Selection and Testing of Biological Control Agents for Control of French Broom *Genista monspessulana* (L.) L. Johnson

Oregon Department of Agriculture
ODA project 801 GR

Final Report

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Acknowledgements

Australian Cooperative Research Centre for Weed Management Systems who jointly funding this work. Janine Lloyd (CRC) for use of her data from Australia and Europe and data jointly collected in Europe, Thierry Thomann and Sylvie Agret (CSIRO) for assistance with data collection and processing and Janine Vitou (CSIRO) for assistance with mounting specimens and arranging to have them identified.

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Executive summary

This project final report addresses *tasks* as outlined in the Task List included in ODA 801 GR grant agreement between Oregon Department of Agriculture (ODA) and CSIRO Entomology signed on the 8th September 2000 with completion on or before 31st December 2000 on the selection and testing of biological control agents for control of French broom *Genista monspessulana* (L.) L. Johnson. The task list, drawn up by ODA and the Californian Department of Forestry and Fire Protection, addresses research needs of the latter that provided the funding for the project and represents the first research activities funded from within the USA for biological control against this particular weed. This project builds on a similar and much longer standing CABI Bioscience research project funded through ODA, Australia and New Zealand to work on the biological control of Scotch broom (*Cytisus scoparius* (L.) Link) and a two year CSIRO Entomology project funded by the Australian Cooperative Research Centre for Weed Management Systems on the biological control of *G. monspessulana.*

French broom is a widespread environmental weed of National, State and urban parks and fallow land mainly in Central California and southern Oregon. In key areas it co-occurs with Scotch broom posing a risk of weed replacement following control efforts. In California it has been estimated to invade at least 100,000 acres (40,000 ha). Invaded habitats include coastal plains, mountain slopes, riverbanks, road cuts, forest clear-cuts grassland and open canopy forest on a wide range of soil types. The problems caused by French broom in its exotic range result from its tendency to form mono-specific stands that shade out native species, slow reforestation, and increase fire frequency and intensity.

It is a perennial leguminous shrub (fixes nitrogen), reproducing by seed from the 2nd year and twice a year when young. It lives 5-12 years and seed production increases asymptotically with age. Annual seed rain can reach about 5000 seeds m^{-2} setting up seedbanks of between 30K – 100K m^{-2} with a seedbank decay rate is about 30-50% per annum. Its long-lived seedbank and capacity to fix nitrogen makes it a strong competitor on poor soils. It also poses a direct threat to rare and endangered native species. In the native Mediterranean range the plant is shorter lived (5-8 years), generates smaller seedbanks 5-900 m^{-2} and suffers high levels of herbivory from goats, stem miners, insects in seed pods and post dispersal seed predation by rodents. Native populations in the Mediterranean tend to be small and scattered, either as a low density and spindly understorey component of disturbed cork oak/pine forest or as dense but transient populations in post-fire regenerating '*maqui*' communities in zones of rich acidic soil and relatively high rainfall (>700 mm).

This research project has carried out literature searches for the weed and known natural enemies in all relevant abstracting journals, unpublished reports and entomological collections. Twenty-eight species of herbivorous arthropod have been recorded from French broom. Quantitative surveys for potential biological control agents of French broom as well as collecting ecological data, in Mediterranean regions of Spain, France, Italy and Greece provided 82 species of phytophagous species on French broom, and one rust attacking old leaves in spring/summer *Uromyces genistae* Fuckel. Potential biological control agents include the seed weevil, *Lepidapion argentatum* Gerstacker, the psyllid, *Arytainilla hakani* Loginova, and the stem-mining fly, *Chyliza leptogaster* (Panzer) (this fly has also been recorded from *Physocarpus,*

Forsythia and *Neottia* so existence of host races needs investgation). Other species of interest at this stage include the moths *Trifurcula serotinella* H.S. and *Coleophora trifarella* Zeller (leaf miners, not seen, but recorded from French broom and a tribe level host-range in the literature) and the beetles *Bruchidius villosus* F. (specific to tribe - seed feeder) and *Peritelus senex* Boheman (root feeder - adult collected from French broom, host range supposedly includes *Astragalus* and *Ulex* but needs checking). Prospects for biological control are good because the plant is infrequent and transient in its native range. As such, natural enemies in the native range are likely to be food-limited, a situation they will escape from if released as biological control agents. High attack rates by *C. leptogaster* have been observed killing local populations.

This report proposes a test plant list for the specificity testing of potential biological control agents for French broom for the U.S., as well as suitable testing procedures for three types of agents commonly used against weeds in the Genisteae, together with time lines for future activity in this area. A research plan is also presented for a longer- term research project taking into account work to be accomplished in Europe and in North America. Only limited exploratory field-testing could be commenced within the scope of the budget associated with this project. A small amount of host-range testing work is presented as part of this project. This work, conducted on *B. villosus*, the broom bruchid already present in the USA, suggests further testing of North American Lupines against this species would be highly advisable as past testing has been ambiguous.

Task 1.

*Literature review. CSIRO will conduct a review of scientific literature on French broom (*Genista monspessulana *(L.)) with emphasis on ecology, control, native distribution, and relatedness to other species of legumes. CSIRO will also review scientific reports on arthropod and pathogenic organisms known to or found to attack French broom within its native range.*

Introduction

An extensive literature survey was carried out for references relating to *G. monspessulana* within Biological Abstracts 1989 –1998, Agricola 1970 – 1998, Ecological abstracts 1983 –1999 and CABI Abstracts online. Only 18 references where located which specifically discuss research carried out on *Genista monspessulana,* rather than on the organisms it supports, and none relate to work carried out in the native range. Eight references describe the quality and relevance of *G. monspessulana* as an exotic fodder species in various parts of the world and the remaining ten discuss it as a weed in its exotic range. The following summary of the ecology of *G. monspessulana* within its exotic range comes from the unpublished work mainly of Janine Lloyd a PhD student with the Australian Cooperative Research Centre for Weed Management Systems (CRC) and direct field data collected as part of this or an earlier CRC project described above. Other ecological work on this weed is still ongoing by a) Martin Pareja; MSc project to develop an ecological and biological control model for French broom, Department of Biology Imperial College London, b) Karen Haubensak; PhD project on the importance of soil nitrogen in the invasive capacity, Department of Integrative Biology University of California, Berkeley and c) Janine MacDonald; MSc project on the basic ecology of French broom, Department of Integrative Biology University of California, Berkeley.

Taxonomic considerations

Genista monspessulana (Tribe Genisteae, Family Fabaceae) is part of a large Eurasian genus of some 87 species. Four species in this genus, *G. monspessulana, Genista linifolia* (L.) Webb & Berth., *Genista canariensis* (L.) Steud and *Genista stenopetala* Webb & Berth., are frequently treated as being in a separate genus *Teline* Medikus, the remaining species being divided into ten sections within the genus *Genista* (Tutin et al. 1968). While opinion on the taxonomic relevance of these divisions may be an academic one, it is interesting to note that a) the only *Genista* species recorded as invasive weeds outside their native range are included within the four species frequently placed in *Teline,* b) that while the taxonomic character used to separate *Teline* from *Genista* (i.e. that the 'standard' or large upper petal is longer than the lower keel petals) may appear to be minor, the upright spreading growth form, height (up to 3 m +), leafy spineless shoots, and racemes of showy flowers is common two all 4 species and of poor representation elsewhere in the genus, and distant from what is commonly perceived by the term "genistiform", and c) all 4 species prefer Mediterranean habitats on acid soils with relatively high rainfall (>700mm). Apart from *G. monspessulana*, the other species within "*Teline*" are restricted in native distribution to either the western Mediterranean or various Atlantic islands. Clearly such species were initially imported for their floral beauty, which sets them aside from other *Genista* species. Surveys of natural enemies on *Genista* in Europe, support the *Teline* division (though a molecular taxonomic study would need to be carried out to confirm this) and, therefore, phytophagous arthropods with host records that include other species of *Genista* not in this group,

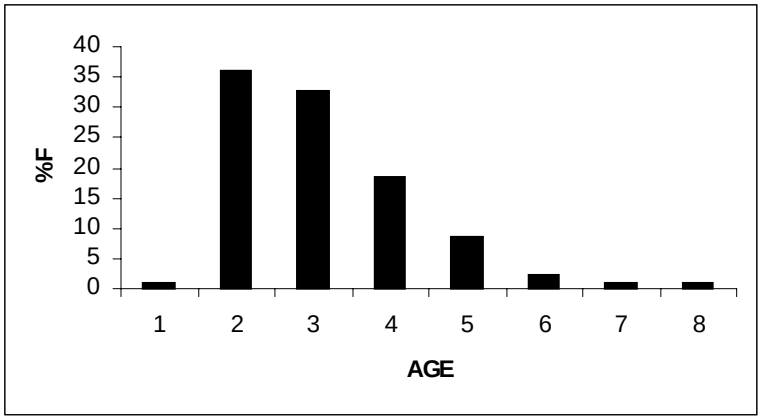
should be considered in the same light as species with other related genera (e.g. *Cytisus*) within the host range.

