Biocontrol **News and Information** *1999 Vol. 20 No. 1* 17N – 34N

Review Article

The potential for biological control of Scotch broom (*Cytisus scoparius*) (Fabaceae) and related weedy species

P. Syrett[1], S. V. Fowler[2], E. M. Coombs[3], J. R. Hosking[4], G. P. Markin[5], Q. E. Paynter[6] and A. W. Sheppard[7]

[1] Landcare Research, P. O. Box 69, Lincoln, Canterbury, New Zealand
[2] Landcare Research, Private Bag 92170, Auckland, New Zealand
[3] Oregon Department of Agriculture, 635 Capitol St. NE, Salem, Oregon, USA
[4] New South Wales Agriculture and Fisheries, RMB 944, Tamworth, NSW, Australia
[5] Forestry Sciences Laboratory, Montana State University, Bozeman, MT 59717-2780, USA
[6] CABI Bioscience, c/o CSIRO Biological Control Unit, Campus Internationale de Baillarguet, Montferrier sur Lez, France
[7] CSIRO Division of Entomology, GPO Box 1700, Canberra, ACT 2601, Australia

Abstract

Cytisus scoparius (Scotch broom) is an aggressive invader of agricultural, forestry, and conservation lands in many parts of its exotic range. Biological control programmes for Scotch broom with insects began in the USA in the 1950s, in New Zealand in 1981, and in Australia in 1990. Two insect species (*Exapion fuscirostre* and *Leucoptera spartifoliella*) have been intentionally introduced into the USA, two (*Bruchidius villosus* and *Arytainilla spartiophila*) into New Zealand and three (*L. spartifoliella*, *B. villosus* and *A. spartiophila*) into Australia. Also, nine broom-feeding species were accidentally introduced into North America, and one into New Zealand. Scotch broom remains a problem weed in all three regions, and other related 'brooms' in the tribe Genisteae, also of European origin (*Cytisus striatus*, *Genista monspessulana*, *Genista linifolia*, *Genista stenopetala*, and *Spartium junceum*), now give cause for concern. In Europe 243 phytophagous insects and mites are associated with Scotch broom, and from these, and species recorded from other brooms, further possible insect biological control agents have been identified. Insufficient host specificity, and the risk of damage to closely related non-target plants, may limit the use of some oligophagous insect species. However, several host-specific insect and mite species have been identified that may contribute to managing Scotch broom throughout its exotic range. Pathogens have been identified that could be used as classical biological control agents, or developed into mycoherbicides. The development of insects, mites, and pathogens for control of broom species will contribute to sustainable management of an important group of problem weeds.

Introduction

Several plants in the tribe Genisteae, subtribe Genistinae (Fabaceae) have become weeds since they were introduced to areas outside their native ranges. A group within this subtribe known colloquially as 'brooms' includes *Cytisus* spp., *Genista* spp. and *Spartium junceum*. Gorse (*Ulex* spp.), also from the Genistinae, has traditionally been treated separately from the 'brooms', and neither it nor the spiny *Calicotome spinosa*, will be discussed in detail here. The group of brooms that is the subject of this review are those species that have become weedy in their exotic habitats (Table 1). *Cytisus multiflorus* is a common species from southwestern Europe that has naturalized widely but has not yet been recognized as a pest. *Chamaecytisus* (= *Cytisus*) *palmensis* (tree lucerne, or tagasaste), originating from the Canary Islands, is adventive in New Zealand and Australia. It occurs in reserves and along roadsides on Banks Peninsula, Canterbury, New Zealand, and may also be a minor weed in parts of southern Australia. This review summarizes the current status of biological control programmes for Scotch broom and related weedy broom species in North America, New Zealand, and Australia, and outlines future directions for these programmes. The potential of specialized broom-feeding insects as biological control agents and their relative priorities for further study are discussed.

Cytisus (= *Sarothamnus*) *scoparius* (Scotch broom) is the most serious of the broom weeds in all three regions. It was widely grown as an ornamental plant and has escaped from cultivation. It is occasionally a minor weed in Europe (e.g. Rousseau & Loiseau, 1982) but is much weedier in its exotic range: Australia, Canada, Chile, India, Iran, New Zealand, South Africa, and the USA (Fowler *et al.*, 1996). In New Zealand it is the only broom species that is a noxious weed. It is widespread and abundant in the drier eastern areas of the country, invading open grasslands on both productive and conservation lands. Scotch broom causes economic losses to agricultural and forestry operations, and detracts from conservation values (Syrett, 1996). In Australia, Scotch broom is the only *Cytisus* species declared noxious (Parsons & Cuthbertson, 1992). It is mainly a weed of native vegetation such as open *Eucalyptus* forests in New South Wales (NSW), Victoria, and South Australia, posing a serious threat in some national parks. It is also a problem in pasture grazed by cattle and in some commercial forestry in NSW, Victoria, and Tasmania (Hosking *et al.*, 1998). Other broom species that are considered weeds in Australia are, in order of importance, Cape or Montpellier broom (*Genista monspessulana*), needle-leaved broom (*Genista linifolia*) and Madeira broom (*Genista stenopetala*). *Genista monspessulana* and *G. linifolia* are also declared noxious weeds in Australia, and *C. scoparius* and *G. monspessulana* have been declared targets for biological control (Hosking *et al.*, 1998).

In North America Scotch broom has become a serious pest in the Pacific Northwest of the USA (Andres & Coombs, 1995). Scotch broom also occurs in several states along the Atlantic seaboard of the eastern USA where it is widely used as an ornamental, and is rarely found in the wild (G. P. Markin, pers. obs.). In the Pacific Northwest it has invaded disturbed sites with well-drained soils in logged areas, pastures, rights-of-way, river flood plains, and along roadsides. The primary economic impacts are from competition with pasture forage species, with seedling conifers on logged lands, and vegetation management on rights-of-way (Parker *et al.*, 1994). Loss of native species diversity in native habitats is also a major concern. Other broom species that have more recently been identified as weedy in North America are Portuguese broom (*Cytisus striatus*), Spanish broom (*S. junceum*), and French or Montpellier broom (*G. monspessulana*) (Miller, 1992).

A biological control programme for Scotch broom with insects began in the USA in the 1950s but was discontinued, partly because of increasing interest in the value of shrubby legumes as ornamental and landscape plants (Andres, 1979). Concern for the escalating economic costs of controlling weedy brooms as they rapidly spread into new areas has led to the recent revival of a programme to control Scotch broom and other brooms in the USA. The New Zealand biological control programme for Scotch broom began in 1981 in collaboration with the International Institute of Biological Control (now part of CABI Bioscience), and in 1990 Australia began their programme, also in collaboration with CABI. In 1997 the USA began contracting work on biological control agents for broom from CABI, and now all three programmes are closely interlinked.

Existing Insect Fauna of Brooms in their Exotic (Introduced) Ranges, Including Specialist Broom-feeding Species Accidentally Introduced from Europe

The fauna of Scotch broom in its exotic range is better known than that of the other brooms (Waloff, 1966; Syrett, 1993; J. R. Hosking, unpubl. data). The fauna comprises indigenous species that have transferred from their native hosts (usually polyphagous species, but also oligophages feeding on other Fabaceae), introduced generalists (often cosmopolitan species) and accidentally introduced specialist broom-feeding species. A much larger number of specialists have been recorded from Scotch broom in the Pacific Northwest of North America than in any of the other exotic regions.

Table 1. Broom species (Fabaceae; tribe Genisteae) that have become invasive in North America, New Zealand, and Australia.

Problem weed species	Exotic region where weed is a problem	Region of origin	References
Cytisus scoparius (broom, Scotch broom)	North America, New Zealand Australia	western Europe	Parker *et al.* 1994 Williams 1981 Hosking *et al.* 1998
Cytisus striatus (Portuguese broom)	North America	central Spain Portugal	Miller 1992 Anon. 1998
Genista monspessulana (French or Montpellier broom)	North America Australia	Mediterranean Region	Hosking *et al.* 1998
Genista linifolia (needle-leaved broom)	Australia	western Mediterranean Region	Hosking *et al.* 1998
Genista stenopetala (Madeira broom)	Australia	Madeira Canary Islands	Hosking *et al.* 1998
Spartium junceum (Spanish broom)	Australia North America	southwestern Europe Mediterranean Region	Hosking *et al.* 1998 Miller 1992

North America

Diabrotica duodecimpunctata (F.) (Col., Chrysomelidae) is a native species that is abundant on Scotch broom and other legumes throughout the Pacific Northwest. Large numbers of adults and larvae were collected by Waloff (1966). *Uresiphita reversalis* (Guenée) (Lep., Pyralidae) is a North American species that feeds on *Cytisus* and *Genista* as well as on lupins (Bernays & Montllor, 1989). It occurs in California and other regions of North America.

North America has a large fauna of introduced insects. The specialist broom seed-feeding beetle, *Bruchidius villosus* F. (Col., Chrysomelidae) has been recorded from the mid-eastern coast of the USA (Southgate, 1963) and now occurs throughout the range of Scotch broom in the east. From 50% to 80% of seed produced may be destroyed by the beetle (Markin, unpubl. data). It is likely to be approved for release in Oregon in 1998-99 (E. M. Coombs, pers. obs.). The European aphid *Ctenocallis setosa* Kaltenbach (Hem., Aphididae), also a broom specialist, has been recorded from British Columbia (Foottit & Richards, 1993), and from eastern North America (Markin, pers. obs.). *Gargara genistae* F. (Hem., Membracidae) is widespread on Scotch broom throughout Washington and Oregon. It is not found in sufficiently high numbers to be damaging. Downes (1957) recorded *G. genistae* from British Columbia in Canada, but Waloff (1966) did not find it in California. *Arytainilla spartiophila* (Förster) (Hem., Psyllidae) is common and abundant on Scotch broom throughout the Pacific Northwest and has also been recorded from the eastern USA (Pfeiffer, 1986). It was found in enormous numbers in British Columbia (Downes, 1957) and in California (Waloff, 1966). We believe that this insect may be having a substantial impact on some Scotch broom stands in North America. *Dictyonota fuliginosa* (Costa) (Hem., Tingidae) was reported from British Columbia, but not from California by Waloff (1966). It has been found at a number of sites in the Willamette Valley in Oregon, but not in large numbers. Three species of mirids that feed on Scotch broom and are partly predatory have been recorded. *Orthotylus* (= *Melanotrichus*) *concolor* Kirschbaum has been recorded from both British Columbia and California (Waloff, 1966) and was the most abundant mirid on Scotch broom in California. *Orthotylus virescens* Douglas & Scott was the more common species in British Columbia, reaching very high numbers, and is common in Oregon. Both species probably have an impact on broom and also predate other elements of the broom fauna. *Asciodema obsoletum* Fieber was reported from Scotch broom by Downes (1957) in British Columbia, but no current information on this species is available.

Leucoptera spartifoliella Hübner (Lep., Lyonetiidae) was released in California in 1960 (Frick, 1964) but was found to be already established in both Oregon and Washington by 1960 (see 'Insects Intentionally Introduced as Part of Planned Biological Control Programmes' below), probably accidentally imported with broom plants brought in as ornamentals (Ritcher, 1966). In Oregon, moth populations appear to have declined, possibly as a result of predation and parasitism (Andres & Coombs, 1995) or competition with *Arytainilla spartiophila. Agonopterix nervosa* Haworth (Lep., Oecophoridae) was first recorded in North America in about 1920 from Vancouver Island, British Columbia, and was first collected and identified in Oregon in 1963 in Salem on Scotch broom (Andres & Coombs, 1995). It is a species of European origin that also feeds on *Ulex europaeus.* In North America it is highly parasitized, and damage to *U. europaeus* is more severe than to Scotch broom. The European gall mite, *Aceria genistae* (Nalepa) (Acari, Eriophyidae), has been recorded from both *U. europaeus* and *G. monspessulana* in California but appears to have no significant impact on plants (Chan & Turner, 1998). This mite was also found on Scotch broom and on gorse in Oregon (P. D. Pratt, B. A. Croft & E. M. Coombs, unpubl. data).

