Introduced leaf beetles of the Maritime Provinces, 7: *Cassida rubiginosa* Müller and *Cassida flaveola* Thunberg (Coleoptera: Chrysomelidae)

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Abstract

Cassida rubiginosa Müller is newly recorded in Nova Scotia and on Prince Edward Island. *Cassida flaveola* Thunberg is newly recorded in Nova Scotia, on Prince Edward Island, and in the Maritime Provinces as a whole. The systematics, identification, introduction history, distribution, zoogeography, biology, parasitism, predation, host plant preferences, and biocontrol potential of both species are surveyed in detail. Early records of *C. flaveola* are also recounted and questions are posed with respect to its presence and origins in the region and whether it may have been introduced via human agency. Although previously considered an introduced Palearctic species, recent evidence indicates that *C. flaveola* is, at least in part, a native species with a Holarctic distribution.

Key words: Coleoptera, Chrysomelidae, Cassidinae, Cassidini, *Cassida flaveola, Cassida rubiginosa*, Canada, Maritime Provinces, introduced species, adventive beetles, biocontrol, thistles

Introduction

Cassida Linnaeus, 1758 is a diverse and widely distributed genus of leaf beetles in the Palearctic region with 419 described species (Borowiec & Świętojańska 2007). Five species of *Cassida* have been recorded in North America including the native *Cassida relicta* Spaeth, 1927; the introduced Palearctic *Cassida azurea* Fabricius, 1801 (intentionally released and established in Alberta, Manitoba, and Saskatchewan in 1989 as part of experiments to control the population of bladder campion (*Silene vulgaris* (Moench) Garcke, Caryophyllaceae) (Harris 2005); the introduced Palearctic *Cassida rubiginosa* Müller, 1776 which has become established in North America; *Cassida nebulosa* Linnaeus, 1758 which has been recorded on the continent (in California and New York) but is not established (Riley *et al.* 2003); and *Cassida flaveola* Thunberg, 1794 whose status is discussed below. They are distinctive tortoise beetles in the tribe Cassidini Gyllenhal, 1813 within the subfamily Cassidinae Gyllenhal, 1813.

Additional research on the biodiversity of Coleoptera in the Maritime Provinces has now revealed further records of *Cassida rubiginosa* and *C. flaveola* which will be presented here together with a review of the systematics, history, biology, distribution, and origins of the species.

Methods and conventions

Codens of collections (following Evenhuis 2007) referred to in the text are:

ACNS   Agriculture and Agri-Food Canada, Kentville, Nova Scotia, Canada
ACPE   Agriculture and Agri-Food Canada, Charlottetown, Prince Edward Island, Canada
CBU   Cape Breton University, Sydney, Nova Scotia, Canada
CGMC   Christopher G. Majka Collection, Halifax, Nova Scotia, Canada
CNC   Canadian National Collection of Insects, Arachnids, and Nematodes, Ottawa, Ontario, Canada
GSC   Gary Selig Collection, Bridgewater, Nova Scotia, Canada
JOC   Jeffrey Ogden Collection, Truro, Nova Scotia, Canada
NSAC   Nova Scotia Agricultural College, Bible Hill, Nova Scotia, Canada
NSMC   Nova Scotia Museum Collection, Halifax, Nova Scotia, Canada
NSNR   Nova Scotia Department of Natural Resources, Shubenacadie, Nova Scotia, Canada
RWC   Reginald P. Webster Collection, Charters Settlement, New Brunswick, Canada
UPEI   University of Prince Edward Island, Charlottetown, Prince Edward Island, Canada

Information was compiled from voucher specimens of *Cassida flaveola* and *C. rubiginosa* from the Maritime Provinces in the reference collections listed above. The number of specimens is indicated in parentheses together with the collection coden.

Systematics and identification

The genus *Cassida* has been divided into a large number of subgenera, three of which are represented in North America. *Cassida nebulosa*, *C. relicta*, and *C. rubiginosa* have been placed in the subgenus *Cassida* L.; *C. azurea,* a member of *Mionycha* Weise, was introduced in the Prairies as a biolcontrol agent; and *C. flaveola* has been treated in the subgenus *Pseudocassis* Steinhausen, which is transcontinental in Canada (LeSage 1991). Borowiec (2007), however, argued that most subgenera of *Cassida* are artificial groups. Many appear to be polyphyletic, or else if monotypic, have been described on the basis of questionable characters. Almost one half of described species have not been placed in any subgenus. He recommends the elimination of all subgeneric names and categories. North American species can be readily identified using the keys in Barber (1916), Wilcox (1954), Chagnon & Robert (1962), Riley (1986a, 1986b), Downie & Arnett (1996), and Riley *et al.* (2002). European species are fully treated in Bordy (2000).

The genus *Cassida* has been historically placed within the subfamily Cassidinae of the family Chrysomelidae (Spaeth 1914; Seeno & Wilcox 1982; Borowiec 1999). Riley *et al.* (2002) transferred the group to a tribe, the Cassidini, within the subfamily Hispinae. Staines (2002) then formally synonymized the Cassidinae and Hispinae, proposing the former as a valid name, and in the most recent catalogue of the North American fauna (Riley *et al.* 2003) they were again treated as a tribe within the Cassidinae.

Cassida rubiginosa Müller, 1776

Identification. Live adults of *C. rubiginosa* are vivid green on dorsal surface, often with yellowish elytral margins, and are black underneath. This green pigment is ephemeral, and dried specimens preserved in collections quickly turn brownish. Its medium size (6-8 mm), confused elytral punctures, and the vivid light green color make adults recognizable immediately, even by non-experts (Fig. 1).

The first instar larva was described and illustrated by Świętojańska (2004). Egg bursters are absent (Cox 1994a). The mature larva was described by Paterson (1931, *sub Cassida viridis*) and illustrated by Peterson

(1951). It can be identified using the key to species of the British cassidine larvae (Van Emden 1962).