***Genista monspessulana*: Exotic range**

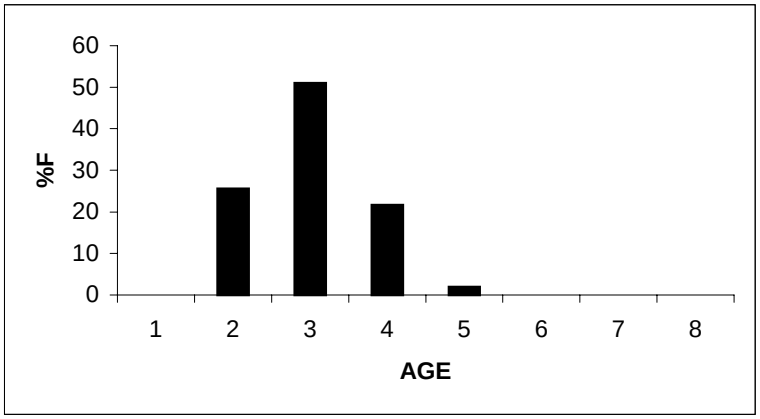
French broom is a perennial leguminous shrub, reproducing only by seed from the 2nd year and twice a year when young. It lives 5-12 years (e.g. see Fig. 1) and seed production increases asymptotically with age. Annual seed rain can reach about 5000 seeds m^{-2} setting up seedbanks of between 30,000 - 100,000 m^{-2} with a seedbank decay rate is about 30-50% per annum largely resulting from failed germination. The problems caused by French broom in its exotic range result from its tendency to form mono-specific stands following disturbance either anthropogenic disturbance or fire. Following invasion it tends to shade out native species, slow reforestation in forestry gaps and plantation, and increase fire frequency and intensity. Its long-lived seedbank and capacity to fix nitrogen makes it a strong competitor on poor soils. It also poses a direct threat to rare and endangered native species in some parts of the world

Figure 1. Age distributions of individuals in two French broom populations a) exotic and b) native (J. Lloyd unpublished data)

a) Number of French broom plants in different age classes in Australian populations



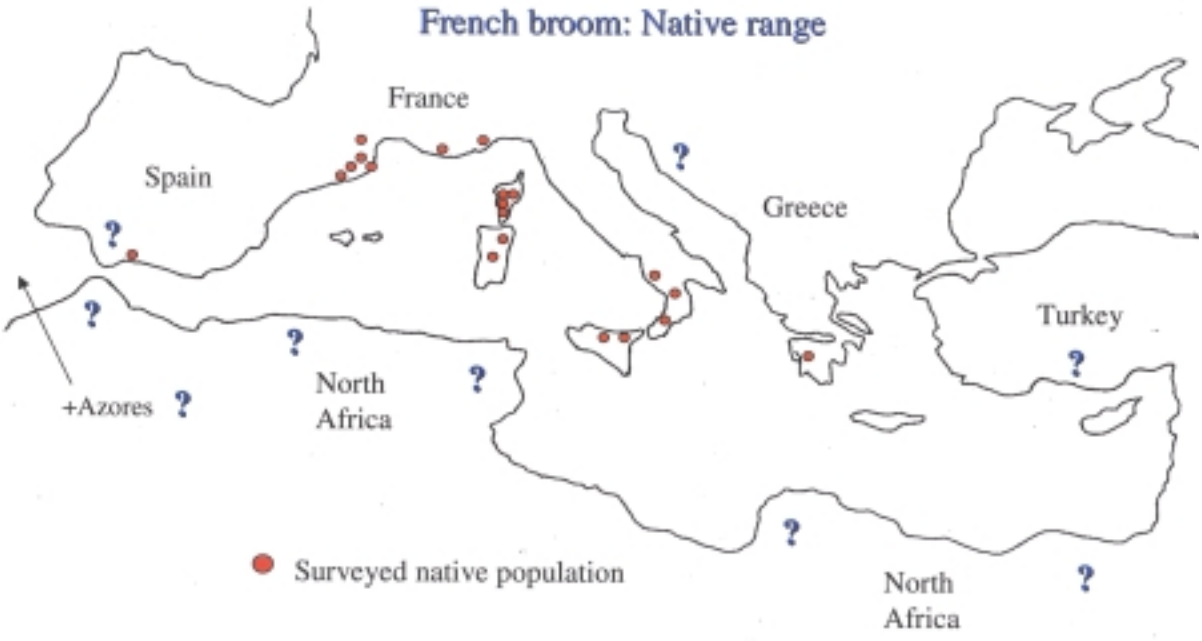
b) In European populations



Genista monspessulana: Native range

Probably the main reason so little work has been carried out in the native range, is that, while it is widespread around the Mediterranean basin (Tutin et al. 1968), it is rarely a common species and when it is present, amongst other Genisteae, is it usually subdominant to *Cytisus villosus, Calicotome villosa* or *Calicotome spinosa*. Other Genisteae observed co-occurring with *G. monspessulana* are, *Cytisus arboreaus*, *Cytisus scoparius* and *Spartium juncaeum*. Surveys associated with this project have only found *G. monspessulana* to be abundant in south-west Corsica (where *G. monspessulana* does co-occur with *Cytisus scoparius*) and in north-west Catalonia (Spain) so far. Native populations in the Mediterranean tend to be small (90% of populations observed had less than 100 individuals) and scattered, either as a low density and spindly understorey component of disturbed cork oak/pine forest or as dense but transient populations in post-fire regenerating '*maqui*' communities in zones of rich acidic soil and relatively high rainfall (>700 mm). This association with higher rainfall areas in the Mediterranean, becomes immediately apparent in Greece where the plant is only found on one 100 km^2 area in the western Peloponissos, the only place in Greece where acid soils occur at sufficient altitude for the necessary rainfall, in an area that does not experience hard continental winters. In the native Mediterranean range the plant is shorter lived (5-8 years; Fig. 1), generates smaller seedbanks 5-900 m^{-2} and suffers high levels of herbivory from goats, stem miners, insects in seed pods and post dispersal seed predation by rodents (J. Lloyd and A. Sheppard unpublished data). Goats are probably another significant factor in the native range limiting the abundance of this plant, given their ubiquitous occurrence, and that most Mediterranean species in the Genisteae are spiny. Germination occurs mainly in the autumn, although seedlings were rarely observed in the native range where French broom regeneration is episodic relating to forest

Figure 2. Native distribution (sources survey trips and eight different regional floras)



disturbance or fire cycles. Native populations appear to be mainly early successional, being replaced by more typical maqui species (e.g. *Arbutus unedo* or *Erica arborea*). As such, nowhere in the native range is this plant considered a weed, and many goat herders must see it as beneficial. The only other factor observed to be directly killing *G. monspessulana* in its native range were herbivorous arthropods (see below). No published data are available on the impact of natural enemies of French broom in the native range, and only one or two for the exotic range, where damage is slight.

Control methods for French broom

Only two studies found have looked in depth at possible management strategies for French broom and both these studies are unpublished. The first relates to and IWM experiment carried out by Carla Bossard in Jackson State Experimental Forest (CA), while the second was a similar study carried out be Janine Lloyd in the Adelaide hills (South Australia). Bossard and Lloyd found similar results. Management is most effective using fire-based IWM in areas that cannot wait for the long-term biocontrol solution. Before burning, curing the broom using herbicides (Triclopyr basal applications or glyphosate to protect natives) increases fire intensity, thereby stimulating or killing a maximum amount of the resident weed seed bank. Fire is most effective on pre-sprayed or slashed broom as this also keeps fire low to the ground. Lloyd also found that smoke stimulated seed germination in plots not directly affected by the fire. Targeting the seed bank in this way with fire achieved 85-95% losses in both trials even with quite low intensity burns. Follow up treatments must be carried regularly to kill regenerating plants just before seed set i.e. about 2 years after the fire. Such follow-up treatments kept broom cover to <5% after 3 years in California. Many land managers perceive management with fire as too risky and also little is probably known about the effects of such control burns on the natives that should be encouraged to replace the weed.

Work in Australia on broom management with goats, suggests this is another option with potential. It can be effective on disturbed/agricultural land where native regeneration is not trying to be encouraged. Meat or dairy goats should be used as these are the easiest to handle and cannot jump the fences. Goats can be trained to be quite selective at least within the vegetation structure, for example they can effectively strip flowers. Goat management may require providing access trails and follow up herbicide treatments once the goats have been moved on.

Mechanical control of broom presents another option. Mulching can be effective when the broom is thick enough to produce deep mulch. Over-sowing with a perennial grass layer should also be considered, an option, which may also be effective following fire. Slashing or whacking re-growth is another option to herbicide use, while bulldozing is not recommended; due to the soil disturbance generated and effect this has on burying the seedbank. Hand removal of individuals prior to seed fall in sensitive areas, particularly for isolated individuals at flowering is an effective strategy in National Parks where the walking public can be trained to recognize and remove broom.