New Zealand

The fauna of Scotch broom in New Zealand is meagre compared to that in its native Europe, as measured by both diversity of species and numbers of insects (Syrett, 1993). Caterpillars of both native and introduced leaf-rolling caterpillars (Lep., Tortricidae) include Scotch broom among the wide range of plant species they feed on. By destroying growing shoot tips that they web together, these caterpillars often damage bushes. Larvae of the native *Oemona hirta* (F.) (Col., Cerambycidae) mine the thicker stems, often near the base, and can cause substantial portions of a bush to die. This beetle also has a wide host range, including important cultivated plants such as citrus species. Similar damage is sustained from *Anisoplaca ptyoptera* Meyrick (Lep., Gelechiidae) whose larvae girdle stems by mining just beneath the bark. This insect is found more commonly on gorse than on Scotch broom, and is thought to have transferred to these two exotic hosts from native *Carmichaelia* (Fabaceae) species (Holder, 1990). Small numbers of the introduced *Acyrthosiphon pisum* (Harris) (Hem., Aphididae) occur on Scotch broom in New Zealand, but are far less numerous than *Acyrthosiphon pisum* ssp. *spartii* (Koch) in Europe (Syrett, 1993).

Two specialist broom-feeding invertebrates of European origin have been recorded feeding on Scotch broom in New Zealand. These are a foliage-feeding mite, *Bryobia variabilis* Manson (Acari, Tetranychidae), and the twig-mining moth *Leucoptera spartifoliella* (Syrett, 1993). Although the mite was common, it did not appear very damaging. Larvae of *L. spartifoliella* mine green stems of Scotch broom during winter and spring causing substantial die-back, and, when they are in sufficiently large numbers, death of branches or whole bushes. An insecticide exclusion experiment, carried out on paired Scotch broom bushes with high populations of *L. spartifoliella* in North Canterbury, showed that the insects were exerting a substantial impact on growth of bushes (Memmott *et al.*, 1997). Further assessment of the impact of the broom twig miner is in progress at three other sites. *Leucoptera spartifoliella* has been established in New Zealand since at least 1950, which is the date on the first recorded specimen of this moth in the New Zealand Arthropod Collection (NZAC), collected from Rotorua, in the North Island. The moth is now established throughout most of New Zealand, having spread at the rate of about 6 km per year between 1983 and 1990 (Syrett & Harman, 1995). The twig miner has been found on ornamental varieties of *Cytisus scoparius*, but not on bushes of *Cytisus multiflorus*, *Cytisus striatus*, *Chamaecytisus palmensis*, *Spartium junceum*, or *Genista monspessulana* growing close to infested Scotch broom bushes (P. Syrett & S. V. Fowler, pers. obs.).

Australia

In Australia a number of native and introduced generalist species are found on Scotch broom but, as is the case in New Zealand, the fauna is poor when compared with Europe. In southern NSW larvae of four cerambycids have been reared from girdled stems. The larger ones, *Uracanthus bivittata* Newman and *Strongylurus arduus* Elliott & McDonald, are probably responsible for the girdling, and the smaller ones, *Pentacosmia scoparia* Newman and *Sybra acuta* Pascoe, are probably secondary borers in dead girdled stems (Wapshere & Hosking, 1993). Caterpillars of the native leaf roller *Epiphyas postvittana* (Walker) (Lep., Tortricidae) web stems together and feed inside the webbed area. They are not common in major broom infestations in the Barrington Tops National Park (in northern NSW), but may be more common at lower altitude and in warmer areas. The characteristic froth of *Philagra parva* (Donovan) (Hem., Aphoridae) and *Philaenus spumarius* L. (Hem., Cercopidae) can be found on Scotch broom but numbers are usually low. Other Hemiptera such as *Acyrthosiphon pisum*, *Zygina zealandica* (Myers) (Cicadellidae), *Nysius vinitor* Bergroth (Lygaeidae), and

Austropeplus sp. ?*annulipes* Poppius (Miridae) may be locally common. *Acyrthosiphon pisum* is not as common as *A. pisum* ssp. *spartii* in Europe.

Seeds in pods of Scotch broom are destroyed by *Etiella behrii* (Zeller) (Lep., Pyralidae) (Hosking, 1995), an insect pest of a number of leguminous crops (Common, 1990). However, the number destroyed in this way is small when compared with the number destroyed by seed-feeding insects in Europe. Large numbers of *Thrips imaginis* Bagnall (Thysanop., Thripidae) can be found amongst Scotch broom flowers throughout NSW. The scale insect *Nipaecoccus ericicola* (Maskell) (Hem., Pseudococcidae) is commonly seen on Scotch broom in NSW and Victoria and has a broad host range in the literature (Williams, 1985). The European scale *Parthenolecanium rufulum* (Cockerell) (Hem., Coccidae) is found on Scotch broom in NSW, probably the result of an accidental introduction. While the scale is reported to have a wide host range in Europe (Singh, 1967), in Australia it has been found only on *Cytisus scoparius.* In a field trial conducted near Canberra, the scale was the primary cause of a 33% reduction in seed production of control versus insecticide-treated Scotch broom bushes in their first year of seed production (A. W. Sheppard & P. Hodge, unpubl. data). The mealybug *Vryburgia brevicruris* (McKenzie) (Hem., Pseudococcidae) has also been identified from roots of Scotch broom at the Barrington Tops National Park. It is not common on broom and has been recorded from twelve other species, mainly from the roots (Williams, 1985).

The European aphid *A. pisum* ssp. *spartii* that colonizes woody Genistineae has been recorded from Tasmania. Recent searches in Tasmania have not found any aphids present in large numbers on Scotch broom (Hosking & Sheppard, unpubl. data) and there is now some doubt as to whether this subspecies is established in Tasmania.

Insects Intentionally Introduced as Part of Planned Biological Control Programmes

North America

From 1951, field surveys were conducted in central Europe to look for phytophagous insects associated with Scotch broom. Two species were selected for host-range testing: *Leucoptera spartifoliella* and *Exapion* (= *Apion*) *fuscirostre* (F.) (Col., Apionidae). Both species were released in the field in California in 1960 and 1964 respectively (Andres *et al.*, 1967) (Table 2). *Exapion fuscirostre* was released in Oregon in 1983 and in Washington in 1989 (Andres & Coombs, 1995). High populations of weevils in the coastal mountain areas of California resulted in up to 60% of seeds being destroyed. Isaacson (1993) reported that in Oregon *E. fuscirostre* destroyed 75-90% of seed produced by Scotch broom. Nearly 500 releases of adult weevils have been made in 11 counties west of the Cascade Mountains, and in 1996 a random survey of 129 Scotch broom sites showed that weevils were present at 60 sites. At the weevil-infested sites, an average 65% of pods were attacked, producing an average 3.1 weevils per pod. The average number of viable seeds produced in uninfested pods was 8.5 compared with 2.8 in infested pods. A parasitic wasp, *Pteromalus sequester* Walker (Hym., Pteromalidae) was found attacking *E. fuscirostre* in Oregon in 1997 (Markin & Coombs, unpubl. data).

The broom twig miner, *L. spartifoliella* was intentionally released in California in 1960. Populations of the moth established, and initially caused severe damage across sizeable areas of Scotch broom (Hawkes, 1963). However, soon after its release in California, the moth was discovered to have been present in Washington at least since 1941, and in Oregon (Frick, 1964). At the Washington site, and at sites in California where the moth had been accidentally released, it was found to be parasitized by the eulophid parasitoid *Tetrastichus evonymellae* Bouché (Hym., Eulophidae), its most common natural enemy in Europe.

Table 2. Insects that have been released intentionally for biological control of Scotch broom *Cytisus scoparius* (Julien 1992, with updated information).

Agent	Date released	Status and degree of control	References
Leucoptera spartifoliella Hübner (Lep., Lyonetiidae)	1960	**USA** ex France: established; impact negligible; accidentally introduced and heavily parasitized.	Frick 1964 Andres & Coombs 1995 Wapshere & Hosking 1993
	1993	**Australia** ex New Zealand (where accidentally introduced). Established, too early to assess impact.	
Exapion fuscirostre (F.) (Col., Apionidae)	1964	**USA** ex Italy: established in western USA, destroys upwards of 60% seed.	Frick 1964 Andres & Coombs 1995 Isaacson *et al.* 1995
Bruchidius villosus F. (Col., Chrysomelidae)	1987	**New Zealand**: established, destroying 60% seed at early release site.	Syrett & O'Donnell 1987 Harman *et al*. 1996
	1991	**Australia**: established.	J.R. Hosking pers. obs.
Arytainilla spartiophila Förster (Hem., Psyllidae)	1993	**New Zealand**: established, too early to determine impact.	Harman *et al*. 1996 A.W. Sheppard pers. obs.
		Australia: released, establishment not confirmed.	

Although twelve specialized broom-feeding insects have established in North America, both intentionally and accidentally, there is little quantitative information on how damaging they are to their host plant. Bossard & Rejmanek (1994) conducted an insecticide check experiment that showed no effect of herbivory on growth of Scotch broom seedlings in their first two growing seasons in California. Waloff (1966) suggested that the stressed appearance of Scotch broom plants growing in British Columbia compared to California might reflect the higher number of broom-feeding insects found in British Columbia. Large numbers of three insect species (*L. spartifoliella, Arytainilla spartiophila,* and *E. fuscirostre*) that cause noticeable damage to Scotch broom have been recorded in the USA, but these insects may not affect young plants, as they were not present on experimental plots in the study by Bossard & Rejmanek (1994). The impact of insects accidentally introduced into North America is limited by the effect of some of their natural enemies that have been introduced with them. The twig-mining moth *L. spartifoliella* does not attain high populations as reported regularly from New Zealand, probably because of the inadvertent introduction into North America of one of the moth's most important parasitoids, and the psyllid *A. spartiophila* may be prevented from exerting its maximum effect by a predatory mirid species (*Heterotoma merioptera* (Scopoli)), which may also have been introduced with Scotch broom (Waloff, 1966).

New Zealand

The first introduction into New Zealand for biological control of Scotch broom was *Bruchidius villosus* in 1987 from the UK (Harman *et al.,* 1996) (Table 2). Seed-feeding species were investigated first because they posed no threat to existing stands of Scotch broom and conflicts of interest concerning biological control of the weed had still to be resolved (Syrett, 1987). Host-specificity tests indicated that *B. villosus* is restricted to *Cytisus scoparius* (Syrett & O'Donnell, 1987). Releases averaging 1000 adult beetles have now been made at 73 sites throughout New Zealand. They are confirmed as established at 18 sites (by summer 1997-98) (L. M. Hayes, Landcare Research, Lincoln, pers. comm.). Most of the other releases have been made too recently for establishment to be confirmed. At a site in Lincoln, Canterbury, where beetles were released in 1991, the seed infestation rate was 40% in 1996-97 and 60% in 1997-98 (J. J. Sheat & P. Syrett, unpubl. data). It is still apparently increasing. Parasitism by *P. sequester* is a primary source of mortality in Europe (Agwu, 1971), but so far levels of *P. sequester* have been low in *B. villosus* in New Zealand compared to *Exapion ulicis* Förster in gorse seed (Sheat & Syrett, unpubl. data). The psyllid *A. spartiophila* was first released in 1993 (Harman *et al.*, 1996) and is now established in at least two regions. It is too early to conclude whether the psyllid will have a substantial impact on Scotch broom, but experiments are in progress to study its interaction with the widely established *L. spartifoliella*.

