17 CANADA THISTLE

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PEST STATUS OF WEED

Canada thistle, *Cirsium arvense* (L.) Scop. (Fig. 1), is a vigorous, competitive weed that occurs in a wide range of habitats and is difficult to control due to its ability to regrow from its extensive, deep creeping root system (Nadeau and Vanden Born, 1989).

Figure 1. Canada thistle (*Cirsium arvense* [L.] Scopoli). (Photograph by L. M. Dietz.)

Nature of Damage

Economic damage. Canada thistle causes extensive crop yield losses through competition and, perhaps, allelopathy (Stachon and Zimdahl, 1980) (Fig. 2). The prickly mature foliage also is thought to reduce productivity of pastures by deterring livestock from grazing. Canada thistle is the species most frequently declared noxious under state or provincial weed control legislation in the United States and Canada (Skinner *et al.*, 2000). It is listed as a noxious weed under state weed control legislation in Delaware, Illinois, Indiana, Iowa, Kansas, Kentucky, Maryland, Minnesota, Missouri, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, South Dakota, and Wisconsin (USDA, NRCS, 1999).

Figure 2. Canada thistle (*Cirsium arvense* [L.] Scopoli) infestation in canola (*Brassica rapa* L.). (Photograph by A. S. McClay.)

Ecological damage. Canada thistle can be an invasive species in some natural communities, including prairie potholes and wet or wet-mesic grasslands in the Great Plains and sedge meadows in the upper Midwest (Nuzzo, 1997). It usually is a problem in disturbed areas and moister sites. Canada thistle was among the most prevalent weeds on Conservation Reserve Program (CRP) land in Minnesota, occurring in 65 to 75% of CRP fields throughout the state. Canada thistle ground cover in these fields frequently reached 50 to 75%, giving rise to concern about seed dispersal into neighboring agricultural land (Jewett *et al.*, 1996). It was ranked as "urgent" for control in a review of exotic plants at Pipestone National Monument, Minnesota (Hiebert and Stubbendieck, 1993).

Extent of losses. A density of 20 Canada thistle shoots per m^2 caused estimated yield losses of 34% in barley (O'Sullivan *et al.*, 1982), 26% in canola (O'Sullivan *et al.*, 1985), 36% in winter wheat

(McLennan *et al.*, 1991), and 48% in alfalfa seed (Moyer *et al.*, 1991). Densities of Canada thistle in field infestations can reach 173 shoots per m^2 (Donald and Khan, 1996).

Geographical Distribution

Canada thistle occurs in all eastern U.S. states south to Kansas, Arkansas, Tennessee, and North Carolina, but it is sparsely distributed south of latitude 37° N (USDA, NRCS, 1999). The main areas of occurrence are the northeastern, mid-Atlantic, Great Lakes, and northern Great Plains states. In a survey in Maryland, Canada thistle was found in about 17% of suitable sites in the eastern and central part of the state, but only 10% of sites further west (Tipping, 1992).

BACKGROUND INFORMATION ON PEST PLANT

Taxonomy

Canada thistle is a member of the genus *Cirsium*, subtribe Carduinae, tribe Cardueae, and family Asteraceae (Bremer, 1994). It differs from most other *Cirsium* species by its dioecious flowers, and from most native North American members of the genus by its extensive creeping roots and small, numerous flower heads borne on branched stems. Several varieties have been described based on variations in leaf shape and degree of spininess.

Biology

The biology of Canada thistle was extensively reviewed by Moore (1975), Donald (1994), and Nuzzo (1997). It is a perennial herb with an extensive creeping root system that can give rise to new shoots from adventitious root buds. The stems usually die back over winter and new shoots are produced each spring from old stem bases or root buds. Canada thistle is almost perfectly dioecious and can produce abundant seeds, which are dispersed by wind (Lloyd and Myall, 1976). It is a long-day plant, requiring a photoperiod of at least 14 to 16 hours (depending on ecotype) for flowering to be induced (Hunter and Smith, 1972). It occurs in a wide range of habitats and soil types.

Analysis of Related Native Plants in the Eastern United States

The genus *Cirsium* is a large one, with 92 native species in North America, of which 20 occur in the U.S. states that fall wholly or in part east of the 100th meridian (USDA, NRCS, 1999). One of these, *Cirsium pitcheri* (Torrey) Torrey and Gray, is listed as threatened under the Endangered Species Act. This species occurs in sand dunes along the shores of the Great Lakes in Illinois, Indiana, Michigan, Wisconsin, and Ontario. Phylogenetic studies of North American and Eurasian *Cirsium* species are needed to elucidate relationships among species in the genus and to provide a basis for planning host-specificity tests and interpreting resulting data. Studies have been initiated using the external transcribed spacer (ETS) region of ribosomal DNA to develop a phylogeny for North American and selected Eurasian *Cirsium* species (D. Kelch, pers. comm.).

HISTORY OF BIOLOGICAL CONTROL EFFORTS IN THE EASTERN UNITED STATES

Canada thistle was among the first 19 weed species selected as targets for biological control when the USDA Rome Laboratory was established in 1959 (Schroeder, 1980). However, most host specificity testing of agents for Canada thistle was conducted from 1961 to 1984 by staff of Agriculture Canada or by the International Institute of Biological Control (now CABI Bioscience) working with Canadian funding. The agents released in the United States have been those that became available as a result of the Canadian program, the results of which were reviewed by Schroeder (1980), Peschken (1984a), and McClay *et al.* (2001). Most releases in the eastern United States were made by USDA, ARS staff at the Beltsville Agricultural Research Center; some studies also were carried out by staff of the Maryland Department of Agriculture. Biological control of Canada thistle in New Zealand has been reviewed by Jessep (1989).

Area of Origin of Weed

Canada thistle is native to Europe, parts of North Africa, and Asia south to Afghanistan, Iran and Pakistan, and east to China. Its exact center of origin within the native range is not known, although it is suggested by Moore (1975) to be in southeastern Europe and the eastern Mediterranean area.

Areas Surveyed for Natural Enemies

Extensive surveys of natural enemies of Canada thistle and other Cardueae species in western Europe were carried out starting in 1959. Other surveys have been carried out in Japan, Iran, and northern Pakistan (Schroeder, 1980), and in China (Wan and Harris, unpub. data). Further surveys in southern Russia, central Asia, and China are currently under way (Gassmann, unpub. data). In addition to surveys specifically carried out for biocontrol purposes, the general European entomological literature contains much information on insects associated with Canada thistle (e.g., Redfern, 1983; Stary, 1986; Volkl, 1989; Freese, 1994; Berestetsky, 1997; Frenzel *et al.*, 2000). The phytophagous insects associated with Canada thistle in Poland are listed by Winiarska (1986).

Natural Enemies Found

Surveys by Zwölfer (1965a) in Europe found 78 species of phytophagous insects feeding on Canada thistle. Of these, six are reportedly monophagous, five are found on Canada thistle and a few related species, 26 are oligophagous on plants in the same subtribe, and the remaining 42 are less specific and of no interest for biological control (Schroeder, 1980).

A number of European insects and pathogens attacking Canada thistle have been accidentally introduced into North America, and some of these have been studied as potential biological control agents. The leaf-feeding tortoise beetle *Cassida rubiginosa* Müller (Coleoptera: Chrysomelidae) occurs widely in the eastern United States, south to Virginia and west to southern Michigan and Ohio, and in Canada (Ward and Pienkowski, 1978a). The seed-feeding weevil *Larinus planus* (F.) (Coleoptera: Curculionidae) was found by Wheeler and Whitehead (1985) to be well established in Pennsylvania, Maryland, Ohio, and New York, with the earliest records dating from 1968 in Ohio. It has also been collected from Indiana and West Virginia (C. W. O'Brien, pers. comm.). The seed-head fly *Terellia ruficauda* (F.) (=*Orellia ruficauda* F.) (Diptera: Tephritidae) is distributed across Canada, and presumably also occurs widely in the eastern United States. A survey showed it to be present in South Dakota (R. Moehringer, S. Dakota Dept. of Agriculture, pers. comm.), and specimens are known from Michigan. The root-feeding weevil *Cleonis pigra* (Scopoli) (Coleoptera: Curculionidae) occurs in New York, Pennsylvania, Michigan, Indiana, Ontario, and Quebec (O'Brien and Wibmer, 1982; Anderson, 1987; C. W. O'Brien, per. comm.). The rust *Puccinia punctiformis* (Strauss) Röhling is widespread in North America.

A phytopathogenic bacterium, *Pseudomonas syringae* pv. *tagetis* (Hellmers 1955) Young, Dye and Wilkie 1978, causing apical chlorosis, has been isolated from Canada thistle. Field tests of applications of this bacterium in a commercial corn field resulted in 57% mortality of Canada thistle as well as damage to several other weedy Asteraceae species. A surfactant is required to allow penetration of the Canada thistle cuticle by the bacterium. Further work on formulation of this agent is under way (Johnson *et al.*, 1996). The bacterium occurs in Maryland (P. Tipping, pers. comm.).

One species which was introduced as a biological control agent for *Carduus* species, the seed-head weevil *Rhinocyllus conicus* (Frölich) (Coleoptera: Curculionidae), also is recorded attacking Canada thistle (Rees, 1977; Youssef and Evans, 1994). This species is widespread in the eastern United States, and has been found attacking Canada thistle in Maryland (P. Tipping, pers. comm.).

Host Range Tests and Results

In the earlier part of the period 1961 to 1984, host specificity testing for agents attacking Canada thistle was focused on assessing potential risks to economic species of Cardueae, of which the two most important are safflower (*Carthamus tinctorius* L.) and globe artichoke (*Cynara scolymus* L.). In later studies, some native North American *Cirsium* species also were tested, but potential impacts of most agents on native non-target *Cirsium* species were not assessed in detail.

The leaf-feeding beetle *Altica carduorum* Guérin-Méneville (Coleoptera: Chrysomelidae) is known in the field in Europe mainly from Canada thistle, with a single record of adults from *Carduus* *pycnocephalus* L. (Zwölfer, 1965a). The host specificity of a population of *A. carduorum* from Switzerland was studied by Harris (1964), using starvation tests with adults and larvae. First instar larvae complete development only on *Cirsium*, *Carduus*, and *Silybum* species. Adults feed readily on all *Cirsium* species tested, which included only two North American species, but their feeding rate is highest on Canada thistle. Similar results were obtained by Karny (1963) and Zwölfer (1965b).

More recently, the host specificity of a biotype of *A. carduorum* from Xinjiang, China, was assessed by Wan *et al.* (1996), who found that in no-choice tests this beetle can complete development on 18 *Cirsium* species (mostly North American) and *Silybum marianum* (L.) Gaertner. A risk analysis approach, however, predicted that North American *Cirsium* species would be safe from attack in the field because host selection requires a series of sequential steps, with the native species being less preferred than *C. arvense* at each stage (Wan and Harris, 1997). It also was suggested that the insect is monophagous in the field because host finding is dependent on aggregation to substances from wounds and feces specific to *C. arvense* (Wan and Harris, 1996). As the Xinjiang biotype was not approved for field release in North America, it has not been possible to test these predictions in the field.

The only known field host plant of the weevil *Ceutorhynchus litura* (F.) (Coleoptera: Curculionidae) in Europe is Canada thistle, except for three collections from *Carduus defloratus* L. in Switzerland (Zwölfer and Harris, 1966). *Ceutorhynchus litura* was screened by Zwölfer and Harris (1966), who found that feeding, oviposition, and larval development are restricted to species in the genera *Cirsium*, *Carduus*, and *Silybum*. Normal larval development occurs on all *Cirsium* species tested, including three native North American species. *Ceutorhynchus litura* was approved for release in Canada and the United States based on its lack of attack on economic Cardueae species. In a more recent European field survey of seven *Cirsium* and *Carduus* species by Freese (1994), *C. litura* was found only in Canada thistle.

The stem- and petiole-galling fly *Urophora cardui* (L.) (Diptera: Tephritidae) is reported in the field in Europe only from Canada thistle (Zwölfer, 1965a) and the closely related species *Cirsium setosum* von Bieberstein (sometimes treated as a synonym of *C. arvense*) (Frenzel *et al.*, 2000). It was screened by Peschken and Harris (1975) against 14 other European Cardueae species and against 11 species, mainly economically important plants, in other tribes and families. In these tests, consistent oviposition was seen only on Canada thistle, with occasional oviposition on *Cirsium vulgare* (Savi) Ten. and *Carduus acanthoides* L.

Host specificity tests on the weevil *L. planus* were conducted by McClay (1989), who found that *L. planus* will not feed on ornamental or economic species in the tribe Cardueae and that Canada thistle is preferred over other *Cirsium* species for feeding and oviposition. These tests suggested that small-flowered *Cirsium* species were more suitable as hosts than native *Cirsium* species, which generally have larger flower heads. However, Louda and O'Brien (2002) found L. planus reducing seed production of the large-flowered native Cirsium undulatum (Nutt.) Spreng. var. tracyi (Rydb.) Welsh in Colorado, indicating that redistribution of this insect poses greater risks to native species than was previously believed.

Cassida rubiginosa is recorded from numerous species of *Arctium*, *Carduus*, *Cirsium*, *Silybum*, *Onopordum*, and *Centaurea*. In feeding tests, adults and larvae accept species from all these genera, as well as from globe artichoke (Zwölfer and Eichhorn, 1966; Zwölfer, 1969). Spring and Kok (1997) found that *C. rubiginosa* shows no oviposition preference between Canada thistle and *Carduus thoermeri* Weinmann; however, mortality of immature stages is lower on Canada thistle. They also observed adults, larvae, and egg masses on burdock, *Arctium minus* (Hill) Bernhardi, in the field, and reared *C. rubiginosa* from egg to adult on this species.

Host specificity testing also was conducted on the lace bug *Tingis ampliata* Herrich-Schäffer (Hemiptera: Tingidae) (Peschken, 1977a) and the leaf beetle *Lema cyanella* (L.) (Coleoptera: Chrysomelidae) (Peschken and Johnson, 1979; Peschken, 1984b). *Tingis ampliata* was never released in North America because of concerns about possible attack on globe artichoke, *Cynara scolymus* L. Limited releases of *L. cyanella* have been made in Canada but no further releases or redistribution are planned (McClay, unpub. data).

Cleonis pigra attacks numerous species of Cardueae in Europe, and is an economic pest of globe artichoke (LaFerla, 1939; Zwölfer, 1965a; Batra *et al.*, 1981). *Terellia ruficauda* has been reared from six *Cirsium* species in Europe (Zwölfer, 1965a).

Releases Made

Information on releases of biological control agents against Canada thistle was obtained from the literature and, for the period between 1981 and 1985, from the USDA, ARS database on natural enemy releases in the United States (ROBO at http://www.ars-grin.gov/nigrp/robo.html). There undoubtedly have been many additional releases that have not been published; for example, 18 releases of *C. litura* and 12 of *U. cardui* were made in the eastern part of South Dakota between 1987 and 1984, and *L. planus* and *C. rubiginosa* also have been released in this area (R. Moehringer, S. Dakota Dept. of Agriculture, pers. comm.).

Releases of *A. carduorum* began in 1966, using material from Switzerland via Canada, and were made in Delaware, Indiana, Maryland, Minnesota, New Jersey, South Dakota, and Wisconsin; in 1970, material from France was released in Maryland, New Jersey, and South Dakota (Julien and Griffiths, 1998). Two releases of *A. carduorum* from a population collected near Rome, Italy, were made in Maryland in 1982.

Releases of *C. litura* began in 1971 (Julien and Griffiths, 1998). This weevil was released in Maryland on 16 occasions from 1982 to 1985 and at one site in New York State in 1984. Most of these releases were made using material imported from Bavaria, Germany, but four releases were made with material from established field populations in Montana.

Urophora cardui was released on nine occasions in Maryland between 1981 and 1984, mostly using material from field collections near Vienna, Austria. Two releases of *U. cardui* from this source also were made in Iowa in 1982 and 1985. Another series of four releases totaling 4,400 adults from the population in British Columbia, Canada, was made in 1985 in Virginia (Kok, 1990).

Cassida rubiginosa was moved from northern Virginia to a southwestern area of the state where it previously had not occurred (Ward and Pienkowski, 1978a).

BIOLOGY AND ECOLOGY OF KEY NATURAL ENEMIES

Altica carduorum Guérin-Méneville (Coleoptera: Chrysomelidae)

This species has a Mediterranean and partly Atlanti distribution in Europe (Zwölfer, 1965b). A closel related species, *Altica cirsicola* Ohno, occurs in Chin and Japan (Laroche *et al.*, 1996); however, RAPD fin gerprinting (a DNA identification method) showe that a population from Xinjiang in western China wa *A. carduorum* (Wan and Harris, 1995). Thus the dis tribution of *A. carduorum* extends from the Medi terranean and eastern Europe, through Kazakhstan Kirghizia and Tadzhikistan to western China (Wa and Harris, 1995).

In Switzerland, overwintering adults of *A carduorum* begin to appear on foliage of Canad thistle in mid-April and oviposition starts in earl May. Larvae are present on the leaves from mid-Ma through late July. Newly emerged adults feed heavil on foliage in August and September before leaving the plant to seek overwintering sites (Zwölfer, 1965b) Females oviposit on the underside of Canada thistl leaves, usually laying about 12 eggs per day. Unde laboratory conditions, eggs hatch in about 11 days larval development requires about one month, an pupa develop to adults in 10 to 11 days. Larvae fee on the undersurface of leaves, producing "windows" of clear epidermis. Adult feeding damage is evenl dispersed over the whole plant; heavy adult feeding can cause the collapse of plants both in the laboratory and in the field (Karny, 1963).

Cassida rubiginosa Müller (Coleoptera: Chrysomelidae)

This univoltine shield beetle feeds on foliage of several Cardueae species, both as adults and larvae. In Virginia, adults appear in late winter and oviposit, mainly on the underside of thistle leaves, from mid-March to early July. Eggs are laid in oothecae containing about five eggs. Development from egg to adult requires 435 degree-days above a threshold of 10.4°C. New generation adults begin to appear in late spring and can be found on plants up to November. Females produce an average of 815 eggs under laboratory conditions (Ward and Pienkowski, 1978a).

In the field, *C. rubiginosa* is attacked by several larval parasitoids including *Tetrastichus rhosaces* (Walker) (Hymenoptera: Eulophidae) and *Eucelatoriopsis dimmocki* (Aldrich) (Diptera: Tachinidae) (Ward and Pienkowski, 1978b). However, Ang and Kok (1995) felt that parasitism did not limit *C. rubiginosa* populations in Virginia. Tipping (1993) found that adults released on Canada thistle in Maryland remained in close proximity to the release point and that most oothecae were laid within 1.6 m of the release point. Parasitism in this study was 10.5%, with the most common parasitoid being *E. dimmocki*. Larvae and pupae are heavily predated by larvae of *Coccinella septempunctata* L. (Coleoptera: Coccinellidae) in Maryland (P. Tipping, pers. comm.). Spring and Kok (1999) found about 21% overwintering survival of adult *C. rubiginosa*.

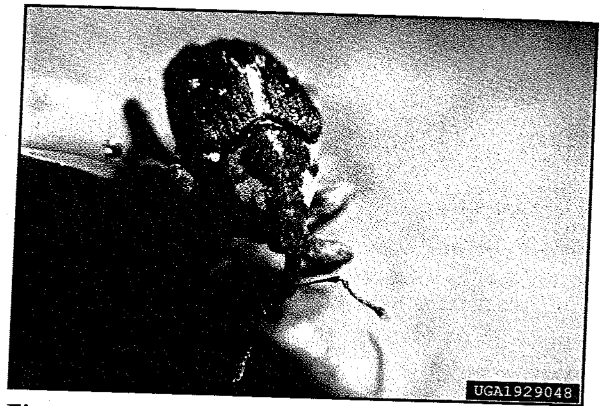

Figure 3. *Ceutorhynchus litura* (F.) adult. (Photograph by A. S. McClay.)

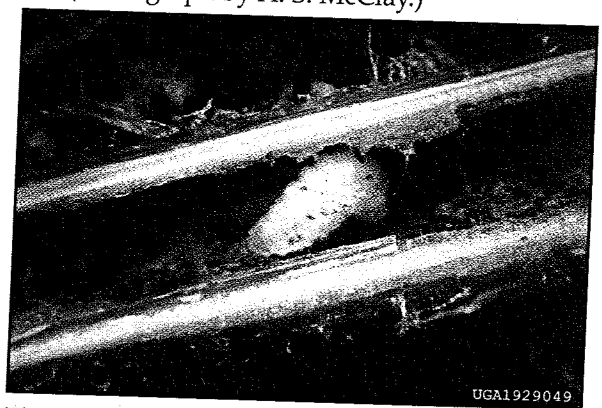

Figure 4. *Ceutorhynchus litura* (F.) larva in stem base of Canada thistle.. (Photograph by A. S. McClay.)

Ceutorhynchus litura (F.) (Coleoptera: Curculionidae)

This stem- and root-mining weevil occurs in France, Switzerland, Austria, Germany, Britain, and southern Scandinavia (Zwölfer and Harris, 1966) (Fig. 3). Females oviposit into the mid-veins of rosette leaves of Canada thistle leaves in spring. Eggs are laid in groups of one to five in a cavity made with the rostrum in the underside of a young leaf. Larvae hatch after five to nine days and mine down through the vein into the base of the stem and upper tap root (Fig. 4). There they form a feeding tunnel that may cause the stem to become somewhat inflated into an indistinct gall. Mature larvae leave the stem and pupate in a cocoon of soil particles, from which they emerge in late summer (Zwölfer and Harris, 1966; Peschken and Beecher, 1973). Adults overwinter in the soil or leaf litter.

Cleonis pigra (Scopoli) (Coleoptera: Curculionidae)

Adults of this large weevil emerge from overwintering sites in May and feed on Canada thistle foliage in June and July. The females oviposit into the lower portions of Canada thistle stems. The larvae mine down through the stem base into the root, which develops a spindle-shaped gall around the feeding site. Pupation occurs in the root, and adults emerge in late summer or fall (Anderson, 1956).

Larinus planus (F.) (Coleoptera: Curculionidae)

Adults of this weevil (Fig. 5) feed on Canada thistle foliage, but generally cause little damage. Females oviposit into the unopened flower buds, where larvae feed on the developing achenes and receptacle tissue. Larvae pupate in a cocoon formed of chewed host plant tissue (Fig. 6.). Only one larvae can complete development in each head. Adults emerge in late summer and overwinter in the litter (McClay, 1989).

Puccinia punctiformis Strauss (Röhling) (Uredinales: Pucciniaceae)

This fungus is an autecious brachycyclic rust that produces systemic infections on the spring-emerging shoots of Canada thistle. Systemically infected shoots are pale and die before flowering, but spermogonia and uredosori are formed before plant death. Later in the season, infection of other shoots by uredospores leads to local infection followed by

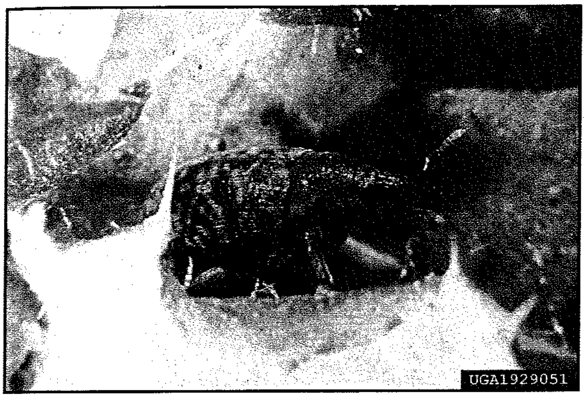

Figure 5. *Larinus planus* (F.) adult. (Photograph by A. S. McClay.)

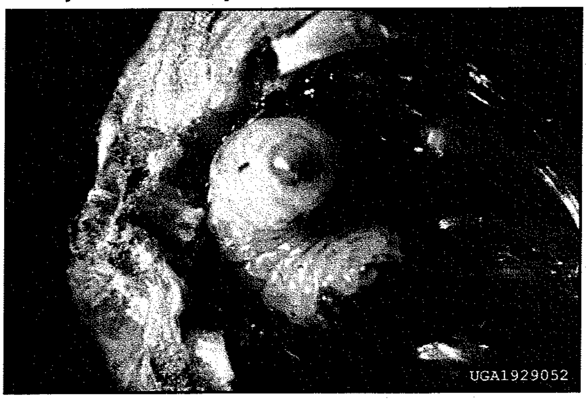

Figure 6. *Larinus planus* (F.) larva in seed head of Canada thistle. (Photograph by A. S. McClay.)

the formation of teliospores in autumn (Van Den Ende *et al.*, 1987). Teliospores are responsible for the systemic form of infection (Van Den Ende *et al.*, 1987; French and Lightfield, 1990). Germination of teliospores is stimulated by volatile compounds from germinating Canada thistle seeds and root cuttings (French *et al.*, 1988; French *et al.*, 1994). The germination rate of teliospores is highest in the temperature range of 10°C to 15°C (Frantzen, 1994). Systemic infection may be induced in the laboratory in root buds or seeds inoculated with teliospores (French and Lightfield, 1990; French *et al.*, 1994), but it is not yet clear how root infection from teliospores could take place in the field (French *et al.*, 1994). Systemically infected shoots are taller than uninfected ones but fail to flower and their root biomass is reduced (Thomas *et al.*, 1994). Cumulative mortality of infected shoots in a field study in Maryland was 80% compared with less than 10% for healthy shoots (Tipping, 1993).