Descriptions and illustrations of the pupa of *C. rubiginosa*, are found in Paterson (1931) (*sub C. viridis*) and Palij & Klepikova (1957). A key, including *C. rubiginosa*, is provided by Palij & Klepikova (1957).
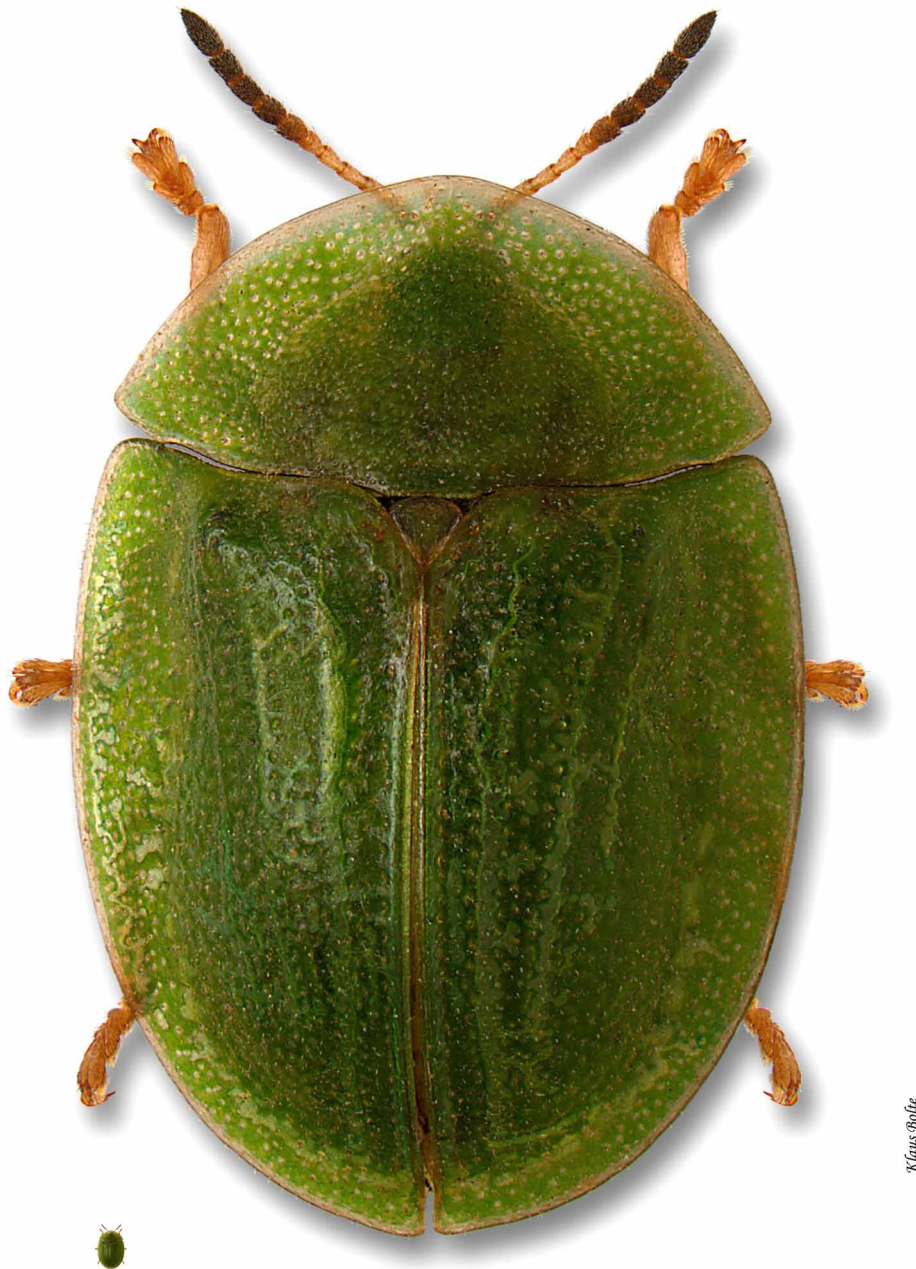
Cassida rubiginosa

FIGURE 1. Habitus of *Cassida rubiginosa*, dorsal view.

History and distribution. *Cassida rubiginosa* was first discovered in North America in 1902 in Lévis, near Québec City, where beetles were observed to be defoliating burdock (*Arctium minus* (Hill.) Bernh., Asteraceae) (Fyles 1902, 1903; Roy 1902). Schaeffer (1903, 1904a, 1904b) contributed to clarify its identity. It was subsequently reported by Brown (1940) on burdock, in Montréal, at Knowlton and Brome in the Eastern Townships of Québec, and in Shediac, New Brunswick. The species is now widely established both across Canada from Alberta east to New Brunswick, and in the United States from Maine south to Virginia and west through Ohio to Wisconsin and South Dakota (Riley *et al.* 2003). In the Old World, it is found throughout con-

tinental Europe (not yet recorded in the Netherlands) from Fennoscandia south through the Baltic republics to Greece and Spain, in Great Britain, and across Siberia to the northern Far East of Russia (Audisio 2005b).

Biology. *Cassida rubiginosa* has been well studied in Europe by Kleine (1917a) and Kosior (1975). In Eastern Canada, *C. rubiginosa* is found in habitats where Canada thistle and burdocks grow, such as agriculture lands, pastures, abandoned fields, sparsely wooded meadows, neglected orchards, clear cut areas, or similar open and/or disturbed habitats.

The species is univoltine in Ontario and Québec (LeSage, personal observations), in Virginia (Ward & Pienkowski 1978a), and very likely so in the Maritime Provinces. Hibernation is in the adult stage. In Poland, Kosior (1975) observed a migration of adults from thistles to forest floor litter in the fall. In Virginia, Spring & Kok (1999) found that leaf litter was the preferred hibernaculum of field caged adults, and inability to access preferred hibernating locations combined with fluctuating winter temperatures may result in the survival of less that one in four beetles. Adults leave their winter shelters in early spring. The earliest specimens in the Canadian National Collection (CNC) were collected on April 2 in southern Ontario and on May 15 in the Ottawa area. The earliest adults collected in the Maritime Provinces are from May 31 (Kentville, Nova Scotia).

Females began to oviposit between mid-March and April in Virginia (Ward & Pienkowski 1978a). In Europe, Kosior (1975) stated that oviposition started 3-7 days after mating according to temperature, day length, rain, and wind. Eggs are usually laid on the underside of the leaves, more rarely on the upper surface, and sporadically on the stem.

Ward & Pienkowski (1978a) referring to the midrib, observed that 74% of the oöthecae were deposited on the abaxial surface, and 18% on the adaxial surface. The number of eggs in oöthecae is variable but is usually three, although oöthecae with only one egg are not rare (Kosior 1975). In Virginia, Ward & Pienkowski (1978a) found an average of 4.6 eggs per oötheca, and Spring & Kok (1997) found an average of 61.1 oöthecae laid per individual female over a 15-week period. In Maryland, Tipping (1993) observed that many oöthecae were laid on leaves closest to the soil. In laboratory rearing, the fecundity averaged 815 eggs per female; eggs hatched in two weeks at 18°C, in four days above 32°C (Ward & Pienkowski 1978a). The egg-laying period lasted 12 weeks (Kosior 1975).

The eggs are usually laid on the lower surface of the leaves. Each egg is enclosed in secretion which turns from whitish to brown in about ten minutes, and finally, the oötheca is closed with a layer of excreta (Engel 1935; Bibolini 1973). Excremental coverings are thought to conceal eggs or act as physical or chemical barriers to repel natural enemies (Muir & Sharp 1904; Damman & Cappucino 1991; Olmstead 1996). Egg deposition, coverings, and oviposition were reviewed by Hilker (1994), Olmstead (1994), and Selman (1994).

Damman & Cappucino (1991), who studied this form of double defense (egg clumping and excrement cover) in the hispine *Microrhopala vittata* (Fabricius), found that the fecal covering significantly reduced egg mortality. Since the parasites generally attacked the bottom egg, and while the predators rarely penetrated the fecal covering, egg masses were virtually protected against all natural enemies likely to pose a threat. Such a protection can be expected in *Cassida rubiginosa* which also lays small oöthecae of a few eggs (Kosior 1975; Ward & Pienkowski 1978a).