Australia

The first biological control agent to be released in Australia was the broom twig-mining moth, *L. spartifoliella,* which was released in NSW in February 1993 (Wapshere & Hosking, 1993). This species was sourced from New Zealand where the insect had established accidentally. The insect has established at most release sites in NSW and Victoria. It is still too early to determine the level of damage likely to be caused by this moth in Australia. The broom psyllid, *A. spartiophila,* was released in December 1994 and January 1995 at a number of sites in NSW but establishment of this species has yet to be confirmed. The psyllid was initially released as early instars in young broom plants. Following successful establishment of this insect in New Zealand from adult releases, the technique is to be adopted in Australia using psyllids that have been reintroduced from New Zealand through quarantine in Canberra. A third agent, the broom seed-feeding beetle, *B. villosus*, was released near Katoomba and near Braidwood at the end of 1995. Large releases of *B. villosus* were made late in 1996 in the Barrington Tops National Park and at Braidwood from insects field-collected in New Zealand and quarantined in Australia. This technique was again used in early 1998 for further releases made in Victoria and NSW. It is too early to determine whether or not *B. villosus* has established. The parasitoid *P. sequester* is present and widespread in Australia (Boucek, 1988; R. Holtkamp, NSW Agriculture and Fisheries, Tamworth, pers. comm.) and may affect populations of seed-feeding beetles.

Opportunities for Further Insect Introductions from the Fauna of Broom Species in their Native Europe

Syrett *et al.* (1996) reported that 243 phytophagous insect and mite species have been recorded from Scotch broom in Europe. Since many of these are specialist feeders on broom and closely related species, there is a rich source of potential agents for biological control of Scotch broom in its exotic habitats. Phytophagous species feeding on other brooms are less well known, so the information presented on them is incomplete, and further field surveys will be required to find a full range of potential control agents.

Scotch broom is widely distributed through western and central Europe. However, in the southern parts of its European range *Cytisus scoparius* is restricted to hilly, less-developed country: for example in southern France it is most common between altitudes of 600 m and 1300 m above sea level. Although several of the other problem weed species listed in Table 1 have relatively restricted native ranges within Europe, they have since been introduced more widely to a range of European countries. *Spartium junceum* has been planted as an ornamental throughout northwestern Europe, well outside its native range, and in recent times *Cytisus striatus* has been sown extensively along newly created roadside verges in northern France, Germany, and the UK. *Genista monspessulana* is grown widely as an ornamental, but not in the UK, probably because it is frost tender. *Spartium junceum* and *G. monspessulana* commonly occur at lower altitudes, down to sea level along the Mediterranean coast of France. Except for *S. junceum,* most broom species are absent from areas of calcareous soils. The most diverse fauna associated with a plant group is likely to be found within its natural range, and close to the centre of origin of the plant group (Wapshere, 1974). For the genera *Cytisus, Genista,* and *Spartium,* this is in southwestern Europe.

The insect fauna of Scotch broom, *C. scoparius,* in southern England is well known from extensive studies carried out in the 1950s and 1960s at Silwood Park, Ascot, UK, by staff and students of Imperial College, London (Waloff, 1968). Surveys of Scotch broom in central Europe were undertaken as part of a biological control programme for the weed in the USA from 1951 (Clausen, 1978). In order to sample the centre of origin, and areas climatically matched to areas where Scotch broom is a problem in its exotic range, recent surveys have been conducted in France, Spain, and Portugal as part of current biological control programmes for the weed in New Zealand and Australia (Figure 1). Collections have been made from other *Cytisus* spp., *Genista* spp., and *S. junceum* as part of a study to determine the natural host-range of species feeding on Scotch broom (Syrett & Emberson, 1997). Several Curculionidae and Chrysomelidae that feed on plants in the tribe Genisteae in central Spain have been studied by a group based at the Universidad Autonoma in Madrid (Velázquez de Castro *et al.,* 1990; García Ocejo *et al.,* 1992). A list of oligophagous and monophagous insects feeding on *C. scoparius* and some of its close relatives is presented in Table 3. Information was gathered from the literature and from field surveys (1989-96).

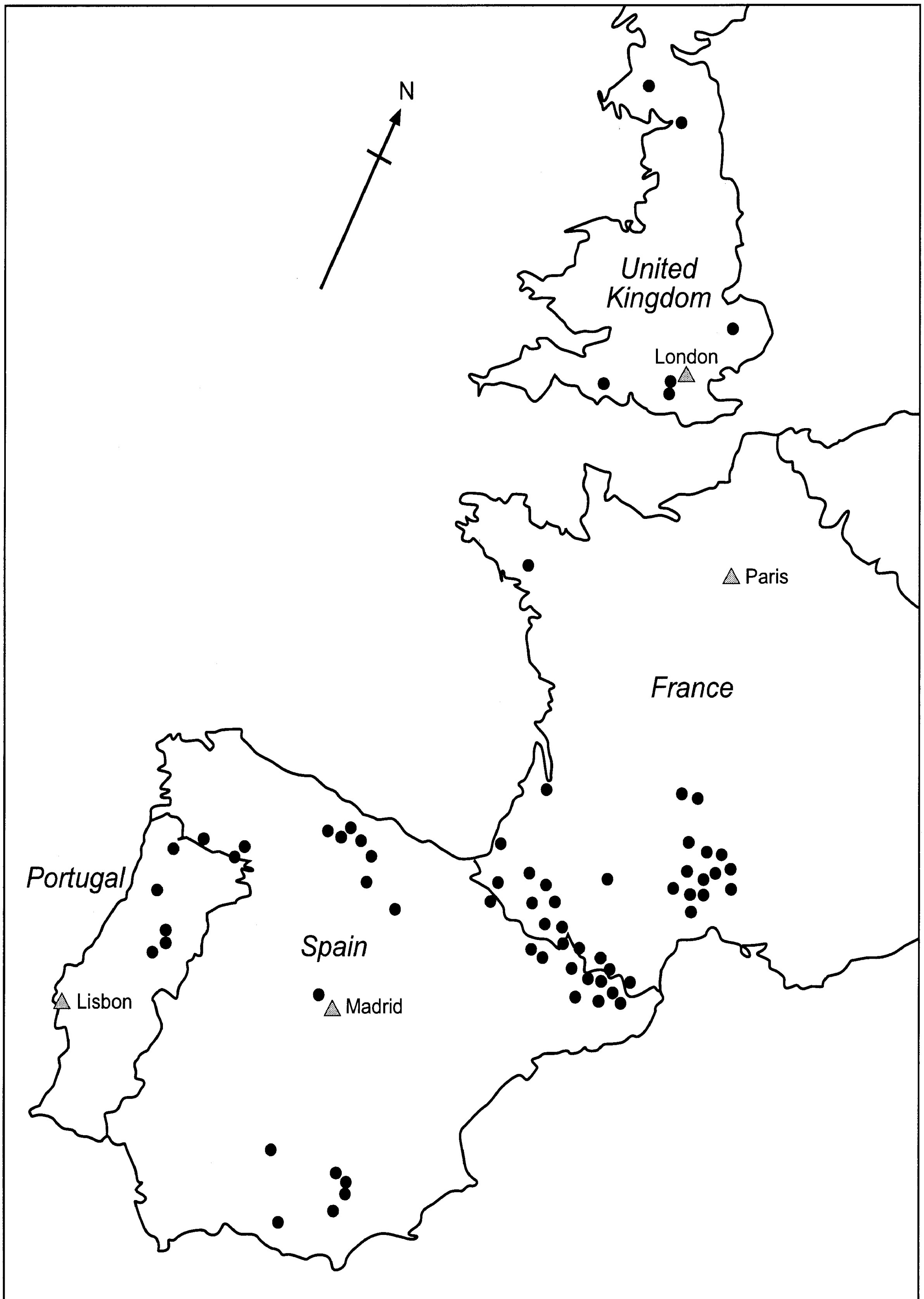

Figure 1. Locations of sites in Europe where field collections were made. Insect species collected are listed in Table 3.

Table 3. Host specific and oligophagous herbivores to be considered for biological control of broom Cytisus spp. and related weedy brooms.

Feeding site	Damage	Host plants	Distribution[1]	Reference	Field collections[2]
SEED FEEDERS					
Apionidae					
Exapion compactum (Debrochers)	larvae develop in seeds	*Genista* spp., *Cytisus* spp.	Mediterranean	Gurrea *et al*. 1991	
Exapion elongatissimum (Debrochers)	larvae develop in seeds	*Cytisus striatus*	Iberian Peninsula	Gurrea *et al*. 1991	1: S, P
Exapion fuscirostre (F.)[3]	larvae develop in seeds	*Cytisus* spp.	Europe, N. Africa, western N. America	Parnell 1966 Gurrea *et al*. 1991 Andres *et al*. 1967	1: E, F, S, P 2: F, S 3: E, F, S 4: F, S
Exapion genistae (Kirby)	larvae develop in seeds	*Genista*	Europe, Atlantic	Morris 1990	
Exapion laufferi (Schilsky)	larvae develop in seeds	*Genista*	Iberian Peninsula	Gurrea *et al*. 1991	
Exapion putoni (Ch. Brisout)	larvae develop in seeds	*Genista* spp.	Iberian endemic	Gurrea *et al*. 1991	1: S
Lepidapion squamidorsum Desbrochers	?associated with seeds	*Genista cinerea*	Iberian Peninsula, N. Africa	Velàzquez de Castro *et al*. 1988	1: S
Lepidapion spp.	?associated with seeds	Genisteae: *Retama, Genista, Cytisus, Ulex*	Mediterranean, Canary Is.	Alonso Zarazaga 1990	
Curculionidae					
Pachytychius sparsutus (Olivier)	larvae feed in pods	*Cytisus, Genista,* other Genisteae	C. & S. Europe	Sanz Benito *et al*. 1989	1: S, P 2: F (reared) 3: F 4: F
Chrysomelidae					
Bruchidius lividimanus (Gyllenhal)	larvae develop in seeds	*Cytisus* spp., other Genisteae	France, Spain	Brandl 1981	1: F, S, P 2: F, S 3: F 4: F, S
Bruchidius villosus (F.)[3,4]	larvae develop in seeds	*Cytisus scoparius*	Europe, eastern N. America	Syrett & O'Donnell 1987 Chantal 1972 Southgate 1963	1: E, F, S, P 2: F, S 3: E, F 4: F, S
BUD & FLOWER FEEDERS					
Gelechiidae					
Mirificarma mulinella (Zeller)	in flowers	*Ulex, Cytisus, Genista*	UK	Emmet 1988	
Apionidae					
Protopirapion atratulum (Germar)	larvae feed in flowers	*C. scoparius*	Europe, Algeria	Noe-Nygaard 1978	1: E, F, S, P 3: E, F, S 4: F, S
Curculionidae					
Tychius parallelus (Panzer)	larvae feed in buds	*Cytisus* spp.	Europe, Algeria	Velàzquez de Castro & Alonso Zarazaga 1988	1: F, S, P 3: F 4: F
DEFOLIATORS					
Chrysomelidae					
Cryptocephalus octoguttatus (L.)	adults feed on foliage	*Cytisus* spp., *Genista* spp.	Iberian Peninsula, S. France	García Ocejo et al. 1992	1: S, P
Cryptocephalus tibialis (Ch. Brisout)	adults feed on foliage	*Cytisus*	Spain	García Ocejo *et al*. 1992	1: S, P 3: F
Gonioctena leprieuri Olivier	adults and larvae feed on foliage	*Genista*	Spain	García Ocejo & Gurrea 1991	1: S

Table 3. Host specific and oligophagous herbivores to be considered for biological control of broom Cytisus spp. and related weedy brooms. (continued)

