areas near population centres is desirable from a human point of view.

6.4. Ecological relationships

Wildlife. The replacement of leafy spurge by native flora will be beneficial by opening the habitats for native plants and wildlife.

Insects. Leafy spurge is frequented by parasitoids, predators and bees as a source of food. It is not regarded as an important honey plant by beekeepers. The replacement vegetation may well provide a more sustained honey flow. Leafy spurge is an introduced plant and is not attacked by specialized native herbivores. Thus, replacement of leafy spurge will have no negative effect on native insects.

Other biological control agents. There will be no direct (interference) competition between *Ch. crassicornis* and other biocontrol agents. Partial overlapping of the geographical distribution of *Ch. crassicornis* and *Ch. astatiformis* cannot be excluded but this will not be detrimental to the biological control of leafy spurge.

Native spurges; endangered and threatened species. No endangered and threatened spurge species will be affected by the establishment of *Ch. crassicornis* in North America. Native flora and fauna in general will benefit from leafy spurge biocontrol.

Livestock and domestic animals. *Ch. crassicornis* will not cause any adverse effects on livestock and domestic animals. On the contrary, latex in leafy spurge gives cattle scours, mouth blisters and in large quantities can cause death. This cause cattle to avoid grazing in areas with a spurge cover of 10% or more. The reduction of leafy spurge will cause an increase in forage plants and thus will be beneficial to livestock.

6.5. Cumulative impact

The cumulative environmental impact from the establishment of *Ch. crassicornis* will be to increase plant diversity on mesic-dry sites presently dominated by leafy spurge. The effect of the moth will be to recycle leafy spurge, which is presently a largely unused resource, through other food chains. However, the main effect on native wildlife both vertebrate and invertebrate will be to increase diversity as the result of the increased plant diversity.

Biocontrol of leafy spurge will reduce the use of herbicides on uncultivated areas and the subsequent contamination of ground water. It will also help reduce social conflict between regulators and environmentalists trying to prevent the use of herbicides in these habitats and land owners trying to prevent the spread of leafy spurge to other sites.

6.6. Mitigative measures

It is not foreseen that any measures to mitigate the effects of *Ch. crassicornis* will be necessary or desirable.

7. Conclusion

The direct effect of *Ch. crassicornis* on leafy spurge will be the return of a diverse community of native herbaceous plants. The forage value of spurge infested land and the attractiveness of amenity land will increase. The amount of herbicides used for the control of leafy spurge will be reduced as biological control takes effect. Thus there will be a direct beneficial effect on the environment.

Ch. crassicornis has a narrow host range, climatic and habitat requirements that will restrict it to the main leafy spurge infestations on the Prairies on both sides of the Canadian-USA border

Ch. crassicornis is suited for release in North America in mesic-dry habitats on the prairies.

Acknowledgement

Special thanks to I. Tosevski for identifying *Ch. crassicornis*, L. E. Wendel and P. E. Parker for providing North American native spurges. The technical assistance of A. Buchholz and L. Wilson is greatly acknowledged.

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Table 1. Larval survival of *Ch. crassicornis* on potted plants (1993).

Plant species	No. Ll transferred	Percent survival (larval instars)
Geraniales		
Euphorbiaceae		
Subgenus ESULA:		
* *E. virgata*	27	33.3 (3L2/3L3/3LA)
* *E. cyparissias*	20	15.0 (2L3/1L4)
N-A leafy spurge	18	27.8 (5L2)
* *E. lucida*	20	–
* *E. seguieriana*	20	–
** *E. incisa*	25	28.0 (4L2/3L3)
* *E. amygdaloides*	20	–
* *E. myrsinites*	20	–
* *E. polychroma*	20	5.0 (1L3)
E. lathyris	20	5.0 (1L3)
Subgenus AGALOMA		
** *E. corollata*	20	–
** *E. discoidalis*	25	–
** *E. marginata*	30	–
E. antisyphilitica	20	–
Subgenus POINSETTIA		
E. pulcherrima	20	–
** *E. cyathophora*	25	–
Subgenus EUPHORBIUM		
E. milii	30	–
E. tirucalli	20	–
Ricinus communis	20	–
Pedilanthus tithymaloides	20	–
Manihot esculenta	20	–
Croton variegatum	20	–
Acalypha hispida	20	–
Mercurialis perennis	20	–
Tubiflorae		
Lamiaceae		
* *Origanum vulgare*	20	–
* *Salvia sclarea*	20	–
* *Mentha spicata*	20	–
Scrophulariaceae		
* *Scrophularia nodosa*	20	–

* host plants of other *Chamaesphecia* species
** native U.S. spurges

Appendix

Development of *Chamaesphecia crassicornis* on non-host plants (Studies by USDA ARS Biological Control Laboratory; modified form Pecora *et al.* (1990).