There are five larval instars in *C. rubiginosa*, each one easy to recognize by its exuviae attached to the caudal fork together with excrement. In addition to the shield and fork, the larvae possess lateral spines, or scoli, that are used as sensory organs, and when they are stimulated the shield is moved to cover the body (Olmstead 1996). This distinctive structure, made of dried exuviae and accumulated fecal wastes, attracted the attention of early naturalists (ex. Réaumur 1737)."Stercoraceous parasol" (Walsh & Riley 1869), "faeces pack" (Rabaud 1915b), and "frass mask" (Engel 1935), were used to described this structure but the term "fecal shield" popularized by Eisner *et al.* (1967) is now in use. The smallest exuviae (first instar) is attached at the extremity of the fork, the largest at base, each sliding on the branches of the new fork after each molt (Rabaud 1915b). As the larvae feed again, the newly produced faeces accumulate behind the previous ones.

Consequently, the fecal shield grows and moves forward at each molt with the result that before pupation, this pack contains the whole series of exuviae and all the faeces produced by the larvae during their life (Rabaud 1915b). The shield is also highly maneuverable and can be moved to cover areas of the body that are stimulated (Olmstead 1994). The anus is extrudable. Consequently, it can be projected and curved over the back and, through the aid of the fork and of some of the lateral spines, it forms the protective fecal shield (Walsh & Riley 1869).

The role of the shield has been the subject of several hypotheses. According to Frisch (1720), cited by Engel (1935), the fecal shield protects the body from rain and pests, while for Huber (1846) and others, it is a protective shelter from insolation, but this assumption was recently rejected (Bacher & Luder 2005). Larvae covered with their fecal shield are similar to droppings which may confuse large predators like birds, but not insect predators. For Eisner *et al.* (1967), ants are undoubtedly among its chief natural enemies. They were always seen foraging in large numbers in the dense herbage that included the beetle's host plants. Confronted with the inanimate shield rather than with the body of the larvae, they were quick to lose interest in such potential prey. Larvae deprived of their shield were bitten and killed, or carried away live into ant nests. On the other hand, these authors noted that the shield did not protect larvae from all predators. For instance, tests with a lycosid spider invariably resulted in the larvae being killed, an observation already made by Engel (1935) with the larvae of *Cassida viridis* Linnaeus. Engel (1935) also stated that the violent movements of the larvae when disturbed actually constitute a protection insofar as they chase away enemies. According to Franz (1941), the shield can protect against parasites although its effectiveness is not absolute.

Eisner *et al.* (1967) argued that the fecal shield of *C. rubiginosa* larvae was effective in deterring ants in laboratory tests. Vencl *et al.* (1999) found that shields were necessary for the survival of the larvae of *Plagiometriona clavata* (Fabricius) and that the chemicals derived from their nightshade host plant (*Solanum dulcamara* L.) formed a deterrent barrier against the ant (*Formica subsericea* Say) attacks. They concluded that the incorporation of deterrent metabolites in shield defenses represented responses to selection from invertebrate predators. The role of these allelochemicals from host plants and other antipredator devices was reviewed by Blum (1994).

Olmstead & Denno (1992) estimated that the cost of bearing fecal shields was minimal. Being made of recycled waste products, fecal shields provide an inexpensive mode of protection from certain natural enemies. Tipping (1993) noticed that smaller larvae were very susceptible to generalist predators, especially coccinellids. However, Olmstead & Denno (1993) observed that predators with short mandibles, such as coccinellids, were effectively deterred by the larval shields of cassidines whereas nabids and pentatomids with long piercing mouthparts easily circumvented the shield defense. Consequently, a particular kind of defense does not provide complete protection against generalist predators in natural habitats.

Müller (2002) found that feeding by the lacewing larvae *Chrysoperla carnea* (Stephens, 1836) was not influenced by fecal shields, and concluded that the effectiveness of shields of tansy-feeding cassidine larvae (*C. denticollis* and *C. stigmatica*) varied with predators and might be based more on mechanical than on chemical modes of action. Shields also proved to be useless against the paper wasp *Polistes domidulus* Christ and ultraviolet radiation (Bacher & Luder 2005).

Larvae of *C. rubiginosa* are not very mobile and tend to remain on the same ramet throughout their development. The main larval feeding activity is postponed to a period when the nitrogen content of the leaves had dropped to 50% of its initial value, but when the host plant biomass had increased by 30% (Obermaier & Zwölfer 1999). Early-season larval feeding had no measurable effect on Canada thistle growth while late-season feeding significantly reduced shoot growth (Bacher & Schwab 2000).

When full grown, the larvae discard their load of excrement and exuviae, attach their last 2-3 ventral abdominal segments to the plant by means of a sticky secretion, and pupate there. The preferred site for pupation is along the midrib of leaves or on the main plant stalk (Ward & Pienkowski 1978a). According to these authors, the pupation period averaged 9.6 days at 17.8°C and 3.5 days at 32.5°C. In Germany, adults of the

new generation appear in mid-July onwards with a peak in late August (Obermaier & Zwölfer 1999), an emergence period that roughly corresponds to what we have observed in Eastern Canada.

Larvae and adults do not eat leaves from the edges but attack them from a surface, usually the upper face. Rabaud (1915a) stated that the under face remained untouched but this is true only for younger larvae. Adults and larger larvae can skeletonize and severely damage the leaves (Batra *et al.* 1981).

According to Koji & Nakamura (2006) in Japan, the population of *C. rubiginosa* was characterized by a high density of over-wintered adults and a low variability in annual population density for both over-wintered and new adults. This exceptional stability for a herbivorous insect population was attributed to the longevity of the adults, some being still alive after three years.

Parasitism. Parasitism of Chrysomelidae by Hymenoptera and Diptera was extensively reviewed by Cox (1994b), and this topic is treated in detail for several European *Cassida* species, including *C. rubiginosa*, by Kosior (1975). The following paragraphs primarily concern the North American populations.

According to Tschanz *et al.* (2005), the degree of exposure of *C. rubiginosa* larvae on plants had a significant effect on predation but the rate of parasitism was equal on exposed or hidden plants. Ten years after the release of this cassidine in southwestern Virginia, Ang & Kok (1995) estimated that parasitism and incomplete development were two major mortality factors.

In North America, six species of parasitoids have already been identified from larvae and pupae of *C. rubiginosa,* but none from eggs and adults (Ward & Pienkowski 1978b; Tipping 1993; Ang & Kok 1995; Olmstead 1996). In Europe, Girault (1914) reported the hymenopteran eulophid *Oomyzus gallerucae* Fonscolombe (*sub Tetracampe galerucae* Jonsc.) as an egg parasite but questioned its identity. Delucchi (1960) listed the mymarid *Anaphes pannonica* Soyka as an egg parasite of *C. rubiginosa*. According to Muir & Sharp (1904), the fecal covering of the oöthecae do not protect against parasites.

Tetrastichus rhosaces (Walker) is a gregarious obligate European eulophid endoparasitoid of the larvae and pupae (Kaufmann 1933; Graham 1991). According to Ward & Pienkowski (1975, 1978b), it is the most important parasitoid of *C. rubiginosa* in North America, accounting for 14.2-23.8% of the total parasitism. The numbers of parasites reached an average of 9.9 per host, most of them being commonly located in the anal or cephalic regions. In larvae, signs of parasitism were not evident until the last larval instar when parasitized larvae showed a noticeable discoloration. Affected pupae became slightly darker. Tipping (1993) did not find it in Maryland in his field study of *C. rubiginosa* on Canada thistle. Ang & Kok (1995) assumed that the *Aprostocetus* sp. collected by them in southwestern Virginia was *T. rhosaces* which parasitized up to 9% of the larvae and as much as 96% of the pupae.