Feeding site	Damage	Host plants	Distribution[1]	Reference	Field collections[2]
Gonioctena olivacea (Förster)	adults and larvae feed on foliage	*Cytisus* spp.	Europe & Asia	Richards & Waloff 1961 Syrett *et al.* 1997	1: E, F, S, P 2: F, S 3: E, F 4: F
Gonioctena variabilis (Olivier)	adults and larvae feed on foliage	Genisteae	Mediterranean	García Ocejo *et al.* 1992	1: S (reared)
Geometridae					
Chesias legatella (Denis & Schiffer-müller)	foliage	C. *scoparius*, other spp.?	C. & S. Europe, N. Africa	Wall 1975	1: E, F 3: E, F 4: F
Chesias rufata (F.)	foliage	*C. scoparius*, other spp.?	C. & S. Europe, N. Africa	Wall 1975	
Isturgia limbaria (F.)	foliage	C. *scoparius*	C. Europe	Carter & Hargreaves 1986	3: F 4: F
Pseudoterpna pruinata (Hufnagel)	foliage	*Ulex, Cytisus, Genista*	C. & SE Europe	Carter & Hargreaves 1986	3: F 4: F
Scotopterix moeniata (Scopoli)	foliage	*Cytisus*	C. Europe	Meyrick 1928	
Scotopterix mucronata Scopoli	foliage	*Ulex, Cytisus*	widespread Europe	Carter & Hargreaves 1986	
Scotopterix peribolata Hübner	foliage	*Cytisus, Ulex, Genista*	C. Europe	Skinner 1984	
Coleophoridae					
Coleophora saturatella Stainton	mines leaves, especially from tips	*Cytisus, Genista*	UK	Emmet 1988	4: F
Gelechiidae					
Anarsia spartiella (Shrank)	feeds in spun shoots	*Ulex, Cytisus, Genista*	UK	Emmet 1988	3: E
Heterogynidae					
Heterogynis penella Hübner	foliage	*Genista, Cytisus*	S. Europe	Carter & Hargreaves 1986	3: F
Noctuidae					
Apopestes spectrum (Esper)	foliage	*Genista, Spartium, Cytisus, Retama*	S. Europe	Carter & Hargreaves 1986 Martín Cano 1981	1: S
Oecophoridae					
Agonopterix assimilella (Treitschke)	foliage	C. *scoparius*	C. & S. Europe	Emmet 1988	3: E, F 4: F, S
Agonopterix scopariella (Heinemann)	foliage	*Cytisus, Genista*	C. & S. Europe, N. Africa	Emmet 1988	3: E, F
Agonopterix nervosa (Haworth)	foliage	*Cytisus, Genista, Ulex*	Europe, British Columbia	Emmet 1988 Andres & Coombs 1995	3: E
Pyralidae					
Uresiphita polygonalis (excl. *maorialis*) (Denis & Schiffermüller)	foliage	*Genista, Cytisus*	Europe, Asia, South Africa, Hawaii	Emmet 1988 Kloet & Hincks 1972 Leen 1997	
Tenthredinidae					
Rhogogaster genistae (Benson)	larvae feed on foliage	*Cytisus, Genista*	C. & E. Europe	Benson 1952 Kloet & Hincks 1978	
Rhogogaster picta (Klug)	larvae feed on foliage	*C. scoparius*	C. & E. Europe, N. Africa	Benson 1952 Kloet & Hincks 1978	

Table 3. Host specific and oligophagous herbivores to be considered for biological control of broom Cytisus spp. and related weedy brooms. (continued)

Feeding site	Damage	Host plants	Distribution[1]	Reference	Field collections[2]
SAP-SUCKERS					
Tetranychidae					
Bryobia sarothamni Geijskes	sap feeding	*Cytisus*	Europe	Pritchard & Baker 1955	
Aphididae					
Acyrthosiphon pisum ssp. *spartii* (Koch)	leaves & green stems, developing pods	*C. scoparius*	UK, France	Smith 1966	2: F 3: E, F 4: F
Aphis cytisorum Hartig	foliage, stems developing pods	*Cytisus, Laburnum, Spartium, Chamaecytisus palmensis*	UK, W. Europe, Canary Is.	Wink *et al.* 1982 Torres del Castillo *et al.* 1992	1: F 2: F, S 3: E 4: F
Callaphididae					
Ctenocallis setosa (Kaltenbach)	foliage, flattened against mid rib on upper leaf surface	*Cytisus scoparius*	UK, France Introduced: British Columbia	Stroyan 1977 Foottit & Richards 1993	3: E, F 4: F, S
Diaspididae					
Quadraspidiotus sulci Balachowsky	bark	*Cytisus, Genista*	E. Europe	Kosztarab & Kozár 1988	
Membracidae					
Gargara genistae (F.)[4]	foliage	*C. scoparius*	UK, W. Europe Introduced: N. America	Kloet & Hincks 1964 Downes 1957	1: E 2: F, S 3: E, F 4: F
Pentatomidae					
Piezodorus lituratus (F.)	foliage	*Cytisus, Ulex, Genista*	Europe	Waloff 1968 Beck 1977	1: E, F, S 2: F, S 3: E, F 4: F
Psyllidae					
Arytaina genistae (Latreille)	foliage	*Cytisus, Genista*	Europe	Watmough 1968 Hodkinson & Hollis 1987	1: E, F, S, P 2: F, S 3: E, F 4: F, S
Arytainilla algeriensis Burckhardt	foliage	*Cytisus arboreus*	Algeria	Burckhardt 1989	
Arytainilla gredi (Ramirez Gomez)	foliage	*C. scoparius?*	Spain	Hodkinson & Hollis 1987	
Arytainilla spartiicola (Sulc)	foliage	*C. scoparius*	France	Hodkinson & Hollis 1987	
Arytainilla spartiophila (Förster)[3,4]	foliage	*C. scoparius*	Europe Introduced: N. America	Watmough 1968 Hodkinson & Hollis 1987 Pfeiffer 1986	1: E, S, P 2: F, S 3: E, F 4: F, S
Tingidae					
Dictyonota fuliginosa Costa[4]	foliage	*C. scoparius*	UK Introduced: British Columbia, W. USA	Scudder 1960 Göllner-Scheiding 1968	1: E, S 2: F, S 3: E, F
STEM BORERS					
Apionidae					
Pirapion immune (Kirby)	larvae mine and gall stems	*Cytisus* spp.	Europe, N. Africa	Williams 1968 Gurrea Sanz *et al.* 1986 Syrett *et al.* 1995	1: E, F, S, P 2: F, S 3: E, F 4: F, S

Table 3. Host specific and oligophagous herbivores to be considered for biological control of broom Cytisus spp. and related weedy brooms. (continued)

Feeding site	Damage	Host plants	Distribution[1]	Reference	Field collections[2]
Buprestidae					
Agrilus biguttatus (F.)	larvae tunnel under bark	*Cytisus?*	Italy	Pemberton & Hoover 1980	
Anthaxia funerula (Illig.)	larvae tunnel under bark	Genisteae	Europe?	Simandl & Kletecka 1987	
Cerambycidae					
Deilus fugax (Olivier)	larvae bore stems	Genisteae	Europe, N. Africa	Simandl & Kletecka 1987	1: S, P
Scolytidae					
Phloeophthorus rhododactylus (Marsham)	larvae tunnel under bark	*Cytisus, Spartium*	W. & C. Europe, N. Africa	Simandl & Kletecka 1987	1: E, F, S, P 4: F
Gracillariidae					
Phyllonorycter scopariella (Zeller)	mines green bark	*C. scoparius*	E. Europe, local UK, France	Emmet 1988	3: E, F
Lyonetiidae					
Leucoptera spartifoliella Hübner[3,4]	mines in bark of green stems	*C. scoparius*	N. & C. Europe	Agwu 1974 Scheele & Syrett 1987 Memmott *et al*. 1997 Ritcher 1966	1: E, F 2: F 3: E, F 4: F, S
Nepticuliidae					
Trifurcula immundella (Zeller)	mines bark & leaves	*C. scoparius*	C. & SE Europe, N. Africa	Meyrick 1928 Emmet 1988	
ROOT FEEDERS					
Chrysomelidae					
Calomicrus circumfusus (Marsham)	larvae found in roots	Genisteae	Europe	García Ocejo *et al*. 1990	1: F, S, P 3: F 4: F
Curculionidae					
Sitona regensteinensis (Herbst)	larvae feed in root nodules	*Cytisus*, other Genisteae?	C. & S. Europe, Algeria	Danthanrayana 1969 Syrett 1992	1: E, F, S, P 2: F, S 3: E, F, S 4: F, S
Lixus spartii Olivier	larvae feed in roots	*Cytisus, Genista*	Mediterranean	Sanz Benito & Gurrea Sanz 1991	1: F
Polydrusus confluens Stephens	larvae feed in roots	*Cytisus*, other Genisteae?	Europe	Sanz Benito *et al*. 1990	1:F, S, P 3: F
GALL FORMERS & LEAF MINERS					
Eriophyidae					
Aceria genistae (Nalepa)	galls stems	form probably specific to *Cytisus*	Europe	Castagnoli 1978 Keesing 1981	1: S, P 2: F 3: E, F 4: E, F, S
Aceria spartii (Canestrini)	galls stems	*Spartium junceum*	Italy	Castagnoli 1978	4: S
Agromyzidae					
Agromyza johannae de Meijere	mines leaves	*Cytisus, Genista, Ulex, Spartium*	Europe	Spencer 1990	3: E 4: F, S
Hexomyza sarothamni (Hendel)	galls twigs	*Cytisus, Genista?*	W. Europe	Spencer 1990	3: F 4: F, S
Cecidomyiidae					
Asphondylia pilosa Kieffer	bud gall	*Cytisus*	UK	Kloet & Hincks 1976	3: E 4: F

Table 3. Host specific and oligophagous herbivores to be considered for biological control of broom Cytisus spp. and related weedy brooms. (continued)

Feeding site	Damage	Host plants	Distribution[1]	Reference	Field collections[2]
Asphondylia sarothamni Loew	pod and bud gall	*Cytisus*	Europe	Kloet & Hincks 1976	3: E 4: E, F, S
Contarinia pulchripes Kieffer	pod gall	*Cytisus, Genista*	UK	Parnell 1963	4: F, S
Contarinia scoparii (Rübsaamen)	galls buds and petioles	*C. scoparius*	UK	Kloet & Hincks 1976 Paynter *et al.* 1996b	4: F
FUNGI					
Uromyces sarothamni Guyot & Massenot	pustules on leaves and young stems	*Cytisus*	Europe	Guyot & Massenot 1958	

1 C.: central.
2 1 Syrett, 2 Hosking, 3 Fowler, 4 Paynter (collections); E England, F France, S Spain, P Portugal (locations).
3 Intentionally introduced into exotic regions for biological control.
4 Accidentally introduced into exotic regions.

Visible damage to Scotch broom plants throughout the native range is often substantial, and on occasions it appears that attack by insect herbivores can cause mortality of both young and established plants (Fowler, pers. obs.). An experiment using insecticide to suppress insect populations on broom at Silwood Park, UK, was conducted for 11 years (Waloff & Richards, 1977). This experiment involved comparisons between an insecticide-treated plot and an untreated plot. Bushes in the untreated plot supported higher numbers of insect herbivores, did not grow as tall, and had higher mortality than bushes in the treated plot. Seed production over the average ten-year lifespan of untreated bushes was reduced by 75% compared to that of bushes protected with insecticide (Waloff & Richards, 1977). During these experiments, aphids (*Acyrthosiphon pisum*) and psyllids (*Arytaina genistae* (Latreille) and *Arytainilla spartiophila*) reached very high numbers in some years causing apparent stress to plants, but herbivore impact could not be attributed to any one species.

As part of the programme for biological control of Scotch broom, manipulative experiments are being conducted to study the impacts and interactions of Scotch broom herbivores so as to improve the predictability of their efficacy as biological control agents (Hinz, 1992; Memmott *et al.*, 1993; Fowler *et al.*, 1996; Paynter *et al.*, 1996a; Paynter *et al.*, 1998).

