An attack strategy against *Chrysanthemoides monilifera*, a weed of native vegetation in Australia

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Abstract. The southern African shrub *Chrysanthemoides monilifera* is extensively naturalized in south eastern Australia where it invades native vegetation and causes a decline in biological diversity. *Chrysanthemoides monilifera* is targeted for classical biological control and six agents have been approved for release while another 10 await detailed evaluation. In Australia, seed production of *C. monilifera* can be as much as 44 times that recorded in South Africa, and this is a major factor contributing to the plant's success as a weed. Biological control agents such as the shoot-tip feeding geometrid, *Comostolopsis germana*, seed-feeding tephritid flies, *Mesoclanis* spp. and a stem-boring cerambycid, *Obereopsis pseudocapensis,* damage the seed-producing organs and reduce seeding-levels or have considerable potential to do so. Additionally, highly destructive foliage-feeding organisms, particularly the tortricid leaf-roller '*Tortrix*' sp. and the systemic rust fungus *Aecidium osteospermi* are expected to contribute significantly to a decline in the reproductive fitness of *C. monilifera*. Biotic resistance by indigenous invertebrates, particularly ants and spiders has prevented the establishment of three species of leaf-feeding *Chrysolina* beetles. Integration of biological control with other control methods that promote the restoration of competitive indigenous species is likely to reduce infestations of *C. monilifera* to acceptable levels. Chemical control, fire and hand-removal methods play an important role in this respect.

Introduction

The southern African shrub ' *Chrysanthemoides monilifera* (Asteraceae: Calenduleae) has become extensively naturalized in south eastern Australia where it has invaded native vegetation and caused a decline in conservation values and recreational opportunities. Six subspecific taxa of *C. monilifera* occur in southern Africa (Norlindh 1943). Two of these are naturalized in Australia, *C. m. monilifera* (boneseed) and *C. m. rotundata* (bitou bush) (Gray 1976), occupying cool-temperate, and warm-temperate to sub-tropical climatic zones, respectively.

In Australian native vegetation, techniques for weed suppression include the use of herbicides (Cooney *et al.* 1982; Earl 1990), mechanical methods (Dyason 1989) and fire (Lane and Shaw 1978), but high levels of non-target damage or disturbance, high costs or difficulties with access, restrict these applications to relatively small areas. Biological control of *C. monilifera* has considerable potential in Australia due to the weed's low level of taxonomic affinity with native plants and species of commercial importance in Australia, and the rich source of prospective biological agents in the country of origin (Scott and Adair 1995). The focus of the biological control programme is to reduce the fitness of *C. monilifera* by suppressing reproduction and growth rates, which leads to "numerical swamping of other species" (Noble and Weiss 1989), to an ecological threshold that facilitates the re-establishment of indigenous vegetation. In this respect, the integration of biological control agents with non-biological management methods (Noble and Weiss 1989; Weiss 1993), particularly fire and herbicides, offers the greatest prospects for success. This paper deals with the development of biological control of *C. monilifera* and the potential for integrated control.

Plant-feeding insect agents

Foliage-feeding taxa
Attempts to suppress *C. monilifera* in Australia through biological control commenced with the

establishment of the shoot-tip feeding geometrid *Comostolopsis germana* on *C. m. rotundata* in New South Wales. Since 1989, the insect has been released at 78 locations in south eastern Australia with establishment recorded from 44 of these, all but one being on *C. m. rotundata* in New South Wales; the other being on *C. m. monilifera* in Victoria. By 1992, flowering and seed production at Port Macquarie had been reduced by 50 and 70%, respectively, with larval densities of 400 m^{-2} (Holtkamp and Maguire 1993). The insect has its greatest impact on infestations with exposed aspects such as dune fronts and headlands, and is less abundant where *C. m. rotundata* occurs on deep sandy dunes due to the lower density of shoots with soft, young tips that are favoured by the insect.