Best practice in broom management will require a specific strategy for each situation. Areas should be designated for containment versus treatment where resources are limiting. Fire or goats can be the basis of integrated broom management strategies depending on the situation. Without

these options (e.g. in containment areas) biological control remains the only solution. All successful management requires a communication strategy to explain and encourage adoption and adaptive management (trying new ideas in parallel to traditional wisdom) should be encouraged at all times.

Natural enemies

A literature search was conducted for natural enemies of *Genista* spp. in general and French broom in particular in Biological Abstracts 1989 –1998, Agricola 1970 – 1998, Zoological Record 1978 –1999 and CABI Abstracts online. This search was complemented by scanning host records within a further 25 taxonomic books covering all orders and families of Eurasian phytophagous arthropods known to be the pre-eminent works for these groups and by consulting a number of unpublished lists (Pauline Syrett, Rowan Emberson and John Hosking unpublished) generated by researchers that have worked on the *C. scoparius* biocontrol project in Europe since the early 1980's and by screening key insect collections made as part of this project and now located in Canberra (Australia), Montpellier (France) and Christchurch (New Zealand). From these searches, 166 species of phytophagous arthropods have been recorded attacking the genus *Genista*. For 51 species the host was described as being simply *Genista* sp., but the source and locality data suggested that none of these are likely to have been *G. monspessulana* and most such species had an apparently broad host range. For 28 of the species *G. monspessulana* was a named host (see Table 1). Of these species, one, the psyllid *Arytainilla hakani* Loginova had only *G. monspessulana* as a host. None of the others were restricted to hosts in the genus *Genista*. Ten species had additional hosts that included only genera within the Fabaceae, tribe Genisteae and seven species had reported host ranges restricted to the Fabaceae. The rest had reported host ranges that included other plant families.

Table 1. Phytophagous arthropods for which a literature search indicated that *Genista monspessulana* was a known host, including the other recorded host genera and references.

Genus	Species	Author	Other *Genista* sp.	Other Host Genera	References
Acarina					
Aceria	*genistae*	Nalepa	*tinctoria*	*Cytisus, Ulex, Spartium,*	Castagnoli 1978, Farkas 1965, Manson 1989, Roivainen 1953, Chan & Turner 1998
Hemiptera					
Arytainilla	*hakani*	Loginova			Burckhardt 1989
Lepiodptera					
Trifurcula	*serotinella*	H.S.		*Chamaespartium*	Suire 1951,1962, Nieukerken van 1986
Mirificarma	*cytisella*	Treitschke	*sp.*	*Cytisus, Calicotome, Ononis, Laburnum,*	Suire 1951,1962, Pitkin 1984
Coleophora	*trifariella*	Z.	*tinctoria, pilosa*	*Cytisus, Spartium*	Suire 1951,1962,
Coleophora	*niveicostella*	Z.		*Cytisus, Thymus, Potentilla*	Suire 1951,1962
Coleophora	*serenella*	Z		*Astragalus, Colutea, Coronilla, Anthyllis, Caragana, Laburnum, Lotus, Vicia*	Suire 1951,1962, Baldizzone 1979
Micrurapteryx	*kollariella*	Z.	*sp.*	*Spartium, Cytisus, Lupinus, Laburnum, etc.*	Suire 1951,1962, Kuznetsov & Tristan 1985
Leucoptera	*laburnella*	Stt.	*tinctoria*	*Laburnum*	Emmet & Heath 1992, Suire 1951,1962
Callophrys	*rubi*	L.	*sp.*	*Cytisus, Ulex, Lotus, Helianthemum, Vaccinium, Rhamnus, Rubus, Cornus etc.*	Carter & Hargreaves 1986, Higgins & Riley 1973, Emmet & Heath 1992
Agonopterix	*nervosa*	Haworth	*tinctoria, germanica, hispanica, sp.*	*Cytisus, Calicotome, Ulex, Spartium, Ilex, Coriaria*	Emmet 1988, Kloet Hincks 1972, Meyrick 1928, Suire 1951,1962, Sheppard unpublished
Uresiphita	*polygonalis*	Denis & Shiffermuller	*germanica, tinctoria,sp.*	*Cytisus, Ulex, Spartium, Chamaecytisus, Lupinus, Laburnum, Sophora, Pericopsis, Bolusanthus, Baptisia, Anagyris, Piptanthus, Retama, Acacia, Polygonium*	Emmet 1988, Kloet & Hincks 1972, Leen 1997, Suire 1951,1962
Uresiphita	*reversalis*			*Cytisus, Ulex, Spartium, Chamaecytisus, Lupinus, Laburnum, Sophora, Pericopsis, Bolusanthus, Baptisia, Anagyris, Piptanthus, Hovea, Templetonia, Acacia*	Montllor et al. 1990, 1995, Wink et al. 1991, Leen 1997
Cydia	*succedana*	Denis & Shiffermuller	*anglica, radiata, tinctoria, cinerea,*	*Cytisus, Ulex, Spartium, Chamaespartium, Lotus, Dorycnium, Ononis,*	Emmet 1988, Kloet & Hincks 1972, Suire 1951,1962

Coleoptera					
Lepidapion	*argentatum*	Gerstacker	*anglica, umbellata*	*Adenocarpus*	Hoffmann 1950, 1958, Alonzo-Zarazaga 1985, Ehret 1990
Lepidapion	*acuminatum*	Schilsky		*Adenocarpus*	Alonzo-Zarazaga 1985
Bruchidius	*lividimanus*		*sp.*	*Cytisus, Calicotome etc.*	Syrett et al. 1999, Brandl 1981
Bruchidius	*villosus*		*hispanica, tinctoria*	*Cytisus, Spartium, Laburnum, Petteria, Chamaecytisus*	Szentesi Á. and Wink M. (1991), Syrett et al. 1999, Frick 1962
Pachytychius	*sparsutus*	Ol.	*cinerea, tinctoria, pilosa, florida*	*Cytisus, Ulex, Chamaespartium, Echinospartium, Erica,*	Caldara 1978, Gurrea Sanz et al. 1988, Hoffmann 1958, Sanz Benito & Gurrea Sanz 1991, Sanz Benito et al. 1989, 1990, Velazquez de Castro et al. 1990, Hoffmann 1958, Syrett & Emberson pers. comm.
Polydrusus	*griseomaculatus*	Desbrochers	*pilosa,*	*Fagus, Corylus*	Hoffmann 1958
Polydrusus	*cervinus*	(L.)		*Dactylis*	Hoffmann 1958
Polydrusus	*prasinus*	Olivier		*Cytisus, Calicotome, Quercus, Almnus, Fagus*	Syrett & Emberson pers. comm., Hoffmann 1958
Phyllobius	*piri*			*Cytisus*	Syrett & Emberson pers. comm.
Sitona	*gressorius*	F	*anglica*	*Lupinus*	Hoffmann 1958
Miccotrogus	*cuprifer*	Panzer		*Trifolium (main host)*	Caldara 1990, Anderson & Howden 1994
Peritelus	*senex*	Boheman		*Ulex, Astragalus,*	Hoffmann 1958
Uredinales					
Uromyces	*genistae*	Fuckel	*pilosa, sp.*	*Chamaespartium*	Guyot, A.L. and M. Massenot. 1958.

Task 2.

Selection and collection of test plant materials. CSIRO will develop and submit a list of species of plants to be included in experiments to determine the specificity of candidate biological control agents for French broom. CSIRO will collect, store, propagate and maintain test plant material of European origin as needed. CSIRO will also receive, store and propagate and maintain North American test plant material permitted through appropriate countries' regulatory agencies.

Introduction

The system used for selecting test plants for testing host specificity of potential biological control agents for French broom, follows the internationally accepted approach defined by Wapshere (1974). In this phylogenetic approach the test list includes species closely related to the target, species within the same taxonomic tribe, species in the same taxonomic family and then species in other families with chemical, physical similarities to the target. The number of species to be tested in each of these group decreases with the relatedness of the group to the target. The evolutionary arguments for the benefits of this approach for defining host range of potential biological control agents are argued elsewhere (Harris and McEvoy 1995).

Here it is proposed to restrict testing for the United States to members of the Fabaceae given the size and variety therein, with an emphasis on the most closely related taxa, particularly those containing members of the North American flora not previously exposed. The test plant list takes into account considerations of taxonomic affinity and occurrence of plants of certain Fabaceae genera in the same climatic regions as French broom.

Taxonomic affinities in the Fabaceae

French broom, *G. monspessulana*, is a member of the *Genista* group of the *Cytisus-Genista* complex within the tribe Genisteae of the Faboideae (= Papilionoideae), one of the subfamilies of the Fabaceae. Apart from the genus *Genista* and *Cytisus* in which there are some ornamental species, only the exotic genera *Lembotropis*, *Petteria* and *Laburnum* are planted as ornamentals in USA. It is also proposed to test common ornamental hybrids of *Genista* (*Cytisus* x *spachianus*, *Cytisus* 'Porlock') as this will give us greater resolution on the specificity of the potential biological control agents as well as assessing likely risks to the Horticultural industry (Aitkinson and Sheppard 2000). Outside the *Genista* group, the *Cytisus-Genista* complex contains the exotic invasive genera *Spartium, Calicotome, Genista* and *Ulex*. Species of all these genera are weedy in North America.