Seed feeders

Large seed banks of Scotch broom in soil in Europe indicate that seed- and pod-feeding insects have limited potential for controlling existing stands of the weed (Hosking, 1995). However, Rees & Paynter (1997) predicted from modelling studies that seed feeders may be effective in forest understorey and highly disturbed habitats, dominated by young, pre-reproductive plants. Also, if potential biological control agents were able to escape the high levels of predation and parasitism in Europe (Waloff, 1968) their impact might be substantially greater. Seed feeders may slow the rate of spread of Scotch broom into uninfested areas, since it has not yet attained its potential distribution in exotic regions (Paynter *et al.*, 1996a). This may be even more relevant for broom species of more limited distribution than Scotch broom. There are large numbers of seed-feeding insects that specialize on the Genisteae (Table 3), particularly species from the genera *Exapion* and *Lepidapion*. Taxonomic identification of the estimated 15 or so species in the genus *Lepidapion* is difficult (Alonso Zarazaga, 1990), but current studies of the taxonomy and host relationships of this group may reveal host-specific seed feeders of weedy Genisteae targetted for biological control (Y. Jiménez Ruiz, Universidad Autonoma, Madrid, pers. comm.). Mazay (1993) found that in southern France the most common seed-feeding insects were *Bruchidius lividimanus* (Gyllenhal) and *Pachytychius sparsutus* (Olivier) (Col., Curculionidae) although attack rates were much lower than for *Bruchidius villosus* and *Exapion fuscirostre* in New Zealand and Oregon respectively.

Bud and flower feeders

Bud and flower feeders are not usually accorded high priority as biological control agents because a high proportion of buds and flowers are often aborted naturally by plants that produce many times the number of propagules required to maintain the population. However, the demonstrated success of a flower feeder in contributing to control of *Sesbania punicea* (Fabaceae) in South Africa (Hoffmann & Moran, 1998), and recent work showing that reducing seed set reduces the rate of invasion and abundance of Scotch broom (Rees & Paynter, 1997) raised the priority of *Protopirapion atratulum* (Germar) (Col., Apionidae) (Table 3) whose larvae feed in developing broom flowers. Tests to determine the specificity of *P. atratulum* (Paynter, 1998) showed that it feeds on *Lupinus arboreus* (Fabaceae) as well as on *Cytisus* species.

Defoliators

Defoliating insects have experienced mixed popularity as biological control agents. Chrysomelid species such as *Chrysolina* spp. on *Hypericum perforatum* (Hypericaceae) have been spectacularly successful (Julien, 1992) while the ability of plants to compensate for high levels of defoliation (e.g. *Senecio jacobaea* (Compositae) recovers completely from total defoliation by *Tyria jacobaeae* L. (Lep., Arctiidae) (Islam & Crawley, 1983)) has made biological control practitioners sceptical as to the efficacy of some foliage-feeding species. Scotch broom has photosynthesizing green stems that may assist it in compensating for defoliation. Potential new, defoliating control agents fall into three groups: the chrysomelid beetles, Lepidoptera, and sawflies (Table 3). There is currently a proposal to introduce into New Zealand a chrysomelid beetle (*Gonioctena olivacea* (Förster)) common and widespread in Europe, that can cause spectacular damage to broom seedlings (Syrett *et al.*, 1997). Tests have shown that there is some risk of damage to non-target plants such as tree lucerne and lupins, which may prevent its widespread use. As only the adults of the *Cryptocephalus* species listed in Table 3 feed on live plant material, they have not at this stage been accorded high priority for further study. Several foliage-feeding caterpillars show some promise. *Agonopterix assimilella* (Treitschke) (Oecophoridae) is a damaging species in Europe, and this species is undergoing host-range testing at present (Shaw & Fowler, 1996). Two *Chesias* species are probably specific to *Cytisus*, and work is well advanced with *Chesias legatella* (Denis & Schiffermüller) (Geometridae), although further testing is required with *Lupinus* spp. (Fowler *et al.,* 1993). *Isturgia limbaria* (F.) and *Pseudoterpna pruinata* (Hufnagel) (both Geometridae) have a narrow host range, but probably feed on plants outside the genus *Cytisus* (Table 3).

The biology of the sawflies, *Rhogogaster* spp., is not well known, but the larvae feed on foliage. *Rhogogaster genistae* (Benson) (Hym., Tenthredinidae) has also been recorded from *Genista tinctoria*, and although the only host plant record for *Rhogogaster picta* (Klug) is *C. scoparius*, its recorded range includes North Africa, indicating that it must use other hosts (Kloet & Hincks, 1978). Only two species of sawflies have been recorded as biological control agents, and only one has established (Julien, 1992). However, the sawfly *Monophadnus spinosa* (Klug) (Tenthredinidae) is considered a promising control agent for *Clematis vitalba* (Ranunculaceae) in New Zealand (Groppe, 1991).

Sap suckers

Many sap-sucking species, including species that are both phytophagous and predatory, have already been accidentally introduced into North America (Waloff, 1966). If introduced into other regions as biological control agents, the predatory species are likely to use native prey species as well as feeding on broom, so are unlikely to be approved for release. Solely phytophagous species such as *Arytaina genistae* and *Dictyonota fuliginosa* may have potential in Australia and New Zealand. The aphid, *Ctenocallis setosa*, is uncommon and patchily distributed in Europe. However, it is easy to culture, and may be limited in the field through mirid predation (Q. E. Paynter, pers. obs.). Tests showed that it could develop on tree lucerne, so it is not a high priority for further study (Paynter *et al.,* 1996b). *Acyrthosiphon pisum* ssp. *spartii* is very common on broom in the UK and frequently attains damaging population levels (Smith, 1966).

Stem borers

The stem-boring weevil *Pirapion immune* (Kirby) (Col., Apionidae) showed an ability to develop on *Sophora microphylla* (Fabaceae), an important native tree in New Zealand (Syrett *et al.*, 1995), so was not introduced as a biological control agent. It may also pose a threat to tree lucerne and lupins, so is unlikely to be suitable for introduction to Australia or North America. Of the other stem-boring species listed in Table 3, *Phyllonorycter scopariella* (Zeller) (Lep., Gracillariidae) is likely to be the most restricted in host range as it is recorded only from *Cytisus scoparius*.

Root feeders

Sitona regensteinensis (Herbst) (Col., Curculionidae), a root-feeding weevil, has proved difficult to rear and therefore to test (Syrett, 1992). Initial tests with adult beetles indicated that the weevil has a narrow host range, but larval tests have been less conclusive. As female beetles deposit eggs indiscriminantly on the soil surface, larval specificity is crucial. There are also indications that *S. regensteinensis* may not be as damaging as previously thought (Shaw & Fowler, 1996). Adults of two other beetles with root-feeding larvae (*Calomicrus circumfusus* (Marsham) (Chrysomelidae) and *Lixus spartii* Olivier (Curculionidae)) are commonly collected from other plants in the tribe Genisteae, indicating that they have a broader range within the Genisteae, but field records of *Polydrusus confluens* Stephens (Curculionidae) indicate that it may be more restricted (Syrett & Emberson, 1997). Therefore *P. confluens* may warrant further study.

Gall formers and leaf miners

Gall-forming insects and mites can be debilitating to plants, and have been highly successful as biological control agents (e.g. *Trichilogaster acaciaelongifoliae* Froggatt (Hym., Pteromalidae) on *Acacia longifolia* (Leguminosae) in South Africa (Dennill & Donnelly, 1991)). The gall-forming mite '*Aceria genistae*' is probably a complex of sibling species, each restricted to a single host plant. Castagnoli (1978) showed that mites infesting *Spartium junceum* are a separate species, *Aceria spartii* (Canestrini), from those on Scotch broom. Mites identified as *A. genistae* from gorse in New Zealand (Manson, 1989) caused galls on gorse but not on Scotch broom, and tests with *A. genistae* collected from Scotch broom in France produced no galls on *Ulex europaeus* (Paynter *et al.*, 1996b). Two gall-forming flies, *Hexomyza sarothamni* (Hendel) (Agromyzidae) and *Asphondylia sarothamni* Loew (Cecidomyiidae) are both damaging to Scotch broom, and are likely to have a restricted host range. However, they are proving difficult to rear (Paynter, 1997), so progress has been delayed. Mazay (1993) found that *A. sarothamni* produced galls on 19% of pods. Mines of *H. sarothamni* result in stem galls that can kill the stems. Parasitism levels of over 90% may explain why this gall fly is rare in the field (Paynter, 1997).

Pathogens with Potential for Control of Brooms

Although pathogens were not considered as potential control agents in early work on Scotch broom, CABI is compiling a list of plant pathogens recorded from various broom species as part of the search for suitable biological control agents for introduction into Australia. Experimental studies in the UK and France are using fungicides to quantify the effects of pathogens on establishment and survival of Scotch broom seedlings and young plants (Paynter *et al.,* 1998). High rates of mortality of both seedlings and established plants have been observed. Two primary pathogens have been identified in France. The first, *Pleiochaeta setosa* (Kirchn.) Hughes (Hyphomycetes/Mitosporic fungi), causes patchy seedling mortality and stem tip die-back. It has a wide host range, and a worldwide distribution (Paynter *et al.,* 1996b). The second, *Uromyces sarothamni* Guyot & Massenot (Uredinales, Puccinaceae) is a rust that is present throughout the range of its host plant *Cytisus scoparius* (Guyot & Massenot, 1958). It is common throughout northwestern Europe, and is most evident in autumn. In host tests the rust attacked tree lucerne, but did not sporulate on tree lupin leaves (M. Jourdan & Q. E. Paynter, unpubl. data).

From a survey of Scotch broom and gorse in New Zealand Johnston *et al.* (1995) identified a fungus *Fusarium tumidum* Sherb. (Hyphomycetes/Mitosporic fungi) that caused substantial damage to its host plants. Work is progressing with selected strains of *F. tumidum* to formulate a mycoherbicide for inundative control of Scotch broom and gorse (Morin *et al.,* 1996).

Discussion

The programme for biological control of Scotch broom is well advanced, with several species already established and having a measurable impact (*Leucoptera spartifoliella* in New Zealand, *Exapion fuscirostre* and *Arytainilla spartiophila* in North America). There are 70 potential control agents for introduction (Table 3). Non-target impacts on desirable plant species, in particular tree lucerne and lupins, will reduce the numbers that are usable in a particular country. In both Australia and New Zealand tree lucerne is grown as a forage crop (Snook, 1986), and North America (especially through the Rocky Mountains) is an important habitat for native *Lupinus* species (Barneby, 1989). A list of those potential biological control agents that we consider to have high priority for further study is presented in Table 4. This list represents our 'best guess', based on existing knowledge, as to which agents will have a narrow host range and be effective against target brooms in exotic habitats. However, priorities will change as we gain knowledge from ecological studies and host-specificity testing of potential control agents, making it important to retain the longer list in Table 3.

Ecological studies to compare the impacts of insects and fungi on the population dynamics of Scotch broom in its native and exotic habitats (Memmott *et al.*, 1993, Fowler *et al.*, 1996) are designed to enable us to better predict those biological control agents that will be useful, thus removing the costs and environmental risks associated with introducing species that prove ineffective (McEvoy, 1996). The seed-feeding beetle *Bruchidius villosus* was selected ahead of *E. fuscirostre* for introduction into New Zealand because it was thought that competition between the species might inhibit establishment of *B. villosus*. In 1998 *B. villosus* is to be released in Oregon where *E. fuscirostre* is already established, allowing this scenario to be tested. An additional factor that might discourage the introduction of *E. fuscirostre* to New Zealand is that it would probably suffer attack from the parasitoid *Pteromalus sequester* that destroys gorse seed weevils, *Exapion ulicis*, in New Zealand. Studies in North America on the accidentally introduced broom-feeding species could be used to predict the likely efficacy and impacts on non-target species of these species in Australia and New Zealand. For example, in Oregon less than 10% of *E. fuscirostre* are currently attacked by *P. sequester* (Coombs, unpubl. data).