Test plants	No. Ll transferred	Percent larval survival October 1985	Percent adult emergence July 1986
Plants tested during 1985			
E. virgata (control)	66	10.0	11.1
Leafy spurge (Nebraska)	66	10.0	8.3
Leafy spurge (Montana)	105	10.0	6.7
Leafy spurge (Wyoming)	18	11.1	
Leafy spurge (Oregon)	18	11.1	
Plants tested during 1988			
E. virgata (control)	15	26.7	
E. esula s.str. (Italy)	15	13.3	
E. lucida	15	6.7	
E. lathyris	15	20.0	
E. tirucalli	15	0	
E. antisyphilitica	15	0	
E. pulcherrima	15	0	
E. corollata	15	0	
Ricinus communis	15	0	

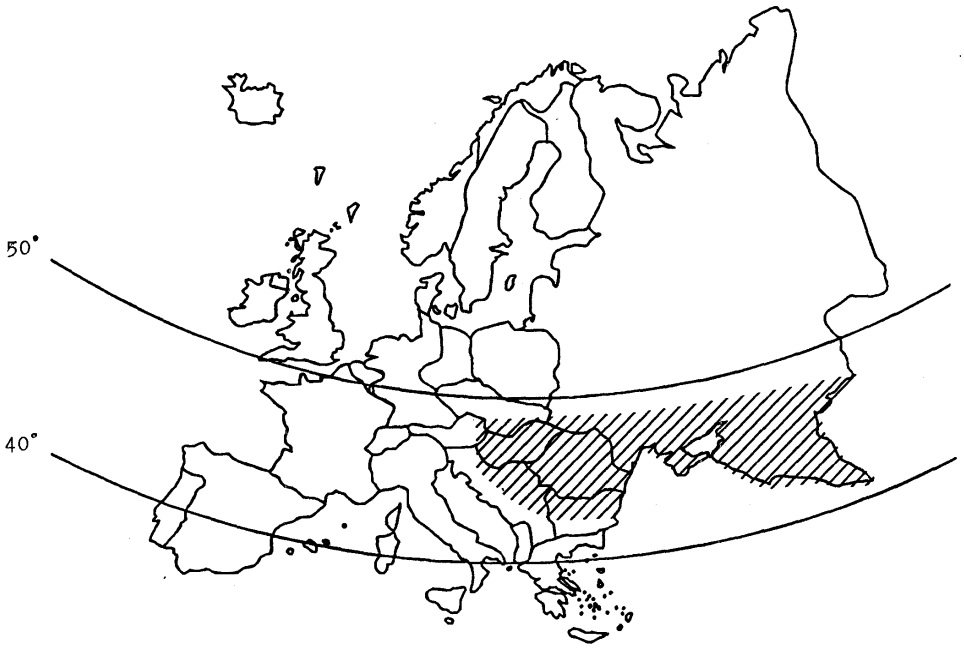

Fig. 1: European distribution of *Chamaesphecia crassicornis.*

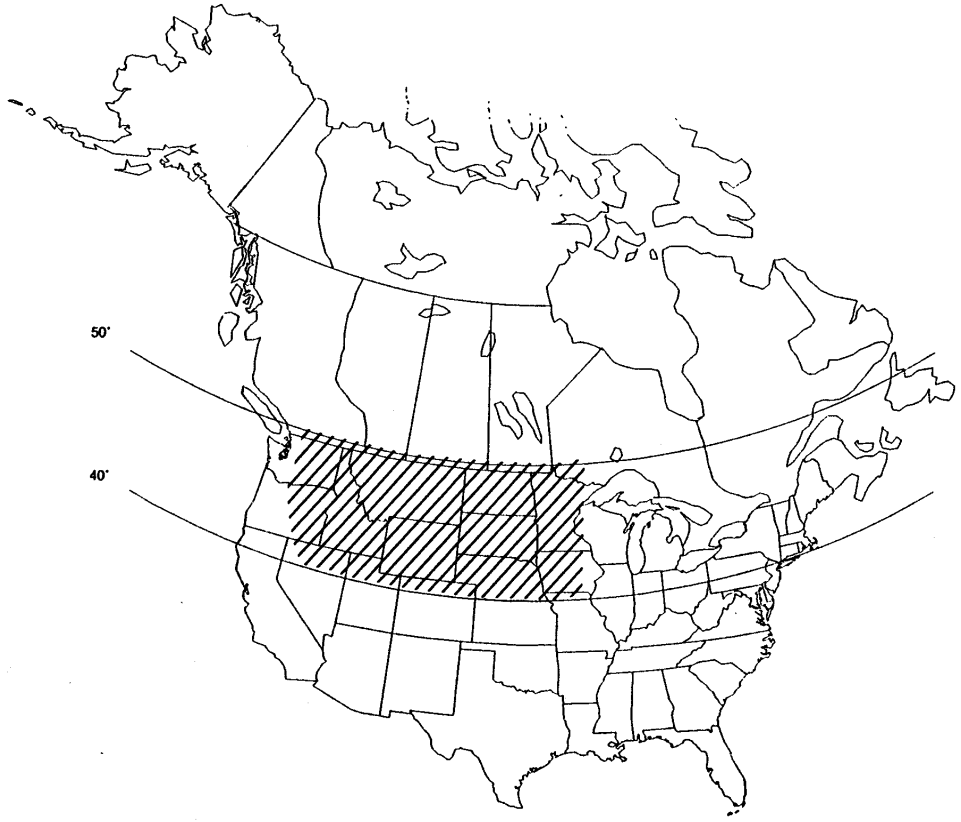

Fig. 2: Potential distribution of *Chamaesphecia crassicornis* in North America.