Post-fire growth of *C. m. rotundata*, either as seedling regeneration or coppicing from basal buds, is readily attacked by *C. germana* and observations of high larval densities after fire (R. Holtkamp personal communication) may reflect a higher nutritional status of the regrowth. Colonization of *C. germana* on regrowth after a fire renders this insect compatible with the 'spray-burn-spray' control option (Weiss 1993), providing that unburnt refugia for the insects are incorporated into control plans. In areas extensively burnt by wildfire, systematic reinoculation with *C. germana* would be required to suppress seed production in the first post-fire flowering period, which can be as soon as six months after a fire (Noble and Weiss 1989). Considering spread rates of 2.5 km yr^{-1} (Holtkamp and Maguire 1993), inoculations at intervals of at least 1-1.25 km would be required to have an impact in the first post-fire flowering peak.

Despite numerous releases of *C. germana* on *C. m. monilifera* in cool-temperate to Mediterranean-type climates of Victoria, Tasmania and South Australia, establishment has only been achieved at one site in Victoria. As *C. m. monilifera* is a natural host of *C. germana* in South Africa and is recorded from regions with Mediterranean-type climates in South Africa (Adair and Scott 1989), poor climate-matching may be limiting the establishment of this insect in parts of Australia. The extent of genetic variation in *C. germana* in relation to climate types in South Africa is unknown, but would be worthy of investigation for the possible selection of better-matched collections of *C. germana* for temperate south eastern Australia.

Leaf-feeding Coleoptera form 57% (26 out of 46 species) of the defoliating taxa found on *C. monilifera* in South Africa. Five species, *Chrysolina* sp. 1 (Adair

and Scott 1991), *Chrysolina picturata*, *Chrysolina* sp. 2 (= *C. oberprieleri*), *Cassida* sp. (Kleinjan and Scott personal communication) and *Ageniosa electoralis* (Adair and Scott 1993) have been evaluated for host-specificity and the three *Chrysolina* species and *Cassida* sp. have been released. Field-based choice tests are required for *A. electoralis* to clarify the host range of this insect.

In South Africa, the *Chrysolina* species associated with *C. monilifera* can cause considerable defoliation damage, but all have restricted geographic distributions with feeding limited to one or two subspecific taxa. *Chrysolina picturata* is the only chrysomelid recorded naturally on *C. m. monilifera*, but in laboratory tests all three *Chrysolina* species develop as well, or better, on *C. m. monilifera* as on *C. m. pisifera*, the dominant natural host for each *Chrysolina* species. Poor survival of the three *Chrysolina* species occurs on *C. m. rotundata*. Extensive releases of *Chrysolina* species on *C. m. monilifera* in Tasmania, South Australia and Victoria have failed to establish self-perpetuating colonies of these insects. Extinction at release sites occurs after a short-term persistence (6-12 months) of small numbers of adults or larvae.

In the case of *Chrysolina* sp. 1 (black boneseed leaf-beetle), a foliage-ovipositing species, severe predation of eggs by native invertebrates, particularly arboreal-dwelling ants (*Iridomyrmex* and *Crematogaster* species), which are attracted to scale-insect (*Parasaissetia nigra*) infestations, and spiders (*Chiracanthium* spp.), is a major factor in the lack of establishment success of this insect (Meggs 1995). *Chrysolina picturata* and *Chrysolina* sp. 2 oviposit in the soil, but immature stages are also likely to be susceptible to predation pressure. Chemical defence-mechanisms reported in the eggs of other *Chrysolina* species and Chrysomelidae (Hilker 1994) appear to be poorly developed in the *Chrysolina* species associated with *C. monilifera*.

Future releases of *Chrysolina* species in Australia will concentrate on young post-fire regenerating *C. m. monilifera* as these infestations may experience temporal gaps with low predator-levels due to the destruction by fire of scale infestations and resident predator-populations. The importance of edaphic conditions in determining the establishment success of *Chrysolina* species in Australia has not been evaluated, but may be of importance as each *Chrysolina* species is confined to a narrow range of soil-types, mostly sandy soils, in South Africa and is absent from near-by areas

with the same host growing on different soils (Scott personal communication).