Table 4. Summary list of potential biological control agents for brooms selected from Table 3 that are currently accorded high priority for further study.

Feeding niche	Species	Target plant	Reasons for selection
Seeds	*Exapion elongatissimum*	*Cytisus striatus*	Reportedly monophagous on *C. striatus*.
	Exapion genistae	*Genista* spp.	Reportedly attacks only *Genista* spp.
Buds and flowers	*Protopirapion atratulum*	*Cytisus* spp.	Modelling work suggests that reducing seed-set can be effective, especially in combination with other controls.
	Tychius parallelus	*Cytisus* spp.	May be more host specific than *P. atratulum.*
Defoliators	*Gonioctena olivacea*	*Cytisus* spp.	Can be very damaging, especially to broom seedlings.
	Agonopterix assimilella	*Cytisus* spp.	Can be very damaging, and field records indicate it should be host specific.
Stem borer	*Phyllonorycter scopariella*	*Cytisus scoparius*	Recorded only from *C. scoparius*, and may outperform *Leucoptera spartifoliella* in North America if imported without its natural enemies.
Root feeder	*Polydrusus confluens*	*C. scoparius*	May be more host specific than other root feeders
Gall formers	*Aceria genistae*	*Cytisus* spp.	Can kill young plants and branches. Its taxonomy needs to be resolved.
	Asphondylia sarothamni	*C. scoparius*	Relatively common in Europe, and early oviposition results in no seed production.
	Hexomyza sarothamni	*C. scoparius*	Damaging. If released from parasitism, may be more numerous than in its native range.
Pathogens	*Uromyces sarothamni*	*C. scoparius*	Stem infection causing die-back has been observed in the Pyrenees.
	Fusarium tumidum	*C. scoparius*	Is being developed as a mycoherbicide.

From literature and field surveys, the fauna feeding on *Cytisus* species is reasonably well known. Apart from extreme specialists such as *Exapion elongatissimum* (Debrochers) on *Cytisus striatus*, the complex of insect species found on the *Cytisus* species is very similar to that on *Cytisus scoparius*. Syrett & Emberson (1997) provided some records of phytophagous species occurring on *Genista* spp. and *Spartium* and some additional ones are listed in Table 3, but they are far from exhaustive. Common elements of the *Cytisus* fauna are not found on *Spartium junceum* in southern France (Fowler, pers. obs.), so both literature surveys and further field surveys will be necessary to identify promising biological control agents for these weeds.

So what are the prospects for achieving successful biological control of broom weeds? The overall success rate of introductions for biological control of weeds up to 1985 was about 25% (Julien, 1989). To obtain this estimate, each agent released in each country was assessed as to whether it resulted in a consistent reduction in the target weed population, as reported in published data or by personal communication. These criteria represent high expectations of a control agent: that it will be successful in the absence of complementary controls. Hoffmann (1995) assessed the success of 23 out of 40 biological control programmes in South Africa that had been in existence long enough for evaluation to be meaningful, as 26% of target weeds under complete control, 57% under substantial control, and 17% under negligible control, a substantially higher success rate than recorded by Julien (1989). Certain plant attributes make control less likely, and some groups of control agents have been more successful than others, but the predictability of success in any specific instance is limited by a large number of complex and interacting factors (Crawley, 1989). The prognosis has generally been regarded as poor for perennial plants with substantial powers of regeneration. However, the shrubby tree, *Sesbania punicea*, in the same family as the brooms, has been successfully controlled with insects in South Africa in spite of earlier predictions to the contrary (Hoffmann, 1995). In New Zealand six species have been introduced for biological control of gorse (Harman *et al.*, 1996), and gorse spider mite (*Tetranychus lintearius* Dufour (Acari, Tetranychidae) has been shown to markedly reduce gorse growth (T. P. Partridge, Landcare Research, Lincoln, in prep.). Scotch broom does not re-sprout well following mechanical damage compared to gorse (J. J. Sheat, Landcare Research, Lincoln, pers. obs.). Also there are many more potential control agents for broom: gorse has relatively few host specific arthropods feeding on it in Europe, and only one, gorse spider mite, that causes appreciable damage (Zwölfer, 1963, R. L. Hill, pers. comm.). Already broom twig miner is having a substantial effect on broom in New Zealand (Memmott *et al.*, 1997), and the seed-feeding weevil *E. fuscirostre* is destroying large numbers of seeds in the USA (Isaacson, 1993). In their model Rees & Paynter (1997) showed that a reduction of only 75% in seed production had a dramatic impact on Scotch broom abundance, in contrast to several published predictions.

Blossey (1995) concluded that existing protocols for selecting the most promising candidates for introduction as biological control agents were unsatisfactory, and suggested that more studies of single and multiple species herbivory following release of agents would result in more effective agent selection. Studies on biological control agents for Scotch broom could contribute to the development of improved protocols for selecting agents for control of other brooms and for weeds in general.

Acknowledgements

We are very grateful to our colleagues who have contributed unpublished data and observations to this review. We would like to express our thanks to the following people who identified material for us: Dr D. Hollis and Mr V. Eastop (Natural History Museum, UK) and Drs M. L. Cox, R. G. Booth, and J. D. Holloway (CABI Bioscience, UK) for identification of European broom fauna; Dr P. Gullan (Australian National University), Dr J. Lawrence, Mr T. Weir, Dr. B. Halliday and Dr G. Cassis (Australian National Insect Collection, Canberra), Drs G. Brown, A. Clift, and M. Fletcher and Ms D. Knihinicki (NSW Agriculture, Sydney) and Dr G. Watson (CABI Bioscience, UK) for identification of Australian broom fauna. The work of the senior author was funded by the Foundation for Research, Science and Technology under contract C09403.

References

Agwu, S.I. (1971) Notes on the parasites of *Leucoptera spartifoliella* (Hübner) (Lep. Lyonetiidae) in southeastern England. *The Entomologist* **104**, 317-320.

Agwu, S.I. (1974) The population dynamics of *Leucoptera spartifoliella* Hübner (Lep. Lyonetiidae) in south-eastern England. *Journal of Animal Ecology* **43,** 439-453.

Alonso Zarazaga, M.A. (1990) Revision of the supraspecific taxa in the Palaearctic Apionidae Schoenherr 1823 (Coleoptera, Curculionoidea). 2. Subfamily Apioninae Schoenherr 1823: introduction, keys and descriptions. *Graellsia* **46,** 19-156.

Andres, L.A. (1979) Biological control (using seed weevil *Apion fuscirostre*). Will it solve the broom problem (*Cytisus scoparius*) in California? *Fremontia* **7(3),** 9-11.

Andres, L.A.; Coombs, E.M. (1995) Scotch broom. *In:* Nechols, J.R.; Andres, L.A.; Beardsly, J.W; Goeden, R.D.; Jackson, C.G. (*eds*) Biological control in the western United States: accomplishments and benefits of regional research project W-84. Berkeley, CA, USA; University of California, Division of Agriculture and Natural Resources Publication No 3361, pp. 303-305.

Andres, L.A.; Hawkes, R.B.; Rizza, A. (1967) Apion seed weevil introduced for biological control of Scotch broom. *California Agriculture* **21,** 13.

Anon. (1998) Noxious weed policy and classification system. Salem, OR, USA; Oregon Department of Agriculture, 8 pp.

Barneby, R.C. (1989) Fabales. *In:* Cronquist, A.; Holmgren, A.H.; Holmgren, N.H.; Reveal, J.L.; Holmgren, P.K., (*eds*) Intermountain flora. Vascular plants of the Intermountain West, USA. New York; The New York Botanical Garden, 279 pp.

Beck, C. (1977) *Piezodorus lituratus* (F.) (Hemiptera, Pentatomidae) ny for Danmark. *Entomologiske Meddelelser* **45,** 164-166.

Benson, R.B. (1952) Hymenoptera 2. Symphta section (b). Handbook for the identification of British insects. Volume 6, part 2(b). London; Royal Entomological Society of London, 88 pp.

Bernays E.A.; Montllor, C.B. (1989) Aposematism of *Uresiphita reversalis* larvae (Pyralidae). *Journal of the Lepidopterists' Society* **43,** 261-273.

Blossey, B. (1995) A comparison of various approaches for evaluating potential biological control agents using insects on *Lythrum salicaria*. *Biological Control* **5,** 113-122.

Bossard, C.C.; Rejmanek, M. (1994) Herbivory, growth, seed production, and resprouting of an exotic invasive shrub, *Cytisus scoparius*. *Biological Conservation* **67,** 193-200.

Boucek, Z. (1988) Australasian Chalcidoidea (Hymenoptera). Wallingford, UK; CAB International.

Brandl, P. (1981) Bruchidae. *In*: Freude, H. (*ed*) *Die Kafer Mitteleuropas* **10,** 7-21.

Burckhardt, D. (1989) The psyllids (Insects Homoptera: Psylloidea) of Algeria. *Archives des Sciences* **42,** 367-424.

Carter, D.J.; Hargreaves, B. (1986) A field guide to the caterpillars of butterflies and moths in Britain and Europe. London; Collins, 296 pp.

Castagnoli, M. (1978) Ricerche sulle cause di deperimento e moria dello *Spartium junceum* L. in Italia. *Eriophyes genistae* (Nal.) e *E. spartii* (G. Can.) (Acarina, Eriophyoidea): ridescizione, cenni di biologia e danni. *Redia* **61,** 539-550.

Chan, K.L.; Turner, C.E. (1998) Discovery of the gall mite *Aceria genistae* (Nalepa) (Acarina: Eriophyidae) on gorse and French broom in the United States. *Pan-Pacific Entomologist* **74,** 55-57.

Chantal, C. (1972) Additions à la faune Coléoptérique du Québec. *Le Naturaliste Canadien* **99,** 243-244.

Clausen, C.P. (*ed*) (1978) Leguminosae. Scotch broom (*Cytisus scoparius* (Linnaeus) Link). *In*: Introduced parasites and predators of arthropod pests and weeds: a world review. USDA Agriculture Handbook No. 480, pp. 393-395.

Common, I.F.B. (1990). Moths of Australia. Melbourne, Australia; Melbourne University Press, 535 pp.

Crawley, M.J. (1989) The successes and failures of weed biocontrol using insects. *Biocontrol News and Information* **10,** 213-233.

Danthanrayana, W. (1969) Population dynamics of the weevil *Sitona regensteinensis* (Hbst.) on broom. *Journal of Animal Ecology* **38,** 1-18.

Dennill, G.B.; Donnelly, D. (1991) Biological control of *Acacia longifolia* and related weed species (Fabaceae) in South Africa. *Agriculture, Ecosystems and Environment* **37,** 115-135.

Downes, W. (1957) Notes on some Hemiptera which have been introduced into British Columbia. *Entomological Society of British Columbia* **54,** 11-13.

Emmet, E.M. (1988) A field guide to the smaller British Lepidoptera, 2nd edition. London; British Entomological and Natural History Society, 288 pp.

Foottit, R.G.; Richards, W.R. (1993) The insects and arachnids of Canada. Part 22: The genera of aphids in Canada (Homoptera: Aphidoidea and Phylloxeroidea). Ottawa; Agriculture Canada, 766 pp.

Fowler, S.V.; Cross, A.E.; Shaw, R.H. (1993) Report on weed work for New Zealand, 1993. International Institute of Biological Control, Ascot, UK. Unpublished report, 38 pp.

Fowler, S.V.; Harman, H.M.; Memmott, J.; Paynter, Q.; Shaw, R.; Sheppard, A.; Syrett, P. (1996) Comparing the population dynamics of broom, *Cytisus scoparius,* as a native plant in the UK and France, and as an invasive alien weed in Australia and New Zealand. *In:* Moran, V.C.; Hoffmann, J.H. (*eds*) Proceedings of the IX International Symposium on Biological Control of Weeds, Stellenbosch, South Africa, 21-26 January 1996. Cape Town, South Africa; University of Cape Town, pp. 19-26.