Terellia ruficauda (F.) (Diptera: Tephritidae)

Ovipositing females of this fly select female Canada thistle flower heads one day away from blooming. Eggs are laid between immature florets and the larvae feed on developing achenes through a hole drilled in the pericarp. Third instar larvae form cocoons of pappus hairs in which they overwinter; pupation and emergence take place in the spring (Lalonde and Roitberg, 1992).

Urophora cardui (L.) (Diptera: Tephritidae)

This univoltine stem-galling fly oviposits in the axillary buds of Canada thistle (Fig. 7). The eggs hatch in seven to 10 days. Larvae induce development of multi-chambered galls in the form of a swelling in the stem up to 23 mm in diameter (Lalonde and Shorthouse, 1985) (Fig. 8). Pupation and overwintering occur in the gall, from which adults emerge in early summer. Larvae in the galls are preyed on by birds, ants, and an unidentified mite (Acari: Pyemotidae) in Maryland (P. Tipping, pers. comm.).

Figure 7. *Urophora cardui* (L.) adult. (Photograph by A. S. McClay.)

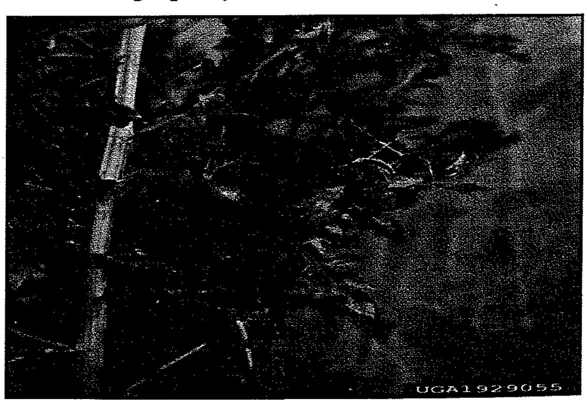

Figure 8. *Urophora cardui* (L.) galls on stem of Canada thistle. (Photograph by A. S. McClay.)

EVALUATION OF PROJECT OUTCOMES

Establishment and Spread of Agents

There is no evidence that *A. carduorum* has become established in the United States. Peschken (1977b) attributed the failure of this species to establish in Canada to predation. *Ceutorhynchus litura* is reported to be established in Maryland, North Dakota, South Dakota, and Virginia (Julien and Griffiths, 1998; P. Tipping, pers. comm.). *Urophora cardui* is reported to be established in Maryland and Virginia (Julien and Griffiths, 1998), although the species is probably not currently established in Maryland (P. Tipping, pers. comm.). Galls of *U. cardui* were found at all Virginia field sites visited in 1986 but at only two sites in 1987; however, numbers of galls had increased at these two sites in 1987 (Kok, 1990). No recoveries are recorded in Virginia since 1987. *Urophora cardui* is common along the Hudson River and in other areas in New York state (B. Blossey, pers. comm.). Its establishment status in Iowa is unknown. *C. rubiginosa* became established in southwestern Virginia and has persisted there for more than 20 years (Ang and Kok, 1995).

Suppression of Target Weed

There has been little work done to evaluate the effectiveness of biological control agents for Canada thistle in the eastern United States. Using Canada thistle root cuttings transplanted to caged field plots, Ang *et al.* (1995) showed that feeding by *C. rubiginosa* significantly reduced biomass and survival of Canada thistle. The effects of *C. rubiginosa* were stronger than those of plant competition from tall fescue (*Festuca arundinacea* Schreb.) and crownvetch (*Coronilla varia* L.). Similar results were obtained by Bacher and Schwab (2000) in Switzerland.

Forsyth and Watson (1986) evaluated the stress inflicted on Canada thistle by four insect species and one pathogen in Québec, Canada. The seed head predator *O. ruficauda* reduced seed production by about 22%. Root mining by *C. pigra* sometimes killed plants. Main shoot galling by *U. cardui* reduced plant height and number of flowers, but side-shoot galling had less impact. Reports of the impact of *C. litura* have been varied. Based on field sampling, Rees (1990) suggested that this species had a significant impact on survival of Canada thistle in Montana. Peschken and Derby (1992), however, found in controlled experiments that combined attack by this species and *U. cardui* had no significant effect on most performance parameters of Canada thistle. The impact of biological control of Canada thistle in terms of economic benefits or recovery of native plant communities has not been evaluated.

RECOMMENDATIONS FOR FUTURE WORK

Future Needs for Importation or Evaluation

The impact of currently established agents needs to be evaluated by controlled experimental methods, preferably using naturally-occurring densities of agents in field weed stands (McClay, 1995). The extent of non-target damage from the currently established agents also need to be further assessed. Such damage has been shown repeatedly for the seed weevil *R. conicus*, released as a biocontrol agent for *Carduus* and *Silybum* species (Rees, 1977; Louda, 1999; Herr, 2000). As with *R. conicus*, most of the agents released against Canada thistle have laboratory host ranges that include many native *Cirsium* species, but it is not known whether any of these native species are in fact being damaged, or are at risk of damage, in the field. Information on this would provide a valuable test of the reliability of laboratory host-range tests in predicting non-target utilization in the field.

The European range of Canada thistle has been extensively explored for potential biocontrol agents, and it seems unlikely that there are promising agents yet undiscovered in this region. Further exploration in Central Asia and China may identify other possible candidate agents, and such exploration is planned (A. Gassmann, pers. comm.).

Other Comments

Canada thistle may be a difficult target for biological control for two reasons. Firstly, it is a significant agricultural weed in its native range in Europe (Schroeder *et al.*, 1993), suggesting that its natural enemies there are not very effective in limiting its population density, at least under agricultural conditions. There has been little study of the impact of herbivory on natural populations of Canada thistle in Europe; however, Edwards *et al.* (2000) found that exclusion of insects with chemical pesticides had no effect on recruitment or density of Canada thistle in cultivated soil or grassland in southern England. Secondly, Canada thistle is congeneric with a large number of native North American *Cirsium* species, raising concerns about non-target damage to native species by introduced biological control agents (Louda, 1999; Louda and O'Brien, 2002). Although some phytophagous insects associated with Canada thistle, such as *U. cardui*, appear to be virtually monophagous, others have a broad host range within the genus *Cirsium* and also will accept species of *Carduus* or related genera. In the past, several agents have been approved for release against Canada thistle on the basis of host specificity tests that would not be considered sufficient justification for release today.

Future progress in classical biological control of Canada thistle will depend on the identification of new, adequately host specific herbivores from its native range, and will require improvements in host-testing procedures to allow better prediction and evaluation of non-target impacts.

ACKNOWLEDGMENTS

I thank Philip Tipping, André Gassmann, Dean Kelch, Charles O'Brien, and Ron Moehring for comments on the manuscript and for providing unpublished information.

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18 Musk Thistle (Nodding Thistle)

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PEST STATUS OF WEED

Musk thistle, *Carduus nutans* L., is an invasive weed that has become widespread in the contiguous states of the United States. It is a highly competitive weed of Eurasian origin that has replaced much of the native vegetation in pastures and disturbed areas (Surles et al., 1974; Kok, 1978a,b).

Nature of Damage

Economic damage. Musk thistle invades pastures, rangeland, and forest lands, and areas along roadsides, railroad right-of-ways, waste areas, and stream banks. In agricultural systems, the invasive nature and prolific seed production of musk thistle result in large populations of the weed, which compete with crops for space, nutrients, and light. Thus, infestations may reduce productivity of pasture and rangeland by suppressing growth of desirable forage plants, as well as preventing livestock from eating plants growing in the vicinity of thistles due to the sharp spines on their stems, leaf margins and blooms (Trumble and Kok, 1982; Desrochers *et al.*, 1988a). In the northeastern United States, the highest economic losses due to musk thistle infestations occur on fertile soils formed over limestone.

Ecological damage. Musk thistle generally does not pose a great threat to high-quality natural areas, although it has been known to invade native and restored grasslands despite the presence of dense, native prairie vegetation. Musk thistle may retard natural secondary succession processes. Because musk thistle is unpalatable to wildlife and livestock, selective grazing leads to severe degradation of native meadows and grasslands as grazing animals focus their foraging on other plants, giving musk thistle a competitive advantage. Successful biological control of musk thistle (Kok and Surles, 1975) is often accompanied by increased growth and coverage of pasture grasses such as fescue (*Festuca arundinaria* Schreb.) and orchard grass (*Dactylis glomerata* L.), or less desirable plants such as spotted knapweed (Kok and Mays, 1991).

Extent of losses. The rate of expansion of musk thistle populations in North America has been very rapid since the mid-1950s, when it was first recognized as a weed (Dunn, 1976). A single musk thistle per 1.49 m^2 can reduce pasture yields by 23%. In Canada, stands of 150,000/ha have been observed (Desrochers *et al.*, 1988a). Direct losses are difficult to quantify due to lack of long-term monitoring programs and data.

Geographical Distribution

Musk thistle was first reported in the United States in 1953 at Harrisburg, Pennsylvania (Stuckey and Forsyth, 1971). In the 1970s, the musk thistle complex (see Taxonomy for definition) has been found in at least 3,068 counties in 42 of the mainland states, with 12% of those counties rating their infestations as economically severe (Dunn, 1976). Musk thistle is declared a noxious weed in some 20 states, including Illinois, Iowa, Kansas, Kentucky, Maryland, Minnesota, Missouri, Nebraska, North Carolina, Ohio, Oklahoma, and Pennsylvania (USDA, NRCS, 1999). Thus, musk thistle extends from the east to west coast in both the deciduous forest and prairie biomes. It grows from sea level to about 2,500 m elevation. It prefers moist alluvial soils but will grow in eroded uplands without difficulty.

BACKGROUND INFORMATION ON PEST PLANT

Taxonomy

The *C. nutans* complex in North America has been treated either as one species with four subspecies (subsp. *nutans*, subsp. *leiophyllus* [Petrovic] Stoj. and Stef., subsp. *macrolepis* [Peterm.] Kazmi, and subsp. *macrocephalus* [Desf.] Nyman), or as three species: *Carduus nutans* with two subspecies (subsp. *nutans* and subsp. *macrolepis*), *C. thoermeri* Weinm., and *C. macrocephalus* Desf. (McCarty, 1978; Desrocher *et al.*, 1988b). Recent work by Desrochers *et al.* (1988b) has supported the existence, in Canada, of only two closely related groups of taxa referred to as subsp. *nutans* and subsp. *leiophyllus*. *Carduus thoermeri* Weinm. and *C. nutans* subsp. *leiophyllus* refer to the same taxon. In North America, *C. nutans* ssp. *macrocephalus* has only been collected from the United States. *Carduus nutans* ssp. *nutans* is distinguished from ssp. *leiophyllus* by its moderate to dense pubescence on leaves and phyllaries, by its generally smaller head diameter (1.5 to 3.5 cm in subsp. *nutans* and 1.8 to 4.5 cm in subsp. *leiophyllus*) and by the shape of its phyllary. In subsp. *nutans*, the lower portion of the phyllary is more or less equal to the upper portion, while in subsp. *Leiophyllus,* the lower portion is distinctly narrower than the upper portion. The two subspecies also can be separated by their flavonoid compounds. *Carduus nutans* subsp. *macrocephalus* differs from subsp. *nutans* by a wider head diameter and phyllaries. It also differs from subsp. *leiophyllus* by being pubescent on leaves and phyllaries, and by having phyllaries that have the lower portion more or less equal to the upper portion. Hybridization between *C. nutans* and *Carduus acanthoides* L. also has been reported (Warwick *et al.*, 1990). Presumably, the distribution of subsp. *nutans* in the United States is similar to its distribution in Canada, where it is mainly distributed in the eastern part of the country, while only subsp. *leiophyllus* and subsp. *macrocephalus* are present in the Great Plains (McGregor, 1986).

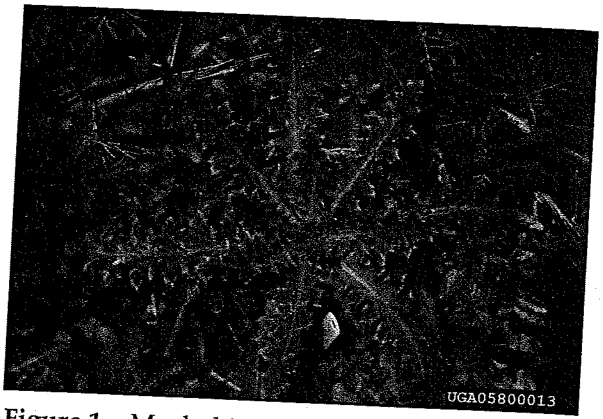

Figure 1. Musk thistle rosette. (Photograph by L.-T. Kok.)

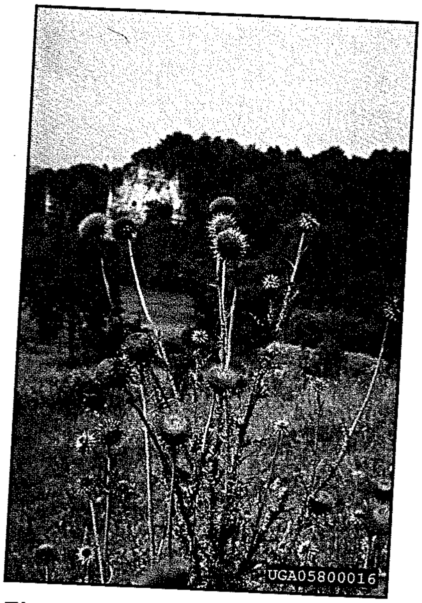

Figure 2. Musk thistle in bloom. (Photograph by L.-T. Kok.)

Biology

The biology of musk thistle has been reviewed by Desrochers *et al.* (1988a). *Carduus nutans* L. is a herbaceous biennial though occasionally it becomes a winter annual. It is 20 to 200 cm tall, with a long, fleshy taproot. The taproot is large, corky, and hollow near the surface of the ground. One or more highly branched stems grow from a common rootcrown. Musk thistle grows in all soil textures, although the soils must be well drained. Leaves are dark green with light green midribs with a white margin (Fig. 1). The plant blooms in May and June. The showy flowers (Fig. 2) are terminal, large, solitary, and nodding (slightly bent). They are deep rose to violet or purple in color. The seeds are straw colored and do not have a light requirement for germination, but are affected by temperature. Higher germination rates occur at temperatures between 20 and

28 °C. Musk thistle does not appear to have any specific climatic requirements other than a cool period of vernalization, a minimum of 40 days below 10 °C for flowering. It does not reproduce vegetatively and is propagated by seeds dispersed primarily by wind. Most seeds are deposited within 50 m of the release point and less than 1% are blown farther than 100 m (Smith and Kok, 1984). Up to 11,000 achenes may be produced per individual with as many as 1,500 seeds per flower head. Seed viability remains high for more than ten years.

Analysis of Related Native Plants in the Eastern United States

There are no native North American species in the genus *Carduus*. *Carduus nutans* belongs to the tribe Cardueae (family Asteraceae) which is largely an Old World group. The tribe is further divided into four subtribes (Echinopsidinae, Carlininae, Carduinae, and Centaureinae) including some 13 genera in North America (Bremer, 1994; USDA, NRCS, 1999). From these, only three contain native species – *Centaurea* (two species, subtribe Centaureinae), *Saussurea* (seven species, subtribe Carduinae, but the position of the genus in the tribe remains uncertain), and *Cirsium* (subtribe Carduinae). The genus *Cirsium* includes about 100 native species, of which 21 species occur in the eastern United States. One of these, *Cirsium pitcheri* (Torr. ex Eat.) Torr. and Gray, is listed as threatened under the Endangered Species Act. This species occurs in sand dunes along the shores of the Great Lakes in Illinois, Indiana, Michigan, Wisconsin, and Ontario.

HISTORY OF BIOLOGICAL CONTROL EFFORTS IN THE EASTERN UNITED STATES

Musk thistle was among the first 19 weeds selected for biological control when the USDA overseas laboratory was established at Rome, Italy in 1959. In the early 1960s, staff of the USDA intensively surveyed *Carduus* spp. in Italy, whereas the Commonwealth Institute of Biological Control (now CABI Bioscience), funded by Canada Department of Agriculture, extended the survey area across Europe from western France to eastern Austria on more than 30 species in the subtribe Carduinae. The history of biological control of thistles was reviewed by Dunn (1978) and by Schroeder (1980).

Area of Origin of Weed

The genus *Carduus* is native to the Eastern Hemisphere, where its distribution extends over Europe, central Asia, and East Africa. Franco (1976) recognized 48 species in *Flora Europaea*. Several taxa have been reported in North America and separated into three groups: the slender-flowered thistles (*Carduus tenuiflorus* Curt. and *Carduus pycnocephalus* L.), the small-flowered thistles (*Carduus acanthoides* L. and *Carduus crispus* L.), and the large-flowered thistle (*Carduus nutans s.l.*). Southern Europe is considered to be the center of origin for *Carduus* because of the many endemic *Carduus* species found there.

Areas Surveyed for Natural Enemies

Areas surveyed included southern England, France, Austria, Germany, Italy and the northern part of the former Yugoslavia (Zwölfer, 1965; Boldt and Campobasso, 1978). Other surveys have been carried out in Pakistan, Iran, and Japan (Schroeder, 1980).

Natural Enemies Found

Some 130 insect species have been recorded on *C. nutans s.l.* in Europe (Zwölfer, 1965; Boldt and Campobasso, 1978). In Italy alone, 109 species from six orders and 33 families fed or reproduced on musk thistle. Some 25 species were reported to be broadly oligophagous on plants in the subtribe Carduinae (Table 1), and only very few were considered to have a host range restricted to plants in the genera *Carduus*, *Cirsium*, and *Silybum*, or to be monophagous. Since there was no concern about non-target impact on native thistles in the earliest phase of the program, oligophagy on several thistle species in the genera *Carduus*, *Cirsium*, and *Silybum* was considered as an advantage and only those species recorded as economic pests were eliminated from further consideration. After a few other candidate biological control agents had been discarded on the grounds that they did little damage to the target weeds, fewer than 10 species were considered as potential biological control agents of *Carduus* species and bull thistle, *Cirsium vulgare* (Savi) Tenore. Preference was given to seed-

Table 1. Oligophagous Arthropods (Restricted to Carduinae) Recorded on Selected European Thistles (With Contributions from A. McClay)

Insect Species	*Carduus nutans s.l.*	*Carduus acanthoides*	*Carduus tenuiflorus/ pycnocephalus*	*Cirsium vulgare*	*Cirsium arvense*	Food Niche
DIPTERA						
Agromyzidae						
Agromyza n.sp.nr. reptans	b					Leaf miner
Liriomyza soror Hendel					a	Leaf miner
Melanagromyza aeneoventris (Fallen)	d	d		d	d	Stem
Phytomyza cardui Hering				a		Leaf miner
Anthomyiidae						
Pegomya nigricornis (Strobl)			c			Stem?
Cecidomyiidae						
Clinodiplosis cirsii Kieffer					a	Flower head
Jaapiella cirsiicola Rübsammen				a	a	Flower head
Macrolabis cirsii Rübsammen					a	Flower head
Syrphidae						
Cheilosia albipila (Meigen)	d	d		d	d	Root collar
C. corydon (Harris)	b released		c released			Root collar
C. cynocephala Loew	b					Root collar
Tephritidae						
Orellia winthemi Meigen		a				Flower head
Tephritis hyoscyami L.	a	a				Flower head
T. cometa (Loew)					a	Flower head
Terellia serratulae L.	a b (1)	a	a c	a		Flower head
T. ruficauda Fabricius					a (2)	Flower head
Urophora cardui (L.)					a d released	Stem gall
U. sibynata Rondani	b					Flower head
U. solstitialis (L.)	a b released	a released	c			Flower head
U. stylata Fabricius	b	a		a released	a	Flower head
Xyphosia miliaria Schrank	a b			a	a	Flower head

Table 1. Oligophagous Arthropods (continued)

Insect Species	*Carduus nutans s.l.*	*Carduus acanthoides*	*Carduus tenuiflorus /pycnocephalus*	*Cirsium vulgare*	*Cirsium arvense*	Food Niche
COLEOPTERA						
Apionidae						
Apion carduorum Kirby	a b	a	a	a	a	Root collar/stem
A. gibbirostre Gyllenhal	d	d			d	Root collar/stem
A. onopordi Kirby	d			d	d	Root collar/stem
Curculionidae						
Ceuthorhynchidius horridus (Panzer)	a released	a released	c		a	Root collar/stem?
C. urens Gyllenhal					a	Root collar/stem?
Ceutorhynchus litura Fabricius					a d released	Root collar/stem
C. trimaculatus Fabricius	a b (1)		a c	d		Root collar/leaf buds
Cleonus piger Scopoli	a	a		a	a (2)	Root collar/ stem
Larinus cynarae Fabricius	b					Flower head
L. jaceae Fabricius	a	a	c			Flower head
L. planus (Fabricius)	a	a	a	a	a (2)	Flower head
L. turbinatus Gyllenhal				a	a	Flower head
Lixus cardui Olivier	a b	a	a c		a	Stem
L. elongatus Goeze	a b d	a d	a c	a d	a	Stem
Rhinocyllus conicus Frölich	a b released	a released	a c released	a	a	Flower head
Cerambycidae						
Agapanthia dahli Richter		d				Stem
Chrysomelidae						
Altica carduorum Guérin-Méneville					a released	Leaf
A. cirsii Israelsen					a	Leaf
Cassida deflorata Suffrian			a c		a	Leaf
C. rubiginosa Müller	a b		a	a	a (2)	Leaf
Lema cyanella (L.).					a (1)	Leaf
Psylliodes chalcomera (Illiger)	b released		c			Leaf buds/leaf
Sphaeroderma testaceum Fabricius	a b			a	a	Leaf

Table 1. Oligophagous Arthropods (continued)

Insect Species	*Carduus nutans s.l.*	*Carduus acanthoides*	*Carduus tenuiflorus /pycnocephal-us*	*Cirsium vulgare*	*Cirsium arvense*	Food Niche
LEPIDOPTERA						
Cochylidae						
Aethes badiana Hübner				a		Root/stem?
A. cnicana Westwood				a		Root/stem?
Lobesia fuligana Haworth					a	Stem
Noctuidae						
Gortyna flavago Den. & Schiff.		d				Root
Porphyrinia purpurina Den. & Schiff.	b			a	a	Root crown/stem
Olethreutidae						
Epiblema pflugiana (Haworth)	b					Root crown/leaf
Pyralidae						
Myelois cribrumella (Hübner)	d	a		d		Stem/flower head
Sesiidae						
Euhagena palariformis (Lederer)					f	Root
HETEROPTERA						
Lygaeidae						
Tingis ampliata Herrich-Schäffer				a	a	Leaf
T. cardui L.	a b	a	a	a	a	Leaf

Table 1. Oligophagous Arthropods (continued)

Insect Species	*Carduus nutans s.l.*	*Carduus acanthoides*	*Carduus tenuiflorus /pycnocephal-us*	*Cirsium vulgare*	*Cirsium arvense*	Food Niche
HOMOPTERA						
Aphididae						
Aphis acanthi Schrank					a	?
Brachycaudus cardui (L.)	b g			g	g (2)	Leaf/stem/ root
Capitophorus braggi Gyllenhal					a (2)	Leaf/stem
C. carduinus Walker	a g (2)	a		a g	g (2)	Leaf/stem
C. flaveolus Walker		a			a	?
Chomaphis cirsii Börner					a	?
Dactynotus aeneus HRL.	a g	a			g	Leaf/stem
D. cirsii HRL					a g (2)	Leaf/stem
Psyllidae						
Trioza agrophila Loew					a	?
ACARINA						
Eriophyidae						
Aceria anthocoptes (Nalepa)					e (2)	Flower/leaf

a = from Zwölfer (1965) and Zwölfer and Harris (1984). Survey area: s-England, France, s-Germany, Austria, northern former Yugoslavia, n-Italy
b = from Boldt and Campobasso (1978). Survey area: Italy
c = from Goeden (1974) and Dunn (1978). Survey area: Italy and Greece
d = from Freese (1993). Survey area: Germany
e = from Petanovic *et al.* 1997. Survey area: Yugoslavia
f = from Tosevski (pers. com). Survey area: Turquey
g = from Redfern (1983). Survey area: western Europe
(1) studied but not released in the United States
(2) accidental introduction in the United States (from Maw, 1976; Story et al., 1985; Julien and Griffiths, 1999 ; http://www.sel.barc.usda.gov/acari/content/eriophyoidea.html)

feeding insects for biological control of *Carduus* spp. and bull thistle because these weeds are short-lived species and reproduce by seeds. In contrast, defoliating beetles were selected for the perennial thistle *Cirsium arvense* (L.) Scop. (see Chapter on Canada thistle).