The foliage-feeding tortricid '*Tortrix*' sp. at times causes extensive damage to *C. monilifera* and is considered the most destructive organism on *C. monilifera* in South Africa (Scott and Brown 1992). Its potential as a biological control agent is considerable as the insect is highly damaging, occurs on all *C. monilifera* taxa in South Africa and is found over the full geographic range of the host genus. During periods of low parasitoid activity, outbreaks of '*Tortrix*' sp. can lead to complete defoliation of bushes resulting in the death of branches and whole plants. Although in South Africa '*Tortrix*' sp. has only been found on *C. monilifera*, starvation tests under caged, laboratory conditions indicate that the insect is capable of completing development on a broad range of non-target taxa, thus complicating evaluation procedures. Field-based multiple choice tests in South Africa are required to clarify the 'natural' host range of this insect.

Flower- and seed-feeding taxa

Fruit production and soil seed-bank levels in Australian populations of *C. monilifera* may be up to 44 times higher than those in South Africa (Weiss and Milton 1984), which we attribute to substantial differences in phytophagy between the two countries. Major seed destroyers in South Africa, the tephritids *Mesoclanis polana*, *M. magnipalpis* and *M. dubia*, feed in developing *C. monilifera* fruits and can result in high seed losses during periods of peak fly abundance, with seed destruction up to 74% per plant and 64% per site (Edwards and Brown unpublished observations). However, seed destruction levels are often lower due in part to the suppression of *Mesoclanis* species by a guild of hymenopteran parasitoids. Although many of the same parasitoid genera are present in Australia, we anticipate that lower parasitoid activity will occur in Australia than in South Africa due to the absence of specialist parasitoids that are well synchronized with the biology and phenology of *Mesoclanis* species (Edwards *et al.* this Volume).

The genus *Mesoclanis* contains six species that are known only from *C. monilifera* in southern Africa (Munro 1950). The genus is distributed throughout the range of *C. monilifera*, with *M. polana* restricted to the sub-tropical summer rainfall areas of Natal, where it occurs on *C. m. rotundata*, while *M. magnipalpis* and *M. dubia* occur in Natal and the eastern and southern Cape coastal areas and Cape Peninsula on *C. m. pisifera*, *C. m. rotundata* and *C. m. monilifera* (Edwards and Brown unpublished observations). The broad climatic range of *Mesoclanis* species in South Africa and its natural occurrence on *C. m. monilifera* and *C. m. rotundata* allow a similarly-wide geographic range to be targeted for release in Australia. *Mesoclanis polana* was approved for release in 1995 and is destined for release on *C. m. rotundata* infestations in northern New South Wales. As *M. magnipalpis* and *M. dubia* are most abundant on *C. monilifera* from the southern Cape, more temperate areas of *C. monilifera* in Australia would be used as release locations for these insects.

If *Mesoclanis* species establish in Australia, seed destruction by these tephritids should complement the action of *C. germana*, which although effective on foredune and fertile sites, has only a limited impact on *C. m. rotundata* occurring on nutrient-poor, deep sandy dunes. Ninety-two percent of coastal dunes in New South Wales contain infestations of *C. m. rotundata* (Bergs 1986). These areas are likely to be utilized by the three *Mesoclanis* species under consideration, as the tephritids, unlike *C. germana*, are not dependent on vigorous shoot-development for their survival. Noble and Weiss (1989) proposed that at least 95% pre-dispersal seed destruction would be required to control *C. m. rotundata* in Australia. While seed destruction by *Mesoclanis* species alone may not reach this level, we aim to achieve effective suppression of seeding levels by utilizing combinations of compatible biological control agents with non-biological control methods.

Root-feeding taxa

Root- and crown-development in *C. monilifera* vary considerably. Erect taxa such as *C. m. monilifera* have poorly-developed crowns and a weak root-network, while sprawling taxa such as *C. m. rotundata* have robust, deeply penetrating roots and sometimes substantial crown material. Remarkably few organisms (2.6% of the total number of potential agents, J.K. Scott unpublished data) have been found to be associated with the root system of *C. monilifera* in South Africa and none are considered suitable as biological control agents.