Within the remainder of the Genisteae, as defined by Polhill (1981), North American native representatives are included in the subtribe Lupininae. Given the importance of lupines in the native flora and as agricultural fodder crops at least eight species were included on the test list in which the key species is likely to be tree lupine *Lupinus arboreus* (Dennis Isaacson pers. Comm.).

The interpretation of the relationship between the various tribes of Faboideae has varied over time, but some broad groupings are fairly constant. The most recent interpretation is that of Polhill (1981). The Genisteae are seen as one of a basal group of tribes along with the Thermopsidae, Euchresteae, Podalyrieae, Liparieae, Brognartieae, Crotalarieae, Mirbelieae and

Bossiaeeae. Polhill (1981) goes on to propose four natural groupings of tribes, the first group being the Sophoreae forming the base or stem of the group, the second group being the Genisteae-Podalyrieae complex and two groups based on the Galegeae and the Tephrosieae.

Of the tribes that could be considered close to the Genisteae, only the Thermopsidae, contains North American species and so *Thermopsis* has been included for testing. Two further native species have also been included as representatives of the tribes Sophoreae (*Sophora*) and Loteae (*Lotus*). Tribes of particular importance to agriculture include the Loteae (*Melilotus*), the Phaseoleae (*Glycine* (soya) and *Phaseolus* (beans)), the Trifolieae (*Medicago* (alfalfa) and *Trifolium* (clovers)), and the Vicieae (*Pisum* (peas), *Vicia* (faba bean), *Lathyrus* (sweet pea)). These too have been included in the test list. Outside this group of tribes, it does not seem necessary to carry out systematic additional testing.

The test plant list (Table 2) has been adapted from a list provided by Dennis Isaacson and published in an ODA report (Isaacson 1998) for the testing of potential biological control agents

Table 2. List of plants proposed for testing of potential biological control agents for French broom *Genista monspessulana* for the Western USA.

A. ESSENTIAL

Tribe Genisteae

Subtribe Genistineae

Cytisus scoparius (L.) Link
Cytisus striatus (Hill) Rothm.
Cytisus 'Porlock'⊗
Cytisus x *spachianus* ⊗
Genista monspessulana (L.) L. Johnson
Ulex europeaus L.
Spartium junceum L.

Subtribe Lupininae

Lupinus latifolius J. Agardh*
Lupinus albifrons Benth.*
Lupinus rivularis Lindley*
Lupinus varicolor Steudel*
Lupinus arboreus Sims*
Lupinus polyphyllus Lindley*
Lupinus sulphureus Hook*. **!**
Lupinus lepidus Lindley***!**

Tribe Sophoreae

Sophora sp.* **!**

Tribe Phaseoleae

Glycine max (L.) Merr.
Phaseolus vulgaris L.

Tribe Loteae

Lotus scoparius (Torrey & A. Gray) Ottley*
Melilotus alba Medikus

Tribe Vicieae

Pisum sativum L.
Vicia faba L.
Lathyrus odorata L.

Tribe Trifolieae

Medicago sativa L.
Trifolium repens L.

Tribe Thermopsideae

Thermopsis sp.* **!**

B. DESIRABLE

Tribe Genisteae

Subtribe Genistineae

Lembotropis nigricans (L.) Griseb **!**
Petteria ramentacea (Sieber) C. Presl **!**
Calicotome spinosa (L.) Link
Laburnum anagyroides Medikus

Subtribe Lupininae

Lupinus bicolor Lindley*
Lupinus angustifolius L. (grain lupine)
any 3-5 spp. of available annuals from these ;
- *Lupinus affinis* Agardh*
- *Lupinus arizonicus* (S. Watson) S. Watson*
- *Lupinus concinnus* Agardh*
- *Lupinus densiflorus* Benth.*
- *Lupinus luteolus* Kellogg*
- *Lupinus sparsiflorus* Benth.*
- *Lupinus stiversii* Kellogg*!
- *Lupinus succulentus* K. Koch*
- *Lupinus argenteus* Pursh*!

Tribe Psoraleeae

Psoralea pinnata L. **!**

Tribe Galegeae

Caragana sp. **!**

* native species **! species not in stock at Montpellier**

⊗ Note on horticultural varieties: The horticultural varieties presented are considered to have the following parentage (Aitkinson and Sheppard 2000, Cooke 1997). *Cytisus* x *spachianus* has a range of varietal names (*Cytisus racemosus* Hort, *Cytisus* 'Racemosus Nana', *Cytisus praecox* 'Nana', *Cytisus* 'Racemosus Scoparius Nanus', *Genista racemosa* Hort, *Genista hispanica* sensu Macoboy, *Genista* x *spachiana* and is considered to be a hybrid between *Genista canariensis* and *Genista stenopetala*). *Cytisus* 'Porlock' is considered to be a hybrid between *Genista monspessulana* and *Cytisus* x *spachianus*.

against Scotch broom (*Cytisus scoparius*). The changes include a) substituting horticultural broom varieties with "*Teline*" parentage for those with *Cytisus* parentage, b) the selection of

Lotus scoparius as a native representative of that genus occurring in the area infested by the broom, and considered to be at risk by Californian botanists (Chuck Williams pers. comm.) and c) selecting possible species available at Montpellier where Dennis only indicated a genus. The list is divided by Dennis Isaacson into those species where host specificity testing is considered essential and some other species where it may be desirable to continue some further testing, although testing may not be appropriate in some cases if the life cycle of the plant does not fit with the life cycle of the potential agent. Any unexpected long-term agent survival on previously unrecorded host species will lead either to direct rejection of the agent or an extended testing program using species closely related to the 'new host' and/or testing conditions more natural to the test organism.

Test list modification

The list presented is simply a draft. It now requires circulation to all parties generally consulted in such cases including representatives of West Coast native plant societies. It may also need to be reconsidered for each agent type. While the list included in Table 2 has followed the format and listing constructed by Dennis Isaacson, further modification could be considered to justify a reduction and rationalisation in the length of the test list. However, such considerations would need to be accepted by the local authorities. For example, recent molecular work on the taxonomic affinities within the genus *Lupinus* (Ainouche and Bayer 1999), suggest 5 major clades of relatedness with a biogeographic pattern. Given this it may only be necessary to test representatives of each clade. Given current stocks this might be, for example:

Clade A (Eastern New World Lupines)	*Lupinus texensis* Hook
Clade B (Smooth seeded Old World Lupines)	*Lupinus angustifolius* L.
Clade C (Rough seeded Old World Lupines)	*Lupinus pilosus* Murr.
Clade D (Other Old World Lupines)	*Lupinus micranthus* Guss
Clade E (Western New World Lupines) [1]	e.g. *Lupinus arboreus* Sims
	Lupinus latifolius J. Agardh
	Lupinus albifrons Benth
	Lupinus polyphyllus Lindley
	Lupinus sulphureus Hook**!**

Nearly all of the native *Lupinus* currently on the list in Table 2 are from the Western US and therefore only in one of these clades. This is perhaps a shortcoming of the current list. It is important to remember that host specificity testing is aimed at defining potential host range of biological control agents in a academic sense and should not be used to screen all related rare and endangered plant species. Clearly when a species to be selected can come from an area sympatric to the distribution of the target this is an added bonus and should be applied.

[1] These 5 species come from different groupings in the Ainouche & Bayer (1999) analysis

Table 3. Stocks of seeds and plants for the testing of potential biological control agents against French broom for the USA together with phenology and *Lupinus* phylogenetic relationships (after Ainouche and Bayer 1999).

Test species	Phenology	Clade[c]	Stock plants	Stock seeds
Cytisus scoparius (L.) Link [d]	P		+	+
Cytisus striatus (Hill) Rothm.	P		5	+
Cytisus 'Porlock'	P		5	+
Cytisus x *spachianus*	P		5	+
Genista monspessulana (L.) L. Johnson [d]	P		+	+
Ulex europeaus L.	P		5	+
Spartium junceum L.	P		5	+
Glycine max (L.) Merr.	A		0	+
Phaseolus vulgaris L.	A		0	+
Pisum sativum L.	A		0	+
Vicia faba L.	A		0	+
Lathyrus odorata L.	A		0	+
Medicago sativa L.	P		5	+
Trifolium repens L.	P		5	+
Calicotome spinosa (L.) Link	P		4	+
Laburnum anagyroides Medikus	P		5	+
Lupinus affinus Agardh	A	E1	0	+[g]
Lupinus albifrons Agardh	P	E2	10	0
Lupinus angustifolius L. [a]	A	B	0	+
Lupinus arboreus Sims	P		31	+
Lupinus arizonicus Wats	A	E	0	(+)[g]
Lupinus bicolor Lindley	A	D	0	+[g]
Lupinus concinnus J. Agardh	A	E	0	+[g]
Lupinus densiflorus Benth.	A	E1	0	+[g]
Lupinus elegans H.B.K.	P	E	0	+[g]
Lupinus latifolius J. Agardh	P	E3	0	+
Lupinus luteolus Kellogg	A	E1	0	+[g]
Lupinus littoralis Dougl.	P	E2	0	+
Lupinus micranthus Guss	A	D	0	+
Lupinus microcarpus Sims [a]	A	E1	0	+[g]
Lupinus pachylobus Greene	A		0	+[g]
Lupinus pilosus Murr. [a]	A	C	0	+[g]
Lupinus polyphyllus Lindl.	P	E	0	+
Lupinus pusillus Pursh.	A	E1	0	+[g]
Lupinus rivularis Lindley	P		0	+
Lupinus sparsiflorus Benth.	A	E	0	+[g]
Lupinus succulentus Koch	A	E3	0	+[g]
Lupinus texensis Hook [b]	A	A	0	+[g]
Lupinus varicolor Steudel	P		1	0

[a] Old world, [b] eastern US, [c] see Ainouche and Bayer 1999, [d] western US material, [g] glasshouse grown

North American test plant material

The current reserves of test plant material in Europe to carry out testing of potential biological control agents of French broom are given in Table 3. All annual species are grown each year from seed. The seed is harvested at the end of each year for maintaining the stock. Losses to this list have occurred since stock were originally supplied for work on *C. scoparius*, however these usually only occur when perennial species die unexpectedly without sufficient seeds in reserve to re-propagate the species. Separate annual permits are required through the French authorities to a) import and b) grow outside non-native species to France. The project ensures such permits are available as necessary.