Frick, K.E. (1964) *Leucoptera spartifoliella* an introduced enemy of Scotch broom (*Cytisus scoparius*) in the western United States. *Journal of Economic Entomology* **57,** 589-591.

García Ocejo, A.; Gurrea, P. (1991) Relación entre los hábitos tróficos y la distributión por pisos bioclamáticos de la Sierra de Gredos de Chrysomelidae (Coleoptera) asociados a Genisteas. *Miscellània Zoológica* **15,** 137-145.

García Ocejo, A.; Gurrea Sanz, P.; Sanz Benito, M.J. (1990) Crisomélidos característicos del sotobosque de Genisteas y de los piornales de la Sierra de Gredos. *Actas de Gredos Boletin Univesitario* **10,** 33-41.

García Ocejo, A.; Gurrea, P.; Petitpierre, E. (1992) Chrysomelidae (Coleoptera) de la Sierra de Gredos (Sistema Central): datos faunísticos, ecológicos y fenológicos. *Miscellània Zoológica* **16,** 81-92.

Göllner-Scheiding, U. (1968) Über de Heteropteren des Besenginsters (*Sarothamnus scoparius* (L.) Wimmer). *Entomologische Berichten (Berlin)* **1-48,** 19-23.

Groppe, K. (1991) Literature review and preliminary survey of biotic agents associated with old man's beard, *Clematis vitalba* L. in Europe. International Institute of Biological Control, Delémont, Switzerland. Unpublished report, 28 pp.

Gurrea, P.; José Sanz, M., García, A. (1991) Patrones de comportamiento en gorgojos seminívoros de genisteas (Coleoptera: Curculionoidea). *Bulletin of the European Association of Coleopterology, Elytron Supplement* **6,** 261-267.

Gurrea Sanz, P.; Alonso Zarazaga, M.A.; Gajate, J. (1986) Los pirapion de la Sierra de Gredos (España Central) (Coleoptera, Curculionoidea). Actas de las VIII Jornadas A & E Sevilla, pp. 548-560.

Guyot, A.L.; Massenot, M. (1958) Les rouilles des gênets et des cytises [*Uromyces genistae-tinctoriae* (Pers.) Wint. Sensu lato]. *Uridineana* **5,** 507-523.

Harman, H.M.; Syrett, P.; Hill, R.L.; Jessep, C.T. (1996) Arthropod introductions for biological control of weeds in New Zealand, 1929-1995. *New Zealand Entomologist* **19,** 71-80.

Hawkes, R.B. (1963) Progress in biological control. Oregon Weed Conference Proceedings, 12th Annual Conference, pp. 43-46.

Hinz, H.L. (1992) Studies on the two seed-feeding beetles *Apion fuscirostre* F. (Coleoptera: Apionidae) and *Bruchidius villosus* F. (Coleoptera: Bruchidae): potential biological control agents for broom (*Cytisus scoparius*). MSc thesis, University of London, UK.

Hodkinson, I.D.; Hollis, D. (1987) The legume-feeding psyllids (Homoptera) of the west Palaearctic region. *Bulletin of the British Museum (Natural History), Entomology* **56,** 1-86.

Hoffmann, J.H. (1995) Biological control of weeds: the way forward, a South African perspective. *In:* Weeds in a changing world. Proceedings of a symposium, Brighton, UK, 20 November 1995. British Crop Protection Council Symposium Proceedings No. 64: Farnham, UK; BCPC, pp. 77-89.

Hoffmann, J.H.; Moran, V.C. (1998) The population dynamics of an introduced tree, *Sesbania punicea,* in South Africa, in response to long-term damage caused by different combinations of three species of biological control agents. *Oecologia* **114,** 343-348.

Holder, P. (1990) Aspects of the biology and morphology of *Anisoplaca ptyoptera* Meyrick (Lepidoptera: Gelechiidae), a potential biological control agent for gorse. M. Appl. Sci. thesis, Lincoln University, New Zealand, 169 pp.

Hosking, J.R. (1995) The impact of seed and pod feeding insects on *Cytisus scoparius* (L.) Link. *In:* Delfosse, E.S.; Scott, R.R. (*eds)* Proceedings of the VIII International Symposium on Biological Control of Weeds, Lincoln University, Canterbury, New Zealand, 2-7 February 1992. Melbourne, Australia; DSIR/CSIRO, pp. 45-51.

Hosking, J.R.; Smith, J.M.B.; Sheppard, A.W. (1998) *Cytisus scoparius* (L.) Link subsp. *scoparius*. *In:* Panetta, F.D.; Groves, R.H.; Shepherd, R.C.H. (*eds*) The biology of Australian weeds. Volume 2. Melbourne, Australia; R.G. & F.J. Richardson, pp. 77-88.

Isaacson, D.L. (1993) In search of *Apion*. Salem, OR, USA; Oregon Department of Agriculture. *Broom/Gorse Quarterly* **2,** 3.

Isaacson, D.L.; Miller, G.; Coombs, E.M.; Butler, T.V. (1995) Use of geographical systems (GIS) distance measures in managing dispersal of *Apion fuscirostre* for control of Scotch broom *Cytisus scoparius*. *In*: Delfosse, E.S.; R.R. Scott (*eds*) Proceedings of the VIII International Symposium on Biological Control of Weeds, Lincoln University, Canterbury, New Zealand, 2-7 February 1992. Melbourne, Australia; DSIR/CSIRO, pp. 695-99.

Islam, Z.; Crawley, M.J. (1983) Compensation and regrowth in ragwort (*Senecio jacobaea*) attacked by cinnabar moth (*Tyria jacobaeae*). *Journal of Ecology* **34,** 531-564.

Johnston, P.R.; Parkes, S.L.; Broadhurst, P.G. (1995) Fungi associated with gorse and broom in New Zealand. *Australasian Plant Pathology* **24,** 157-167.

Julien, M.H. (1989) Biological control of weeds worldwide: trends, rates of success and the future. *Biocontrol News and Information* **10,** 299-306.

Julien, M.H. (1992) Biological control of weeds. A world catalogue of agents and their target weeds, 3rd edition. Wallingford, UK; CAB International, 186 pp.

Keesing, J.L.S. (1981) Newcomers to Britain's gall-causing fauna. *AES Bulletin* **40,** 16-17.

Kloet, G.S.; Hincks, W.D. (1964) A checklist of British insects, 2nd edition, part 1, small orders – Hemiptera. Handbook for the identification of British insects, volume XI. London; Royal Entomological Society of London, 119 pp.

Kloet, G.S.; Hincks, W.D. (1972) A checklist of British insects, 2nd edition, part 2, Lepidoptera. Handbook for the identification of British insects, volume XI. London; Royal Entomological Society of London, 153 pp.

Kloet, G.S.; Hincks, W.D. (1976) A checklist of British insects, 2nd edition, part 5, Diptera: Siphonaptera. Handbook for the identification of British insects, volume XI. London; Royal Entomological Society of London, 139 pp.

Kloet, G.S.; Hincks, W.D. (1978) A checklist of British insects, 2nd edition, part 3, Coleoptera and Strepsiptera. Handbook for the identification of British insects, volume XI. London; Royal Entomological Society of London.

Kosztarab, M.; Kozár, F. (1988) Scale insects of Central Europe. Dordrecht, Netherlands; Dr W. Junk, 456 pp.

Leen, R. (1997) Larval hosts of *Urisiphita* Hübner (Crambidae). *Journal of the Lepidopterists' Society* **51,** 139-148.

Manson, D.C. (1989) New species and records of eriophyid mites from New Zealand. *New Zealand Journal of Zoology* **16,** 37-49.

Martín Cano, J. (1981) El nicho ecologico de *Apopestes spectrum* (Esp.), *Xylina exoleta* (L.) y *Pachygastria trifolii* (D. et Schiff.) (Lep. Noctuidae et Lasiocampidae). *Boletín de la Estación Central de Ecología* **10,** 79-88.

Mazay, S. (1993) Etude de la faune entomologique s'attaquant à la reproduction du cytise à balais, *Cytisus scoparius* (L.) Link (Fabaceae) en Cévennes méridionales. Thèse d'Ingénieur Agronome, Université Libre de Bruxelles, Belgium, 67 pp.

McEvoy, P.B. (1996) Host specificity and biological pest control. *Bioscience* **46,** 401-405.

Memmott, J.; Fowler, S.V.; Syrett, P.; Hosking, J.R. (1993) What makes broom a major problem? *In*: Brighton Crop Protection Conference (Weeds). Proceedings of an international conference, Brighton, UK, 22-25 November 1993. Volume 2. Farnham, UK; British Crop Protection Council, pp. 753-758.

Memmott, J.; Fowler, S.V.; Syrett, P. (1997) Impact of broom twig miner on broom growth and florifory in Canterbury, New Zealand. *In*: O'Callaghan, M. (*ed*) Proceedings of the 50th New Zealand Plant Protection Conference, Lincoln University, Canterbury, 18-21 August 1997. Rotorua, New Zealand; New Zealand Plant Protection Society, pp. 457-461.

Meyrick, E. (1928) A revised handbook of British Lepidoptera. London; Watkins and Doncaster, 914 pp.

Miller, G. (1992) Scotch broom and its cousins. *Broom and Gorse Quarterly* **1,** 2-3.

Morin, L., Howarth, A.F.; Johnston, P.R. (1996) Potential of *Fusarium tumidum* as a bioherbicide to control gorse and broom in New Zealand. *In:* Moran, V.C.; Hoffmann, J.F. (*eds*) Proceedings of the IX International Symposium on Biological Control of Weeds), Stellenbosch, South Africa, 21-26 January 1996. Cape Town, South Africa; University of Cape Town, pp. 231-232.

Morris, M.G. (1990) Orthocerous weevils: Coleoptera: Curculionidae (Nemonychidae, Anthribidae, Urodontidae, Attelabidae and Apionidae). Handbook for the identification of British insects, vol. 5(16). London; Royal Entomological Society of London, 108 pp.

Noe-Nygaard, B. (1978) Aspects of the biology of *Apion striatum* Kirby (Coleoptera: Curculionidae). *Entomologiske Meddelelser* **46,** 97-101.

Parker, B.; Miller, G.; Burrill, L.C. (1994) Scotch broom, *Cytisus scoparius* (L.) Link. Pacific Northwest Weeds Bulletin No. 103, revised July 1994. Corvallis, OR, USA; Oregon State University Cooperative Extension Service, 4 pp.

Parnell, J.R. (1963) Three gall midges (Diptera: Cecidomyidae) and their parasites found in the pods of broom (*Sarothamnus scoparius* (L.) Wimmer). *Transactions of the Royal Entomological Society of London* **115,** 161-274.

Parnell, J.R. (1966) Observations on the population fluctuations and life histories of the beetles *Bruchidius ater* (Bruchidae) and *Apion fuscirostre* (Curculionidae) on broom (*Sarothamnus scoparius*). *Journal of Animal Ecology* **35,** 157-188.

Parsons, W.T.; Cuthbertson, E.G. (1992) Noxious weeds of Australia. Melbourne/Sydney, Australia; Inkata Press, 692 pp.

Paynter, Q.E. (1997) European work for the USA broom biocontrol programme. International Insitute of Biological Control, Montferrier-sur-Lez, France. Unpublished report, 23 pp.

Paynter, Q.E. (1998) Report on weed work for Washington State Noxious Weeds Board. CABI Bioscience, Ascot, UK. Unpublished report, 10 pp.