The endoparasitoid solitary tachinid fly, *Eucelatoria dimmocki* Aldrich, accounted for 2.7-7.5% of the total parasitism in a study of the parasites in northern Virginia (Ward & Pienkowski 1978b), 0-2% in southwestern Virginia (Ang & Kok 1995), and 19.5% in Maryland (Tipping 1993). It is a native polyphagous parasitoid of larvae and pupae which has been previously recorded from several other cassidine hosts including *Chelymorpha cassidea* (Fabricius), *Plagiometriona clavata* (Fabricius, *sub Deloyala clavata*), *Charidotella sexpunctata bicolor* (Fabricius, *sub Metriona bicolor*), and *Agroiconota bivittata* (Say, *sub Metriona bivittata*) (Aldrich 1932; Stearns 1933).

Ward & Pienkowski (1978b) measured only 0.7-2.1% of parasitism by the hymenopteran chalcidid *Conura albifrons* (Walsh, *sub Spilochlacis albifrons*). It is a polyphagous, solitary endoparasitoid. In North America, Musesebeck *et al.* (1951) and Peck (1963) listed 38 other hosts in 14 families in 4 orders. This chalcid is also a hyperparasite of Tachinidae and Braconidae (Ward & Pienkowski 1978b).

Tipping (1993) reported that *Conura side* (Walker, *sub Spilochalcis side*) emerged from 1.4% of the pupae. It is another polyphagous, solitary endoparasitoid with at least 45 known hosts, mostly Lepidoptera (Peck 1963). In western Virginia, this parasitoid (*sub Cornura torvina* (Walsh)) appeared late in the season and accounted for the second highest rate of parasitism with 0-8% of the pupae parasitized (Ang & Kok 1995).

The hymenopteran eupelmid *Macroneura vesicularis* (Retzius, *sub Eupelmella vesicularis*) is another polyphagous, solitary endoparasitoid, but of negligible importance in *C. rubiginosa*. Its level of parasitism in this species did not exceed 0.1% (Ward & Pienkowski 1978b). At least 70 additional hosts, in various orders and families, are known for this parasitoid (Muesebeck *et al.* 1951; Krombein 1958; Peck 1963).

In their two-year study of the parasites of *C. rubiginosa*, Ward & Pienkowski (1978b) recovered only one individual of the solitary ichneumonid, *Itoplectis conquisitor* (Say). In Maryland, it accounted for 1.4% of the total parasitism (Tipping 1993). In southern Virginia, it was found at all sites but without exceeding 2% of the hosts affected (Ang & Kok 1995). This solitary parasite is polyphagous with over 100 hosts recorded in North America (Muesebeck *et al.* 1951; Krombein 1958; Peck 1963; Krombein & Burks 1967).

Parasitic nematodes are known but not yet reported in North America. In Europe, *Hexamermis* sp. (96%) is the most important parasite of larvae and pupae, whereas *Mermis* sp. (2%) and *Agamermis* sp. (2%) (Mermithidae) are occasionally found; adults were primarily parasitized by *Mermis* sp. (84%) and *Hexamermis* (15%) (Kosior 1975). Loktin & Ivanova (1970), using suspensions of *Neoaplectana* sp. (Steinernematidae) larvae, killed 33-60% of the larvae of *C. rubiginosa* in the field.

Predation. Very little is known about the predators of *C. rubiginosa* in North America, although the subject has been well treated in Europe (Kosior 1975; Olmstead 1996). In Virginia, Ward & Pienkowski (1978b) reported that the phalangiid *Leiobunum* sp., the reduviids *Arilus* sp. and *Sinea diadema* (Fabricius), the pentatomid *Podisus maculiventris* (Say), and the neuropteran chrysopid *Chrysoperla* (*sub Chrysopa*) *carnea* (Stephens) fed on *C. rubiginosa* in the field but did not specify the life stage preyed upon. In Maryland, Olmstead & Denno (1993) studied the predation of some mandibulate, piercing/sucking, and chelicerate predators of *Charidotella sexpunctata bicolor* (Fabricius) and of *Deloyala guttata* (Olivier). The selected mandibulate predators were the coccinellid beetles *Coleomegilla maculata* (DeGeer), *Coccinella septempunctata* Linnaeus, and the carabid *Lebia fuscata* Dejean. *Geocoris punctipes* (Say) was a short rostrum species whereas the heteropteran nabid *Nabis americoferus* Carayon, and *P. maculiventris* had long beak. For the chelicerate predators, two spiders were selected: *Oxyopes salticus* Hentz (Oxyopidae) and a *Phidippus* sp. (Salticidae). The larvae were protected against the short mandibulate coccinellids but not from haustellate bugs which could pierce the shield or insert their long rostrum under the shield and feed. All these predators are generalists and common in the Northeast. Consequently, they are very likely to prey on *C. rubiginosa* larvae as well.

Research on insect predators of *C. rubiginosa* is currently ongoing in Europe. In Switzerland Schenk & Bacher (2002) estimated that the paper wasp *Polistes dominulus* Christ (Vespidae) was responsible for 99.4% of the predation on *C. rubiginosa* larvae, and thus may cancel the effect of mass releases of the beetle as biocontrol agent. Tschanz *et al.* (2005) in Switzerland, found that exposure significantly affected predation by this wasp, and consequently larvae on hidden plants were less likely to be killed than larvae on exposed leaves. Schenk & Bacher (2004), also in Switzerland, demonstrated that predation by *Nabis mirmicoides* Costa (Heteroptera: Nabidae), and *Chrysoperla carnea* can be proved using the monoclonal antibody (Mab) CRL5-1.

Host plants. From the extensive literature review of Clark *et al.* (2004) it is clear that *C. rubiginosa* is polyphagous, but upon closer examination, it is apparent that it exhibits preferences for the Cardueae in the Asteraceae (Zwölfer & Eichhorn 1966; Batra *et al.* 1981; Obermaier & Zwölfer 1999; Bacher & Schwab 2000).

In North America, it was first reported on burdock (*Arctium minus* (Hill.) Bernh.) from Lévis, near Québec City (Roy 1902; Fyles 1902; Brown 1940). Peterson (1951) mentioned this plant species in his description of the larva from Ohio, whereas Wilcox (1954) in his treatment of leaf beetle fauna of this state, mentioned that it had been reported from Canada on thistle but did not give the sources of his information. Later, he added burdock to the known list of host plants (Wilcox 1979).

Chagnon (1917, 1939, 1940), and Chagnon & Robert (1962) mentioned both thistle (*Cirsium* sp.) and burdock (*Arctium* sp.) as hosts in Québec but did specify which species was involved. From our own collecting,

and on the basis of the specimens studied here, only *A. minus* and *Cirsium arvense* (L.) Scop. are true hosts of *C. rubiginosa* in eastern Canada.