In 1964, the seed-feeding weevil *Rhinocyllus conicus* (Frölich) was the first insect selected for biological control of *Carduus* species. Zwölfer (1971) believed that because of *R. conicus*' high egg potential and a tendency to disperse its eggs, this weevil should exert strong pressure on its host plant, especially after the weevil was released from limitation by its coevolved competitors and parasitoids. Shortly after biological studies had started with *R. conicus*, the rosette weevil *Trichosirocalus horridus* (Panzer) and the two rosette beetles *Ceutorhynchus trimaculatus* (F.) and *Psylliodes chalcomera* (Illiger) also were considered because they occupy different food niches and have different phenologies. Concern about non-target impact was increasing and, in the early 1980s, permission for field release of *C. trimaculatus* and *P. chalcomera* was denied. Consequently, more specific species were selected to complement the impact of *R. conicus* and *T. horridus*. The syrphid root-crown fly *Cheilosia corydon* (Harris) has the same feeding niche as *T. horridus* but it has a different phenology. The seed-feeding tephritid fly *Urophora solstitialis* (L.) was selected for biological control of *C. acanthoides* because *R. conicus* was not well synchronized with this thistle in many parts of North America (Surles and Kok, 1977). Later, Dunn and Campobasso (1993) showed that native North American *Cirsium* species were not exploited by *P. chalcomera* under field test conditions, and this flea beetle was finally released in the United States in 1997. Thistle insects discovered in Asia have not been exploited yet. The host specificity of *Terrelia serratulae* L., a trypetid fly from Pakistan, has been examined (Baloch and Khan, 1973), but it has not been considered further.

Host Range Tests and Results

***Rhinocyllus conicus* (Frölich).** Field host records for the seed-feeding weevil *R. conicus* in Europe include thistles in several genera in the subtribe Carduinae (*Carduus, Cirsium, Sylibum,* and *Onopordum*)(Zwölfer and Harris, 1984). The plant species tested in the screening trials in the 1960s included primarily agricultural crops and horticultural species in the Asteraceae family, plus a few European thistles. Since the cultivated plants tested (*Cynara scolymus* L., *Carthamus tinctorius* L., *Helianthus annuus* L., *Lactuca sativa* L.) were not used by the weevil, and the potential use of native North American *Cirsium* species was not a concern at that time, *R. conicus* was approved and released in Canada (in 1968) and in the United States (in 1969). Feeding by *R. conicus* on native Cirsium species in North America was first reported by Laing and Heels (1978) and Rees (1978). *Rhinocyllus conicus* has been reported in flowerheads of nearly 20 native *Cirsium* spp. in the west and in the central plains and mountains (Louda, 2000). Genetic variation among populations of *R. conicus* does exist, but its role in host plant use is not well understood. The concept of host races associated with the main thistle species in Europe (Zwölfer and Preiss, 1983) has been challenged recently (Klein and Seitz, 1994; Briese, 1996).

***Trichosirocalus horridus* (Panzer).** Field records of the rosette weevil *T. horridus* in Europe include a few genera in the subtribe Carduinae (*Carduus, Cirsium, Onopordum,* and *Galactites*). Host range studies were carried out in the late 1960s and early 1970s (Ward *et al.*, 1974; Kok, 1975). As for *R. conicus*, the plant species tested included cultivated plants and a few European thistles. Some larval feeding occurred on lettuce (*L. sativa*), cauliflower (*Brassica oleracea* L.) and artichoke (*C. scolymus*), but none of these species supported normal larval development. Preferred hosts were species of *Carduus, Cirsium,* and *Onopordum*. *Trichosirocalus horridus* has only occasionally been reported to feed and develop on native North American thistles (McAvoy *et al.*, 1987).

***Cheilosia corydon* (Harris).** In Europe, the root-crown fly *C. corydon* has been reared from *Carduus nutans s.l.*, *Carduus crispus* L., and *Carduus pycnocephalus* L., and rarely from *Cirsium vulgare*, *Cirsium eriophorum* (L.) Scop., and *Cirsium palustre* (L.) Scop. In laboratory tests, larvae survived on all six *Carduus* species tested as well as on the native North American species, *Cirsium crassicaule* (Greene) Jeps. None of the other nine *Cirsium* species (including six native North American species) were suitable for *C. corydon* development. In field trials in Italy, oviposition was recorded on *Carduus nutans* but not on the seven native *Cirsium* species tested (Rizza *et al.*, 1988).

***Ceutorhynchus trimaculatus* (Fab.).** Field records of this thistle-rosette weevil in Europe include

Carduus spp., *Cirsium* spp., *Onopordum* spp., *Silybum marianum* (L.) Gaertn., and *Galactites tomentosa* Moench (Boldt *et al.*, 1980). *Ceutorhynchus trimaculatus* was found to complete development on artichoke (*C. scolymus*) and several *Cirsium* species in quarantine screening tests (Kok *et al.*, 1979, 1982; Kok and McAvoy, 1983). In field tests carried out in Italy in 1984 and 1985, larvae of *C. trimaculatus* were found on all three North American native *Cirsium* spp. exposed, but not on artichoke (Dunn and Campobasso, 1993).

***Psylliodes chalcomera* (Illiger).** Under experimental conditions, adult feeding, oviposition, and larval development by this thistle-rosette weevil occurred on European *Carduus* and *Cirsium* species (Dunn and Rizza, 1977). Adult feeding and oviposition, but no larval development, were recorded on artichoke under no-choice conditions. In field tests carried out in Italy between 1987 and 1989, this flea beetle did not use any of the three North American *Cirsium* species offered (Dunn and Campobasso, 1993).

***Puccinia carduorum* Jacky.** This rust has been accidentally introduced to North America and also was the first plant pathogen tested and released in the United States for biological control of musk thistle. In greenhouse tests, limited infection occurred on some species of *Cirsium*, *Cynara*, *Saussurea*, and *Sylibum*, but older plants were resistant. Attempts to maintain *P. carduorum* on 22 native North American species of *Cirsium* and *C. scolymus* failed. Musk thistle was the only host that became severely diseased (Politis *et al.*, 1984; Bruckart *et al.*, 1996). No rust development was observed on any of the non-target plants (10 North American *Cirsium* spp. and artichoke) in a field trial carried out in 1988 in Virginia (Baudoin *et al.*, 1993). *Puccinia carduorum* has not been reported from native North American *Cirsium* species. It has spread rapidly in the eastern United States and was found in Missouri in 1994 (Baudoin and Bruckart, 1996). It can be transmitted by the thistle insects *R. conicus, T. horridus,* and *Cassida rubiginosa* Müller (Kok and Abad, 1994).

Releases Made

Information in this section is from Rees *et al.*, 1996; Julien and Griffiths, 1999; and shipment records of L. T. Kok.

Rhinocyllus conicus. Introductions of *R. conicus* from eastern France via Canada began in 1969 in the United States with releases in Virginia, California, Montana, and Nebraska. Following excellent results in Virginia, weevils were collected in Virginia and released in most of the thistle-infested 48 contiguous states. These included Alabama, Illinois, Indiana, Iowa, Kansas, Kentucky, Maryland, Minnesota, Missouri, New Jersey, New York, Ohio, Oklahoma, Pennsylvania, Tennessee, Texas, West Virginia, and more recently in the southern states of Alabama, Georgia, and North Carolina.

Trichosirocalus horridus. This species was first released in Virginia in 1974 (Kok and Trumble, 1979). Weevils collected from Virginia were subsequently released in many other states, including Alabama, Colorado, Georgia, Illinois, Indiana, Kansas, Kentucky, Maryland, Montana, North Carolina, Oklahoma, Tennessee, Texas, Washington, Wyoming, several western states, and also in Argentina and Canada.

Cheilosia corydon. This fly has been released in low numbers in Maryland, New Jersey, Montana, Nevada, Oregon, and Texas.

Urophora solstitialis. This species was released in 1996, only in Montana.

***Ceutorhynchus trimaculatus*:** This species was not released because it feeds and develops on native *Cirsium* species (Kok *et al.*, 1979, 1982; Kok and McAvoy, 1983).

Psylliodes chalcomera. This species was released in 1997, in Kansas and Texas (DeQuattro, 1997).

Puccinia carduorum. This pathogen was deliberately introduced in Virginia in 1987 (Baudoin *et al.*, 1993), but had been accidentally introduced to North America before 1987 (Julien and Griffiths, 1999).

BIOLOGY AND ECOLOGY OF KEY NATURAL ENEMIES

Rhinocyllus conicus (Coleoptera: Curculionidae).

The biology of this seed-feeding weevil has been described by Zwölfer and Harris (1984). Following adult emergence from overwintering sites in litter and sheltered areas, mating and oviposition occur in spring and early summer. In Virginia, overwintered adult weevils (Fig. 3) were observed to become active in mid-to-late April (Surles and Kok, 1977). Eggs are laid externally on bud bracts (Fig. 4), either individually or in small clusters of two to five eggs. Caps

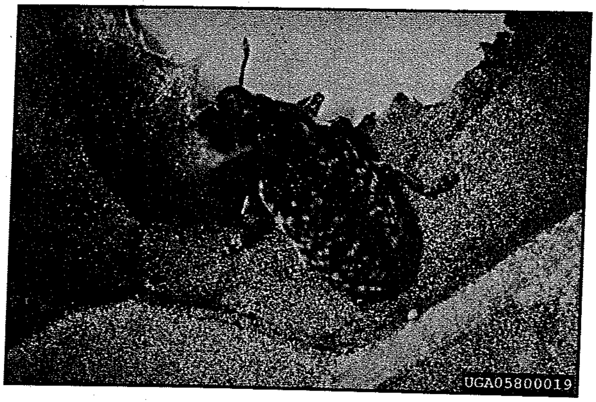

Figure 3. *Rhinocyllus conicus* adult. (Photograph by L.-T. Kok.)

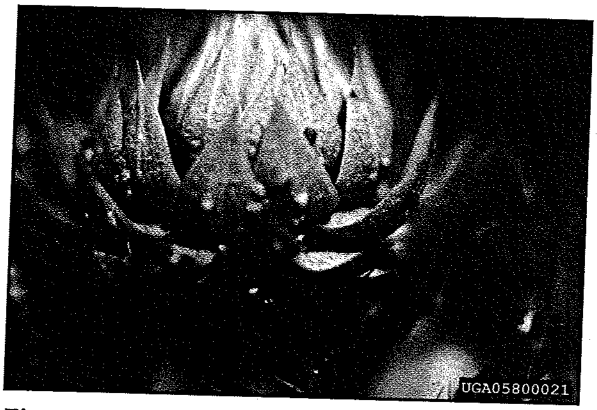

Figure 4. *Rhinocyllus conicus* eggs on thistle head. (Photograph by L.-T. Kok.)

Figure 5. *Rhinocyllus conicus* larva feeding on receptacle of thistle head. (Photograph by L.-T. Kok.)

Figure 6. Tufts of hair arising from *R. conicus* infested thistle head. (Photograph by L.-T. Kok.)

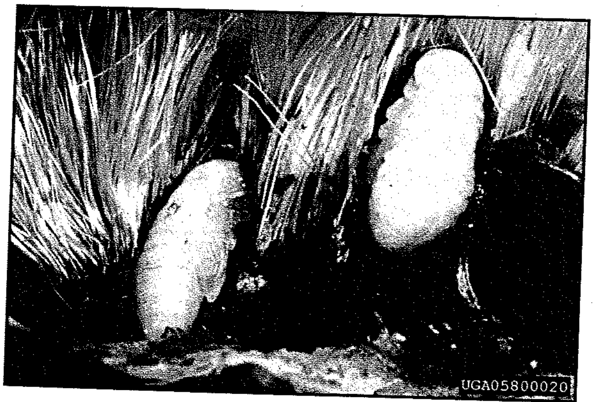

Figure 7. *Rhinocyllus conicus* pupa. (Photograph by L.-T. Kok.)

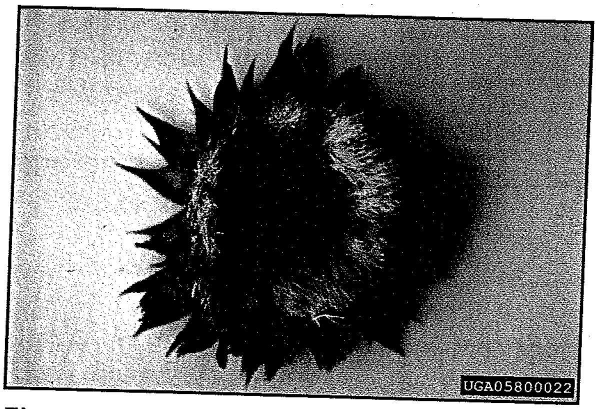

Figure 8. Thistle head showing pupation chambers of *R. conicus.* (Photograph by L.-T. Kok.)

of masticated host plant material, which appear as "warts," cover and protect the eggs from predation. Larvae hatch after six to nine days and bore through the bracts into the receptacle. Larvae feed on both the developing receptacles (Fig. 5) and the florets, pushing out characteristic tufts of hair from an infested head (Fig. 6), and sometimes the supporting peduncle under the head. Four larval instars complete development in about four to six weeks (Rowe and Kok, 1985). Larval feeding induces the formation of a gall-like callus of modified parenchyma tissue that provides the larvae with additional food and shelter (Shorthouse and Lalonde, 1984). Larval survivorship is strongly density-dependent, suggesting intraspecific competition causes much of the observed larval mortality (> 80%) within heavily infested inflorescences (Zwölfer, 1979). In North America, *R. conicus* has acquired a large number of parasitoids, but levels of parasitism are low (Rees, 1977; Goeden and Ricker, 1977, 1978; Puttler *et al.*, 1978; Dowd and Kok, 1981, 1982, 1983; Smith and Kok, 1983). The pupal period is seven to 10 days, and pupae (Fig. 7) usually are found from mid-June through July. A partial second generation may be found in late August and September. Adults usually remain within pupation cells (Fig. 8) for several more weeks, before emerging to disperse to overwintering sites in litter. Phenology and life-cycle details vary geographically according to local climate. Zwölfer and Harris (1984) indicated that a partial second generation could occur for individuals that complete development early, if the photoperiod exceeds 16 hours.

Trichosirocalus horridus (Coleoptera: Curculionidae).

This rosette weevil has a single generation per year. Eggs are laid on the lower side of leaves along the midrib and the primary veins and hatch in about 13 days. Larvae migrate down the petiole to rosette crowns to feed soon after hatching. Mature larvae abandon the plant and enter the soil near the roots where they create pupation cells, made from silk and soil particles (Kok *et al.*, 1975). In Virginia, oviposition occurs from mid-December until early April, and larvae are found in rosettes from late December (first instars) through late May (third instars) (Trumble and Kok, 1979). *Trichosirocalus horridus* may overwinter as an adult, egg, or larva (Kok and Mays, 1989). Teneral adults appear from mid-May through June and aestivate in July through September. This life cycle is similar to that of *T. horridus* in southern Europe, although the climatic conditions in southwestern Virginia resemble conditions of central Europe, where the life history of *T. horridus* is substantially different. In central Europe, oviposition of *T. horridus* occurs from the middle of May through June. Pupation occurs in July and August, and adults emerge in September and overwinter.

Cheilosia corydon (Diptera: Syrphidae)

In southern Europe, adults of this root-crown fly emerge at the end of February or March, and eggs are laid from mid-March to mid-April. Larvae feed in thistle crowns and large flower-bearing stems. Eggs are laid on young leaves in the center of the thistle rosette and young shoots. Newly hatched larvae mine directly into tender, young shoots. As shoots grow, the second and third instars mine up and down the stems. There are three larval instars. In May, larvae tunnel into the shoot base and the root. Pupation occurs in November (Rizza *et al.*, 1988). *Cheilosia corydon* has one generation per year.

Ceutorhynchus trimaculatus (Coleoptera: Curculionidae)

This rosette weevil has one generation per year. Adults emerge at the end of April and feed on the leaves of new rosettes or mature plants for three to four weeks. At the end of May, weevils enter the soil to aestivate. Adults gradually become active again in autumn and feed on the leaves of young rosettes. Oviposition starts in November and continues through March or April. Larvae feed gregariously, boring into leaf buds or growing tips, and moving down into the crown. Pupation occurs in the soil (Boldt and Campobasso, 1981; Kok and McAvoy, 1983).

Psylliodes chalcomera (Coleoptera: Chrysomelidae)

In southern Europe, adults of this thistle-rosette flea beetle emerge in early June, feed heavily on maturing *Carduus* plants, and begin aestivation during late June. Aestivation ends in early November. Oviposition takes place between January and June. Eggs are laid at the base of plants or into soil adjacent to plants. Larvae feed on leaf buds and on young rosette leaves. Larvae mature in mid-May, and pupate in the soil nearby. In the laboratory, some females are long-lived and go through two aestivation and two oviposition periods (Dunn and Rizza, 1976).

EVALUATION OF PROJECT OUTCOMES

Establishment and Spread of Agents (from Julien and Griffiths, 1999)

Rhinocyllus conicus. Establishment of this seed-feeding weevil has been confirmed in Iowa, Illinois, Kansas, Kentucky, Maryland, Minnesota, Missouri, North Dakota, South Dakota, Pennsylvania, Tennessee, Texas, New York, and Virginia as well as in several western states. In recent years, it also has become established in the southern states of Georgia (Buntin *et al.*, 1993) and North Carolina (McDonald and Robbins, 1993). In Virginia, dispersal was only 1.6 km three years after release, but after six years, both eggs and adults were detected 32 km from the original release site (Kok and Surles, 1975).

Trichosirocalus horridus. Establishment of the rosette weevil was confirmed within two years of its release in Virginia study sites, and weevil populations had reached high levels by the third year. The weevil was found 27 km from release sites four years after initial introduction. By 1981, *T. horridus* was well established in the immediate release area and covered approximately 609 km^2. By 1985, the weevil had extended its range to 4,345 km^2 despite having had to move across forested areas where no thistles occur as well as areas with low thistle populations. Dispersal by flight probably occurs after aestivation during late summer or early fall (McAvoy *et al.*, 1987). *Trichosirocalus horridus* also is established in North Carolina (McDonald and Robbins, 1993), Kansas, Maryland, Missouri, and several western states.

Cheilosia corydon. Establishment has not been confirmed.

Urophora solstitialis. Establishment has not been confirmed.

Psylliodes chalcomera. Establishment has not been confirmed.

Puccinia carduorum. This species is established in Virginia and Missouri (Baudoin *et al.*, 1993; Baudoin and Bruckart, 1996) and was recorded in Wyoming in 1996.

Suppression of Target Weed

Rhinocyllus conicus. Effects of the weevil on *C. nutans* in Virginia were not apparent until 1973, after a steady increase in weevil densities. By 1974, 16 out of 20 releases resulted in successful establishment, and six showed more than 75% reduction in thistle density (Surles *et al.*, 1974; Kok 1978a, b). Establishment rates were better for spring releases of reproductive adults than summer releases (Kok, 1974). At one location, 90% of the plants were heavily infested, and in 1975 all but one of the 11 plots showed at least 90% reduction in thistle density (Kok and Surles, 1975; Kok and Pienkowski, 1985). Biological control is usually achieved in five to six years (Kok and Surles, 1975; Kok, 1986; Kok and Mays, 1991) [Figs. 9, 10]. Decrease in thistle density was slower at sites with little competing vegetation. Grass competition was found to be important in restricting thistle growth and keeping weed population levels low. Control by *R. conicus* is enhanced when combined with proper land management, especially prevention of overgrazing.

Figure 9. Musk thistle site before *R. conicus* release. (Photograph by L.-T. Kok)

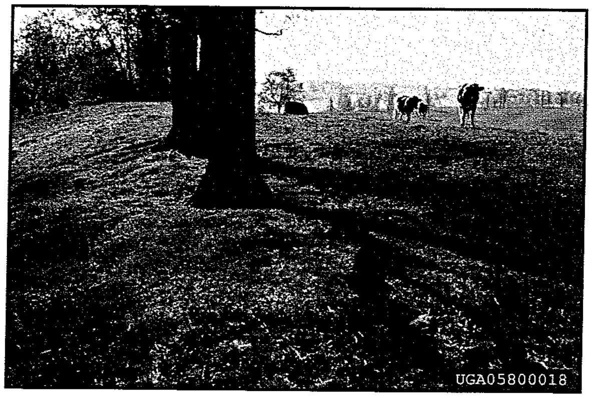

Figure 10. Musk thistle site five years after *R. conicus* release. (Photograph by L.-T. Kok)

Trichosirocalus horridus. Damage results from larval feeding on meristematic tissues in the rosette, resulting in crown tissue necrosis. Cartwright and Kok (1985) found that *C. nutans* changed its growth pattern in response to feeding by *T. horridus*. Infested plants produced more stems and a larger crown than uninfested plants, which did not produce multiple stems in this study. Large thistles were stimulated by weevil damage to produce larger stems and more capitula, but small and medium thistles were shorter and produced fewer seeds and capitula than uninfested thistles. Response of thistles also is influenced by larval density (Sieburth *et al.*, 1983). In Virginia, a 96% reduction of musk thistle density occurred at two of three study sites within six years of initial releases (Kok, 1986). The collapse of thistle populations after three years of heavy weevil attack was not unusual, as pasture plants re-established and reduced thistle recruitment. The extent of thistle reduction caused by *T. horridus* varies. If weevil populations are large and grass competition is strong, thistle densities can be reduced dramatically. Suppression of musk thistle growth is greatest when the two weevils (*R. conicus* and *T. horridus*) act in conjunction with plant competition. Tall fescue grass (*Festuca arundinacea* Schreb.) together with thistle weevils suppressed musk thistle growth more quickly than the use of thistle weevils alone (Kok *et al.*,1986).

RECOMMENDATIONS FOR FUTURE WORK

The musk thistle program has been reassessed recently (Nechols, 2000). For a long time, the debate has focused on the effect of the biological control agents on the population level of the target thistle and the degree of their non-target feeding. Of the five insects approved for release, two have established with certainty – the seed head weevil, *R. conicus*, and the rosette weevil, *T. horridus*. Long-term impact studies conducted in Virginia (Kok, 1986; Kok and Mays, 1991) suggest that the two weevils are capable of exerting some control of *C. nutans,* although experimental data are generally lacking from most of the other states. Thus, long-term experiments are needed in which post-dispersal seed mortality, various levels of plant competition, and the impact of both weevils (alone and combined) are considered.

Both the seed head and the rosette weevils have relatively broad host ranges. In addition to various exotic thistles, *R. conicus* feeds and develops in nearly 20 native North American *Cirsium* species, and in some cases, heavy infestations cause significant reduction in seed (Louda, 2000). There is considerable controversy over whether or not biotypes *R. conicus* (or other thistle head insects like *U. solstitialis*, reviewed by Gassmann and Louda, 2000) might exist, each with a somewhat narrower host range. The existence or absence of such biotypes has important implications in the biological control program against *C. nutans* and other exotic thistles in North America. This controversy might be due in part to the lack of an accepted definition of the term itself, but the existence of weevil biotypes with inherited differences in their ability to use different hosts still needs to be demonstrated. Genetic variation occurs in *R. conicus* reared from different thistle species (Unruh and Goeden, 1987), but the extent to which this genetic variation drives host selection and acceptance is unknown. Rather, the evidence available to date suggests that the phenology of thistle species in the subtribe Carduinae plays a major role in their exploitation by *R. conicus*. Therefore, the redistribution of *R. conicus* in areas where the weevil has not spread naturally should not be considered without an ecological assessment of the targeted area.

In contrast to *R. conicus*, *Trichosirocalus horridus* has been reported only occasionally from native North American *Cirsium* species (McAvoy *et al.*, 1987). In light of available evidence to date, two questions need to be considered. (1) Is intensive exploitation of native thistles by *T. horridus* just a matter of time even though it has not been commonly found on non-target weeds after 25 years of release? (2) Is the exploitation of native *Cirsium* by *R. conicus* the result of the broad diet of the weevil, or the combination of phenology, host plant affinities, and other biological characteristics? The availability of reproduction sites (synchronization with flowering periods of "any" thistles) rather than preference, weevil aggregation, or altered competitive ability of *R. conicus* in the flower heads of thistles may play an important role in the exploitation of native *Cirsium* species by *R. conicus* (Gassmann and Louda, 2000). If this is the case, it follows that insects with biological characteristics different from those of *R. conicus*, such as *T. horridus*, will not necessarily exploit native North American *Cirsium* species in the same way as *R. conicus*.