Paynter, Q.; Fowler, S.; Hinz, H.; Memmott, J.; Shaw, R., Sheppard, A.; Syrett, P. (1996a) Seed predation, seed banks and seed limitation: are seed-feeding insects of use for the biological control of broom? *In:* Moran, V.C.; Hoffmann, J.H. (*eds*) Proceedings of the IX International Symposium on Biological Control of Weeds, Stellenbosch, South Africa, 21-26 January 1996. Cape Town, South Africa; University of Cape Town, pp. 495-501.

Paynter, Q.; Fowler, S.V.; Shaw, R.H. (1996b) European work for the Australian broom programme. Report from April 1993 – July 1996. International Institute of Biological Control, Ascot, UK. Unpublished report, 23 pp.

Paynter, Q.E.; Fowler, S.V.; Memmott, J.; Sheppard, A.W. (1998) Factors affecting the establishment of *Cytisus scoparius* in southern France: implications for managing both native and exotic populations. *Journal of Applied Ecology* **35,** 582-595.

Pemberton, R.W.; Hoover, E.M. (1980) Insects associated with wild plants in Europe and the Middle East. Biological control of weeds surveys. USDA Miscellaneous Publication No. 1388, 33 pp.

Pfeiffer, D.G. (1986) *Arytainilla spartiophila* (Förster) (Hemiptera: Psyllidae) on *Cytisus scoparius* (L.) Link in Virginia: first record in eastern North America. *Journal of the Entomological Society* **21,** 214-218.

Pritchard, A.E.; Baker, E.W. (1955) A revision of the spider mite family Tetranychidae. Memoirs Series Volume 2. San Francisco, USA; Pacific Coast Entomological Society, 472 pp.

Rees, M.; Paynter, Q. (1997) Biological control of Scotch broom: modelling the determinants of abundance and the potential impact of introduced insect herbivores. *Journal of Applied Ecology* **34,** 1203-1221.

Richards, O.W.; Waloff, N. (1961) A study of a natural population of *Phytodecta olivacea* (Förster) (Coleoptera: Chrysomeloidea). *Philosophical Transactions of the Royal Society of London (B)* **244,** 205-257.

Ritcher, P.O. (1966) Biological control of insects and weeds in Oregon. Salem, OR, USA; Agricultural Experimental Station Technical Bulletin No. 90, 30 pp.

Rousseau, J.; Loiseau, A. (1982) Structure et cycle de dévélopment des peuplements à '*Cytisus scoparius* L.' dans la chaine des puys. *Acta Oecologia Applicata* **3,** 155-168.

Sanz Benito, M.J.; Gurrea Sanz, P.; (1991) Inventario y analysis biogeografico preliminar de las especies de Curculionoidea (Coleoptera) de Genisteae en Las Sierras del Sistema Central (Peninsula Iberica). *Graellsia* **47,** 117-127.

Sanz Benito, M.J.; Gurrea Sanz, P.; García Ocejo Izquierdo, A. (1989) Aspectos sobre la biologia y fenologia de *Pachytychius sparsutus* Ol. 1807 (Coleoptera: Curculionoidea) en el Macizo Central de la Sierra de Gredos (Sistema Central). *Actas de Gredos Boletin Universitario* **9,** 1-8.

Sanz Benito, M.J.; Gurrea Sanz, P.; de los Mosos Pascual, M.; Martin Cano, J.; Munguira, M. L. (1990) Distribución del nicho ecológico de los Curculionoidea (Coleoptera) in los *Cytisus* en la Sierra de Alcaraz. *In*: Jornados sobre el medio natural Albacentense, Albacete, pp. 203-205.

Scheele, S.M.; Syrett, P. (1987) The broom twigminer, *Leucoptera spartifoliella* (Lepidoptera: Lyonetiidae), in New Zealand. *New Zealand Entomologist* **10,** 133-137.

Scudder, G.G.E. (1960) *Dictyonota fuliginosa* Costa (Hemiptera: Tingidae) in the Nearctic. *Proceedings of the Entomological Society of British Columbia* **57,** 22.

Shaw, R.H.; Fowler, S.V. (1996) Report on weed work for New Zealand, 1996. International Institute of Biological Control, Ascot, UK. Unpublished report, 47 pp.

Simandl, J.; Kletecka, Z. (1987) Community of xylophagous beetles (Coleoptera) on *Sarothamnus scoparius* in Czechoslovakia. *Acta Entomologica Bohemoslovaca* **84,** 321-329.

Singh, S.R. (1967) Studies on *Parthenolecanium* spp. (Coccidae) on broom, *Sarothamnus scoparius* (L.) Wimmer. PhD thesis, University of London.

Skinner, B. (1984) Colour identification guide to moths of the British Isles (Macrolepidoptera). Harmondsworth, UK; Viking/Penguin, 267 pp.

Smith, B.D. (1966) Effects of parasites and predators on a natural population of the aphid *Acyrthosiphon spartii* (Koch) (Homoptera: Aphididae) on broom (*Sarothamnus scoparius* L.). *Journal of Animal Ecology* **35,** 255-267.

Snook, L.C. (1986) Tagasaste, tree lucerne, high production fodder crop. Shepparton, Australia; Night Owl Publishers, 102 pp.

Southgate, B.J. (1963) The true identity of the broom bruchid (Coleoptera) and synonymic notes on other species of *Bruchidius*. *Annals of the Entomological Society of America* **56**, 795-798.

Spencer, K.A. (1990) Host specialization of the world Agromyzidae (Diptera). *In*: Series Entomologica 45. Dordrecht, Netherlands; Kluwer Academic Press, 444 pp.

Stroyan, H.L.G. (1977) Homoptera, Aphidoidea (part), Chaitophoridae and Callaphididae. Handbook for the identification of British insects. Volume 2(4a). London; Royal Entomological Society of London, 130 pp.

Syrett, P. (1987) The biological control of broom (*Cytisus scoparius*) in New Zealand: an environmental impact assessment. Christchurch, New Zealand; DSIR, 118 pp.

Syrett, P. (1992) The feeding range of *Sitona regensteinensis* Hbst. (Coleoptera: Curculionidae), a potential agent for biological control of *Cytisus scoparius* (L.) Link (broom) in New Zealand. *Biocontrol, Science and Technology* **2,** 292-295.

Syrett, P. (1993) The insect fauna of broom in New Zealand. *New Zealand Entomologist* **16,** 75-83.

Syrett, P. (1996) Insects for biological control of broom (*Cytisus scoparius*) in New Zealand. *In:* Shepherd, R.C.H. (*ed*) Proceedings of the 11th Australian Weeds Conference, University of Melbourne, pp. 525-28.

Syrett, P.; Emberson, R.M. (1997) The natural host range of beetle species feeding on broom, *Cytisus scoparius* (L.) Link (Fabaceae) in south-west Europe. *Biocontrol, Science and Technology* **7,** 309-326.

Syrett, P.; Harman, H.M. (1995) *Leucoptera spartifoliella* Hübner as a biological control agent for broom in New Zealand. *Plant Protection Quarterly* **10,** 75-78.

Syrett, P.; O'Donnell, D.J. (1987) A seed-feeding beetle for biological control of broom. *In*: Popay, A.J. (*ed*) Proceedings of the 40th New Zealand Weed and Pest Control Conference, Nelson, 11-13 August, 1987, pp. 19-22.

Syrett, P.; Harman, H.M.; Fowler, S.V. (1995) Identification of risk to kowhai, a New Zealand native plant *Sophora microphylla* Ait., from a potential biological control agent for broom, *Cytisus scoparius* (L.) Link. *New Zealand Journal of Zoology* **22,** 305-309.

Syrett, P.; Fowler, S.V.; Emberson, R.M. (1996) Are chrysomelid beetles effective agents for biological control of weeds? *In*: Moran, V.C.; Hoffmann, J.H. (*eds*) Proceedings of the IX International Symposium on Biological Control of Weeds, Stellenbosch, South Africa, 21-26 January 1996. Cape Town, South Africa; University of Cape Town, pp. 399-407.

Syrett, P.; Fowler, S.V.; O'Donnell, D.J.; Shaw, R.H.; Smith, L.A. (1997) Introduction of *Gonioctena olivacea* (Coleoptera: Chrysomelidae) into New Zealand for biological control of broom, *Cytisus scoparius*. An Importation Impact Assessment. Landcare Research report, Lincoln, New Zealand, 36 pp.

Torres del Castillo, K.; Mendez, P.; Carnero, A.; Fernandez, M.; (1992) Pests of cultivated *Chamaecytisus proliferus* (L. fil.) Link spp. *palmensis* (Christ.) Kunkel in the Canaries. *Boletin de Sanidad Vegetal, Plagas* **18,** 488-489.

Velázquez de Castro, A.J.; Alonso Zarazaga, M.A. (1988) Biologia de *Tychius parallelus* (Panzer) en la Sierra de Guadarrama (Coleoptera: Curculionidae). *In*: Actas III Congreso Iberico de Entomología, December 1988, Grenada, pp. 503-510.

Velázquez de Castro, A.J.; Outerelo, R.; Alonso Zarazaga, M.A. (1988) New records of Curculionoidea from the Iberian peninsula (Coleoptera). *Elytron* **2**, 37-39.

Velázquez de Castro, A.J.; Alonso Zarazaga M.A.; Outerelo, R. (1990) Curculionoidea (Coleoptera) de Navacevada, Sierra d Guaderrama, Spain. *Boletin de la Real Sociedad Española de Historia Natural* (*Sección Biologica*) **85,** 17-37.

Wall, C. (1975) The biology of the British species of *Chesias* (Lepidoptera: Geometridae). *Entomologist's Gazette* **26,** 89-106.

Waloff, N. (1966) Scotch broom, *Sarothamnus scoparius* (L.) Wimmer and its insect fauna introduced into the Pacific Northwest of America. *Journal of Applied Ecology* **3,** 293-311.

Waloff, N. (1968) Studies on the insect fauna of Scotch broom *Sarothamnus scoparius* (L.) Wimmer. *Advances in Ecological Research* **5,** 87-208.

Waloff, N.; Richards, O.W. (1977) The effect of insect fauna on the growth, mortality and natality of broom, *Sarothamnus scoparius*. *Journal of Applied Ecology* **14,** 787-798.

Wapshere, A.J. (1974) Host specificity of phytophagous organisms and the evolutionary centres of plant genera or sub-genera. *Entomophaga* **19,** 301-309.

Wapshere, A.J.; Hosking, J.R. (1993) Biological control of broom in Australia. *In*: Swarbrick, J.T.; Henderson, C.W.L.; Jettner, R.J.; Streit, L.; Walker, S.R. (*eds*) Proceedings of the 10th Australian and 14th Asian-Pacific Weed Conference, Brisbane, Australia, 6-10 September 1993, pp. 94-98.

Watmough, R.H. (1968) Population studies on two species of Psyllidae (Homoptera: Sternorhyncha) on broom (*Sarothamnus scoparius* (L.) Wimmer). *Journal of Animal Ecology* **37,** 293-341.

Williams, D.J. (1985) Australian mealybugs. London; British Museum (National History), 431 pp.

Williams, P. (1968) The larvae of *Apion immune* Kirby and *Apion malvae* (F.) (Coleoptera: Curculionidae). *Proceedings of the Royal Entomological Society of London (A)* **43,** 21-26.

Williams, P.A. (1981) Aspects of the ecology of broom (*Cytsius scoparius*) in Canterbury, New Zealand. *New Zealand Journal of Botany* **19,** 31-43.

Wink, M.; Hartmann, T.; White, L.; Rheinheimer, J. (1982) Interrelationship between quinolizidine alkaloid producing legumes and infesting insects: exploitation of the alkaloid-containing phloem sap of *Cytisus scoparius* by the broom aphid *Aphis cytisorum. Zeitschrift für Naturforschung C* **37,** 1081-1086.

Zwölfer, H. (1963) *Ulex europaeus* project. European investigations for New Zealand. Report No. 2. Commonwealth Institute of Biological Control, Delémont, Switzerland. Unpublished report, 30 pp.