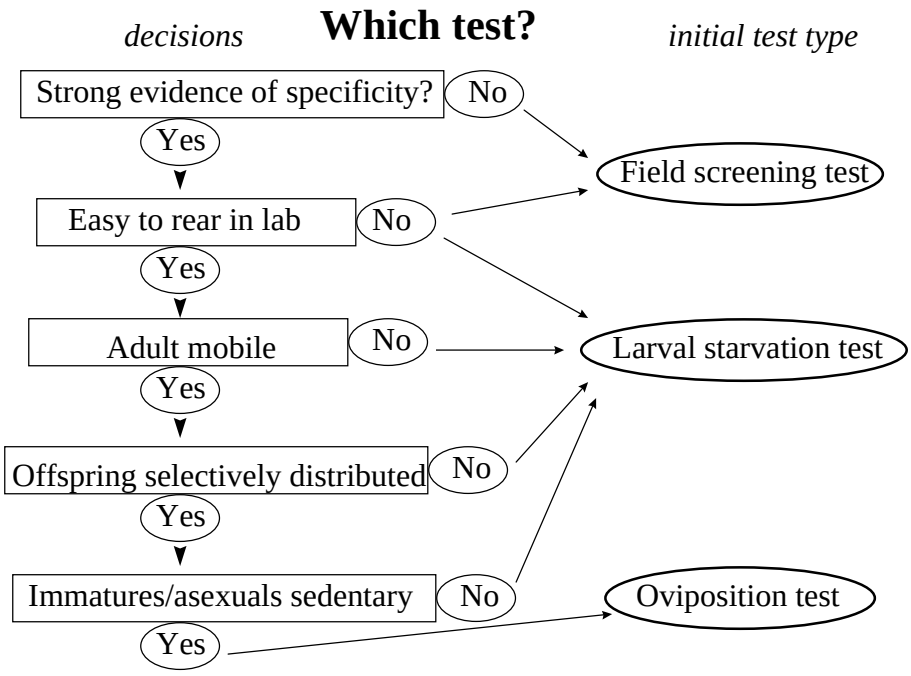
Task 3.

Testing protocols. CSIRO shall propose general plans for experimental testing of candidate agents of particular interest and shall suggest a general timetable for carrying out host specificity tests of potential biological control agents.

Introduction

In this section testing protocols are suggested for three agent types likely to be encountered in a biological control program against French broom. These hypothetical agent types are a) a shoot feeding Lepidoteran, b) a sap-sucking plant louse or psyllid, and c) a seed feeding beetle. The general methodology of such tests and precautions against false results are discussed elsewhere (Harley and Forno 1992, Withers et al. 1999). Clearly the details of the testing procedures will vary depending on the precise biology of each agent. A general guide as to how the biology of the agent will affect host-range test type is given in Figure 3. These protocols relate to laboratory testing which is normal procedure. Where possible, however, field tests would also be used for choice tests as this presents the most natural conditions for the agent to demonstrate its true host range and gives the best first approximation to likely acceptability of hosts.

Figure 3. Flow chart generalising decisions involved in the selection of an initial host specificity testing procedure for the biological control of weeds (adapted from Sheppard 1999).



Shoot feeding Lepidoteran

All plants on the test list are presented in a no choice test. For each test, ten adults (50:50 sex ratio) are confined per test plant in a cage. Each test is replicated at least 5 times. Adults are supplied with a honey solution and left with the plants until they die. Each test plant cage has a similar cage with the target weed and moths as a control. All plants are examined after a 2 month

period and dissected once larval development has ceased. The number of eggs laid and the amount of feeding by larvae are quantified. All plants where development occurred, including target plants are held until pupae develop. Pupae are counted and stored in suitable conditions for normal adult emergence. This procedure can be repeated for choice tests by including a choice of test plants in the cage, however choice tests should only be considered after no-choice tests have been completed.

Sap-sucking plant louse

Three stages of testing would be used. Initial tests using all plants on the test list present either cut shoots or whole plants to the nymphs in no-choice tests. Each test is run with a paired target plant or cut shoot as a control. For plant species where development to adult occurs on cut shoots a whole plant no-choice tests are also conducted. The third and final stage consists of an oviposition tests on key test plant species. Cut shoot tests are conducted by confining 5 first or early second instar nymphs in cages on each test plant cut shoot until insect death or adult emergence. Test cages are plastic tubes with the top replaced with fine gauze. Holes on the sides of the tubes covered with fine gauze prevent high humidity and assist airflow. Whole plant tests use 5 or 10, first or early second instar nymphs placed on each growing tip of the test plants and control broom plants. Shoots and/or whole plants are examined every one to two days to ensure the condition of the test plants and to check on survival of the nymphs. Oviposition tests are made by placing fecund newly emerged adults on either test plants or target plants and kept under similar summer conditions. The adults would usually die within a few weeks and then plants are dissected four months later (a necessary time for eggs to hatch into sedentary first instar nymphs) to look for oviposition scars and eggs.

Seed feeding beetle

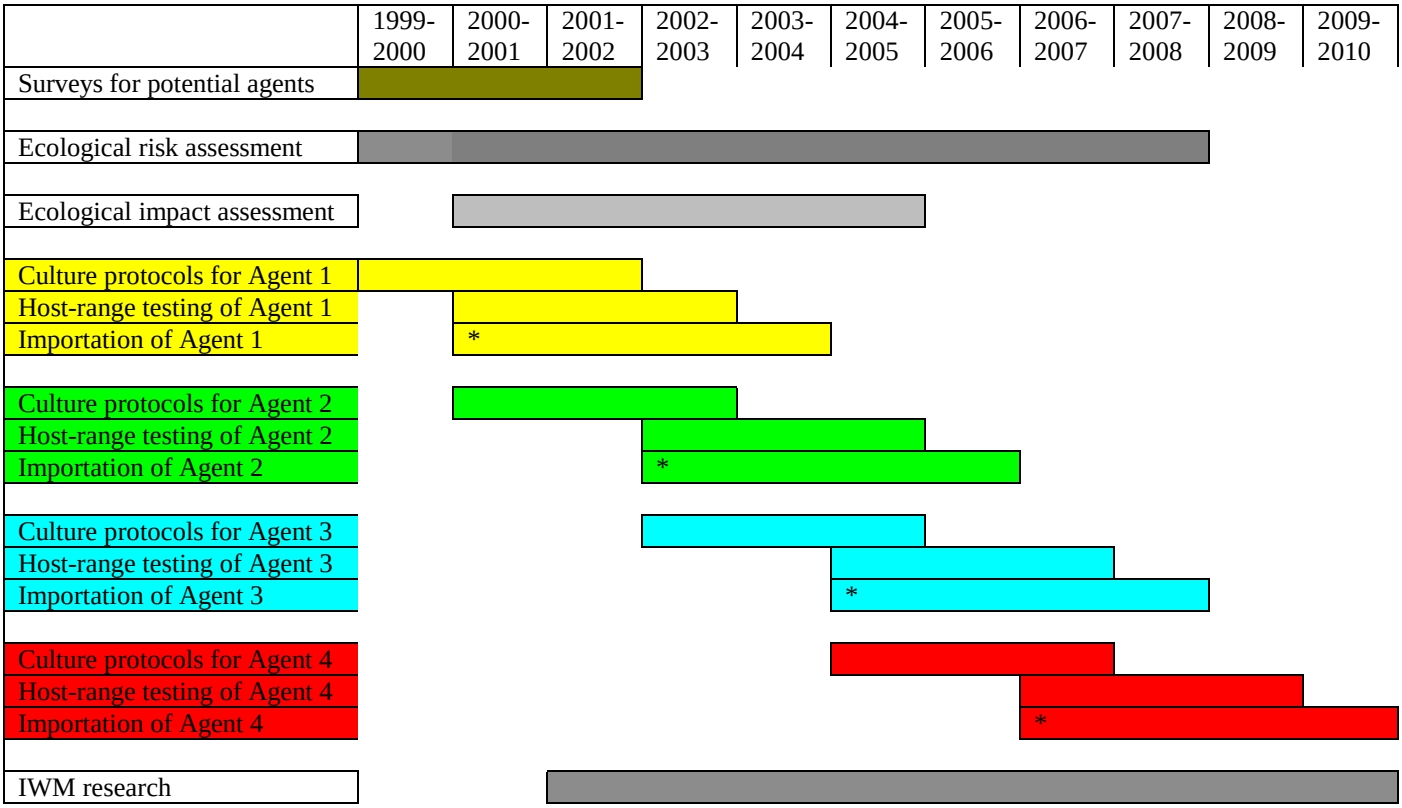
No-choice tests are carried out using whole plants, where possible, and also cut shoots. Both test and control plants must have similar amounts of seedpods on them at the time of testing. Twenty mature beetles are added to cages with a control target plant or shoot. After egg laying on the control plant/shoot is confirmed, the test plant/shoot are added to the cage and the control plant/shoot removed. Fresh control plants are again added later in the testing period to check that eggs were being produced at all times. All plants or shoots are removed after five days in the cages, dissected and checked for any oviposition. When whole plants are used this can be extended into seeing if adults develop. If whole plants can't be used then test plant species receiving eggs should be tested in field experiments to ensure normal larval development can be achieved. It is important that test plants have pods at the same stage of development at the target plants at the rime of the test. Cold treatments and artificial pollination may need to be used to ensure this synchrony in phenology.