In Saskatchewan, Maw (1976) reared *C. rubiginosa* from *Cirsium arvense*, *Centaurea jacea*, *Arctium* sp. and *Carduus* sp. In West Virginia, Hacker (1977a) first reported that larvae fed heavily on leaves of bull thistle (*Cirsium vulgare* (Savi) Tenore) at Mineral Wells, and later collected adults and larvae in various counties on *Cirsium pumilum* (Nutt.) Spreng., *Carduus crispus* L., and *Carduus nutans* L. (Hacker 1977b). In Maryland and Pennsylvania, Batra (1978) observed that *C. rubiginosa* was most abundant on *Carduus nutans* and *C. acanthoides*, but later reported its preference for *Cirsium*, *Carduus,* and *Silybum,* also mentioning some feeding on *Cynara*, *Carthamus* and other plants (Batra *et al.* 1981). In Virginia, Ward & Pienkowski (1978a) listed five host thistles: bull thistle (*C. vulgare*), Canada thistle (*C. arvense*), field thistle (*C. discolor* (Mühl.) Spreng.), musk thistle (*Carduus nutans*), and plumeless thistle (*C. acanthoides* L.). Peschken (1984a) stated that *C. rubiginosa* overwhelmingly fed on introduced weeds, with only one report on the native *Cirsium muticum* Michx. and *C. discolor* (Muhl. ex Willd.) Spreng.

Of the host plant genera in the Asteraceae reported by Clark *et al.* (2004), all except *Pulicaria* and *Saussurea* are found in the Maritime Provinces, and many species are widely distributed in the region (Erskine 1960; Hinds 1986; Roland 1998).

Biocontrol potential. Canada thistle, known in Europe as the creeping thistle, is one of the world's worst weeds (Holm *et al.* 1977; Hays 1991; White 1996). It is a very aggressive colonizer that quickly produces stands on lands disturbed by agriculture or other human activities. The weed is difficult to control because the root system can extend several feet down and spread extensively horizontally, and the roots can persist even when broken by plowing. Their prolific seed production, seed longevity, competitive ability, and the lack of natural enemies are additional reasons of the success of thistles (Kok 1998).

The world catalogue of agents and their target weeds of Julien & Griffiths (1998) gives the origins of the weeds, the dates of release of control agents, their status, and the degree of control of the weeds. Closer to this region, the reviews of Kok & Gassmann (2002) on bull thistle, McClay (2002) on Canada thistle, and Gassmann & Kok (2002) on musk thistle in eastern United States, also includes information on the situation in Canada. In this country, the biological control attempts of weeds were reviewed four times. *Cassida rubiginosa* was not mentioned in the first review (McLeod 1962). In the second review, for the years 1959-1968, Harris & Zwölfer (1971) stated that *C. rubiginosa* larvae and adults skeletonized leaves and were capable of damaging the plumeless (*C. acanthoides*) and nodding thistle (*C. nutans*), but high parasitism seemed to prevent the build up of populations sufficient to control thistles. In the same review, Peschken (1971) mentioned that *C. rubiginosa* was one of the most conspicuous enemies of *Cirsium arvense,* but could not control the weed below the economic level. In a 1969-1980 review, the authors focused on the impact of the weevils *Hadroplontus litura* (Fabricius), *Rhinocyllus conicus* (Froelich), and *Trichosirocalus horridus* (Panzer), the flea beetle *Altica carduorum* (Guérin-Méneville), the tephritid flies *Urophora cardui* (Linnaeus) and *U. stylata* (Fabricius) (Harris 1984; Harris & Wilkinson 1984; Peschken 1984a). Peschken (1984b) indicated that *C. rubiginosa* was also present in the release pastures of *H. litura*, together with the rust *Puccinia punctiformis* (Str.) Rohl. and the weevil *Cleonus piger* (Scopoli), and consequently assumed that the decline of some thistle patches was caused by one or a combination of these agents. In the last review available, from 1981-2000, McClay *et al.* (2002) cited the previous works of Zwölfer (1969) in Europe and Ward & Pienkowski (1978a) in Virginia, but without new information on *C. rubiginosa* in Canada.

The first concerted attempt at biological control of thistles was initiated in Virginia in 1969 against musk thistle. This program started with the introduction of a head-feeding weevil, *Rhinocyllus conicus*, subsequently followed by the introduction of two rosette feeding weevils, *Trichosirocalus horridus* and *Hadroplontus trimaculatus* (Fabricius) (Kok 1978, 1979). *Cassida rubiginosa* was also considered as a potential biological agent.

In Saskatchewan, Maw (1976) noted that *C. rubiginosa* could be sufficiently numerous at times to defoliate thistles in Saskatchewan. Batra (1978) in Maryland, however, pointed out that the beetle did not significantly reduce the vigor of thistles although leaves could be extensively damaged in some areas. In their study of the stress caused by five organisms on Canada thistle on the island of Montréal (Québec), Forsyth & Watson (1985) estimated that defoliation over 50% was required to reduce weed vigor, but that *C. rubiginosa* rarely achieved this. Cartwright (1984) estimated that an infestation by *C. rubiginosa* was equivalent to a 50-75% mechanical defoliation.

In Maryland, Tipping (1992) reported 72% seed reduction of musk thistle but these exceptional results were obtained with field-caged individuals protected from parasites and predators. In Virginia, Cartwright & Kok (1990) found that the beetle could significantly affect the growth of musk thistle when more than half of the foliage was eaten. Cartwright & Kok (1990) also studied the effects of defoliation by *C. rubiginosa* on the growth of musk thistles in Virginia. They found no reduction in seed yield despite an average 23.6% defoliation, but observed that growth was more adversely affected by multiple than single defoliations, particularly when 50% or more of the foliage was removed. Thus, although it is unlikely that *C. rubiginosa* can control *Carduus* thistles by itself, it can add substantially to the total stress on the weeds if used in conjunction with other biological control agents. The recent attempts to establish the beetle in South Dakota did not succeed (Liu *et al.* 2000; Reed *et al.* 2006).

Ang *et al.* (1994, 1995) looked at the competitive growth of Canada thistle, tall fescue (*Festuca arundinacea* Schreb.), and crown vetch (*Coronilla varia* L.) in the presence of *C. rubiginosa*. Their results indicated that *C. rubiginosa* enhanced the impact of the plant competitors by inhibiting the ability of thistle to compete against other plants.

In another approach, Tipping (1993) in Maryland studied the interaction between Canada thistle, *C. rubiginosa*, and the rust *Puccinia punctiformis* (Strauss.) Röhl. (Uredinales: Pucciniaceae). He found that infected plants suffered or did not bloom but were not more attractive than healthy ones to the beetle. The following year, Kok & Abad (1994) demonstrated that *C. rubiginosa* adults could disperse spores of the rust *Puccinia carduorum* Jacky, an autoecius rust fungus imported from Turkey for the control of musk thistle (Baudoin *et al.* 1993). The spores were attached to the tarsal setae of the adults and consequently the beetles increased the effective control of this weed. According to Kok *et al.* (1996) and Kok (1998, 2001), the longevity, egg production, and larval development of *C. rubiginosa* were not adversely affected by the rust fungus. However, Kluth *et al.* (2001, 2002) in Germany demonstrated that this interaction between *C. rubiginosa* and the rust fungus *P. punctiformis* was antagonistic. Although *C. rubiginosa* transferred spores, the biomass of the adult beetles was significantly reduced, the larval and pupal development tended to be prolonged, and the mortality increased when feeding on infected plants. These results were called into question by the laboratory investigations of Kok *et al.* (1996) who found that adults and larvae of *C. rubiginosa* preferred healthy leaves or pustule-free areas of infected leaves, and consequently the rust did not significantly interfere with the development and reproduction of the musk thistle herbivores.