Stem-boring and galling taxa

The stems of *C. monilifera* in Australia are rarely attacked by stem-boring insects and no galling organisms have been observed in the field. This is in

contrast to the situation in South Africa, where internal-feeding taxa can cause considerable damage. In particular the stem-boring cerambycid *Obereopsis pseudocapensis* feeds in terminal stems of *C. m. rotundata* and *C. m. pisifera* on the southern Cape coast and eastern Cape, causing shoot tips to wilt and die. Adult beetles oviposit in the leaf midvein and larvae tunnel into stem tissue. Field observations and preliminary host-tests indicate that the insect is specific to *C. monilifera* and at times is abundant causing high numbers of wilted tips per bush (P. Muller personal communication). As *C. monilifera* inflorescences are all located in the upper section of outer-canopy stems, destruction of shoot tips by *O. pseudocapensis* has the potential to reduce the seed production of *C. monilifera*.

Coleoptera that complete their development internally in *C. monilifera* are likely to avoid the canopy-dwelling predators believed to be responsible for the failure of *Chrysolina* species to establish in Australia. Cerambycids released in Australia for the biological control of weeds (including species of *Baccharis, Opuntia, Acanthocereus, Lantana, Xanthium*) have a high level of establishment success (seven out of 10 species established) and although few exert effective control (Julien 1992), low resistance-pressures to establishment make this family of interest in the biological control programme against *C. monilifera*.

In the south-west Cape where *O. pseudocapensis* does not occur, larvae of an unidentified Gelechiidae species tunnel in the tips of *C. m. pisifera* and *C. m. monilifera* causing damage similar to that of *O. pseudocapensis*. Two gall-forming species of Cecidomyiidae that feed in petioles or stem apices are found on *C. m. monilifera* and *C. m. pisifera* in the southern Cape. As no biological control agent, besides the one case of *C. germana*, has as yet established on *C. m. monilifera* in Australia, consideration will be given to these insects in the near future.

Pathogens

Three fungi (Doidge 1950) and one mycoplasm (Scott and Adair 1995) are reported from *Chrysanthemoides* species in South Africa. The systemic, microcyclic rust fungus *Aecidium osteospermi* infects shoots causing witches' brooms with swollen stems and short internodes. Infected leaves are small and chlorotic and infected stems produce little or no fruit. Hyphae

advance with the meristematic tips, infecting all new leaves and side shoots (Morris 1982). Infected stems die after one or two seasons and heavily-infected plants appear to succumb more readily to drought stress (Neser and Morris 1985). *Chrysanthemoides m. monilifera* is particularly susceptible to *A. osteospermi*, but the fungus also occurs on *C. m. pisifera*, *C. incana* and *C. m. rotundata* at the southern end of its range. No other host plants are known. *Aecidium osteospermi* is a priority species for evaluation as a biological control agent and current research is concerned with developing reliable inoculation and early-infection detection techniques, and the selection of highly pathogenic strains of *A. osteospermi* for Australian populations of *C. monilifera*.

On morphological characteristics, Australian populations of *C. monilifera* are relatively homogeneous, although greater variation occurs in *C. m. monilifera* than in *C. m. rotundata* (Simmons and Flint 1985). An analysis of the genotypic variation of Australian *C. monilifera*, both within and between populations, using DNA amplification techniques (RAPD and microsatellite loci) is being currently undertaken to ensure that a broad range of genetic variants are incorporated into the process of strain-selection of *A. osteospermi*.

In Australia, endemic pathogenic fungi regularly cause dieback symptoms in *C. m. rotundata* and *C. m. monilifera* with a range of symptoms from shoot tip die-back to the death of large sections of a plant. Cother *et al.* (1994) isolated 55 fungal taxa from *C. m. rotundata* from the New South Wales coast and some, particularly *Sclerotinia sclerotiorum*, are being considered for further evaluation as inundative mycoherbicides.