Time table for host specificity testing

A requirement for commencing host specificity testing is usually the availability of a viable laboratory culture. While this may not always be the case, a viable culture is a requirement to undergo quarantine procedure before release and so is better addressed prior to the commencement of testing. Host specificity testing can take from one to three years depending on

the ease with which they can be carried out through the year. Testing requiring a particular phenological stage in the test plant, or with insects that have a strict annual lifecycle that cannot be easily modified will allow only one round of tests per year. The available testing space and plants for testing then becomes the limiting factor. Speeding up the process of agent screening can be achieved by overlapping work on several agents at the same time. This, however, will require higher staff costs and may again be limited by equipment and space. Figure 4 shows a draft Gantt chart for a French broom project involving two full time staff members.

Figure 4. Draft Gantt chart for a biological control of French broom project over 10 years project fully funded for two full time research staff.



Task 4.

Research planning. CSIRO shall identify future tasks and needs related to French broom biological control research that are needed for the continuation of a longer-term research project. These tasks and needs should take into account not only those to be accomplished in Europe, but also those required to be carried out in North America.

Introduction

The current state of the biological control project against French broom is summarised in Table 4 . Areas where further work should arise for the biological control of French broom are outlined here and should be cross referenced to the proposed time line for a base level funded project in Fig. 4.

Table 4 Summary of project status and countries where the work should be carried out.

Project status	Europe	USA	
Literature survey			Complete
Development of a suitable test plant list		✔	Drafted
Surveys for potential agents	✔		½ completed
Ecological Risk Assessment	✔	✔	Initiated
Ecological Impact Assessment	✔		
Integration with other control strategies	✔	✔	

Host specificity test list

This report outlines a draft host specificity test list for this project. The next stage in its development should take place in the USA. This list should be circulated for review amongst client and stakeholder organizations and USDA staff to help finalise the list. US scientists would then be best placed to handle the process of list acceptance.

Surveys for potential agents

Surveys of potential biological control agents have been only half completed (Fig. 2). Location of *G. monspessulana* populations elsewhere in the native range, however, should now be a relatively simple exercise. For example, the climatic conditions where G. monspessulana is found in the native range (see Task 1) are sufficiently well defined now that we know that in the north eastern Mediterranean it can only occur on granite, schist or sandstone outcrops along the southern Turkish coast and on the few similar coastal outcrops in Israel, Egypt, Libya, Tunisia and Morocco easily located on maps of the region. Local information on land use in these areas will soon indicate whether they are really likely to support the substantial *G. monspessulana* populations necessary to sustain specific natural enemy populations. Comprehensive surveys are also recommended in southern Spain and Portugal, while experience from visits to other Atlantic islands suggests surveying the Azores would reveal little. Such survey work should be completed in the next one to two years, funds permitting.

Ecological Risk and Impact Assessment

Conducting the host-range testing once an agreed test plant list has been accepted, can be done at the CSIRO European laboratory in Montpellier or the USDA quarantine facility in Albany. This work can perhaps be more quickly and economically completed in France once a full suite of test plants is available there, although very few such species are lacking (Tables 2 and 3), because testing can be done outside a quarantine facility, ensuring space is not limiting. Field tests at the very least should be carried out at this facility. Cooperation with US scientists will be necessary for preparing applications for release. The time lines for such testing will depend on the number of agents and the level of funding, but this aspect has been discussed under Task 3. The broom garden in Montpellier (see Task 5) will be an important source of information for this work and will also provide an easy source of agents for shipment to the USA.

Ecological management of French broom

The opportunity of starting an extended research program in Europe for the biological control of French broom should be used to improve our ecological knowledge of this weed. Such ecological data is already being collected (Fig. 1), but there will be plenty of opportunities in Montpellier for outcome-driven student research projects to hang off this research. The CSIRO European Laboratory has a strong reputation in combining basic research as part of its biological control projects at little extra cost, particularly on brooms (Paynter et al. 1996, 1998, 2000, Fowler et al. 2001).

Similarly, not enough is known about the ecology of French broom in the USA. Collaboration with Universities in the development of suitable PhD proposals linked to this project would improve information flow. There would be opportunities for collaboration in areas of both pure and applied weed research. An obvious area for further work would be trying to understand why *G. monspessulana* is such an invasive weed in its exotic range, while being so innocuous in its native range. Such comparative ecological studies have made a major contribution to effective ecological weed control (Sheppard 2000). Ecological population management models are being developed for French broom (see Task 1) and the availability of data from the USA as a baseline for such models will be required to apply these to the US conditions. Other areas that merit further research in the USA include:

a) a full survey of insects and other natural enemies attacking French broom in the US to identify any scope for the use of these for biological control
b) research on genetic variation in broom, given its horticultural origins for introduction, and the importance of this to control strategies,
c) better ecological assessment of the impacts of French broom on US ecosystems and food webs.
d) understanding the invasive limits of broom to work out where and why French broom control may be easiest, or more strategically and economically applied.
e) an economic assessment of the impacts of French broom to help justify future research.

All such projects should be considered in the USA in parallel with this biological control work.

Integration with other control strategies

Developing a full biological control-based integrated weed management (IWM) strategy for French broom is beyond the scope of this project, but should be considered if the support for this project continues to increase. This approach has been successfully used in Australia for Scotch broom where chemical and mechanical control options and fire are considered in a broad-based approach. Fire and biological control are no-longer considered mutually exclusive for weeds within the Genisteae (Rees and Hill 2000). Several management strategy plans have been written in Australia integrating biological control with more conventional techniques. A suitable starting point has been discussed under Task 1 for French broom. Such strategies, however are best developed on a situation by situation basis as local needs and conditions vary. Greater cooperation between scientists on this project an weed scientists in the US will be necessary to achieve this. This should be a long-term aim of this project as presented in Figure 4.

Task 5.

Identification of potential biological control agents. CSIRO shall develop and maintain a list of candidate biological control agents for French broom, and shall prioritize and/or identify candidates of particular interest according to either exceptional specificity to broom or exceptional potential to damage broom.

Introduction

This research project is addressing the prioritization of potential biological control agents against French broom in two ways a) field surveys to find them and b) setting up a broom garden in the grounds of CSIRO European laboratory, to gain direct data on precise specificity and impact.

Surveys for Natural Enemies

This research project has continued surveys of French broom populations for potential biological control agents in the native Mediterranean range as well as collecting ecological data on French broom populations and the natural enemy communities present in them. Funding from this project led to initial surveys of Greece and to completion of surveys in Corsica and Sardinia.

Methods

Genista monspessulana survey sites were specifically selected to also include, where possible, other species in the Genisteae encountered as well as sampling the broadest range of habitat types. Sample locations were selected in all large monospecific stands of *G. monspessulana* or at sites were more than one species were observed co-occurring. Particular effort was made to find sites where *G. monspessulana* and *C. scoparius* co-occurred as the fauna of the latter is now well known such that clear differences in faunal community would be apparent. Sites were visited at least twice during the growing season.

On the first 'mid-flowering' visit sampling consisted of three sharp taps (with a shortened broom handle) to ten plants per Genisteae species per site (where possible) with a 1.5m x 1.5m beating sheet held under each plant. All arthropods were collected except for very numerous species where a sub-sample was collected from a random section of the beating sheet and the numbers of individuals calibrated up for the whole sheet. Plants were then searched visually to collect any obvious endophagous species not sampled by beating. Obvious plant pathogens were also recorded. Samples from individual plants by host species by site were kept separately. All arthropods were sorted counted and identified as far as possible (to family or genus) in the laboratory in Montpellier on return and voucher specimens have been mounted and sent for identification from all species clearly on *G. monspessulana* alone and all individuals the following orders/families; Lepidoptera, Curculionidae, Apionidae, Chrysomelidae, Bruchidae, Cicadellidae, Psyllidae and Miridae. The data collected are being used generate rarefaction curves that will allow assessment of the efficiency of the sampling technique at locating the total number of species present at a site.