In Germany, Kruess (2002) examined the indirect interactions between the necrotrophic fungus *Phoma destructiva* (Plowr.) (Pleosporales: Leptosphaeriaceae), Canada thistle, and *C. rubiginosa*. Adults avoided infected thistles for egg deposition and feeding, the larval development was negatively affected, and larval and pupal mortality was higher.

In Switzerland, Bacher & Schwab (2000) concluded that high levels of plant competition combined with herbivory of *C. rubiginosa* larvae led to 50% mortality of Canada thistle during the growing season. Consequently, they believed that an increase of herbivores in combination with breaking the root system by tillage and the establishment of competitive plants may be a feasible way to control the weed.

Locality records. A total of 57 specimens were examined:

NEW BRUNSWICK: Albert Co.: 7.VII.2004, R.P. Webster, *Cirsium arvense*, (1, RWC); **Westmoreland Co.:** 2.VII.1939 and 4.VII.1939, Shediac, W.J. Brown, on *Arctium minus*, (9, CNC). **NOVA SCOTIA:**

Annapolis Co.: Bridgetown, 7.IX.1958, C.R. MacLellan, (1, ACNS); Granville Ferry, 30.VI.2002, C.G. Majka, coast field on thistle, (1, CGMC); Hampton, 7.VIII.2005, *Cirsium arvense*, (2, CGMC); **Cape Breton Co.:** Glace Bay, 3.VIII.1994, D.B. McCorquodale, (1, CBU); Schooner Pond, 6.IX.2003 and 11.IX.2003, C.W. D'Orsay, (2, CBU); Sydney Tar Ponds, 7.VI.1996, L.A. Hudson, (1, CBU); **Colchester Co.:** Debert, 12.IX.1999, J. Ogden, (1, NSNR); Shubenacadie, 2.VI.2003, J. Ogden, (1, NSNR); Truro, 6.VII.1982, M.A. Bulger and L.H. Lutz, (2, NSAC); **Cumberland Co.:** Amherst, no date indicated, J. Ogden, (1, JOC); **Halifax Co.:** Halifax, 3.VII.1967, K.A. Neil, (1, NSMC); Point Pleasant Park, 30.VI.2001 and 15.VIII.2001, C.G. Majka, *Cirsium arvense*, (2, CGMC); south-end Halifax, 19.VI.2001 and 26.VI.2001, *Cirsium arvense*, (2, CGMC); **Hants Co.:** Enfield, 22.VIII.2005, C.G. Majka, *Cirsium arvense*, (1, CGMC); Maitland, 25.VI.2002, A.J. Hebda, dikeland, (1, NSMC); Noel Shore, 2.VII.2002 and 9.VII.2002, A.J. Hebda, garden, (3, NSMC); **Inverness Co.:** Scotsville, 10.VII.1975, no collector indicated, (1, NSMC); **Kings Co.:** no location indicated, 27.VI.1956, H.B. Specht, (11, NSMC); Canard Creek, 12.VI.1987 and 4.VII.1988, J.A. Adams, (2, NSAC); Kentville, 16.VII.1950 and 6.VIII.1952, V.R. Vickery, (3, NSAC); Kentville, 31.V.2005, C. Sheffield and S. Westby, (1, ACNS); Porter Pt., 15.VII.1948, K.D. Archibald, (1, NSMC); **Lunenburg Co.:** Bridgewater, 5.IX.2002, G.D. Selig, (1, GSC). **PRINCE EDWARD ISLAND:** no locality indicated, 1974-83, UPEI; **Prince Co.:** Freetown, 31.VII.1991, M.E.M. Smith, potato field, (1, ACPE); **Queens Co.:** Cavendish, 14.VII.2002, C.G. Majka, coastal lagoon, (1, CGMC); Charlottetown, 12.VI.1957, F.M. Cannon, (1, ACPE); Charlottetown, 18.VI.1982, L.S. Thompson, (1, ACPE).

Distribution in the Maritime Provinces. The distribution of *C. rubiginosa* in the Maritime Provinces is indicated in Fig. 3. It is newly recorded in both Nova Scotia (commencing in 1948) and Prince Edward Island (commencing in 1957). Although the distribution of the species within Nova Scotia and Prince Edward Island is somewhat uneven, it appears broadly distributed in appropriate open habitats, given the uneven past collecting effort in the region. Collecting of Coleoptera in New Brunswick has been particularly spare and uneven, so further fieldwork there is required to determine if it occurs beyond the southeastern portion of the province where it has been recorded. In some portions of Nova Scotia, *C. rubiginosa* co-occurs on thistles with the adventive leaf beetle, *Sphaeroderma testaceum* (F.) (Majka & LeSage 2006).

Cassida flaveola **Thunberg, 1794**

Identification. Keys for the identification of adult *C. flaveola* are found in Barber (1916), Wilcox (1954), Chagnon & Robert (1962), Riley (1986a, 1986b), Downie & Arnett (1996), and Riley *et al.* (2002). Adults of *C. flaveola* are distinctly smaller (4-5 mm) than those of *C. rubiginosa* (6-8 mm), their elytral punctures are arranged in regular rows whereas they are confused in *C. rubiginosa* (Fig. 1), and the pronotum and elytra are yellowish brown with translucent margins (Fig. 2).

History and distribution. Early records of *C. flaveola* reported by Barber (1916) were from Beaver Dam, Wisconsin (1896 and 1911), Rigaud, Québec (1902), and Duluth and Mora, Minnesota (1907). Barber (1916) also indicated that a specimen reported as *C. nobilis* L. by Mannerheim (1853) from Sitka, Alaska may have been *C. flaveola*. However, this specimen is no longer in the Zoological Institute collection in St. Petersburg, Russia and may now be lost (Riley 1986b). *Cassida flaveola* has subsequently been broadly reported in North America from the Yukon, Northwest Territories, and British Columbia, east across Canada to Québec, and in the United States from New Hampshire south to Maryland and West Virginia, and west to Minnesota, North Dakota, and Montana (LeSage 1991; Riley *et al.* 2003). In the Old World, its distribution is similar to *C. rubiginosa* except that in Europe it has not been recorded from Portugal, Sicily, Croatia, Greece, and southern Russia (Audisio 2005a).

MAJKA & LESAGE

Cassida flaveola

FIGURE 2. Habitus of *Cassida flaveola*, dorsal view.

Biology. Little is known of the biology of *Cassida flaveola* in North America. Open habitats are apparently preferred. Most Nova Scotia specimens were collected in pastures, one was found on seashore on coastal

dunes, and one specimen preserved in the CNC was collected in an alvar in Almonte (Ontario).