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19 Bull Thistle (Spear Thistle)

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PEST STATUS OF WEED

Bull thistle, *Cirsium vulgare* (Savi) Tenore, is an invasive thistle from Eurasia, found throughout the United States and in Canada from Newfoundland to British Columbia. It is capable of invading fields, pastures, wastelands and along roadsides, but will not survive in cultivated fields.

Nature of Damage

Economic damage. Bull thistle occurs in overgrazed pastures, where heavy infestations can exclude livestock from infested areas. It also is common along roadside and vacant fields.

Ecological damage. Although bull thistle is a problem predominantly in disturbed areas, it also can be found in natural areas. The basal rosette may grow to nearly 1 m in diameter before bolting, and, once established, bull thistle outcompetes native plant species for space, water, and nutrients.

Geographical Distribution

Bull thistle was introduced into the eastern United States several times during the 19th century. It is now established in all 48 contiguous states as well as Alaska and Hawaii (USDA, NRCS, 1999). It has been designated as a noxious weed in Maryland, Pennsylvania, Minnesota, Iowa, Oregon, and Colorado.

BACKGROUND INFORMATION ON PEST PLANT

Taxonomy

Bull thistle differs from Canada thistle, *Cirsium avense* (L.) Scop., in that leaves are pubescent on both sides, while those of Canada thistle are not pubescent on top, and may or may not be so on the underside. Flower bracts of bull thistle have spines, in contrast to those of Canada thistle. Leaves are covered with coarse hairs on the upper surface of the leaf blade, and are woolly below. Long spines extend from the leaf blade at the midrib and at each lobe. The leaf bases extend downward on the stem forming long wings.

Biology

Bull thistle is a biennial species that reproduces by seed. The root system consists of several primary roots each with several smaller lateral roots. It does not reproduce by vegetative means. Bull thistle is erect and bushy in appearance, up to 2 m high, and has many spreading branches (Fig. 1). Stems are erect, stout, often branched, and hairy. Leaves are green on the upper side, with woolly gray hairs on the underside, and end in long, pointed, yellow spines. The compact large purple flower heads (2.5 to 5.0 cm in diameter) are borne singly at the tip of a stem (Fig. 2), each producing up to 250 light straw-colored seeds. Mature plants can produce up to 4,000 seeds

Figure 1. Bull thistle stand. (Photograph by L.-T. Kok.)

per plant. Bull thistle grows best on nitrogen-rich, neutral soils with moderate moisture (Klinkhamer and de Jong, 1993). It is not typically found on sand or on soils with high humus content and is absent from pure clay soils. Establishment is promoted by soil disturbance, which increases nutrient, water, and light availability to seedlings and reduces the vigor of competing vegetation (Randall, 1994). Bull thistle does not grow well in shade and drought. Phenolic acids inhibit competing plants through allelopathic effects or serve as a defense, coupled with spines, against herbivory (Klinkhamer and de Jong, 1993).

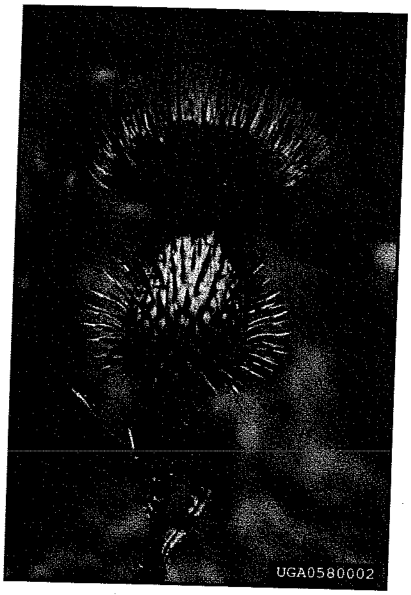

Figure 2. Bull thistle bloom, close up. (Photograph by L.-T. Kok.)

Analysis of Related Native Plants in the Eastern United States

Cirsium vulgare belongs to the tribe Cardueae (family Asteraceae), which is largely an Eastern Hemisphere group. The tribe is further divided into four subtribes (Echinopsidinae, Carlininae, Carduinae, and Centaureinae) including some 13 genera in North America (Bremer, 1994; USDA, NRCS, 1999). Only three of these 13 genera include species native to North America: (1) *Centaurea* (two species; subtribe Centaureinae), (2) *Saussurea* (seven species; assigned to the subtribe Carduinae, but the position of the genus in the tribe remains uncertain), and (3) *Cirsium* (subtribe Carduinae). The genus *Cirsium* includes about 100 native species, of which a few are threatened or endangered plants in the United States (*Cirsium fontinale* [Greene] Jepson var. *fontinale*, *Cirsium fontinale* [Greene] Jepson var. *obispoense* J. T. Howell, *Cirsium hydrophilum* [Greene] Jepson var. *hydrophilum*, *Cirsium pitcheri* [Torr. ex Eat.] Torr. and Gray, and *Cirsium vinaceum* Woot. and Standl.).

Some 20 native *Cirsium* species occur in the eastern United States: *C. altissimum* (L.) Hill, *C. canescens* Nutt., *C. carolinianum* (Walt.) Fern and Schub., *C. discolor* (Muhl. ex Willd.) Spreng., *C. drummondii* Torr. and Gray, *C. engelmannii* Rydb., *C. flodmanii* (Rydb.) Arthur, *C. hilii* (Canby) Fern., *C. horridulum* Michx., *C. lecontei* Torr. and Gray, *C. muticum* Michx., *C. ochrocentrum* Gray, *C. nuttalii* DC., *C. pitcheri* (Torr. ex Eat.) Torr. and Gray, *C. pumilum* (Nutt.) Spreng., *C. repandum* Michx., *C. texanum* Buckl., *C. turneri* Warnock, *C. undulatum* (Nutt.) Spreng., and *C. virginianum* (L.) Michx. (USDA, NRCS, 1999). Of these, *C. pitcheri* is listed as threatened under the Endangered Species Act. It occurs in sand dunes along the shores of the Great Lakes in Illinois, Indiana, Michigan, and Wisconsin.

HISTORY OF BIOLOGICAL CONTROL EFFORTS IN THE EASTERN UNITED STATES

Area of Origin of Weed

Cirsium vulgare is a native of Europe, western Asia, and North Africa.

Areas Surveyed for Natural Enemies

Bull thistle was not considered a priority species when the thistle biological control program started in the early 1960s. However, it was included in the extensive surveys of natural enemies of Canada and musk thistle started in Europe in 1961 by the Commonwealth Institute of Biological Control (now CABI Bioscience), funded by Canada Department of Agriculture. Surveyed areas included southern England, France, Austria, Germany, northern Italy, and the northern part of the former Yugoslavia (Zwölfer, 1965).

Natural Enemies Found

More than 40 species have been recorded on bull thistle by Zwölfer (1965), of which 15 were reportedly broadly oligophagous on plants in the subtribe Carduinae (see Table 1 in the chapter on musk thistle). Only the seed-feeding fly, *Urophora stylata* Fabricius, has been selected and released for biological control of bull thistle. With the exception of *T. horridus*, none of the insect species released against *Cirsium arvense* or those used against *Carduus* species have been used for bull thistle.

Host Range Tests and Results

Oviposition and larval development of *U. stylata* were observed on the target host plant and on *Onopordum acanthium* L. in experimental host range studies carried out in the early 1970s. Oviposition, but no larval development was recorded on *Arctium tomentosum* Miller and *Carduus acanthoides* L. European field records include *Carduus acanthoides*, *Cirsium arvense*, *Cirsium pannonicum* (L.f.) Link, and *Cirsium canum* (L.) All. (Zwölfer, 1972).

Releases Made (from Julien and Griffiths, 1999)

Urophora stylata was released in Maryland and Washington in 1983, and was followed by releases in Colorado, Oregon, Montana, and California.

BIOLOGY AND ECOLOGY OF KEY NATURAL ENEMIES

Urophora stylata (Diptera: Tephritidae)

The adult fly (Fig. 3) lays eggs in the closed flower buds. Gall tissue is formed around each larva separately (Zwölfer, 1972). The gall starts to form around the immature achene and the adjacent region of the receptacle begins to swell. Mature larvae (Fig. 4) overwinter within the flowerheads of bull thistle. Pupation occurs in May and adults emerge in June.

Figure 3. *Urophora stylata* adult. (Photograph by Peter Harris.)

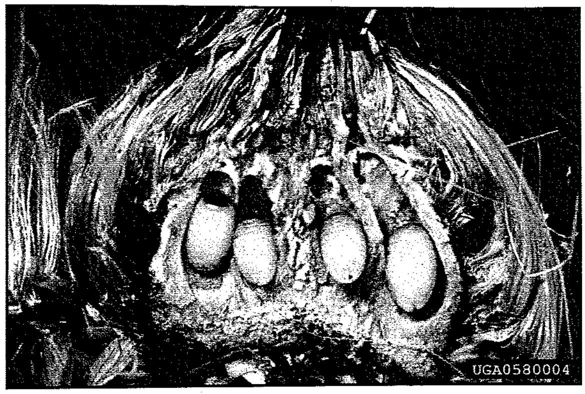

Figure 4. *Urophora stylata* larva. (Photograph by Peter Harris.)

EVALUATION OF PROJECT OUTCOMES

Establishment of *U. stylata* in Maryland has not been confirmed, but this species is established in the western United States, with 60 to 90% of seed heads infested in some areas (Julien and Griffiths, 1999).

Trichosirocalus horridus has been released on bull thistle in Wyoming, but the establishment of the weevil has not been confirmed. Following initial releases on *Carduus acanthoides* in Virginia, some 20% of the bull thistle plants within the release areas also were exploited by this rosette weevil (McAvoy *et al.*, 1987).

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20 Slenderflower Thistle (Winged Slender or Seaside Thistle)

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PEST STATUS OF WEED

Nature of Damage

Like many other *Carduus* species, slenderflower thistle, *Carduus tenuiflorus* Curtis, is associated with pastures, disturbed areas, and vacant lots. Invasion is favored by annual burning of pastures. The thistle protects forage from grazing and is a competitive weed in improved pastures.

Geographical Distribution

Slenderflower thistle occurs in Pennsylvania, New Jersey, and Texas but the most serious infestations occur in California, Oregon, and Washington (USDA, NRCS, 1999). The closely related species, Italian thistle, *Carduus pycnocephalus* L., is known from New York, Alabama, and South Carolina in the eastern United States.

BACKGROUND INFORMATION ON PEST PLANT

Taxonomy

Carduus tenuiflorus is very similar to *C. pycnocephalus*, and the two species are sometimes treated together. Flowering stems are single or multiple from the base, branched, strongly ribbed, and slightly woolly. Spiny wings are continuous on stems to the base of the flower heads, but are discontinuous on *C. pycnocephalus.* The flower heads of *C. tenuiflorus* occur in clusters of five to 20, whereas those of *C. pycnocephalus* are in smaller clusters. The slender flower heads are less than 2 cm long, and lack stalks. Rosette and stem leaves are deeply lobed with numerous spines along the margin.

Biology

Carduus tenuiflorus is a winter annual, sometimes a biennial. Plants can grow from 0.3 to 2.0 m tall. It prefers soils of moderate to high fertility, in areas with moderate rainfalls.

Analysis of Related Native Plants in the Eastern United States

See this section in the chapter on musk thistle.

HISTORY OF BIOLOGICAL CONTROL EFFORTS IN THE EASTERN UNITED STATES

As pointed out by Dunn (1978), the oldest document relating to biological control of *Carduus* thistle was a USDA note from 1956 regarding the abundance of *C. pycnocephalus* and *C. tenuiflorus* in California. The program against this species began in 1959, with the establishment of the USDA overseas laboratory in Rome, Italy. Thistle insect surveys by USDA staff in Italy initially focused on *C. pycnocephalus* but later were extended to *C. tenuiflorus* and *Carduus nutans* L. During the surveys on the latter two species, it was found that musk thistle supported a larger complex of insects than the other *Carduus* species, and work was subsequently concentrated on musk thistle. Slenderflower thistle also was included in the survey of European thistles carried out by the Commonwealth Institute of Biological Control (now CABI Bioscience) in the 1960s and funded by the Canada Department of Agriculture (Zwölfer, 1965). Major surveys for natural enemies of *C. pycnocephalus* were conducted also by Goeden (1974) in central and southern Italy, and in Greece during 1971 and 72.

Area of Origin of Weed

The native range of slenderflower thistle is western and southern Europe and the Mediterranean area, extending northward to Scandinavia.

Areas Surveyed for Natural Enemies

Areas surveyed included southern England, France, Austria, Germany, Italy, the northern part of former Yugoslavia, and Greece (Zwölfer, 1965; Goeden, 1974; Dunn, 1978).

Natural Enemies Found

Most of the *C. tenuiflorus* and *C. pycnocephalus* populations sampled by Zwölfer (1965) were in western and southern France, respectively. Altogether, some 15 oligophagous insect species were recorded on *C. tenuiflorus* and *C. pycnocephalus* in Europe (see Table 1 in the chapter on musk thistle). Although concern about the invasiveness of slenderflower thistles was the reason for the initiation of the *Carduus* biological control program in North America, attention soon was redirected to musk thistle. No biological control agent was specifically targeted for slenderflower thistle. Populations of the seed-feeding weevil *R. conicus* (from *C. pycnocephalus* in Italy) and the root-crown fly *C. corydon* have been released against *C. tenuiflorus* and *C. pycnocephalus* in the United States. The host range and biology of the two species are described in the chapter on musk thistle.

Host Range Tests and Results

See the chapter on musk thistle.

Releases Made (from Julien and Griffiths, 1999)

Rhinocyllus conicus. Releases of this seed-feeding weevil originating from Italy were made on *C. tenuiflorus* in 1973 in California and Oregon only. Releases have been made on *C. pycnocephalus* as well.

Cheilosia corydon. This thistle rosette fly from Italy was released in 1990 in Maryland and New Jersey, as well as in Montana and Oregon. The fly also has been released on *C. pycnocephalus* in Oregon.

BIOLOGY AND ECOLOGY OF KEY NATURAL ENEMIES

See the chapter on musk thistle.

EVALUATION OF PROJECT OUTCOMES

Establishment and Spread of Agents (from Rees *et al.*, 1996; Julien and Griffiths, 1999)

Rhinocyllus conicus. This weevil (Fig. 1) has become established and contributed to the control of slenderflower thistle in Oregon, especially in unburned areas.

Cheilosia corydon. Establishment of this fly has not been confirmed.

Puccinia carduorum. This rust (Fig. 2) has been accidentally introduced in North America. It is recorded on *C. tenuiflorus* in California and Oregon. *Puccinia carduorum* is native to the Mediterranean area but also is reported from Bulgaria and Romania. The fungus was imported from Turkey by the USDA for host range tests at the Foreign Diseases–Weed Research Laboratory in Frederick, Maryland (Politis and Bruckart, 1986). It also was tested and released for musk thistle control in 1992 (Baudoin *et al.*, 1993).

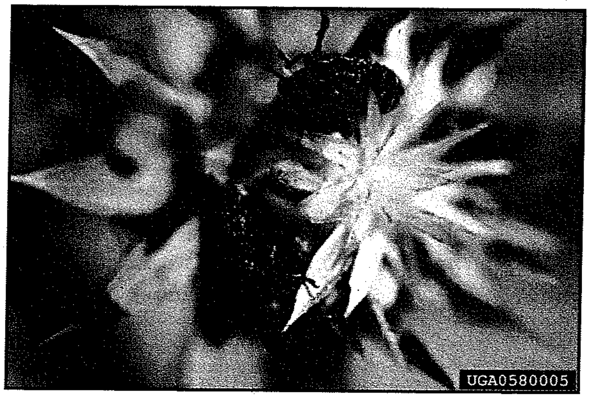

Figure 1. *Rhinocyllus conicus* adult and eggs on thistle head. (Photograph by L.-T. Kok.)

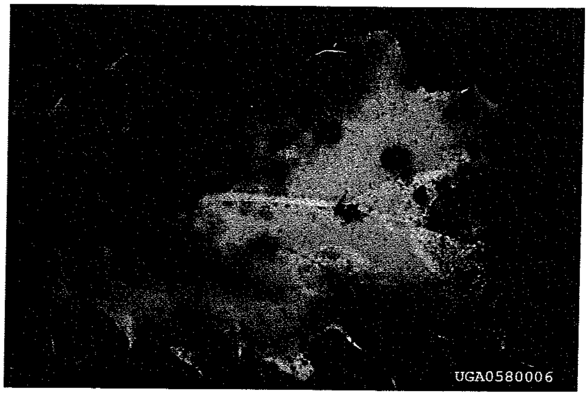

Figure 2. *Puccinia carduorum* infested thistle leaf. (Photograph by L.-T. Kok.)

(For details, see the chapter on musk thistle). The disease appears first as tiny yellow specks. In several days, rust pustules containing thousands of spores become visible (Figs. 3, 4).

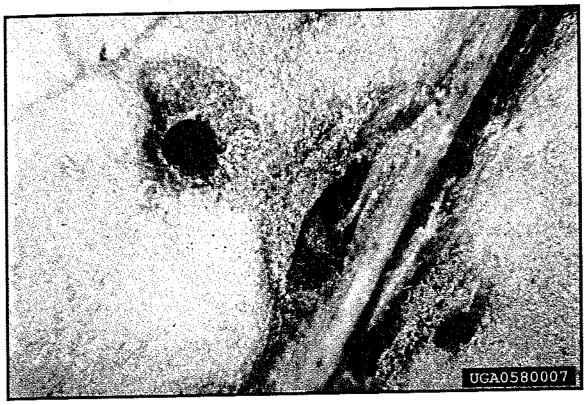

Figure 3. Close up of *Puccinia carduorum* infection. (Photograph by L.-T. Kok.)

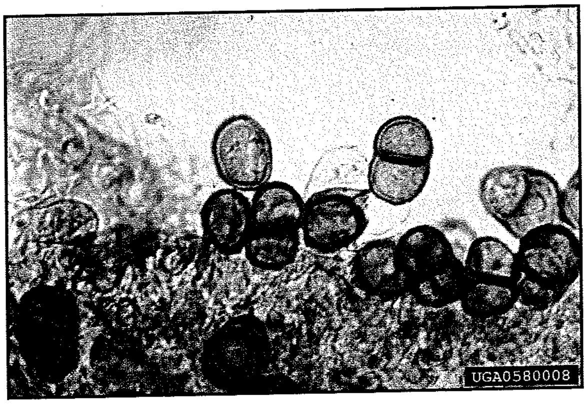

Figure 4. Urediniospores and teliospores of *Puccinia carduorum*. (Photograph by L.-T. Kok.)

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21 PLUMELESS THISTLE (CURLED THISTLE, BRISTLY THISTLE)

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PEST STATUS OF WEED

Plumeless thistle, *Carduus acanthoides* L., is an introduced Eurasian noxious weed in pastures, rangelands, croplands, and along highways in 19 of the contiguous states in the United States (Frick, 1978). *Carduus acanthoides* and *Carduus nutans* L. in the northeastern United States often occupy the same habitats, such as overgrazed pastures and disturbed roadsides, and these species sometimes occur as mixed stands.

Nature of Damage

Economic damage. Plumeless thistle prefers fertile soils developed over limestone, but it is highly adaptable and can even grow in shallow soil, emerging from stone quarries. Infestations of plumeless thistle reduce productivity of pastures and rangeland by suppressing growth of desirable vegetation and preventing livestock from eating plants growing in the vicinity of thistle stands (Desrochers *et al.*, 1988). It is very persistent and has the ability to regenerate because of the longevity and large number of seeds that it produces.

Ecological damage. Plumeless thistle generally does not pose a great threat to high quality areas although it may retard natural secondary succession. Just like musk thistle, livestock avoid it. Selective grazing and the indirect effects of herbicides used for its control result in bare ground that is ideal for its seed germination the following season.

Extent of losses. Carduus acanthoides stands of 90,000 plants per ha were observed in permanent pasture in southern Ontario and parts of Quebec. Such dense infestations are not uncommon in the United States (Desrochers *et al.*, 1988) and result in substantial loss of grazing areas for livestock. As thistles are not subjected to grazing or other stress, they easily outcompete forage grasses to become the dominant vegetation in areas where they have become established. In time, they can spread to dominate entire fields (Kok, unpub.). No documentation is available of the effect of plumeless thistles in agricultural crops because such areas are usually plowed under during cultivation.

Geographical Distribution

The earliest collections of *C. acanthoides* were made at Camden, New Jersey in 1878, and in Virginia in 1926 (Frick, 1978; Kok and Mays, 1991). In the 1940s, plumeless thistle was reported to occur from Nova Scotia to Nebraska, and south to Virginia and Ohio. Later, the weed was reported from the Canadian provinces of Nova Scotia, Quebec, Ontario, and British Columbia. The distribution of *C. acanthoides* in the United States is not as great as that of the *C. nutans* group. It is most widespread in the northeastern United States and in several central and western states (USDA, NCRS, 1999). *Carduus acanthoides* has been declared a noxious weed in Maryland, Minnesota, Nebraska, North Carolina, South Dakota, Virginia, West Virginia, and six western states.

BACKGROUND INFORMATION ON PEST PLANT

Taxonomy

Carduus acanthoides belongs to the small-flowered (sub-globose) group of *Carduus* species and is close to *Carduus crispus* L. The red to purple flowers (13 to 25 mm in diameter) of plumeless thistle are usually about one-third to one-half the size of musk thistle flowers. Flowers may be single or in clusters, are erect on stems, and usually do not droop or nod. Unlike musk thistle, flower stems are branched, with spiny wings extending to the flower heads. Three forms of plumeless thistle have been described, the most common in Virginia being *C. acanthoides* var. *acanthoides* (Kok and Mays, 1991). Hybridization between *C. acanthoides* and *C. nutans* has been reported (referred to as *C.* x *orthocephalus* Wallr.). Flowers of the hybrids are larger than the typical capitula of plumeless thistle, but smaller than capitula of musk thistle (Kok, unpub.).

Biology

Carduus acanthoides is an annual or biennial, reproducing by seed. In the rosette stage (Fig. 1), it may be mistaken for musk thistle. The taproot is large and hollow near the ground surface. The stem is erect, branched, and has spiny wings. The plant is 20 to 150 cm tall (Fig. 2). Leaves are hairy on the undersides and are narrower, more deeply lobed, and finely divided than those of *C. nutans*. *Carduus acanthoides* generally blooms from May to July, but this varies with environmental conditions. The reddish-purple flowers are about 20 mm in diameter (Fig. 3). Seeds are oblong, striate, and slightly curved. The seeds are about one-third the size of musk thistle seeds. Literature on plumeless thistle is much less extensive than that for musk thistle, but the biology, ecology, history, introduction, and control of both thistles are quite similar. However, plumeless thistle is more tolerant of herbicides and requires a higher rate of application. Like *C. nutans*, plumeless thistle does not have specific climatic requirements. In the northeastern United States, it is associated with fertile soils formed over limestone. Plumeless thistle tends to occupy drier, better-drained sites than *C. nutans* within the same pasture. It overwinters either as seeds or rosettes. The many flower heads of plumeless thistle enable it to flower more continuously than *C. nutans*, e.g., between June and October in southern Ontario, and between June and August in Virginia. A typical plant produces 35 to 60 capitula. Mean seed set averages 56 to 83 seeds per seed head for *C. acanthoides* and 165 to 256 for *C. nutans*. Germination occurs mainly in the spring and fall, with resulting plants acting either as winter annuals or as spring or fall biennials (Desrochers *et al.*, 1988).

Analysis of Related Native Plants in the Eastern United States

See this section in the chapter on musk thistle.

Figure 1. Plumeless thistle rosette. (Photograph by L.-T. Kok.)

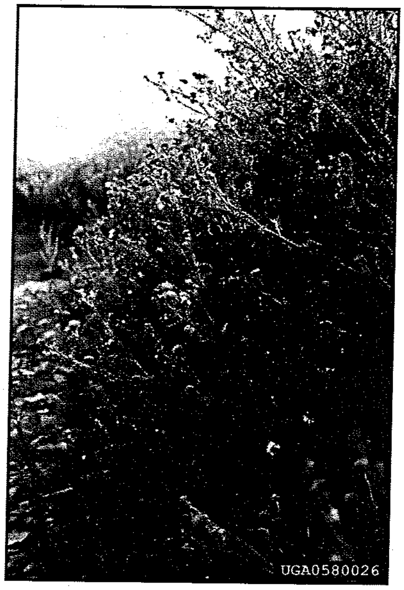

Figure 2. Plumeless thistle stand. (Photograph by L.-T. Kok.)

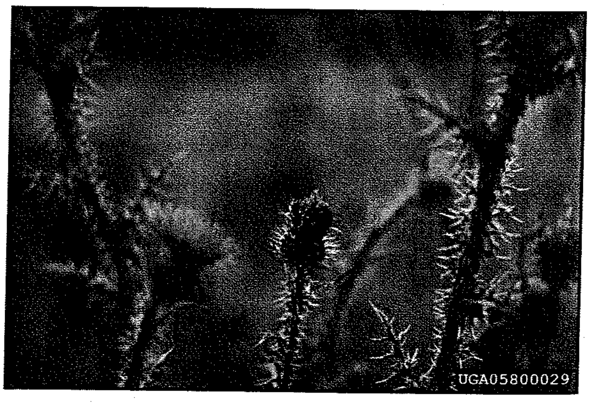

Figure 3. Plumeless thistle bloom, close up. (Photograph by L.-T. Kok.)