A second visit was made to each site just before seedpod maturation either in the same or the subsequent year and all the pods from ten randomly collected plants per species were collected

and dry stored separately. After a minimum of 3 months storage the samples were sorted for emerged phytophagous arthropods from the whole sample and then 30 pods per plant were dissected to quantitatively assess the impact of the different arthropod species to total plant seed production, all such arthropods were or are in the process of being formally identified.

Results

Survey trips supported by this project led to quantitative sampling at six sample sites in Greece (where French broom is very limited in distribution), 8 sites in Corsica and 5 sites in Sardinia. Species in the Genisteae sampled throughout all the survey work for French biroom biological control agents are included in Table 5. If species were rarely sampled with other Genisteae (Table 5 column 2) then this was because they were mainly observed growing alone.

Table 5 Species of Genisteae sampled since January 1999 and whether or not arthropods were found. Surveys included took place in Greece, France, Italy and Spain.

Species	Number of sites sampled alone	Number of sites sampled together with other Genisteae	Total number of sites sampled	Number of sites where arthropods were found on the plant
Natives				
*Genista monspessulana**	5	15	20	20
Genista stenopetala	0	3	3	2
Genista canariensis	0	1	1	1
Genista corsica	0	2	2	1
Cytisus villosus,	0	14	14	14
*Cytisus scoparius**	1	8	9	7
Cytisus arboreus	0	3	3	3
Chamaecytisus proliferus	4	7	11	10
*Spartium junceum**	2	5	7	5
*Calicotome spinosa**	0	3	3	3
Calicotome villosa	0	7	7	7
Adenocarpus foliolosus	0	4	4	2
Spartocytisus filipes	0	1	1	1
*Retama raetam**	1	1	2	0
*Ulex europaeus**	1	1	2	0

* species that are exotics in USA

These quantitative surveys in the northern Mediterranean region have found 82 phytophagous arthropod species on French broom, and the rust, *Uromyces genistae* Fuckel., attacking old leaves in spring/summer (similar sori have been observed in California). Most foliar damage observed was caused by the psyllid *Arytainilla hakani*, while the fly *Chyliza leptogaster* was the only species that was observed killing mature plants, and only at one site in southern France. Seed predation levels in pods to range from 5 to 50% of seeds per plant caused to an equal degree by *Bruchidius villosus*, *Bruchidius lividemanus* and *Lepidapion argentatum.* Many of the other species are currently being formally identified.

A comparison between the native specific phytophagous arthropod community found so far on *G. monspessulana* in relation to the well-studied comparable community on *C. scoparius* (Syrett et al. 1999) is presented in Table 6.

Table 6. A comparison of the specialist insect community on *Cytisus scoparius* versus *Genista monspessulana* (from field collections). Species in bold type are the extreme specialists restricted to one host or the other. * indicates is or has potential as a biological control agent.

Order	**Genus**	**Species on *C. scoparius***	***Species on G. monspessulana***
Eriophyid	***Aceria***	***genistae****	
Psyllid	***Arytaina***	***genistae***	
Psyllid	***Arytainilla***	***spartiophila****	***hakani(*)***
Aphid	*Acyrthosiphon*	*spartii*	
Aphid	***Aphis***	***sarothamni***	***genistae***
Homoptera	*Gargaria*	*genistae*	*genistae*
Homoptera	*Piezodorus*	*lituratus*	*lituratus*
Heteroptera	*Heterocordylis*	*tibialis*	*tibialis*
Moth	***Chesias***	***legatella***	
Moth	*Agonoptryx*	*scopariella* *nervosa*	*scopariella* *nervosa*
Moth	***Leucoptera***	***spartifoliella****	*laburnella*
Moth	*Trifurcula*	*immundella*	*serotinella*
Moth	*Mirificarma*	*cytisella*	*cytisella*
Moth	***Isturgia.***	***limbaria***	
Pod moth	*Cydia*	*succedana*	*succedana*
Stem fly	***Chyliza***		***leptogaster(*)***
Sawfly	*Rhogogaster*	*genistae*	
Bruchid	*Bruchidius*	*villosus** *lividimanus*	*villosus* *lividimanus*
Leaf beetle	***Gonioctena***	***olivacea***	
Apionid	***Apion***	***fuscirostre****	***argentatum(*)***
Apionid	*Pirapion*	*immune*	*immune*
Apionid	*Protopirapion*	*attratulum*	*attratulum*
Root weevil	***Sitona***	*regensteinensis* ***puberulus***	*regensteinensis* ***gressorius***
Root weevil	***Polydrusus***	***confluens*** *prasinus*	***cervinus*** *prasinus*
Flower weevil	***Tychius***	***parallellus***	
Seed weevil	*Pachytychius*	*sparsutus*	*sparsutus*
Root weevil	*Peritelus*		***senex***

Broom garden

As part of this project and part of the CABI project for the biological control of Scotch broom a broom garden has been constructed in the CSIRO European Laboratory in Montpellier with grant funds from the Australian Weeds CRC. Fifty cubic metres of acid soil were used in the garden to set up six parallel beds 10m long, 1 m wide and 50 cm deep into pre-dug trenches of the same dimensions (Fig. 5). In autumn 1999, two year old plants of *Cytisus scoparius, Genista monspessulana,* and *Chamaecytisus palmensis* were planted into the garden in blocks (3 x 1 x 0.5 m) of 10 plants each. Through winter, two plastc tunnel houses to protect the plants, particularly *C. palmensis*, from frosts, covered the garden. This latter species is the key test plant for Australian based CRC research as it is used commonly as a fodder crop in this country. Blocks were used to ensure a sufficient density of host plant in a patch to support a sub-population of any potential biological control agent. Such biological control agents will be progressively released into the garden as they are identified for both *C. scoparius* and *G. monspessulana*. The design of the garden allows for replication (two replicates of three rows) and generates opportunities to monitor movement of such potential agents between closely related species to gain information on their specificity at a high resolution. By releasing starter populations into one block per replicate (one where the target plants are in the middle block) for each relevant weed both establishment, spread and impact can be monitored over time. Spread can be monitored to touching plants of the same species (within block), touching plants of different species (between blocks in the same row), separated plants of the same and different species (between rows). Impact can be measured initially by variation between blocks of the same or different species and later by using insecticide exclusion. Finally by setting up the garden in an area 10's of kilometres from the nearest native population, it may also be possible to assess some levels of impact in the absence (at least initially) of the potential agents' parasitoids and other specific natural enemies.

Figure 5. Plan of broom garden at CSIRO European Laboratory

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Cytisus scoparius (Scotch broom)	*Genista monspessulana* (French broom)	*Chamaecytisus palmensis* (Tagasaste)
Chamaecytisus palmensis (Tagasaste)	*Cytisus scoparius* (Scotch broom)	*Genista monspessulana* (French broom)
Genista monspessulana (French broom)	*Chamaecytisus palmensis* (Tagasaste)	*Cytisus scoparius* (Scotch broom
Cytisus scoparius (Scotch broom)	*Genista monspessulana* (French broom)	*Chamaecytisus palmensis* (Tagasaste)
Chamaecytisus palmensis (Tagasaste)	*Cytisus scoparius* (Scotch broom	*Genista monspessulana* (French broom)
Genista monspessulana (French broom)	*Chamaecytisus palmensis* (Tagasaste)	*Cytisus scoparius* (Scotch broom)

This garden is now one year old and is in a state where potential biological control agents for French broom can be established and assessed within it. Several biological control agents for Scotch broom have already been released (CABI Swiss Laboratory Quarterly Report, June 2000).

Prioritising potential biological control agents for French broom

Survey information has been used to draw up a preliminary list of potential biological control agents (Table 7) and other species that given further work may attain that list. *Arytainilla hakani* and *Lepidapion argentatum* are illustrated in Plate 1. It is important to emphasise, however, that only half of the native distribution of *G. monspessulana* has so far been surveyed and it is premature to suggest that the natural enemy species with the greatest potential as biological control agents have already been discovered. It will be important that survey work for such biological control agents is completed, before the importations of potential agents to the USA are

Table 7. Current short list of potential biological control agents for French broom, based on surveys of half the native distribution.

Current short list of potential biological control agents

Agent 1. *Arytainilla hakani* Loginova; – Sap-sucking plant louse
(Only ever recorded from French broom)

Agent 2. *Lepidapion argentatum* Gerstacker; – Small weevil feeding on seeds
(also recorded from *G. anglica, G. umbellata, ?Adenocarpus* sp. – taxonomy under revision)

Agent 3 ?

Agent 4 ?

Other species which upon further investigation could be added to the short list.