Kosior (1975) investigated the developmental biology of the species in Ojcow National Park in Poland. The following account of the biology of *C. flaveola* is based largely on his investigations. One to two eggs (average 1.6) are laid on host plants. Eggs are laid on the underside of leaves and are covered with a yellow-ish-brown protective layer (Kleine 1917b). Eggs took an average of 18 days to hatch and then the larvae developed through four instars averaging 6.7, 6.5, 7.5, and 7.0 days at each stage. The larvae then pass through a pre-pupal stage (3.2 days) and then pupate, the adults emerging after 9.0 days. Thus, complete development averaged 57.9 days in 1971. In 1970 when ambient temperatures averaged slightly warmer (14.0 ºC versus 11.8ºC) the development time averaged 53.3 days. This was the shortest development time of the four species of *Cassida* that were investigated at the same site. Larvae were present in the field for a period of 2.0-2.5 months. In contrast to many other species of *Cassida*, the larvae of *C. flaveola* do not form a fecal shield of clumps of excrement and exuviae of larval skins. The larvae leave these on the surfaces of leaves on which they are feeding. The larvae feed by perforating the leaves, which can sometimes turn brown and die, however, feeding does not usually kill the plants (Kleine 1917b). Pupation takes place on neighbouring grasses or herbaceous plants. Preceding pupation, the larvae (in the pre-pupal stage) sit motionless on the underside of leaves attached to the substratum with a brown sticky substance secreted from the fifth, sixth, and seventh segments. Pupation then takes place very quickly, in 2-3 minutes.

Adult emergence is also quite rapid, taking only 5 minutes in field conditions. In general, females are larger than males. The adult coloration is light creamy on both dorsal and ventral surfaces. The young imagos sit motionless for approximately 6 hours and begin to feed after 6-9 hours. After 24 hours the colouration has changed to light brown. Adults feed either on the edges of leaves, or else directly on the surface of leaves, however, the opposite side of the epidermis remains untouched (Kleine 1917b). Adult beetles were present in the field for 1.0 to 2.5 months after which dipause commenced (triggered by temperature, humidity, and day length) and the adults moved from the fields where they fed, to neighbouring forests where they burrowed into forest litter to a depth of 5-8 cm to hibernate for the winter. In Poland, adults emerged the following year between 9 May and 7 June. After mating, first-year females lay an average of 242 eggs (range 179-299) in small batches (average 1.6) on suitable vegetation. Second year females also lay eggs, but in much reduced numbers (an average of 38; range 27-48; 1.4 eggs/batch). Females live up to 24 months (average 13.9), whereas males live a maximum of 22 months (average 12.6). Air temperature, wind, rain, and exposure to sunlight all influence the populations and development of all species of Cassidinae, including those of *C. flaveola* (Kosior 1975).

In Poland, *C. flaveola* is an abundant species in meadows throughout the country. Adults are found from May to October (Wasowska 2004). In southern Poland, Wasowska (2004) found it to be the sixth most abundant chrysomelid in both mown and un-mown meadows, with a very stable population structure from year to year.

Parasitism. Kosior (1975) found that different developmental stages of *C. flaveola* were parasitized by *Agamomermis* sp. (Nematoda: Mermithidae), *Foersterella flavipes* (Förster) and *Foersterella erdoesi* Boucek (Hymenoptera: Tetracampidae), *Entedon cassidarum* Ratzeburg (Hymenoptera: Eulophidae), *Ferrierella* sp. (Hymenoptera: Mymaridae), and *Dufouria nitida* von Röder (Diptera: Tachinidae). Parasitic Hymenoptera generally laid one egg inside each *C. flaveola* egg, although instances of as many as four eggs were observed. The proportion of parasitized eggs ranged from 34.5% in 1970 to 31% in 1971. The most important hymenopteran parasite was *Ferrierella* sp. which accounted for 97% of the parasitism in eggs, and *Entedon cassidarum* which accounted for 100% of parasitism in larvae and pupae. The principal parasite affecting adult *C. flaveola* was *Dufouria nitida*, which parasitized and caused a mortality of 20% of adults.

Predation. Kosior (1975) found that different developmental stages of *C. flaveola* were preyed upon by *Anthocoris nemorum* Linnaeus (Heteroptera: Anthocoridae), *Nabis apterus* Fabricius and *Nabis limbatus* Dahlborn (Heteroptera: Nabidae), *Picromerus bidens* Linnaeus (Heteroptera: Pentatomidae), Cantharidae spe-

cies larvae (Coleoptera), Linyphilidae species (Araneida), Lycosidae species (Araneida), *Phalagium* sp. (Opiliones: Phalangiide), *Poecilochirus necrophori* Vitzthum (Acari: Parasitidae), *Pergamasus septentrionalis* (Oudemans) (Acari: Parasitidae), *Microtrombidium* sp. (Acari: Trombidiidae), *Leptus* sp. (Acari: Erythraeidae), *Erythraeus* sp. (Acari: Erythraeidae), and *Anystis* sp. (Acari: Anystidae). The rate of predation found by Kosior (1975) in 1970 in the field was 6.7%.

Host plants. *Cassida flaveola* is a polyphagous species and has been associated with a number of plants in the Caryophyllaceae including *Arenaria peploides* L., *Cerastium vulgatum* L., *Honckenya peploides* (L.), *Malachium aquaticum* (L.) Fr., *Minuartia* sp., *Myosoton aquaticim* (L.) Moench, *Sagina* sp., *Silene latifolia* Poiret, *S. vulgaris, Spergula arvensis* L., *Stellaria graminea* L., *S. holostea* L., *S. media* (L.) Vill., *S. nemorum* L., and *S. uliginosa* Murr. (Kosior 1975; Clark *et al.* 2004). Kosior (1975) reported that the preferred hosts were species in the genera *Stellaria, Spergula,* and *Honckenya*, and the most preferred species is *S. graminea*. Of these host plant genera all except *Malachium, Minuartia,* and *Myosoton* are found in the Maritime Provinces and many species are widely distributed in the region (Erskine 1960; Hinds 1986; Roland 1998). In Bible Hill (Nova Scotia), the species was found feeding on *Stellaria graminea* (grass-leaved stitchwort).

Biocontrol potential. Although it feeds on various species of plants sometimes considered "weeds," *C. flaveola* has a minimal potential as a biocontrol agent (at least in North America) due to its rarity and its incapability to build up to large populations which could affect the growth or dispersal of weeds. In Poland, Kosior (1975) found that *C. flaveola* does have an impact on *Stellaria media*. He found that all four species of *Cassida* that he studied can develop in large numbers under favorable conditions and hence (pp. 371), "a very real possibility occurs of using beetles and larvae of these species in the control of troublesome weeds."

Locality records. A total of 36 specimens were examined.