HISTORY OF BIOLOGICAL CONTROL EFFORTS IN THE EASTERN UNITED STATES

The biological control of *Carduus* spp. started when the USDA overseas laboratory was established at Rome, Italy in 1959. It began with a search of natural enemies in Europe in 1963 (Andres and Kok, 1981). *Carduus acanthoides* was not a primary target weed in the genus *Carduus*. However, this species was included in the European survey carried out by the Commonwealth Institute of Biological Control (now CABI Bioscience) in the 1960s and funded by Canada Department of Agriculture (Zwölfer, 1965).

Area of Origin of Weed

The native distribution of plumeless thistle is Europe and Asia. It is very common in eastern parts of Europe, but absent from most of southwestern and northern Europe (see also this section in the chapter on musk thistle).

Areas Surveyed for Natural Enemies

Areas surveyed included southern England, France, Austria, Germany, northern Italy, and the northern part of the former Yugoslavia (Zwölfer, 1965).

Natural Enemies Found

Most of the *C. acanthoides* populations sampled by Zwölfer (1965) were in southern Germany and eastern Austria. More than 30 insect species were recorded on the target plant. Of these, 15 species were reported to be broadly oligophagous on plants in the subtribe Carduinae (see Table 1 in the chapter on musk thistle). In Europe, fewer phytophagous insect species have been reported from plumeless thistle than from musk thistle. This is probably due to the much smaller geographical distribution of the former species and the lower level of sampling effort directed against plumeless thistle.

The biological control agents that had been selected primarily for musk thistle, i.e., the seed-feeding weevil, *Rhinocyllus conicus* (Frölich) and the rosette weevil, *Trichosirocalus horridus* (Panzer), were used at the same time against plumeless thistle. Attack rates by *R. conicus* on plumeless thistle appear to be low in North America, as they are in Europe, probably because the weevil is poorly synchronized with the plant phenology (Surles and Kok, 1977). Because of increasing concern about effects on non-target species, a more specific agent, the seed-feeding fly *Urophora solstitialis* (L.), was selected in the mid-1980s and released against plumeless thistle. Shortly after, this fly also was used for musk thistle (see also this section in the chapter on musk thistle).

Host Range and Biology

The seed-feeding insects, *R. conicus* and *U. solstitialis*, and the rosette weevil *T. horridus* have been released against plumeless thistle.

***Rhinocyllus conicus* and *Trichosirocalus horridus*.** The host range and biology of these two species released as biological control agents are described in this section in the chapter on musk thistle. The adult of *T. horridus* is a brown weevil of 3.9-4.3 mm in length (Fig. 4). Newly eclosed larvae burrow down the petiole into the growth point. Deterioration of plant tissues due to larval feeding results in blackened necrotic tissues (Fig. 5). There are three larval instars (Kok *et al.*, 1975). Heavy feeding by mature larvae (Fig. 6) can cause collapse and death to young rosettes (Fig. 7).

***Urophora solstitialis* L. (Diptera: Tephritidae).** Literature data include a large number of misleading host records for this species in the tribe Cardueae. Field surveys in Europe indicate that the seed-feeding fly *U. solstitialis* (Fig. 8) is restricted to the genus *Carduus*. In laboratory tests, oviposition and larval development occurred on the three *Carduus* species tested, on one (*Cirsium heterophyllum* [L.] Hill) out of four *Cirsium* species tested, on one (*Arctium lappa* L.) out of two *Arctium* species tested, and on one (*Centaurea montana* L.) out of 10 *Centaurea* species tested (Moeller-Joop and Schroeder, 1986; Moeller-Joop, 1988). This seed-feeding fly overwinters as a fully developed larva in capitula (Fig. 9). The adults then emerge in mid-spring. Adults live for several weeks and lay their eggs in the tubes of developing single florets inside flower buds. Newly hatched larvae mine through tubes and ovules down into the receptacle, inducing a gall. Most larvae developing from eggs laid early in the season pupate and produce a second generation. The proportion of larvae developing to form a second generation declines as the season progresses, and larvae developing late in the season all enter diapause (Moeller-Joop and Schroeder, 1986; Woodburn, 1993).

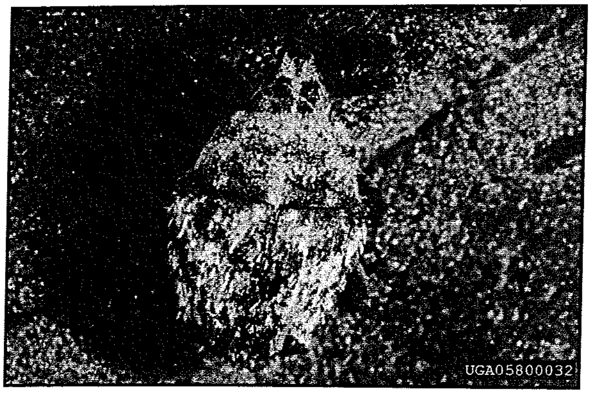

Figure 4. *Trichosirocalus horridus* adult. (Photograph by L.-T. Kok.)

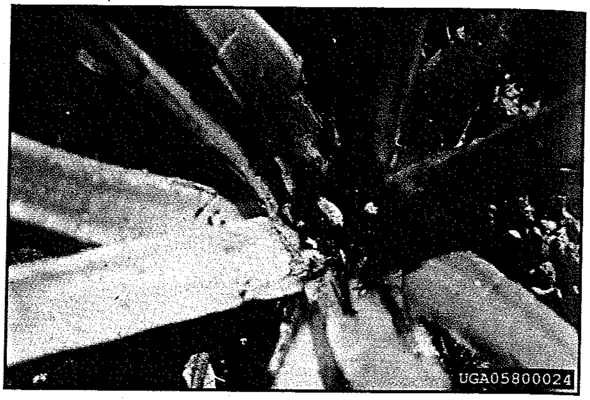

Figure 5. Necrosis of rosette due to feeding of *T. horridus* larvae. (Photograph by L.-T. Kok.)

Figure 6. Close up of *T. horridus* larva (third instar). (Photograph by L.-T. Kok.)

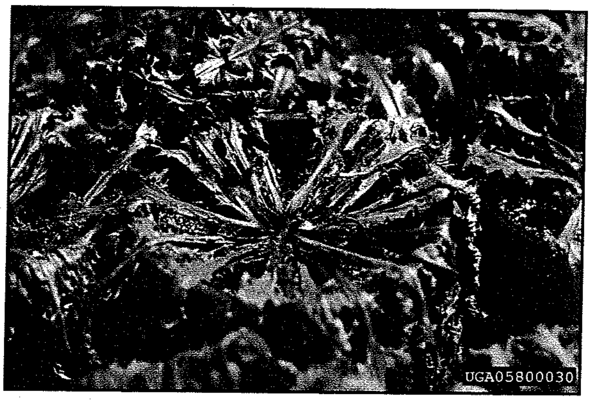

Figure 7. Collapse of thistle rosette infested by *T. horridus* larvae. (Photograph by L.-T. Kok.)

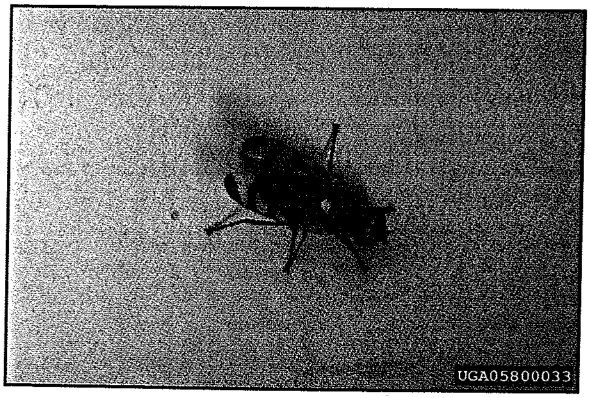

Figure 8. *Urophora solstitialis* adult. (Photograph by Peter Harris.)

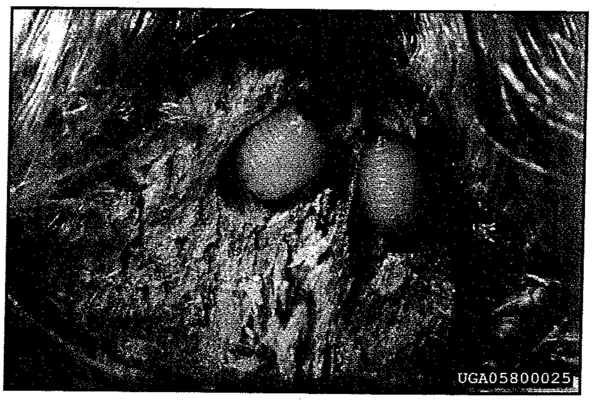

Figure 9. *Urophora solstitialis* larva. (Photograph by Peter Harris.)

Releases Made (from Rees *et al.*, 1996; Julien and Griffiths, 1999)

***Rhinocyllus conicus*.** Introductions of *R. conicus* from eastern France via Canada began on *C. acanthoides* in 1969 in Virginia (Surles *et al.*, 1974). Releases were made also in Maryland, Pennsylvania, Idaho, Washington, and West Virginia.

***Trichosirocalus horridus*.** The weevil originating from Italy was first released on *C. acanthoides* in Virginia in 1974 (Trumble and Kok, 1979). After establishment in Virginia, adult weevils were collected from sites in Virginia and released in Kansas, Maryland, Missouri, New Jersey, West Virginia, and several western states, as well as in Canada and Argentina.

Urophora solstitialis. This fly was released in Maryland in 1993.

EVALUATION OF PROJECT OUTCOMES

Establishment and Spread of Agents (from Julien and Griffiths, 1999)

Rhinocyllus conicus. This seed-feeding weevil is established in Virginia (Surles *et al.*, 1974), Maryland, Pennsylvania, Idaho, Washington, and West Virginia.

Trichosirocalus horridus. Establishment of this rosette weevil has been confirmed in Kansas, Maryland, Missouri, and Virginia, but not in New Jersey. In a study conducted in Virginia from 1976 to 1978, establishment was confirmed at two of seven release sites. By1981, the weevil was established at six of these seven sites, and by 1985 it became established in more than 20 sites (Kok and Mays, 1991). In southwest Virginia, 20% of the *C. acanthoides* plants were infested by the weevil in 1985 compared with 54% of *C. nutans*. In sites with mixed stands of musk and plumeless thistles, musk thistle was preferred over plumeless thistle when weevil populations were low. As the *T. horridus* populations increased, plumeless thistle was subjected to increased attack.

Urophora solstitialis. This seed-feeding fly is not established.

Suppression of Target Weed

Rhinocyllus conicus. Rhinocyllus conicus provides only partial control of *C. acanthoides* because the ovipositional period of the weevil only coincides with the development of the terminal thistle buds, and not that of the lateral buds (Surles and Kok, 1977). The suppressive effect of this weevil is reduced by the long flowering period of plumeless thistle compared with musk thistle. According to Rowe and Kok (1984), females of *R. conicus* survive longer on plumeless thistle than on musk thistle, and peak oviposition on plumeless thistle is delayed about two weeks, suggesting a possible adaptation of *R. conicus* to plumeless thistle.

Trichosirocalus horridus. Damage to *C. acanthoides* by *T. horridus* is caused by larvae feeding on rosette meristematic tissues and results in crown tissue necrosis. Infested plants produced a greater number of stems per plant, but 50% fewer heads than the non-infested plants (Cartwright and Kok, 1985). Studies in Virginia showed that large weevil populations and grass competition together could have a large effect on thistle densities (Figs. 10 and 11). As larval infestation increases, the stressed thistles become less dominant and more susceptible to competition by pasture grasses, which increase in vigor and density. In 1981, thistle reduction ranged from 11.6 to 80.9% at five sites with *T. horridus*, versus an 11.6% increase at one site where *T. horridus* was not established. At two sites, a reduction in thistle density of more than 80% was found to be due in part to the additional presence of *R. conicus* and improved pasture vigor (Kok, 1986). By 1990, despite occasional resurgence of thistles in some years, plumeless thistle density was very low, with reductions of the original density ranging from 87 to nearly 100%. Thus, the collapse of plumeless thistle was evident after 10 to 12 years following weevil releases (Kok and Mays, 1991).

Figure 10. Plumeless thistle stand before release of *T. horridus*. (Photograph by L.-T. Kok.)

Figure 11. Plumeless thistle stand eight years after release of *T. horridus*. (Photograph by L.-T. Kok.)

Recovery of Native Plant Communities and Economic Benefits

The main replacement vegetation at the five sites after collapse of plumeless thistle in Virginia was dense stands of desirable pasture grasses like tall fescue (*Festuca arundinaria* Schreb.), orchard grass (*Dactylis glomerata* L.), and bluegrass (*Poa* spp.) (Kok and Mays, 1991).

RECOMMENDATIONS FOR FUTURE WORK

There are some indications that *T. horridus* may be a good biological control agent for plumeless thistle, alone or in combination with *R. conicus* and grass competition (Kok *et al.*, 1986; Kok and Mays, 1991). The impact by thistle weevils can be greatly enhanced when the insects are used in conjunction with tall fescue grass (Kok *et al.*, 1986). Thus, redistribution of this rosette weevil to other infested areas is being continued. Potential feeding on non-target plants, however, deserves further attention. (See also this section in the chapter on musk thistle.)

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SECTION IV: WEEDS OF OLD FIELDS AND PASTURES

Multiflora Rose
Tropical Soda Apple, Wetland Nightshade, and Turkeyberry
Brazilian Peppertree

22 Multiflora Rose

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PEST STATUS OF WEED

Multiflora rose, *Rosa multiflora* Thunberg ex. Murray, is a non-indigenous rosaceous plant that is native to East Asia (Japan, Korea, and eastern China) (Fig. 1). It has been introduced into North America many times since the late 1700s as garden plants and as root stock for ornamental roses. Rehder (1936) found it listed in the second edition (1811) of the *Catalog of the Elgin Botanic Garden* in New York. Before its weedy characteristics were well understood, it was widely planted in the 1940s to 1960s in the eastern United States as a wildlife plant for erosion control and as a living fence. The hypanthia often are used for tea as a source of vitamin C. It has been declared a noxious weed in at least ten states (Amrine and Stasny, 1993).

Nature of Damage

Economic damage. Lost pasturage in many states, especially states with hilly terrain and pastures on steep slopes, has resulted in significant reduction in potential beef production. This thorned bramble now infests more than 45 million acres throughout the eastern United States (Underwood *et al.*, 1996). Chalamira and Lawrence (1984) reported that multiflora rose was the highest priority agricultural problem in West Virginia. Experimental multiflora control programs in West Virginia during 1980 and 1981 indicated that more than 36,500 hectares were heavily infested and that a ten-year eradication program using herbicides would cost more than $40 million (Williams and Hacker, 1982). Similar burdens and costs were reported from neighboring states; to date, multiflora has been declared a noxious weed in Illinois, Iowa, Kansas, Maryland, Missouri, Ohio, Pennsylvania, Virginia, Wisconsin, and West Virginia (Amrine and Stasny, 1993).

Figure 1. Multiflora rose. (Illustration by Rae Chambers, Pennsylvania State University.)

Ecological damage. Multiflora rose has invaded a large number of habitats, from hillside pastures, fence rows, right-of-ways, and roadsides to forest edges and the margins of swamps and marshes (Scott, 1965). A single, vigorous, mature plant can produce up to half a million achenes (seeds) annually. Where plants have become well established, a huge seed bank develops that can continue to produce seedlings for at least twenty years after removal of mature plants. Severe multiflora rose infestations have lowered land values for agriculture, forestry, and recreation (Underwood *et al.*, 1996). Since the 1960s, multiflora rose has become one of the most noxious weeds in the eastern United States. It is especially troublesome in regions with steep slopes, which prevent access by tractors or mowers for cutting this weed. Multiflora rose forms dense, impenetrable thickets in many regions of the eastern United States. At least ten states have passed noxious weed laws against it, and it is illegal to plant it in many areas (Amrine and Stasny, 1993; Fawcett, 1980; Klimstra, 1956; Kriebel, 1987; Williams and Hacker, 1982; Underwood *et al.*, 1996). Many state publications and web sites list cultural and chemical methods for controlling multiflora rose, but biological control has been a neglected management option (Lingenfelter and Curran, 1995; Underwood and Stroube, 1986; Underwood *et al.*, 1996).

Extent of losses. In West Virginia, projected costs to farmers for controlling multiflora rose from 1981 to 1982 exceeded $40 million (Williams and Hacker, 1982); at today's rates, this cost would exceed $48 million. Similar costs accrue to most eastern states and control costs continue to rise as this noxious weed continues to spread.

Geographical Distribution

In eastern North America, multiflora rose is abundant from the Great Plains (where the species has been planted as wind breaks) to the east coast. It occurs from northern Texas, Arkansas, Mississippi, Alabama, and Georgia in the south, north to the New England coast, central New York, southern Michigan, Wisconsin, and Minnesota. It occurs only as plantings south of central Georgia, probably because of the lack of cold temperatures needed to stimulate seed germination. The plant's northern distribution is limited by its sensitivity to severe cold temperatures.

BACKGROUND INFORMATION ON PEST PLANT

Taxonomy

Multiflora rose is in the Subfamily Rosoïdeae, Tribe Roseae. *Rosa* is the only known genus in the tribe. The most closely related plants are members of the tribes Potentilleae (Sections Rubinae, Potentillinae, Dryadinae), Cercocarpaceae, Ulmariëae, and Sanguisorbeae. The most common genera that would be most closely related to *Rosa* are *Rubus, Potentilla, Fragaria, Geum, Dryas, Adenostema, Purshia, Cercocarpus, Alchemilla, Agrimonia,* and *Poterium.*

Multiflora rose was first described from Japan. It is a stout, thorny, diffusely branched, perennial shrub with numerous arching stems (canes) arising from the crown; plants may reach 3 m height and 6.5 m diameter. Twigs are reddish to green, 1.5 cm in diameter and armed with numerous, recurved thorns; thornless clones occur sparsely throughout the eastern United States. Leaves are odd-pinnately compound, 8 to 11cm long, divided into five to 11 sharply toothed, ovate to oblong leaflets. Basal petioles are 1.0 to1.3 cm long and have finely dissected, usually glandular stipules. Large clusters of showy, fragrant, white to pink 2.5 cm flowers occur in dense to sparse panicles that appear in late May or June. Panicles contain six to 100 (average of 63) hypanthia or hips that are glabrous to pubescent, develop during the summer, and become bright red by mid-September; hips contain an average of seven (one to 21) achenes. Hypanthia become soft after frost and eventually become leathery, remaining on the plant through the winter. Achenes are yellowish to tan, somewhat irregular in shape, about 2 to 4 mm long by 2 mm wide, and enclosed in sharp spicules. Winter-feeding birds often consume fruits by January. Seeds are attacked by the rose seed chalcid, *Megastigmus aculeatus* var. *nigroflavus* Hoffmeyer (Hymenoptera: Torymidae) in many areas (see below).

Biology

Each cane on a large plant may contain 40 to 50 pannicles. Each pannicle can contain as many as 100 hypanthia or hips (average of about 50) and each hip, an average of seven seeds (range of one to 22). Thus each large cane can potentially produce up to 17,500 seeds. Seeds remain viable for a number of years (Evans, 1983; Underwood *et al.*, 1996). We have found as many as 90% of the seed to be viable, in the absence of drought, stress, and seed chalcids. The abundant floral production of this plant may be the result of the plant's evolution in the presence of its seed predator, the multiflora rose seed chalcid, *Megastigmus aculeatus* var. *nigroflavus* Hoffmeyer (Hymenoptera: Torymidae). In Asia, the chalcid may infest 95% of the achenes or seeds (Weiss, 1917). The chalcid reproduces by parthenogenesis (female:male ratio is 200:1), possibly a mechanism to match the huge resource (Shaffer, 1987). Multiflora rose is moderately winter-hardy, tolerant to many North American insects and diseases, and grows rapidly into dense thorny thickets favorable for many species of wildlife. Its abundant fruits are food to deer and birds. The flowers produce large amounts of golden, sweet-tasting pollen that can be harvested by fitting bee hives with pollen traps (Amrine unpublished). The plant has a vigorous root system capable of checking erosion, and if carefully planted and mechanically trimmed, multiflora rose can make living fences capable of restraining some species of livestock (Dugan, 1960). It is still planted as a living fence in southern Delaware to separate herds of horses. Because of these traits, multiflora rose was widely planted throughout the eastern United States from the 1930s until the 1960s as living fences, for erosion control, and to protect and feed native wildlife. In West Virginia, more than 14 million plants were planted in the 1940s to 1960s (Dugan, 1960), and in North Carolina, more than 20 million were planted (Nalepa, 1989). Only a few states (e.g., Kentucky) refused to promote this plant. Consequently, many areas of Kentucky are relatively free of the weed. Since the plant was distributed as rooted cuttings and not from seed, no seed chalcids were distributed.

Some early experiments were conducted to show that spread of multiflora seed by birds was minimal. However, the birds chosen were chickens, doves, pigeons, turkeys, and their relatives—all of which have gizzards containing stones that grind seeds. Songbirds were not tested as potential seed dispersers. Robins, mockingbirds, starlings, red-winged blackbirds, and other species feed heavily on multiflora rose hips in fall and winter, and, because of the numerous spicules in each hip, seeds pass rapidly through their digestive tracts and remain intact. Passage of seeds through digestive tracts of songbirds increases the germination rate, while bird feces provides fertilizer to seedlings (Lincoln, 1978; Scott, 1965).

Analysis of Related Plants in the Eastern United States

According to the *Synonymized Checklist of the Vascular Flora of the United States, Puerto Rico, and the Virgin Islands* and the Texas A&M University Bioinformatics Working Group on the Rosaceae (part of BONAP, theBiota of North America Program), there are 82 species or subspecies of roses that are either native to the eastern United States, have escaped from cultivation, or are grown in gardens. In addition, there are some 8,000 registered cultivars of roses, worldwide, with many new ones registered annually. The following is a list of roses occurring in this region:

1. *Rosa acicularis* Lindl. Cinnamomeae DC. Prickly rose. (native) Eurasia and North America, Zone 4.
2. *Rosa acicularis* ssp. *acicularis*. (native) Alaska, Eurasia, zone 4.
3. *Rosa acicularis* ssp. *sayi* (Schwein.) W. H. Lewis. (native) Alaska through Canada, south to West Virginia, Texas and New Mexico (mountains), Zone 5. Occasionally found at higher altitudes and farther north. Synonymy: *Rosa acicularis* var. *bourgeauiana* (Crépin) Crépin, *Rosa acicularis* var. *sayana* Erlanson, *Rosa bourgeauiana* Crépin, *Rosa collaris* Rydb., *Rosa engelmannii* S. Wats., *Rosa sayi* Schwein.
4. *Rosa* x *alba* L. (pro sp.) [*arvensis* x *gallica*]. European hybrid. Zone 5, mountains and far north.
5. *Rosa arkansana* Porter. Cinnamomeae DC. (native). Prairie rose. New York to Alberta, south to Texas.
6. *Rosa arkansana* var. *arkansana* (native). Known locally as prairie rose. From Wisconsin and Minnesota to Colorado and Kansas; rocky slopes. Synonymy: *Rosa lunellii* Greene, *Rosa rydbergii* Greene.
7. *Rosa arkansana* var. *suffulta* (Greene) Cockerell.(native). Known locally as sunshine rose. New York west to Alberta, south to the District of Columbia, Indiana, Wisconsin, Missouri, Kansas, Texas, and New Mexico. Synonymy: *Rosa alcea* Greene, *Rosa conjuncta* Rydb., *Rosa pratincola* Greene, *Rosa suffulta* Greene, *Rosa suffulta* var. *relicta* (Erlanson) Deam.
8. *Rosa banksiae* Aiton. Non-indigenous rose from China, grown in Georgia. Apparently, it has not escaped.
9. *Rosa blanda* Aiton. Cinnamomeae DC. (native). Smooth rose. Newfoundland to Maryland and West Virginia, west to Kansas and Montana.
10. *Rosa blanda* var. *blanda* Aiton. (native). Distribution same. Synonymy: *Rosa blanda* var. *carpohispida* Schuette, *Rosa rousseauiorum* Boivin, *Rosa subblanda* Rydb., *Rosa williamsii* Fern.