Moths

Trifurcula serotinella H.S., – leaf miner
(not seen, specific to tribe - literature search)

Coleophora trifarella Zeller; – leaf miner
(not seen, specific to tribe -literature search)

Beetles

Bruchidius villosus F. – seed-feeder
(already in the US, also feeds on *Cytisus, Spartium, Laburnum, Chamaecytisus. Further* testing against north American lupines advisable)

Peritelus senex Boheman – root feeder
(collected only from target, but host range supposedly includes A*stragalus* and *Ulex*)

Flies

Chyliza leptogaster (Panzer) – stem miner
(seen killing plants, recorded also from *Physocarpus*, *Forsythia*. *Neottia*, existence of host races needs investigation)

made. The International Broom Initiative proposal (see Appendix 1) is the first step in that direction. The broom garden will also be an important source of data to help prioritise biological control agents.

Plate 1 a) *Arytainilla hakani* Loginova; – Sap-sucking plant louse

Plate 1 b) *Lepidapion argentatum* Gerstacker; – Small weevil feeding on seeds

Task 6.

Laboratory and field-testing. As appropriate, CSIRO will test candidate agents mutually identified as priority candidates; testing shall include feeding, oviposition and/or breeding tests as required. Initiation of testing would commence only if there is consensus among co-operators that there would be reasonable expectation that all required testing could be completed with available funds.

Introduction

At the current time available funds are not sufficient to complete the testing of any of the potential biological control agents. A number of steps would need to be taken before a testing program could begin. Firstly, as explained under Task 5, a decision to commence testing of any potential biological control agents prior to the completion of basic surveys for natural enemies within the native range should only be taken when it is clear that sufficient resources would not be available to complete the surveys. Without this, a finalised priority list of potential agents would not be available and there is a risk of importing species sub-optimal for control of French broom. The International Broom Initiative proposal (see Appendix 1) is the first step in that direction of ensuring sufficient funds to successfully carry out the work on French broom to ensure correct procedure. In addition, testing of any potential biological control agent can require up to three years work depending on the ease of rearing the agent, the phenological stage of the plant that needs to be tested, the life cycle of the insect and the length of the test list (see Task 3). The only potential agent identified where testing might be completed in less than three years is the psyllid *Arytainilla hakani*, but there are not sufficient resources on the project to date to complete the testing of this agent.

Field Host specificity testing of the broom bruchid (*Bruchidius villosus*).

Some testing work relevant to the biological control of French broom was completed under this project. The seed bruchid beetle, *Bruchidius villosus*, currently being released and redistributed as a biological control agent for Scotch broom, *C. scoparius*, was found for the first time during the surveys of this project to also attack and develop in French broom pods. In North America this univoltine (one generation per year) insect was accidentally introduced into the eastern USA prior to 1963 and has since spread as far as Ontario in Canada (Laura Hopper pers. comm.). Releases in the western US have started following a petition by ODA. Clearly not enough was known about the full host range of this species and thus its potential as a fortuitous biological control agent for French broom. To address this issue, a field host specificity experiment was run at the Montpellier lab, using a local population of *B. villosus* known to develop on both *C. scoparius* and *G. monspessulana.*

Methods

Four blocks of 16 test plants were set up in the grounds of the CSIRO European Laboratory in Montpellier, in a separate 15 m x 15 m garden bed of especially imported acid soil to a depth of 50 cm. In each block two replicates of the following species; *Cytisus scoparius*, *Cytisus striatus*, *Genista monspessulana*, *Spartium junceum*, *Chamaecytisus palmensis*, *Genista tinctoria*, *Cytisus* x *spachianus*, and *Coronilla emerus* L. planted (in their 25 cm pots) in a random order. North American test plant species could not be used in this experiment, as their phenology did not

correspond to that of the target plant in the experiment or such plant species produced no pods and could therefore not be used. Supplementary releases of 40 adults per plot were made into the experiment, however these were swamped by the local resident population. The experiment, started in early May 2000 when the plants were in full flower. Half the green pods were collected at random from each test plants species as they reached a stage where full seed could be felt within the pods. These samples were stored by plant in a cold room. A second field sample was made when the pods reached full maturity and browned off. At this time all of the remaining pods were removed from the plant (June-Sept) and stored separately in paper bags in the insectary.

Pods from the first harvest were counted for each plant and searched under the stereomicroscope for *B. villosus* eggs. Eggs were classified as fresh (clear), parasitised (opaque), mature (dorsal sclerites of the larva visible) or hatched. If hatched the success of larval penetration into the pod was noted. A sub-sample of 50 pods was used if egg numbers were high, and even if they weren't then pod length and seed number per pod was recorded from a similar sized sample. Pods from the second harvest were left for three months in the insectary to allow full pod development. The bags were then search for emerged bruchids, and a sub-sample of 50 pods per plant was dissected to assess bruchid larval survival and impact per pod.

Results and Discussion

Data analysis has not been fully completed and so can not be presented in detail, but a clear picture seems to have emerged. *Bruchidius villosus* laid eggs on all species except *Genista tinctoria* and *Cytisus* x *spachianus*, however, these species were both low growing and later flowering (by about a month) relative to the other species. *Genista tinctoria* also had continuous pod maturation from early pod flowering until the end of the experiment. Rearing records do suggest this species can be a host for *B. villosus*, (Frick 1962). The presence of eggs on *Coronilla emerus* was unexpected, albeit only low number. This contradicts previous testing of this genus (Syrett and O'Donnell 1987). Adult *B. villosus* successfully developed to adult on; *Cytisus scoparius*, *Cytisus striatus*, *Genista monspessulana*, *Spartium junceum* and *Chamaecytisus palmensis*. This was the first time that *B. villosus* had been successfully reared from *Genista monspessulana* (cf. ODA 1998), *Spartium junceum* and *Chamaecytisus palmensis* (cf. Syrett and O'Donnell 1987) under experimental conditions suggesting a much broader host range for *B. villosus* within the Genisteae than suggested by past literature. That adults could not develop in *Coronilla emerus* may be in part due to the nature of the pods produced in this genus, which do not dehisce, but break into small pod covered sections. *Bruchidius villosus*'s normal mechanism for exiting broom pods depends on pod dehiscence as they do not make any attempt to eat their way out through the pod wall and if mature pods are prevented from dehiscing then the adults die inside (A. Sheppard personal observation).

Conclusions

While the risk of *B. villosus* attacking and developing on native North American Genisteae (e.g. *Lupinus*) could not be tested in this experiment, a look at past testing of the agent in light of the new records presented here suggests some irregularities. *Bruchidius villosus* has only been tested against the genus *Lupinus* on two occasions. In the first of these tests Syrett and O'Donnell (1987) tested *Lupinus arboreus* and did not observe eggs laid on the pods in no-choice tests. Such

tests, however, also tested two plant species now known to be hosts of *B. villosus*; *C. scoparius* (Parnell 1966, Syrett et al. 1999) and *Laburnum anagyroides* Medikus (Frick 1962, Szentesi Á. and Wink M. 1991). In these tests only *C. scoparius* received eggs suggesting the result for *L. anagyroides* was a false negative. That false negative results were obtained, throws doubt on the results for any other species included in those tests. Similarly, in the second series of tests, J. Littlefield choice-tested 2 species of *Lupinus; L. arboreus* and *L. littoralis* and the hybrid *L. arboreus* x *rivularis* (Isaacson 1998). These tests however also included *G. monspessulana* and failed also to identify this species as a host plant (i.e. a false negative result). This would tend to throw some doubt on Littlefield's results, particularly given that two other series of choice tests with *B. villosus* also led to false negative results with respect to *G. monspessulana, L. anagyroides* and *Chamaecytisus palmensis* (Syrett and O'Donnell (1987), CSIRO unpublished report 1995). That *B. villosus* has never been recorded attacking *Lupinus* species in Europe even when some species are grown as crops, that *Lupinus* is in a different subtribe within the Genisteae, and that *B. villosus* does not feed on all genera in the subtribe that does contain its normal hosts, suggests that the risk of *B. villosus* attacking North American lupines is still slight. Conventional host specificity testing results to date however provides little support for this.

Recommendation

It would appear pertinent that, given the continued efforts in releasing and distributing *Bruchidius villosus* in Western North America against *Cytisus scoparius*, that some field tests involving native lupines and likely exotic hosts in that region (*Spartium junceum, Cytisus striatus, Genista monspessulana,* and *Ulex europaeus*) are carried out in Europe or the US to complete the risk assessment process for this species.

Task 7.

Literature and reports. CSIRO shall provide copies of reports of progress on the French broom biocontrol research efforts and shall include:

a) *copies of the results of Literature reviews of French broom and natural enemies with abstracts and or annotation as appropriate* ✓
b) *proposed list of test plant materials, with notes on inventories and needed species* ✓
c) *descriptions of proposed experimental protocols for laboratory and field testing, including information on design, replication, required equipment and supplies and timetable for completion,* ✓
d) *a general plan of research, outlining a full program of proposed research thought adequate to bring French broom under control by biological means.* ✓

In the body of this report all these aspects have been covered.

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Appendix 1

International Broom Initiative Proposal