NOVA SCOTIA: Colchester Co.: Truro, 6.VII.1982, L.H. Lutz & M.A. Bulger, (2, NSAC); Truro, 3.VII.1984, J.A. Adams, (1, NSAC); Bible Hill, 31.V.2005, S.M. Townsend, pasture, (10, CBU); Bible Hill, 14.VI.2005, S.M. Townsend, pasture, (5, CBU); Bible Hill, 23.VI.2005, S.M. Townsend, pasture, (8, CBU); Bible Hill, 30.VI.2005, S.M. Townsend, pasture, (1, CBU); Bible Hill, 14.VII.2005, S.M. Townsend, pasture, (1, CBU); Bible Hill, 21.VII.2005, S.M. Townsend, pasture, (4, CBU); Bible Hill, 28.VII.2005, S.M. Townsend, pasture, (2, CBU); Bible Hill, 12.VIII.2005, S.M. Townsend, pasture, (1, CBU); Bible Hill, 3.VIII.2007, C.W. D'Orsay, pasture on *Stellaria graminea*, (6, CNC). **PRINCE EDWARD ISLAND: Queens Co.:** Wood Islands, 30.VI.2003, C.G. Majka, seashore, (1, CGMC).

Distribution. The collection sites of *C. flaveola* in the Maritime Provinces are indicated in Fig. 3. The species is newly recorded on Prince Edward Island, Nova Scotia, and in the Maritime Provinces as a whole and has been recorded in the region from at least 1982.

The discovery of *C. flaveola* at Woods Islands, PEI poses interesting questions. It was found in coastal dunes adjacent to the Northumberland Ferries terminal which connects Prince Edward Island to Nova Scotia by ferry. This is an important transportation corridor and raises the possibility that it may have been introduced via human-assisted dispersal. *Scymnus tenebrosus* Mulsant, a native coccinellid, has also been found at Wood Islands. It is otherwise absent on PEI, prompting Majka and McCorquodale (2006) to consider whether its presence there may have been assisted by human activities. Similarly, the introduced carabid, *Ophonus puncticeps* (Stephens), has been found at Caribou, the Nova Scotia terminus of this same ferry route, prompting Majka *et al.* (2006) to consider if human agency was responsible for its presence at that site. Majka & Klimaszewski (2004) and Majka & LeSage (2006) both discuss seaports and transportation corridors in the region as conduits for the introduction of Coleoptera. Further fieldwork in the Maritime Provinces would be desirable to better understand the status of this species in the region.

Zoogeography. Although Barber (1916), Lindroth (1957), Riley (1986), LeSage (1991), and Riley *et al.* (2003) have all regarded *C. flaveola* as a Palearctic species introduced, or probably introduced, to North America, there is reason to reconsider this supposition. As Riley (1986b) points out, "considering its wide range in North America and the fact that its site of introduction and subsequent spread has not been docu-

mented, the possibility that its natural range includes the Nearctic can not be rejected." Supporting this are the archeological discoveries reported by Matthews & Telka (1997) of fossil specimens of *C. flaveola* in sediments at Ch'ijee's Bluff, Yukon from the mid-Wisconsinian glaciation circa 52,000 years B.P. (and possibly also from the Interglacial period 125,000 years B.P.), as well as from Cape Deceit in western Alaska, from the late Pleistocene, circa 1.8 million years B.P. This clearly establishes *C. flaveola*, at least in part, as a Holarctic species (not excluding the possibility of later, additional human-assisted introductions). Thus its present range in North America might be a composite of indigenous, Holarctic populations, and more recent adventive ones. Further research would be required to resolve this question.
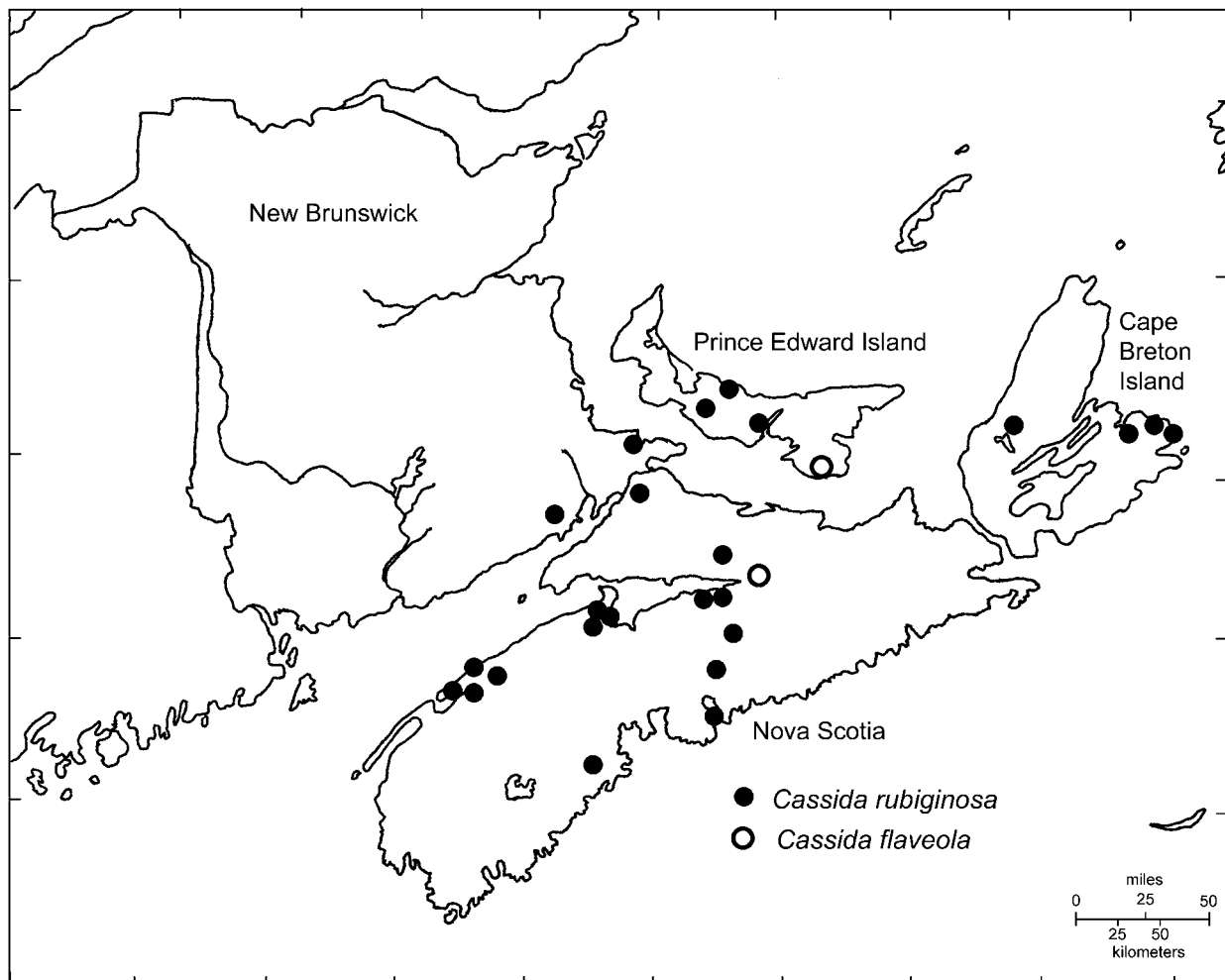
FIGURE 3. Distribution of *Cassida rubiginosa and Cassida flaveola* in the Maritime Provinces of Canada.

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