11. Rosa blanda var. glabra Crépin. (native). Maine south to New York, west to Minnesota. Synonymy: *Rosa johannensis* Fern.
12. Rosa blanda var. glandulosa Schuette (native). Indiana.
13. Rosa blanda var. hispida Farw. (native). Maryland and Indiana.
14. Rosa x borboniana Desportes (pro sp.) [*chinensis* x *damascena*]. Bourbon rose. Non-indigenous hybrid. New York, South Carolina and Louisiana.
15. Rosa bracteata J. C. Wendl. Bracteatae Thory. Known as Chickasaw or Macartney rose. Non-indigenous rose from China. Found in Zone 7, in Texas, Louisiana, Georgia, and other southern states north to Virginia and Kentucky.
16. Rosa canina L. Caninae DC. Dog rose. Non-indigenous rose from Europe and West Asia; Maine south to Alabama, west to Arkansas, Kansas and Wisconsin; western distribution is Washington and Idaho to Utah and California, Zone 4. Present in the CalFlora Database (California distribution map). Synonymy: *Rosa canina* var. *dumetorum* Baker.
17. Rosa carolina L. Carolinae Crépin. (native). Carolina rose, pasture rose. Nova Scotia to Florida, west to Nebraska and Texas.
18. Rosa carolina var. carolina L. (native). Common in the east where it is known as the pasture rose. Synonymy: *Rosa carolina* var. *glandulosa* (Crépin) Farw., *Rosa carolina* var. *grandiflora* (Baker) Rehd., *Rosa carolina* var. *obovata* (Raf.) Deam, *Rosa serrulata* Raf., *Rosa subserrulata* Rydb., *Rosa texarkana* Rydb.
19. Rosa carolina var. deamii (Erlanson) Deam. (native). Indiana.
20. Rosa carolina var. sabulosa Erlanson. (native). Indiana.
21. Rosa carolina var. setigera Crépin. (native). New Hampshire, Vermont and Maine. Known locally as prairie rose, climbing rose.
22. Rosa carolina var. villosa (Best) Rehd. (native). Maine south to Georgia west to Minnesota and Texas. Synonymy: *Rosa carolina* var. *lyonii* (Pursh) Palmer and Steyermark, *Rosa lyonii* Pursh, *Rosa palmeri* Rydb.
23. Rosa centifolia L. Cabbage rose. Non-indigenous rose from Europe; grown by rosarians for attar of rose, an essential oil in the petals. New York and Connecticut south to New Jersey, west to Missouri and Wisconsin. Synonymy: *Rosa centifolia* var. *cristata* Prev. *Rosa centifolia* var. *muscosa* (Ait.) Ser.
24. Rosa chinensis Jacq. Chinese rose, pygmy rose, fairy rose. Non-indigenous rose from China, grown in Zone 7. Arkansas and Mississippi.
25. Rosa cinnamomea L. Cinnamomeae DC. Cinnamon rose. Non-indigenous rose from Eurasia; escaped in North America, Zone 5; Maine south to Virginia, northwest to Wisconsin.
26. Rosa x damascena P. Mill. (gallica x moschata). Damask rose. Introduced from Asia Minor; sporadic: New York, Michigan, Missouri and North Carolina. major source of attar of roses. Synonymy: *Rosa* x *bifera* (Poir.) Pers.
27. Rosa x dulcissima Lunell (pro sp.) (blanda x woodsii). Hybrid rose with native parents; Wisconsin and Iowa west to the Dakotas.
28. Rosa dumetorum Thuill. Corymb rose. Introduced from the Mediterranean region, Zone 6; Kentucky. Synonymy: *Rosa corymbifera* Borkh.
29. Rosa eglanteria L. Caninae DC.- Sweetbrier. Known locally as: sweetbrier. Naturalized from Europe into most of North America, Zone 6. Present in the CalFlora Database (California distribution map). Synonymy: *Rosa rubiginosa* L.
30. Rosa foliolosa Nutt. Ex. Torr. and Gray. (native). Known locally as leafy rose or white praire rose. Kansas and Arkansas to Texas, Zone 6. Synonymy: *Rosa ignota* Shinners.
31. Rosa gallica L. Gallincanae DC. French rose. Non-indigenous rose from Europe and west Asia; used to produce attar of roses. Naturalized in North America, Zone 6; Maine south to South Carolina west to Louisiana and Wisconsin.
32. Rosa gallica var. gallica L. Same distribution as *gallica*.
33. Rosa gallica var. officinalis Thory Missouri and Michigan.

34. <u>*Rosa* x *harisonii* Rivers; also *Rosa* Harison's Yellow (*foetida* x *spinosissima*).</u> A hybrid rose planted by the pioneers where they settled.

35. <u>*Rosa* x *housei* Erlanson (pro sp.) (*acicularis* x *blanda*).</u> A hybrid rose; New York, Michigan and Wisconsin.

36. <u>*Rosa hugonis* Hemsl.</u> Father Hugo's rose, golden rose of China. Non-indigenous rose from China. Cultivated in northeast North America.

37. <u>*Rosa indica* L.</u> Cyme rose. Non-indigenous rose from South Asia; escaped in Puerto Rico.

38. <u>*Rosa laevigata* Michx.</u> Cherokee rose. Non-indigenous rose from China; naturalized in southern United States, Zone 7; North Carolina south to Florida, west to Texas. State flower of Georgia. It has weedy propensities.

39. <u>*Rosa majalis* J. Herrm.</u> Double cinnamon rose. Non-indigenous rose from Europe. Southern New England west to Ohio and Wisconsin. Synonymy: *Rosa cinnamomea* sensu L. 1759, non 1753.

40. <u>*Rosa manca* Greene.</u> Mancos rose. Non-indigenous rose from Europe; Colorado, Utah and Arizona.

41. <u>*Rosa micrantha* Borrer ex Sm.</u> Caninae DC. Small-flower sweetbrier. Non-indigenous rose from Europe, naturalized in North America; most eastern states and the Pacific Northwest.

42. <u>*Rosa moschata* J. Herrm.</u> Musk rose. Non-indigenous rose from southern Europe, northern Africa and western Asia; naturalized in North America, Zone 7; Mississippi and Illinois.

43. <u>*Rosa multiflora* Thunb. ex Murr.</u> Synstylae DC. Multiflora rose, rambler rose. Non-indigenous rose from Japan, Korea and east China-All eastern states west to Texas, Nebraska and Minnesota; also in Washington and Oregon. Synonymy: *Rosa cathayensis* (Rehd. and Wilson) Bailey.

44. <u>*Rosa nitida* Willd.</u> Carolinae Crépin. (native). Shining rose. Newfoundland to Connecticut and Ohio, Zone 4.

45. <u>*Rosa nutkana* K. Presl.</u> (native). Nootka rose. Found from California to Alaska, northern Rocky Mountains.

46. <u>*Rosa nutkana* var. *hispida* Fern.</u> (native). Colorado north to Montana west to Nevada, Oregon and Washington. Synonymy: *Rosa anatonensis* St. John, *Rosa caeruleimontana* St. John, *Rosa jonesii* St. John, *Rosa macdougalii* Holz., *Rosa megalantha* G. N. Jones, *Rosa spaldingii* Crépin, *Rosa spaldingii* var. *alta* (Suksdorf) G. N. Jones, *Rosa spaldingii* var. *hispida* (Fern.) G. N. Jones, *Rosa spaldingii* var. *parkeri* (S. Wats.) St. John.

47. <u>*Rosa nutkana* var. *muriculata* (Greene) G. N. Jones.</u> (native); Washington, Oregon and California.

48. <u>*Rosa nutkana* var. *nutkana* K. Presl.</u> (native); Washington, Oregon, California, andWyoming. Synonymy: *Rosa durandii* Crépin

49. <u>*Rosa nutkana* var. *setosa* G.N. Jones</u>. (native); Washington and California.

50. <u>*Rosa obtusiuscula* Rydberg.</u> (native). Appalachian valley rose. Found in Tennessee.

51. <u>*Rosa odorata* (Andr.) Sweet.</u> Tea rose. Non-indigenous rose from China; one of the parents of tea roses. Found in Pennsylvania, Louisiana and Utah.

52. <u>*Rosa* x *palustriformis* Rydb. (pro sp.) [*blanda* x *palustris*].</u> Hybrid rose with native parents; Maine to Wisconsin, south to Ohio.

53. <u>*Rosa palustris* Marsh. Carolinae Crépin.</u> (native) Swamp rose. A common native rose, found in marshy locations from Nova Scotia to Minnesota, south to Florida and Texas. Synonymy: *Rosa floridana* Rydb., *Rosa lancifolia* Small, *Rosa palustris* var. *dasistema* (Raf.) Palmer and Steyermark.

54. <u>*Rosa* x *rehderiana* Blackb. [*chinensis* x *multiflora*].</u> Polyantha rose. A hybrid non-indigenous rose, similar to multiflora, but canes less than three feet, low and spreading. New York and Louisiana.

55. <u>*Rosa rubrifolia* Vill.</u> Red-leaf rose. Non-indigenous rose from central Europe; Zone 2; Illinois, Maine, Massachusetts, New York and South Carolina. Synonymy: *Rosa glauca* Pourret.

56. <u>*Rosa* x *rudiuscula* Greene (pro sp.) (*arkansana* x *carolina*).</u> Hybrid with native parents; Ohio to Oklahoma, north to Wisconsin.

57. ***Rosa rugosa*** **Thunb.** Cinnamomeae DC. Rugose rose. Non-indigenous rose from China and Japan; it has escaped along the northeast coast, especially in Maine and Long Island, New York. Commonly grown in gardens. Sometimes weedy.

58. ***Rosa sempervirens*** **L.** Evergreen rose. Non-indigenous rose from southern Europe, North Africa; Zone 7; escaped in Puerto Rico.

59. ***Rosa serafinii*** **Viviani.** Non-indigenous rose from the Mediterranean region; apparently has not escaped.

60. ***Rosa setigera*** **Michaux.** Synstylae DC. (native). Climbing rose, prairie rose. A common rose, found from Ontario to Kansas, south to Florida and Texas.

61. ***Rosa setigera*** **var. *setigera* Michaux.** (native). Synonymy: *Rosa setigera* var. *serena* Palmer and Steyermark. Same distribution as *setigera.*

62. ***Rosa setigera*** **var. *tomentosa* Torr. and Gray.** (native). Known locally in Texas as fuzzy rose. Same distribution as *setigera.*

63. ***Rosa spinosissima*** **L.** Pimpinellifoliae DC. Scotch rose. Non-indigenous rose from Europe; Found in Virginia and Tennessee west to Kansas, north to Wisconsin and Maine. Synonymy: *Rosa pimpinellifolia* L.

64. ***Rosa spinosissima*** **var. *spithamea* S. Wats.** Non-indigenous rose from Europe. Synonymy: *Rosa spithamea* var. *solitaria* Henderson

65. ***Rosa stellata*** **Woot.** (native). Desert rose. Found in New Mexico and southern Texas.

66. ***Rosa stellata*** **ssp. *abyssa* A. Phillips.** (native). Found in Arizona. Synonymy: *Rosa stellata* var. *abyssa* (A. Phillips) N. Holmgren

67. ***Rosa stellata*** **ssp. *mirifica* (Greene) W. H. Lewis.** (native). Known locally as desert rose; found in Texas and New Mexico.

68. ***Rosa stellata*** **ssp. *mirifica* var. *erlansoniae* W. H. Lewis.** (native). Found in Texas and New Mexico.

69. ***Rosa stellata*** **ssp. *mirifica* var. *mirifica* (Greene) Cockerell.** (native). Found in Texas and New Mexico. Synonymy: *Rosa mirifica* Greene.

70. ***Rosa stellata*** **ssp. *stellata* Woot.** (native). Found from Texas west to Arizona.

71. ***Rosa tomentosa*** **Sm.** Caninae DC. Whit woolly rose. Non-indigenous rose from E rope and west Asia; apparently has not e caped. Synonymy: *Rosa tomentosa* va *globulosa* Rouy.

72. ***Rosa villosa*** **L.** Apple rose. Non-indigenou rose from Europe and west Asia; apparentl has not escaped. Fruit is eaten and used i drinks.

73. ***Rosa virginiana*** **P. Mill.** Caroninae Crépin (native). Virginia rose. Newfoundland, sout to upland Georgia, Alabama and Tennessee west to Missouri and Illinois.

74. ***Rosa virginiana*** **var. *lamprophylla* (Rydb.) Fern.** (native). Found in Connecticut north to Maine.

75. ***Rosa virginiana*** **var. *virginiana* P. Mill.** (native). Same as *virginiana.*

76. ***Rosa wichuraiana*** **Crépin.** Synstylae DC. Memorial rose. Non-indigenous from east Asia; naturalized in North America, Zone 6, New York and Connecticut south to Florida and Mississippi west to Illinois.

77. ***Rosa woodsii*** **Lindl.** Cinnamomeae DC. (native). Wood's rose. A native rose found from western Ontario and Wisconsin to British Columbia, south to Nebraska, New Mexico, west Texas (mountains), and northern Mexico.

78. ***Rosa woodsii*** **var. *glabrata* (Parish) Cole.** (native). California. Synonymy: *Rosa mohavensis* Parish

79. ***Rosa woodsii*** **var. *gratissima* (Greene) Cole.** (native). California and Nevada. Synonymy: *Rosa gratissima* Greene

80. ***Rosa woodsii*** **var. *ultramontana* (S. Wats.) Jepson.** (native). Washington east to Montana south to New Mexico and California. Synonymy: *Rosa arizonica* Rydb., *Rosa arizonica* var. *granulifera* (Rydb.) Kearney and Peebles, *Rosa covillei* Greene, *Rosa lapwaiensis* St. John, *Rosa pecosensis* Cockerell, *Rosa ultramontana* (S. Wats.) Heller, *Rosa woodsii* ssp. *ultramontana* (S. Wats.) Taylor and MacBryde, *Rosa woodsii* var. *arizonica* (Rydb.) W. C. Martin and C. R. Hutchins, *Rosa woodsii* var. *granulifera* (Rydb.) W. C.Martin and C. R.Hutchins.

81. *Rosa woodsii* var. *woodsii* Lindl. (native). Montana south to New Mexico east to Texas and Wisconsin. Synonymy: *Rosa adenosepala* Woot. and Standl., *Rosa fendleri* Crépin, *Rosa hypoleuca* Woot. and Standl., *Rosa macounii* Greene, *Rosa neomexicana* Cockerell, *Rosa standleyi* Rydb., *Rosa terrens* Lunell, *Rosa woodsii* var. *adenosepala* (Woot. and Standl.) W. C. Martin and C. R. Hutchins, *Rosa woodsii* var. *fendleri* (Crépin) Rydb., *Rosa woodsii* var. *hypoleuca* (Woot. and Standl.) W. C. Martin and C. R. Hutchins, *Rosa woodsii* var. *macounii* (Greene) W. C. Martin and C. R. Hutchins.
82. *Rosa xanthina* Lindl. Hemsl. Non-indigenous rose from north China and Korea; Zone 6; South Carolina. Synonymy: *Rosa hugonis*
83. *Rosa yainacensis* Greene, (native). Cascade rose. Washington to California.

None of the above roses are known to be rare or endangered; many have ranges restricted to mountains, to the northern regions, to marshes, to deserts or to the west. Several introduced roses have become noxious weeds. The Macartney rose (*Rosa bracteata* Wendland) was imported into Texas from eastern Asia and has become a noxious weed along the Gulf Coast, infesting more than 500,000 acres of productive grasslands in 40 southeastern Texas counties (Scott, 1965). The Cherokee rose (*Rosa laevigata* Michaux), another introduced plant from China (however, the State Flower of Georgia), became a severe weed in the Black Belt region (several counties characterized by rich, dark soil) in central Alabama. Land covered by the weed in nine counties could have produced 1.5 million pounds of beef annually, if in productive pasture (Scott, 1965). *Rosa canina* L., a native of Europe and west Asia, has been introduced into most of the eastern United States; it is widely dispersed and occasionally found to be abundant, but has shown no weedy propensity in the east. The large hips of *R. canina* are valued by natural food enthusiasts. *Rosa eglanteria* L., another native of Europe has become widely dispersed in the United States; it is very weedy in New Zealand. *Rosa rugosa* Thunb., another non-indigenous rose from China, has been introduced throughout the eastern US; this species is commonly cultivated as an ornamental species rose; it has escaped and become abundant along the northeast coast, especially in Long Island, New York (Amrine, pers. observ., 2001) and Maine (Peck, 2001).

Common native roses in eastern North America include the prickly rose, *Rosa acicularis* Lindl. (in mountains and northern regions), the smooth rose (*Rosa blanda* Aiton), the prairie rose (*R. setigera*), the swamp rose (*Rosa palustris* Marsh), the Virginia rose (*R. virginiana*) and the pasture rose (*Rosa carolina* L.). None of these native roses have become weeds except in rare instances. Abundant natural controls and seed predators probably prevent them from becoming weeds. The introduced roses, *Rosa eglanteria* L., *R. canina*, and *R. rugosa*, all ornamental species, have escaped and are commonly found in many areas, but have not been observed to be significant weeds.

Related Species

Only the genus *Rosa* occurs in the tribe Roseae. The most closely related plants are members of the tribes Potentilleae (Sections Rubinae, Potentillinae, Dryadinae), Cercocarpaceae, Ulmariëae, and Sanguisorbeae. Thus, genera most closely related to *Rosa* are *Rubus* (blackberries, raspberries, brambles; probably more than 75 species occur in eastern North America), *Potentilla* (cinquefoil, 15 species), *Fragaria* (strawberries, five species), *Geum* (avens, 10 species), *Dryas* (mountain avens, two species in western North America), *Adenostema* (chamise, ribbonwood; two species in California), *Purshia* (antelope bush, two species in western North America), *Cercocarpus* (mountain mahogany, five species in western North America), *Alchemilla* (lady's mantle, parsley-piert; three to four naturalized species in eastern North America), *Agrimonia* (beggar-ticks, about 10 species in eastern North America), *Poterium* (burnet, one species naturalized in eastern North America) and *Filipendula* (meadowsweet, two or three native or naturalized species in eastern North America). Some of the *Rubus* are occasionally attacked by the rose stem girdler, *Agrilus aurichalceus aurichalceus* Redtenbacher; none of the other arthropods or diseases affecting multiflora rose, discussed herein, occur on any of these related plants.

HISTORY OF BIOLOGICAL CONTROL EFFORTS IN THE EASTERN UNITED STATES

Area of Origin of Weed

As mentioned above, *R. multiflora* originated in eastern Asia. It is native to Japan, Korea and northeast China and a wide variety of other deciduous-forest podzol areas of eastern Asia that are similar to those of the eastern United States (Good, 1964). It also occurs in similar areas of Europe.

Areas Surveyed for Natural Enemies and Natural Enemies Found

Hindal and Wong (1988) surveyed West Virginia for arthropods and diseases occuring on multiflora rose. They found several insects and diseases, of which the following were noted: the rose seed chalcid, *Megastigmus aculeatus* var. *nigroflavus* Hoffmeyer (Hymenoptera: Torymidae), introduced from Japan; a native raspberry cane borer, *Oberea bimaculata* Olivier (Coleoptera: Cerambycidae); a native tortricid hip borer, *Grapolita packerdi* Zeller (Lepidoptera: Tortricidae); a native powdery mildew (*Sphaerotheca* sp.); several native fungi that cause cankers (species of *Epicoccum, Leptosphaeria, Phoma,* and *Phomopsis*); and several introduced European stem gall forming species, from which bacteria were cultured that were similar to *Agrobacterium tumefasciens* (E. F. Sm. et Towns.) Conn. Of these, only the seed chalcid appeared to present any possibility of significant biological control. Mays and Kok (1988) found the seed chalcids in roses in Virginia, and Shaffer (1987) reported finding the seed chalcid in all counties of West Virginia that were surveyed as well as in Indiana, Kentucky, Maryland, Ohio, and Pennsylvania. To our knowledge, no surveys have been conducted for natural enemies of multiflora rose in eastern Asia. Consequently, surveys of natural enemies associated with this rose in its native range and compilation from the literature of its known natural enemies, both typical early steps of most plant biological control projects, have not been done.

Host Range Tests and Results

Results of host range tests for the eriophyid mite *Phyllocoptes fructiphilus* Keifer (vector of rose rosette disease [RRD]) and the rose rosette disease virus are given in Tables 1 through 3. Most native roses in the midatlantic region have been tested and can not be infected with RRD; all are excellent hosts for the mite. Most ornamental roses are capable of sustaining the mite and of being infected by RRD. Many cultivars are very susceptible to RRD and these are indicated in the tables in bold type. Only members of *Rosa* can be infected with RRD or serve as hosts for the mite. A large number of other rosaceous plants have been tested for RRD susceptibility and mite acceptance. All tests, including backgrafts to multiflora rose, have been negative. None of the other rosaceous plants support the mite. A number of grafted rosaceous plants have been grown at the West Virginia University Horticulture Farm since 1989; to date, none have shown any symptoms of RRD and backgrafts have been negative. The rose seed chalcid has only been found in seed from multiflora rose; apparently differences in the hips and/or times of flowering prevent the chalcid from successfully developing in seeds of other roses.

Releases Made

To our knowledge, no intentional releases were made of any of the insects, mites, or pathogens discussed in the following section; all are either native North American species or, as in the case of the rose stem girdler and the multiflora rose seed chalcid, were accidentally introduced. Rose rosette disease has been transmitted to target multiflora roses by grafting and by mite releases in Iowa and West Virginia (Amrine and Stasny, 1993; Epstein and Hill, 1994b, 1995b; Amrine *et al.*, 1995; Epstein, 1995; Epstein *et al.*, 1997). Because of the susceptibility of many ornamental roses to RRD and *P. fructiphilus* (Tables 1 and 3), this work has been opposed by the American Rose Society and by rosarians in general (Obrycki, 1995; Philley, 1995; Peck, 2001; Pagliai, pers. comm.). However, augmentation research has provided valuable information on the potential spread of RRD. Experi-

Table 1. Occurrence of Rose Rosette Disease in Species (italics) and Ornamental Roses (varieties in bold are very susceptible) (alphabetical by species or variety, *R.* ignored).

***Rosa* species or Cultivar**	**Citation**	**Location**	**Susceptible (S), Resistant (R) or Tolerant (T)**
Alba Maxima	**19**	**Manassas, Virginia**	**S**
American Pillar (Rambler)	**18**	**Alabama**	**S**
R. arkansana Porter = *suffulta* Greene	1, 7, 8, 9	Nebraska	T
R. banksiae Aiton	15	Georgia	S
Belle of Portugal (CL)	6	California	S
Bibi Mazoon (SH)	15	Tennessee	S
Black Jade (HT)	11	Missouri	S
Bonica	13, 17, 18	Iowa	R (mites)
Buff Beauty (hybrid musk)	**18**	**South Carolina**	**S**
Cara Mia (HT)	10	West Virginia	S
R. canina	1, 7, 8, 9, 10	Nebraska (1,7)	S
		Manitoba (1)	S
		California (8,9)	S
		Indiana (10)	S
Cherry Meidiland (SH)	15	Tennessee	S
Chicago Peace (HT)	11, 14	Missouri	S
Chrysler Imperial (HT)	11, 17	Missouri, Iowa	S
Climbers	7	Nebraska	S
Color Magic	13	Iowa	S
Comtessa de Cayla	15	Alabama	S
Constance Spry (climbing shr.)	**18**	**Georgia**	**S**
Crystalline (HT)	15	Tennessee	S
Double Delight (HT)	15	Tennessee	S
Dr. Huey (CL)	15	Tennessee	S
R. dumetorum Thuill (= *corymbifera* Borkh.)	7, 8, 9	Nebraska	S
R. eglanteria	1, 7, 8, 9	Nebraska	S
R. eglanteria stock w/ hybrids	1	Nebraska	S
English Perfume (HT)	15	Tennessee	S
Europeana (FL)	15	Tennessee	S

Table 1. Occurrence of Rose Rosette Disease in Species (italics) and Ornamental Roses (varieties in bold are very susceptible) (alphabetical by species or variety, *R.* ignored) (continued).

***Rosa* species or Cultivar**	**Citation**	**Location**	**Susceptible (S), Resistant (R) or Tolerant (T)**
Etna	**19**	**Manassas, Virginia**	**S**
First Prize (HT)	**15**	**Tennessee**	**S**
Florabundas	1, 15	Nebraska	S
Fourth of July	15	Georgia	S
Fragrant Cloud (HT)	11	Missouri	S
Francisco Juranville	15	Alabama	S
French Lace (G)	11, 14	Missouri	S
R. gallica L.	1	Nebraska	S
Garden Party (HT)	11, 14	Missouri	S
	15	Tennessee	S
Gertrude Jeckyl (SH)	**15**	**Tennessee**	**S**
Gold Medal (G)	11, 12, 14	Missouri	S
Graham Thomas (Engl. R.)	11, 14	Missouri	S
Grandifloras	1	Nebraska	S
Great Scott (HT)	18	West Virginia	S
Gros Choux d'Hollande	19	Manassas, Virginia	S
Henri Martin	19	Manassas, Virginia	S
R. hugonis Hemsl.	1, 7, 8, 9	Nebraska	S
		California	S
Hybrid Teas	1	Nebraska	S
Hybrid Musk	18	Georgia	S
Ipsilante-Gallica	15	Tennessee	S
Irresistable (M)	**15**	**Tennessee**	**S**
Jean Camiole (M)	1	Missouri	S
Jeanne LaJoie (C-MR)	18	West Virginia	S
Jennifer Heart (HT)	11	Missouri	S
Kathleen Harrop	19	Manassas, Virginia	S
Lady Banksia (species rose)	18	South Carolina	S
La Noblesse	19	Manassas, Virginia	S
Loving Touch (M)	11	Missouri	S
Lynn Anderson	15	Tennessee	S

Table 1. Occurrence of Rose Rosette Disease in Species (italics) and Ornamental Roses (varieties in bold are very susceptible) (alphabetical by species or variety, *R.* ignored) (continued).