Integration of biological control

The integration of classical biological control of *C. monilifera* with other control methods is in the early developmental phase in Australia as the establishment of agents is obviously a prerequisite for this approach to weed control. The comprehensive studies by Weiss (1986) and Noble and Weiss (1989) on the biology of *C. monilifera* in Australia provide a strong basis for the development of integrated control strategies. The spray-burn-spray strategy for *C. m. rotundata* incorporated herbicides to kill standing plants that provided fuel for a controlled fire to reduce the soil

seed-bank and kill seedlings and plants surviving herbicide treatment (Weiss 1993). A second application of herbicides 6-7 months later resulted in negligible resprouting and elimination of most seedlings arising from the initial soil seed-pool. Weiss (1993) recommended that corridors of untreated *C. m. rotundata* should be left for maintaining populations of biological control agents, which would serve as source areas for agents to colonize *C. m. rotundata* regrowth. In this situation only agents with good dispersal abilities are likely to be effective.

Recent advances in control techniques using herbicides have determined that aerial application of low doses of glyphosate and metsulfuron methyl during winter provides selective control of *C. m. rotundata* in native vegetation (Toth *et al.* 1993) providing an option for the large-scale treatment of *C. m. rotundata* infestations, particularly in large, open areas. Utilizing fire to suppress *C. m. rotundata*, may also assist with the restoration of desirable native vegetation, particularly where hard-seeded taxa are present in the soil seed-bank or are directly seeded into treatment areas. In coastal dune systems, *Acacia longifolia* is a native analogue to *C. m. rotundata,* but in Australia is displaced by the latter species (Weiss and Noble 1984). Although *A. longifolia* seed germinates in the absence of fire, heat treatments enhance the germination of this species and many other *Acacia* species (Langkamp 1987; Auld and Connell 1991). In areas where *C. m. rotundata* vigour is suppressed by the action of biological control agents, and this appears to be occurring in areas supporting *C. germana,* vigorous regrowth of native vegetation with extensive canopy-cover is likely to further weaken *C. m. rotundata.* Similarly, the ash-bed created following a fire may enhance the growth of other beneficial coastal species such as *Banksia, Casuarina, Lomandra* and *Leptospermum.* In areas where indigenous soil seed-banks have been depleted, application of seed mixtures will be required for habitat restoration and in large-scale operations, aerial seed-application is likely to be the most practical method. However, limitations on seed availability of virtually all native plants presently restricts direct-seeding to relatively small areas. The development of large seed-orchards of desirable native species would overcome this difficulty.

Chrysanthemoides m. monilifera is fire-sensitive and unlike *C. m. rotundata,* does not coppice following burning. Mild heating leads to the complete germination of weathered seeds (those with open endocarp sutures), but has little effect on fresh seed (Lane and Shaw 1978). High-intensity fire or prescribed fire applied in spring or early summer results in the near-complete germination of soil seed-reserves (Lane and Shaw 1978) and, when followed by seedling control measures initiated before regenerating plants reach sexual maturity (12-18 months), can effectively suppress *C. m. monilifera* infestations. Chemical control or hand-pulling are appropriate for the removal of post-fire regenerating seedlings in small, accessible infestations. A second, low-intensity, prescribed fire applied 12-18 months after the initial fire could eliminate seedlings of *C. m. monilifera* over large areas relatively cheaply, but is likely to have detrimental effects on fire-sensitive native plants with sexual-maturation times exceeding the fire-interval period. Control by fire is risky in areas close to human habitation and difficult where fuel accumulation in the inter-fire period is low.

In the long-term, it is hoped that biological control agents will reduce the reproductive capacity of *C. m. monilifera* and consequently soil seed-loads, so that post-fire regeneration densities of *C. m. monilifera* are low enough to enable ecologically-sensitive control techniques to be applied in a cost-effective manner over large areas. In this respect, the use of community groups involved in hand-removal of plants or spot applications with selective herbicides may become more effective for control of large infestations.

While *C. monilifera* is recognized as one of Australia's most detrimental environmental weeds (Humphries *et al.* 1991) and considerable progress has been made in the development of control techniques, allocation of resources for the implementation of control measures in conservation areas remains low. One of the pressing challenges is to ensure that developments in control strategies for *C. monilifera* are readily available to land managers and that the risks of non-intervention are understood at all levels in land management hierarchies.

Acknowledgements

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