***Rosa* species or Cultivar**	**Citation**	**Location**	**Susceptible (S), Resistant (R) or Tolerant (T)**
Maiden's Blush	**19**	**Manassas, Virginia**	**S**
Mme Alfred Carriere (noisette)	**18**	**Alabama**	**S**
Mary rose	15	Alabama	S
Mermaid	15	Alabama	S
Mons.Tillier	15	Texas	S
R. montezumae Hum. & Bonpl.	7,8	California	S
Mr. Lincoln (HT)	11,14	Missouri	S
R. multiflora Thunb.	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 18	Arkansas (4)	S
		California (6,8,9)	S
		Georgia (18)	S
		Illinois (10)	**S**
		Indiana (10)	S
		Kentucky (10)	S
		Missouri (2,3)	S
		Nebraska (1,7)	S
		Oklahoma (2)	S
		Tennessee (15)	S
		Texas (15)	S
		West Virginia (10)	S
Napoleon	15	Alabama	S
New Dawn	15	Alabama	S
	19	Washington (D.C.)	S
***R. nutkana* Presl.**	**6**	**California**	**S**
R. odorata (Andr.) Sweet.	6	California	S
Old Blush Climber	15	Alabama	S
Old Fashioned Roses	7	Nebraska	S
Olympiad	14	California?	S

Table 1. Occurrence of Rose Rosette Disease in Species (italics) and Ornamental Roses (varieties in bold are very susceptible) (alphabetical by species or variety, *R.* ignored) (continued).

***Rosa* species or Cultivar**	**Citation**	**Location**	**Susceptible (S), Resistant (R) or Tolerant (T)**
Ornamental Roses	**2, 3, 4, 6, 15**	**Alabama (15)**	**S**
		Arkansas (4)	**S**
		California (6)	S
		Georgia (15)	S
		Kansas (2)	S
		Missouri (2, 3)	S
		Oklahoma (2)	S
		Tennessee	S
		Texas (15)	S
		Virginia (15)	S
Othello (Engl. Rose)	**11, 14**	**Missouri**	**S**
Peace	17	Iowa	S
Perfume Delight (HT)	15	Tennessee	S
Petite Orleanaise	19	Manassas, Virginia	S
Pink Peace (HT)	11, 14	Missouri	S
R. pisocarpa Gray	6	California	S
Properity	18	Georgia	S
Ragged Robin (China Rose)	6	California	S
Red Cascade (CM)	15	Georgia	S
Red Meidiland	13, 14	Missouri	S
Rina Hugo (HT)	15	Tennessee	S
Rose de Rescht (PT)	**15**	**Tennessee**	**S**
R. rubrifolia Vill.	6, 7, 8, 9	California (6-9)	S
		Wyoming (6)	S
Salet	19	Manassas, Virginia	S
Seven Sisters (hybrid multifl.)	15	Tennessee	S
Simply Irresistable (FL)	15	Tennessee	S
R. soulieana Crep.	1	Nebraska	S
R. spinosissima var. *altaica* (L.) Rehd.	1,8,9	Nebraska (1)	S
		California (8, 9)	S

Table 1. Occurrence of Rose Rosette Disease in Species (italics) and Ornamental Roses (varieties in bold are very susceptible) (alphabetical by species or variety, *R.* ignored) (continued).

Rosa species or Cultivar	Citation	Location	Susceptible (S), Resistant (R) or Tolerant (T)
Starry Night (shrub rose)	**18**	**South Carolina**	**S**
Sun Flair (G)	**11,14**	**Missouri**	**S**
The Bishop	19	Manassas, Virginia	S
The Fairy (P)	15	Tennessee	S
The Squire (SH)	18	West Virginia	S
Turner's Crimson Rambler	15	Tennessee	S
Veteran's Honor (HT)	15	Tennessee	S
R. villosa L. (= R. *pomifera* J. Herrm.)	7, 8, 9	Nebraska (1, 7)	S
		California (8,9)	S
White Masterpiece (HT)	18	West Virginia	S
***R. wichurana* Crépin (RB)**	**15**	**Tennessee**	**S**
William Lobb	19	Manassas, Virginia	S
R. woodsii Lindl.	1,7,8,9	Nebraska (1, 7)	T
		California (8, 9)	S
R. woodsii var. *ultramontana* (Wats.) (= *R. gratissima* Greene)	5, 8, 9	California	S
Resistant Species, Varieties			
R. arkansana Porter	16	Iowa	R
R. blanda Aiton	16	Iowa	R
R. californica Cham. & Schon.	6	California	R
R. palustris Marsh.	10	West Virginia	R
R. setigera Michx.	10, 16	West Virg., Iowa	R
***R. spinosissima* L.**	**6, 7**	**Nebraska (7)**	**R**
		California (6)	R

Citations: 1) Allington *et al.*,1968, 2) Crowe, 1983, 3) Doudrick and Millikan, 1983, 4) Gergerich and Kim, 1983, 5) Keifer, 1966, 6) Thomas and Scott, 1953, 7) Viehmeyer, 1961, 8) Wagnon, 1966, 9) Wagnon, 1970, 10) Amrine *et al.*, 1995, 11) Finkes, 1991, 12) Worden, 1988, 13) Epstein and Hill, 1998, 14) Sauer, 2001, 15) Peck, 2001, 16) Epstein and Hill, 1994, 17) Epstein and Hill, 1999, , 18) Peck 2002, 19) Higgins 2001.

Abbreviations: CL = Large-flowered climber, CM = Climbing miniature, Engl. R. = English rose, FL = Floribunda, G = Grandiflora, HT = Hybrid Tea, M = Miniature, P = Pollyanna, PT = Portland rose, RB = Rambler, SH = Shrub; R = Resistant, S = Susceptible, T = Tolerant.

Table 2. List of Plants Tested for Susceptibility to Infection by Rose Rosette Disease.

Thomas & Scott, 1953	*Holodiscus discolor*	Cream Bush (grafting only)
	Fragaria chiloensis	Beach Strawberry
	Prunus ilicifolia	Holly-leaved Cherry
Doudrick, 1984	*Malus pumila*	Apple (grafting only)
	Prunus besseyi	Sandcherry
	P. persica atropurpurea	Peach
	P. serrulata	Japanese Cherry
	P. tomentosa	Nanking Cherry
	Pyrus communis	Pear
	Cydonia oblonga	Common Quince
	Gomphrena globosa	(Amaranthaceae)
	Vinca rosea	(Apocynaceae)
	Chenopodium quinoa	(Chenopodiaceae)
	Cucurbita pepo	(Cucurbitaceae)
	Cucuminus sativus	(Cucurbitaceae)
	Phaseolus vulgaris	(Leguminaceae)
	Vigna unguiculata	(Leguminaceae)
Amrine *et al.*, 1990, 1995	*Malus x-domestica*	Apple
	P. persica atropurpurea	Peach
	Fragaria virginiana	Strawberry
(grafting and challenged with	*Rubus sp.*	Blackberry and Raspberry
P. fructiphilus grown on RRD	*Sorbus americana*	Mountain Ash
symptomatic *R. multiflora*)	*Pyrus communis*	Pear
	Prunus avium	Cherry
	Prunus communis	Plum
	Prunus serotina	Black Cherry
	Prunus armeniaca	Apricot

Results: NONE of the above plants were successfully infected with RRD; Amrine and Stasny (unpublished) showed that back grafts were negative.

Table 3. Rosaceous Pants Tested for host preference/acceptance by *Phyllocoptes fructiphilus* and *Phyllocoptes adalius*

Plant Species	Common Name	P. fructiphilus*	P. adalius*
COMMERCIAL FRUIT:			
Fragaria virginiana	**Strawberry**	**0**	**0**
Malus x-domestica	Apple	0	1
Prunus armeniaca	Apricot	0	1
P. avium	Cherry	1	1
P. domestica	Plum	0	0
P. persica	Peach	1	1
Pyrus communis	Pear	0	0
***Rubus* sp.**	**Wild Blackberry**	**0**	**0**
Rubus sp.	Cultivated Blackberry	0	0
Rubus sp.	Wild Raspberry	0	0
ORNAMENTAL TREES:			
Prunus serotina	Black Cherry	0	1
Sorbus americana	Mountain Ash	0	1
SPECIES ROSES:			
Rosa bracteata	McCartney Rose	1	2
R. canina	Dog Rose	2	2
R. carolina	Pasture Rose	1	2
R. fendleri	Wild Rose-Midwest	2	2
R. multiflora	Multiflora Rose	2	2
R. palustris	**Swamp Rose**	**2**	**2**
R. setigera	Prairie Rose	2	2
R. woodsii	Mountain Rose	2	2
ORNAMENTAL ROSES:			
	'Cherish' (florabunda)	2	2
	'Climbing Blaze' (climbing rose)	2	2
	'Headliner' (hybrid tea)	2	2
	'Orange Sunblaze' (miniature)	2	2
	'Queen Elizabeth' (grandiflora)	2	2
	'Red Rascal' (shrub rose)	2	2

0- mites lived less than 3 days (unsuitable).
1- mites lived for a week without laying eggs (unsuitable).
2- mites laid eggs (suitable).

mental increase of the rose seed chalcid was successful in West Virginia; infestation increased in one season from 3.2 to 77.5% (see section on multifloral rose seed chalcid under Biology and Ecology of Key Natural Enemies).

BIOLOGY AND ECOLOGY OF KEY NATURAL ENEMIES

Four agents have been found in the United States that show potential for biological control of multiflora rose. These are a "virus" that causes rose rosette disease, an eriophyid mite (*P. fructiphilus*) that transmits this virus, a seed chalcid (*M. aculeatus* var. *nigroflavus*) that lays its eggs in rose hips and whose larvae feed on immature seeds, and a stem girdler (*Agrilus aurichalceus aurichalceus* Redtenbacher [Coleoptera: Buprestidae]) that kills multiflora rose canes.

Rose Rosette Disease and *Phyllocoptes fructiphilus* Keifer (Acari: Eriophyidae)

Rose rosette disease was first found in California, Wyoming, and Manitoba, Canada in 1941. It was found to occur on ornamental roses and on *Rosa woodsii* Lindl., the common rose in Rocky Mountain uplands and the western plains from Minnesota to British Columbia, south to California, Arizona, and Mexico (Liberty Hyde Bailey, 1976). Rose rosette disease produces symptoms in *R. woodsii* but does not kill the plant (Allington *et al.*, 1968). It was found in Nebraska in 1961 (Viehmeyer, 1961), in Kansas in 1976, in Missouri in 1978, and in Arkansas and Oklahoma in 1982 (Crowe, 1983). It was found in Kentucky and Indiana in 1986 (Hindal et al., 1988). Brown (1995) published a U.S. map showing RRD's known distribution as far east as Ohio, Pennsylvania, Tennessee, and West Virginia in 1994. This native pathogen has caused a fatal epidemic in *Rosa multiflora* from the Great Plains as far east as Berks County, Pennsylvania and Queen Annes County, Maryland, in the Delmarva peninsula (Fig. 2) (Amrine and Stasny, 1993; Epstein and Hill, 1995a, 1999).

Rose rosette disease is a mite-transmitted, graftable "virus" that produces fragments of double-stranded RNA in rose tissue (Frist, pers. comm.; Di *et al.*, 1990; Hill *et al.*, 1995). Various structures found in electron microscope micrographs have been tentatively identified as the agent (Gergerich and Kim, 1983), but none have been conclusively proven to be the agent. It has not yet been taxonomically characterized (Epstein and Hill, 1999). Symptoms of RRD in multiflora rose include red, purplish or dark green veinal pigmentation (Fig. 3); production of bright red lateral shoots (Fig. 4); enlarged stems and stipules; dense, yellowish, dwarfed foliage; and premature development of lateral buds producing many compact lateral branches forming "witches' brooms" (Figs. 5 and 6) (Amrine and Hindal, 1988; Epstein *et al*,. 1993; Epstein and Hill, 1999). Symptomatic canes are cold sensitive and usually die at temperatures below -10°C. Symptoms on ornamental roses include a yellow mosaic pattern on leaves, greatly increased thorniness of stems (Fig. 7), clumped and wrinkled foliage, and witches' brooms; however, the bright red lateral shoots and vein mosaic seen in multiflora rose do not usually occur except on a few varieties (Thomas and Scott, 1953; Allington *et al.*, 1968; Amrine and Hindal, 1988; Epstein *et al.*, 1993; Epstein and Hill, 1998, 1999,).

Rose rosette disease is transmitted by the eriophyid mite, *P. fructiphilus* (Figs. 8, 9, and 10), which develops in high numbers on shoots of RRD-infected multiflora roses and other rose species (Amrine *et al.*, 1988). *Phyllocoptes fructiphilus* was first described from *Rosa californica* Cham. et Schlechtend. in California by Keifer (1940). Since that date, it often has been found associated with RRD in roses throughout the United States (Amrine and Stasny, 1993; Epstein and Hill, 1994b; Epstein and Hill, 1995a, 1999; Amrine *et al.*, 1995; Amrine,1996). The mite often occurs in the absence of the virus, producing no visible symptoms on rose plants. It only develops on tender, rapidly growing tissue and is aerially disseminated (Zhao 2000). Doudrick (1984) and Doudrick et al. (1983) claimed that *Phyllocoptes fructiphilus* could not transmit RRD to multiflora roses. They conducted transmission tests by transferring mites from field collected symptomatic plants onto the foliage of greenhouse plants. Amrine *et al.* (1988) conducted transmission tests on large plants trimmed to the crown, transplanted to greenhouse mist beds and obtained 100% transmission in 17 days when mites were applied to the tips of new, rapidly growing shoots. These experiences show that transmission can be very difficult if mites are applied to older, slower growing plants; it also probably explains the slow rate of spread of RRD since 1989, since most of West Virginia has endured varying states of drought since that time. Return of moister conditions may result in more rapid spread of RRD.

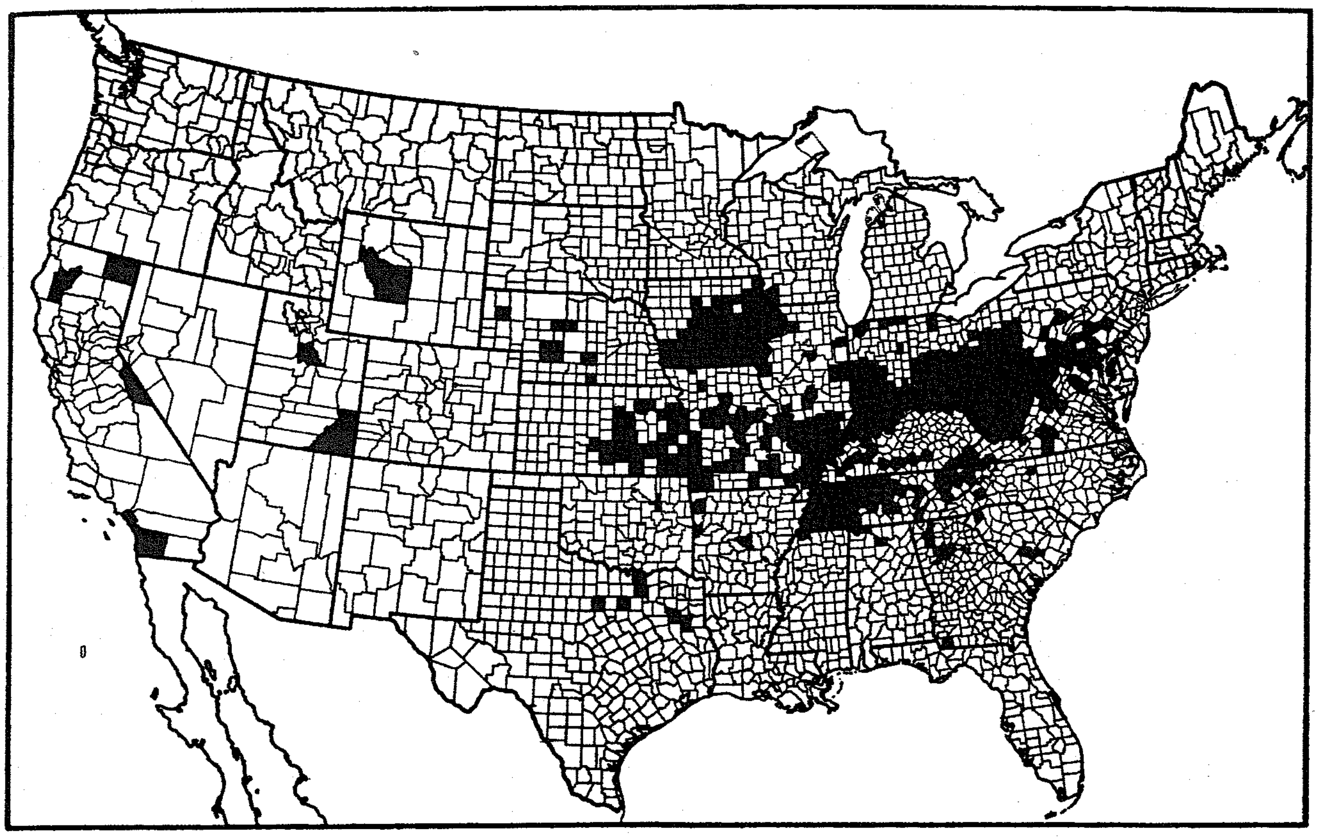

Figure 2. Map of the known distribution of Rose Rosette Disease in the USA; Virginia data from A. Boudoin (2002), J. Amrine, and A. Peck (2002); Maryland data from Tipping & Sindermann (2000), and J. Amrine; data for North Carolina, South Carolina and Georgia from A. Peck (2002).

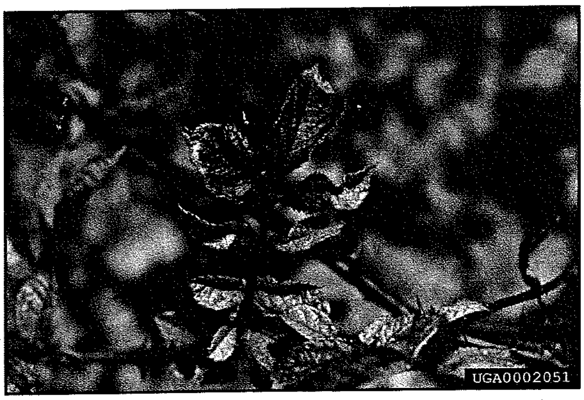

Figure 3. Rose rosette; irregular reddening of leaf caused by RRD. (Photograph by Jim Amrine.)

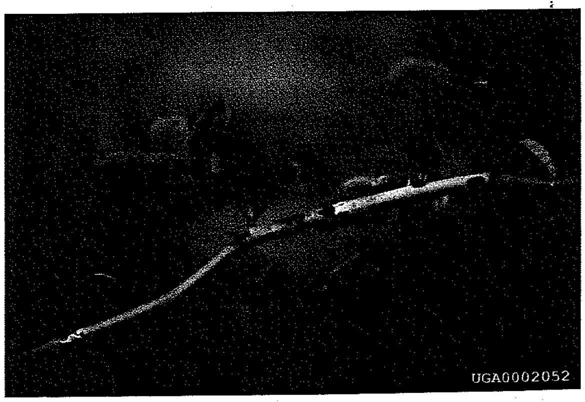

Figure 4. Bright red RRD shoots emerging in the spring. (Photograph by Jim Amrine.)

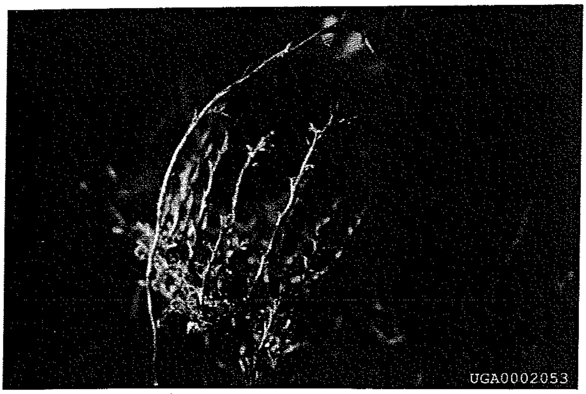

Figure 5. Witches broom of RRD (yellow stems) on multiflora rose, heavily affected by powdery mildew. (Photograph by Jim Amrine.)

Figure 6. RRD-symptomatic inflorescence (red pannicle) on multiflora rose,accompanied by normal flowers on healthy foliage (a separate plant) (Photograph by Jim Amrine.)

Figure 7. Cara-Mia ornamental rose: diseased stem on left with an enlarged thorny stem; normal stem and flower on right (Photograph by Jim Amrine.)

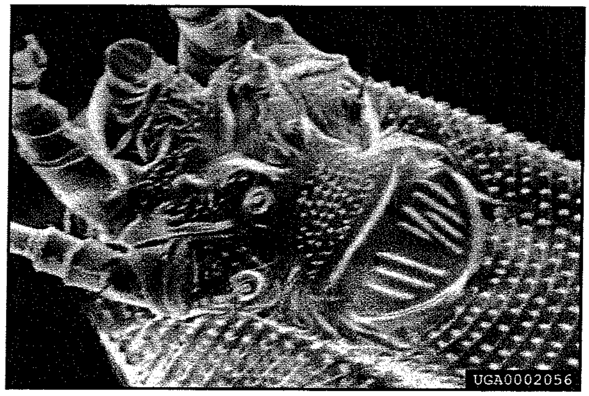

Figure 8. *Phyllocoptes fructiphilus,* ventral surface near head end as seen by the scanning electron microscope; the mite is about 50 microns wide at the genital coverflap. (Photograph by West Virginia University Anatomy Department.)

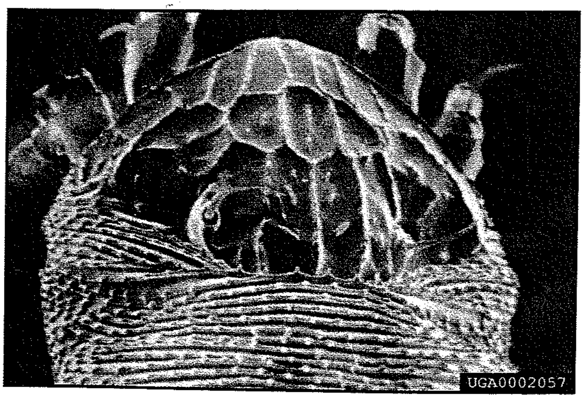

Figure 9. *Phyllocoptes fructiphilus,* dorsal shield of female showing the distinctive pattern that identifies this mite (SEM) (Photograph by West Virginia University Anatomy Department.)

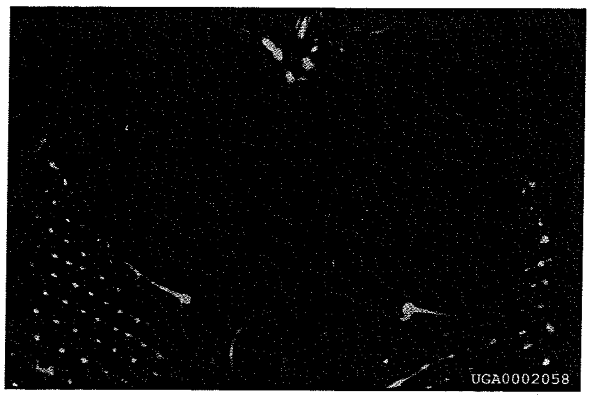

Figure 10. *Phyllocoptes fructiphilus,* dorsal shield of female as seen in the light microscope, using phase contrast microscopy. (Photograph by Jim Amrine.)

Phyllocoptes adalius Keifer is a mite very similar to *P. fructiphilus* and also occurs on many roses in the eastern United States; *P. adalius* occurs as a vagrant, usually on the underside of mature leaf blades of many species and varieties of roses. It has been thoroughly tested as a vector, but can not transmit RRD (Kharboutli, 1987; Kassar and Amrine, 1990; Amrine *et al.*, 1995). Rose rosette disease was first found in West Virginia in 1989, and spread throughout the state by 2000 (Brown and Amrine, unpub.). Several predators, a parasitic fungus, and drought appear to have affected field populations of *P. fructiphilus* in West Virginia and may have slowed the spread of RRD.

Rose rosette disease can also be transmitted by grafting, and experiments in Iowa have shown that this approach can be used to augment the virus in dense stands of multiflora rose (Epstein and Hill, 1994b; Epstein and Hill, 1995b, 1995d, 1998, 1999; Epstein *et al.*, 1997). Obrycki *et al.* (2001) are conducting new trials of RRD releases and augmentation in southern Iowa to reduce multiflora rose in pastureland. They indicate that releases will not be made in areas with ornamental roses. Much of this work has been opposed by the American Rose Society and by rosarians in general (Harwood, 1995; Obrycki, 1995; Philley, 1995; Peck, 2001; Sauer, 2001; Pagliai, pers. comm.). However, augmentation research by Epstein *et al.* has provided valuable information on the potential spread of RRD from multiflora to ornamental roses.

Mites overwinter as adult females on living, green rose tissue (Amrine and Hindal, 1988; Amrine *et al.*, 1995). In early spring, the mites move from wintering sites (clumps of overwintering foliage, loose bark on live stems, old or loose bud scales, etc.) onto developing shoots to lay eggs. A favorite oviposition site is between the stem and basal petiole of young leaves appressed to stems. Females live about 30 days and lay about one egg per day. Eggs hatch in three to four days and the development of each immature stage (protonymph and deutonymph) requires about two days (Kassar and Amrine, 1990; Kassar, 1992). Thus, in warm weather, one generation may be produced per week. Development is continuous throughout the season until weather turns cold in the fall and mites seek protective wintering sites on the plants. Overwintering mites will die if host canes die, as they require green stem or leaf tissue.

In May, 1987, Amrine *et al.* (1990) began a long-term study at Clifty Falls State Park in Madison, Indiana. The site was heavily infested with both healthy and RRD-symptomatic multiflora roses. A total of 180 multiflora rose plants were marked and visited monthly during the growing season for the next five years. The initial average density was 1,200 plants per acre and, at the beginning of the study, 30% of plants were symptomatic and 1% had been killed by RRD. The infection increased each year and leveled off to 94% by September 1991 with a mortality of 88%. The average longevity of infected plants was 22.4 months (range three to 48 months). Mite populations were 14 times larger on symptomatic plants compared to healthy plants in 1987 and 1988. Mite populations were low and sporadic in April and gradually increased to peak abundance by September in most years. At peak abundance, nearly all RRD-symptomatic plants (98%+) were infested with mites. The average number of mites per symptomatic shoot in September of each year (1987 to 90) was 112, 30, 112, and 6.6 respectively (mite density on healthy plants was usually below 10 per shoot). The low average number in 1988 (30) resulted from a severe drought that killed mites on desiccated foliage. The low fall density in 1990 (6.6) resulted from unusually cold weather in December 1989 (-31°C), which killed nearly all above ground RRD-symptomatic canes and thus killed most of the overwintering mites. By the end of the study (1994), 97% of the marked plants were dead or symptomatic and the density of live multiflora roses had dropped to about 800 per acre, many of which were new, small plants.

As of 2001, RRD was present in multiflora roses in all counties in West Virginia and was found as far east as Berks County, Pennyslvania, Queen Anne and Talbot Counties, Maryland and Manassas Battlefield, Virginia (Fig. 2). The disease is probably present in Delaware, New Jersey, New York, and other eastern states. It is likely that RRD will be present throughout the eastern United States within ten years. RRD will have a very significant effect on multiflora rose populations, potentially reducing numbers by 90% or more throughout the region. In each local area, the RRD epidemic is likely to continue until multiflora rose stands are killed. Young seedlings will then sprout and reach moderate size before RRD again reinfects the stand. In Madison, Indiana, for example, a survey in 1994 found that while more than 97% of the original large plants had died of RRD, the infection rate of the abundant, newly sprouted plants was only 20 to 25%. The low percent infection rate reflects the slow build up of the infection in new plants. A visit to Clifty Falls State Park on 26 May 2002 revealed an estimated density of 200-400 multiflora roses per acre with an infestation of 60% RRD. Much of the original grassland has become early stage forest, which will shade future germinating seed and the resulting plants. As another example, RRD was first discovered in Monongalia County, West Virginia in 1989; as of July 2001, the average infection rate throughout the county was 10 to 20%. We expect to see infection rates equivalent to Madison, Indiana (30%) within five more years.

A serious limitation to the use of RRD as a biological control agent is its ability to infect ornamental roses. Many species and varieties of roses are susceptable to the vector and to RRD (Tables 1 and 3). However, other plants in the Rosaceae have been found to be immune to the RRD agent (Table 2). Rose breeders and gardeners throughout the eastern United States will need to reduce local stands of multiflora rose for a one or two mile radius in order to lower the risk of infestation by airborne mites, which transmit RRD. Thomas and Scott (1953), Allington *et al.* (1968), Amrine *et al.* (1995), and Epstein and Hill (1998, 1999) listed varieties and cultivars of ornamental roses that are particularly susceptible to RRD and its vector (also, see listings in bold type in Table 1). Avoiding planting of these varieties can help reduce injury to adjacent ornamental roses. Peck (2001) listed Cygon 2E (citing work by Dr. George Philley, Plant Pathologist, Texas A&M, Overton, Texas) as a treatment for protecting ornamental roses; other chemicals such as Avid (abamectin) may prove effective in controlling the mites. Thomas and Scott (1953), Allington *et al.* (1968), and Amrine *et al.* (1995) discussed varieties of roses resistant to RRD. This information can be used to incorporate resistance into new rose varieties.

Multiflora Rose Seed Chalcid, *Megastigmus aculeatus* var. *nigroflavus* Hoffmeyer (Hymenoptera: Torymidae)

The multiflora rose seed chalcid (*M. aculeatus* var. *nigroflavus*) is a light, yellowish-brown, small torymid (chalcidoid) wasp about 2 to 3 mm long (Fig. 11). It was reported in the United States from New Jersey in 1917, where it caused high mortality of multiflora rose seed imported from Japan for rootstock for ornamental roses (Weiss, 1917). Milliron (1949) reported that the rose seed chalcid was established in several mid-Atlantic states. Scott (1965) found large numbers of the rose seed chalcid at the Patuxent National Wildlife Refuge near Washington D.C. with infestation rates as high as 95%. Mays and Kok (1988) surveyed for the multiflora rose seed chalcid in Virginia in 1985 and 1986 and found average infestation rates of 26.5% (range of 2 to 59%) and 23.9% (range of 2 to 52%). Nalepa (1989) found the chalcid throughout North Carolina; with an average infestation rate of 63%. She also found two possible parasites of the seed chalcid in low numbers, *Eurytoma* sp. (Hymenoptera: Eurytomidae) (n=11) and *Eupelmus rosae* Ashmead (Hymenoptera: Eupelmidae) (n=4), out of 4,295 chalcids reared. Amrine and Stasny (1993) surveyed multiflora rose seed (Figs. 12 and 13) in West Virginia in 1984 and 1985 and found an average of 49.7% (range 0 to 100%) of viable seed infested with the chalcid. A survey of 16 sites from Maryland, Missouri, Oklahoma, Pennsylvania, Tennessee, Texas, and Virginia in 1984 to 1985 found an average infestation rate of 46.7 % (range of 0 to 95%).

The seed chalcid oviposits in the developing receptacle just after petal-fall in June (Fig. 14). Eggs hatch and larvae (Fig. 15) develop in the ovules beginning in mid-August, consuming and killing the seeds. Larvae mature in late September and enter diapause. In winter, larvae may die if exposed to temperatures below -20°C for 12 hours, and mortality reaches 20 to 80% if temperatures fall below -26°C for more than 24 hours. Seed chalcids in rose hips near the ground and in other protected sites survive low temperatures better than those in hips on exposed canes. Larvae in scattered seeds on the ground survive low winter temperatures if the ground is covered by snow. By late May, larvae transform to pupae. At about petal fall (early to mid-June in West Virginia), adult wasps chew their way out of the seed, emerge, mate and begin oviposition into immature rose hips. Most females are parthenogenic but will mate if males are available. The sex ratio was 0.5% males or about one male to 200 females.

Shaffer (1987) found that seed chalcids have limited ability to fly to newly established rose plantings. Most dispersal is by movement of infested seed by birds; seed chalcids rapidly pass the gut unharmed if

Figure 11. The multiflora rose seed chalcid, *Megastigmus aculeatus* var. *nigroflavus* Hoffmeyer; three females in a dissecting tray; the left female is about 2 mm long. (Photograph by Jim Amrine.)

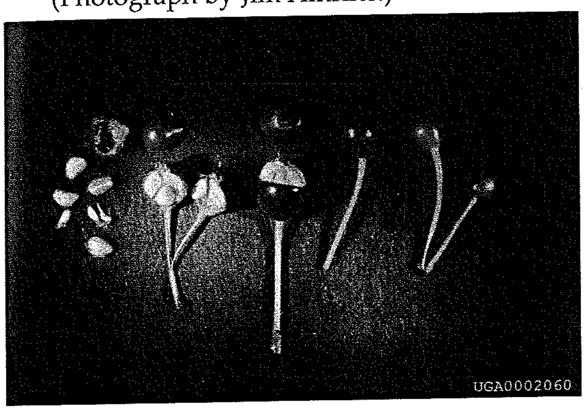

Figure 12. Hypanthia or hips of multiflora rose. (Photograph by Jim Amrine.)

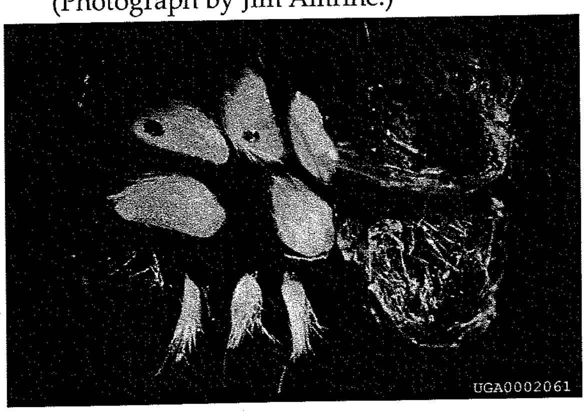

Figure 13. A dissected hip of multiflora rose: the *soft* fruit shell is on the right (typical of mid-November), five normal-sized seed are at the upper left, and three dwarf seed, representing unpollinated ovules at the lower left; note the abundant, sharply tapered fibers that are always present in the hip; they irritate the digestive tract of song birds, causing the seed to move quickly through the gut in just a few hours. (Photograph by Jim Amrine.)

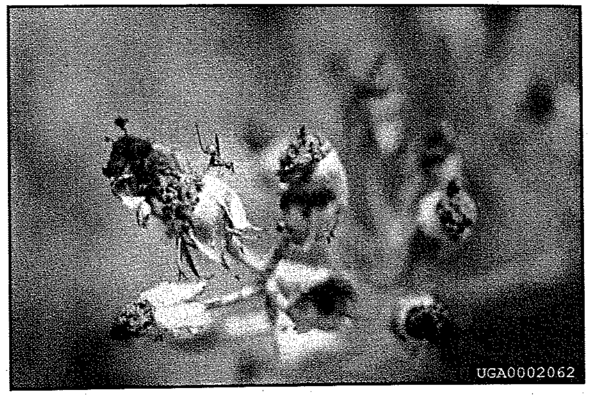

Figure 14. Ovipositing female rose seed chalcid, inserting her ovipositor near the edge of the dried inflorescence. (Photograph by Jim Amrine.)

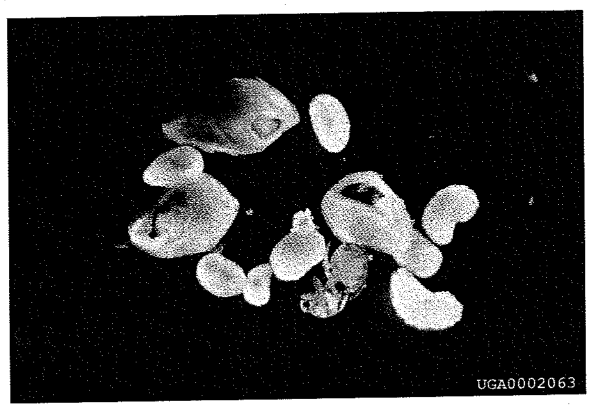

Figure 15. Dissected seeds showing larvae and a pupa of the chalcid that were inside (May). (Photograph by Jim Amrine.)

the seed are eaten by song birds such as robins and mockingbirds (Balduf, 1959; Lincoln, 1978; Nalepa, 1989, Amrine unpubl.). Multiflora roses planted in the eastern United States were set out as rooted cuttings, not planted from seeds. Thus chalcids were not disseminated when plants were initially established. Two or three decades are likely to be required, without active dissemination by humans, before the seed chalcid reaches all multiflora rose stands in the eastern United States.

Research suggests that the seed chalcid can quickly infest multiflora rose stands once it has reached them. For example, in 1988 two 30m rows of multiflora roses, each containing 50 plants, were set out as rooted cuttings in test plots in West Virginia. The plants first bloomed in 1989 and produced abundant seed in 1990 and 1991 (12 samples; 20 hips each produced an average of 125.3 seed per sample; 90.3% were viable). In November 1991, 3.2% (range of 0 to 14%) of seeds in the plot were infested with seed chalcids. Multiflora roses growing within 500 m of the plot had an infestation rate of 74.1% (range of 64 to 79%). The seed chalcids likely had reached the new plantings in droppings of birds that fed on the hips produced in 1990. In fall 1991, numbers of seed chalcids in the plot were augmented by placing about 1,500 rose hips (average of seven seeds per hip), which had an infestation rate of 79%. In December 1992, the seed infestation rate in the plot reached 77.5% (20 samples; 20 hips each; range of 57 to 93%).

Suggestions that this seed chalcid will infest the seed of other roses seem unfounded. Torymid infestation of seeds of *R. setigera, R. palustris, R. carolina*, or *Rosa canina* L., in our study sites over the past 15 years have not been observed. Balduf (1959) reported rearing a dark form of *Megastigmus aculeatus* from *Rosa eglanteria* and *R. virginiana*; these were not reported to be *Megastigmus aculeatus* var. *nigroflavus* Hoffmeyer. Only *R. multiflora* seems to be susceptible, either because of timing of bloom (late May to early June for multifloras in West Virginia versus July for the others), or because the fruits of other roses are too large or thick for the chalcids' ovipositors to penetrate. Of 31 states in the eastern United States sampled by the author, the chalcid was found in all except Florida, Louisiana, Mississippi, Texas, and northern New England. It will continue to spread by feeding birds until all stands of multiflora roses are infested. Weiss's report (1917) about seed from Japan having 95% infestation indicates the probable potential for this seed chalcid to infest the seed of multiflora rose.

It is virtually certain that RRD will greatly reduce the density of multiflora rose. No multifloras have been found that are resistant to the disease (Amrine *et al.*, 1990, Amrine and Stasny,1993; Epstein and Hill, 1998). The reduced populations of multiflora rose remaining after the RRD epidemic are likely to be infested by the seed chalcid at the same rate (90 to 95%) as plants in Korea and Japan. Multiflora rose will then be another occasional plant in the environment, and not the noxious weed that it is today. We estimate that this scenario will transpire within the next three to five decades. Farmers and others wanting eradication of multiflora rose desire human intervention to increase the rate of spread of the disease, the mite and the torymid into uninfested areas. However, rosarians desire that all augmentation work with RRD and the mite cease.

Rose Stem Girdler, *Agrilus aurichalceus* Redtenbacher (Coleoptera: Buprestidae)

Synonyms for this species include *Agrilus viridis* L., *Agrilus viridis* var. *fagi* Ratz., *Agrilus communis* var. *rubicola* Abeille, *Agrilus rubicola* Abeille, and *Agrilus politus* Say. Many reports of this insect in *Rubus* (brambles) were made under the name *Agrilus ruficolis* (Fabricius), the red-necked cane borer, whose symptoms are nearly identical. The two beetles are distinctive and easily separated. This small brownish-golden, metallic buprestid beetle is about 5 to 9 mm long (Fig. 16). It is a non-indigenous species from Europe that has been established throughout eastern North America and is abundant at several sites in Delaware, Indiana, Maryland, Ohio, Pennsylvania, Virginia, and West Virginia. It caused a small degree of control of multiflora rose in Ohio and West Virginia (Amrine and Stasny, 1993). All plant tissue beyond the point where the stem is girdled was killed, including developing rose hips and seeds. Borers overwinter in the previous year's canes, pupate in April, and emerge as adults in May. Douglas and Cowles (2001) state that development may require two seasons, which is contrary to all other reports. Adults can be found on multiflora rose foliage in sunny mornings. Females oviposit on the bark of new canes in May and June. Larvae hatch and burrow under the bark, moving upward from the oviposition site (Fig. 17). The initial burrowing does not kill the cane but by late July the infested stems begin to wilt, and by August-September, canes beyond the girdle die and appear as brown "flags" on rose bushes (Figs. 18-19.)

The largest infestation we observed was a site with 20% of canes infested (Fayette County, Ohio, 1988). Large numbers of larvae were found to be parasitized; 22 parasitic wasps emerged from 45 canes held for the emergence of 23 beetles. These parasites were *Ptinobius magnificus* (Ashmead) (Pteromalidae)(determined by E. E. Grissell), *Eurytoma magdaldis* Ashmead (Eurytomidae) (new host record, determined by E. E. Grissell), *Leluthia astigma* (Ashmead) (Braconidae) (determined by P. M. Marsh), *Metapelma schwarzi* (Ashmead) (Eulophidae) (new host record, determined by M. E. Schauff), and *Tetrastichus agrili* Crawford (Eulophidae) (determined by M. E. Schauff). The last was most abundant. Because of relatively low inci-

Figure 16. The rose stem girdler, *Agrilus aurichalceus aurichalceus*; a mating pair on a multiflora rose leaflet (May); the male is the smaller, upper beetle. (Photograph by Jim Amrine.)

Figure 17. A girdled multiflora rose cane caused by the larva of the rose stem girdler (August); the oviposition site is at the right edge of the girdle; the cane will probably die distal to the girdle. (Photograph by Jim Amrine.)

Figure 18. A 'flag' or dead stem caused by the break of a cane at the girdle produced by the rose stem girdler (August) (Photograph by Jim Amrine.)

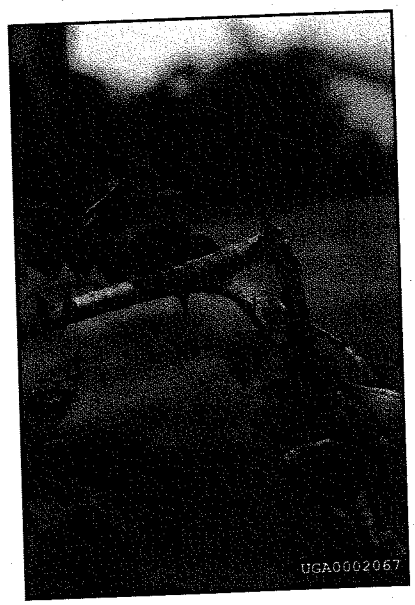

Figure 19. Close up of girdle and broken cane caused by the rose stem girldler. (photograph by Jim Amrine.)

dence and high parasitization, we believe that this insect will have only minor importance as a biological control agent of multiflora rose.

Amrine and Stasny (1993) found girdled rose stems on *Rosa multiflora* only. Douglas and Cowles (2001) report that it occurs on *R. rugosa* and *R. hugonis* in Connecticut. *Agrilus aurichalceus aurichalceus* often was found attacking canes of *Rubus* (blackberries, raspberries, brambles) (Hutson, 1932; Mundinger, 1941; Davis, 1963). Brussino and Scaramozzino (1982) reported it attacking *Rubus fruticosus* L., *Rubus caesius* L., and *Rosa idaeus* L. in Piedmont, Italy, where it also attacked *Rosa alpina* L., *R. canina*, *Rosa damascena* Mill., and *R. rugosa* . It has also been listed as attacking *Ribes*, *Grossularia*, *Crataegus*, and *Prunus* in North America and Europe (Garlick, 1940; Rejzek, 2001); however, these records are in error, and probably represent different species of *Agrilus* (Brussino and Scaramozzino, 1982).

EVALUATION OF PROJECT OUTCOMES

Establishment and Spread of Agents

All four agents have been well established in the eastern United States and should eventually be found in all dense stands of the weeds. Rose rosette disease and *Phyllocoptes fructiphilus* have been found as far east as Berks County, Pennsylvania, Queen Anne and Talbot Counties, Maryland, and Manassas Battlefield, Virginia. Careful surveys would probably find both agents as far east as New Jersey and southern New York. The rose seed chalcid has been found in 30 eastern states, and it probably is found in all regions where multiflora rose has become established. The rose stem girdler also is found in most areas of eastern North America and in Utah.

Suppression of Target Weed

Amrine *et al.* (1990) showed that RRD and *P. fructiphilus* have excellent potential to reduce multiflora rose. Rate of infection of 180 marked plants in Clifty Falls State Park increased from 30% in 1986 to 94% in 1990. Mortality of marked roses increased from 2% to 94% in the same period. However, germination by the vast seed burden replaces most roses killed by RRD. When seed chalcids significantly infest multiflora seed, then reduction will become apparent. This RRD epidemic has now reached equivalent levels in many parts of West Virginia, and it is expected that in the next decade, similar reduction of dense stands of multiflora rose will occur. The rate of infestation of the rose seed chalcid is increasing in all areas surveyed. In some areas of West Virginia, rates of seed infestation now exceed 80% (Amrine, unpub.).

Recovery of Native Plant Communities

In Clifty Falls State Park, multiflora rose was not replaced by native plant species, but by another invasive exotic plant, Japanese honeysuckle (*Lonicera japonica* Thunb.). This weed has covered nearly all of the old dead roses and has invaded nearly every part of the park (as of 1994). In many areas of West Virginia, multiflora rose has been replaced by the noxious weeds, Tatarian honeysuckle (*Lonicera tatarica* L.), autumn olive (*Elaeagnus umbellata* Thunb.), Japanese honeysuckle, and Japanese knotweed (*Polygonum cuspidatum* Siebold et Zucc.). If the alien invasive weeds can be controlled or eliminated, then native vegetation should recover.

Economic Benefits

Millions of dollars now spent annually by farmers in many eastern states to control multiflora rose will be saved when the plant is eventually controlled. In West Virginia, during 1980 and 1981, more than 36,500 hectares were heavily infested with multiflora and a ten-year eradication program using herbicides was estimated to cost more than $40 million (Williams and Hacker, 1982). The same or increased acreage is now infested, and allowing for inflation this cost has probably doubled. However, monetary savings will be slow to develop because of the slow natural spread of both the epidemic and biological control agents.

RECOMMENDATIONS FOR FUTURE WORK

Much work remains to be done to survey for the distribution and intensity of infection/infestation of RRD and *P. fructiphilus* in multiflora roses. The RRD epidemic in multiflora rose stands is expected to increase greatly over the next few decades. Studies and data are not available showing potential recovery of pastureland/farmland and savings involved; this work should be done in areas where significant mortality due to RRD has occurred (Missouri, Illinois, Indiana). Dense stands of multiflora rose will need to be controlled to prevent infection of ornamental roses with RRD. To quote R. Hartzler, "reduction of multiflora rose densities should be a common goal for rose growers and landowners" (Obrycki *et al.*, 2001). Horticulturalists need to breed RRD-tolerant or RRD-resistant roses (Zary, 1995). The rose seed chalcid, now found throughout the eastern United States, should be intentionally released in areas wherever infestation rates are below 50 to 60%. Risk to other rose species from this seed chalcid appears to be minimal, but host range studies should be conducted to confirm the chalcid¢s suspected high specificity. This insect's high potential to reduce seeding of multiflora rose justifies its increased distribution. Even if not deliberately spread, its range will increase by birds. Eventually, multiflora rose will be reduced to low levels, occurrence of RRD will become minimal, as in California, Wyoming and Utah, where it originated, and problems for farmers and rosarians alike should be greatly reduced.

ACKNOWLEDGEMENTS

I would like to dedicate this chapter to the memory of Professor Dale F. Hindal, West Virginia University Plant Pathologist, recently deceased. Our discussion of this possible research at a football brunch in 1985 began our work with multiflora rose, RRD, *Phyllocoptes fructiphilus*, and *Megastigmus nigroflavus.* His insights, humor, deep knowledge of plant pathology and entomology, and excellent teaching ability launched our adventures into this work. I also express my gratitude to the many acarologists, rosarians, plant pathologists, agronomists, and others who have shared important information regarding the mites, multiflora rose, the seed chalcid, the rose stem girdler and other arthropods discussed in this chapter. This work could not have been done without the expert assistance of my assistant, Terry Stasny. Much of our research was supported financially by the West Virginia Department of Agriculture; all of our research was conducted as part of Hatch Project 317, the Davis College of Agriculture, Forestry and Consumer Sciences, at West Virginia University.

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