beetle (*Chrysolina quadrigemina*) have been released at various sites. A total of 16 sites are being monitored. It is probably still too early to fully assess the impact, but early signs are good.

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Towards the integration of control methods for St. John's wort: Workshop summary and recommendations

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Introduction

St. John's wort has been a problem weed in south-eastern Australian landscapes for the last 100 years. Its toxicity to stock and its perennial habit made St. John's wort an early and serious pest of pastures, and led to several attempts at control by chemicals, pasture management and biological control (see Groves 1997, Briese 1997b). Despite subsequent improvements in methodology and some degree of success using these various methods, the weed has still continued to spread; currently, it is becoming increasingly important in natural ecosystems as well as on grazed land.

Given the considerable research effort to date, is it simply a matter of putting all the accumulated knowledge together and combining the most relevant results into an effective integrated package for management; alternatively, is further research still needed in some areas? In 1995, the Co-operative Research Centre (CRC) for Weed Management Systems was set up with the purpose of co-ordinating research and fostering collaboration between groups to promote more effective weed management. As St. John's wort is one of only a few weeds to be considered a problem of both pastoral and natural environments, it is appropriate that the CRC Programs for Perennial Pastures and Natural Ecosystems jointly sponsored a workshop to answer these questions. The workshop brought together researchers from Australia and New Zealand, representing expertise in the ecology of St. John's wort, grazing and pasture management, animal health, herbicide use and biological control, as well as extension workers involved directly in weed control, and end-users, such as landholders and representatives of Landcare groups.

Papers presented at the workshop covered aspects of the weed's ecology / biology (including its history of introduction and spread) and toxicity to stock, as well as control strategies currently being used in pastoral situations and National Parks, including biological control, grazing management and herbicide use. From the formal presentations and ensuing workshop discussion, it became obvious that more research was required on certain aspects of the biology and control of St. John's wort as a basis for more effective integration of different control methods. This paper summarizes the key points emerging from the workshop, and the recommendations made to address those gaps in our knowledge and develop the means to produce integrated management strategies for control of St. John's wort in different ecosystems.

Status and impact of the weed

Since soon after its introduction, summarized by Harris and Gill (1997), St. John's wort has presented a problem to grazing enterprises. The toxic effects of the weed on stock, comprehensively summarized by Bourke (1997), are well known. On this aspect, it is interesting to note that not all species of *Hypericum* contain hypericin; for instance tutsan and the two species native to Australia do not (Mathis and Ourisson 1963). Extrapolations to lost carrying capacity and an assessment of the economic impact of St. John's wort are possible. Costs of herbicides are similarly known (Campbell and Watson 1997) and while an Australia-wide figure is not available, the overall economic impact in pastoral areas is not difficult to estimate for particular properties or regions.

What is not clear is the impact of St. John's wort in non-pastoral situations where the weed may occur on crown land or national parks. Its importance may vary from insignificant, except as a source of infestation for neighbouring land and as a declared weed requiring costly control, to an assumed significant impact in areas of floral and faunal significance. The importance of the weed's competitive effect on native flora and its consequent indirect effect on native fauna, or possible direct toxic effect on native fauna, is completely unknown, however. Some better estimate of this aspect is desirable in assessing priorities for control methods in natural ecosystems.

To translate the existing pasture information and some estimate of conservation significance into a national assessment would require a more up-to-date knowledge of the weed's distribution, but whilst useful, this may not have the highest priority in the short term.

Knowing the target

Knowing sufficient of the biology and ecology of a weed to understand the effect of its environment, including those influences imposed on it by attempted control methods, is the basis of effective management. Briese (1997a) gave a comprehensive summary of what is known regarding St. John's wort, based mainly on the early work of Clark (1953) in Victoria and his own more recent demographic studies. St. John's wort shows considerable variation in growth form and hence in extent of vegetative reproduction, response to stress and flowering frequency. Much of this plasticity can be related to variation in site and it seems that management strategies would need to be site-specific. In general, the weed tends not to be affected unduly by any individual stress, but more often by two or more in combination. The need to break the life cycle completely was emphasised and the concept of aiming at susceptible periods in the cycle was explained.

Variation

Three contributions to the workshop, from Campbell (1997a), Jupp *et al.* (1997) and Mayo and Roush (1997), dealt with genetic, as opposed to phenotypic, variation and this aspect is now assuming considerable importance in relation to biological control. Campbell originally described morphological variation in 1987 and this variation is now being paralleled by differences in susceptibility to the mite *Aculus hyperici*, the most recently introduced, and currently most promising, biological control agent (Jupp *et al.* 1997). Combined with the evidence for different introductions of the weed presented by Harris and Gill (1997), there are almost certainly different genetic populations present. The characterization of these and their distribution, as well as the breeding system of St. John's wort, obviously need resolution and the work recently initiated by Mayo is planned to lay the groundwork for much of this increased understanding.

Herbicidal approach

Whilst control by herbicides is possible, Campbell and Watson (1997) also made it clear that it was expensive and in several cases probably impractical and prohibitively costly. Moreover, it is highly unlikely that the cost of chemicals for control can be reduced. No herbicide gave complete control in a single application. Complete kill was only ever obtained with Starane® and involved an application of 2 L ha^{-1} one year followed by 3 L ha^{-1} the next year. In this respect, Starane probably merited more attention for St. John's wort control. In any herbicidal control program, however, there will remain small pockets of weed which will serve as foci for reinfestation, in addition to the seed pool in the soil. In terms of the life cycle system as presented by Briese (1997a), it represents a one-off break in the cycle that must be repeated if it is the only treatment. Despite this proviso, chemicals still have an important role to play as part of an integrated management program:

- in eradicating new and highly localized infestations,
- in reducing roadside populations to limit dispersal,
- for setting up containment or buffer zones around major infestations,
- as pre-sowing treatments for perennial pastures,
- in the replanting of forest trees or native vegetation.

Herbicides were useful in situations when there was adequate follow up, e.g. by sowing competitive pasture and subsequent management of grazing, and should perhaps only be contemplated if this is possible. For natural ecosystems the use of herbicides is less attractive still, with little information on side effects on native vegetation and no satisfactory follow-up measures. Reflecting Campbell and Watson's (1997) presentation and possibly their own experience, the members of a subsequent discussion group, considering St. John's wort in pasture, rated research on herbicide use as having little or no priority.

Pasture competition and grazing management

Campbell (1997b) pointed out that there had been little research on St. John's wort control by grazing management, but that there were a number of examples where it had been successful as long as care was taken not to expose sheep to grazing for too long. The adage of two weeks on, five weeks off, was still effective, but care was still necessary and some deterioration in stock should still be expected. The most effective system was the use of pastures dominated by phalaris and subterranean clover on arable land combined with controlled grazing, but on non-arable land the situation was more difficult. This was echoed by the experience of Arnott (1997) who found control on flat country no problem, but required more work on hilly country. Careful management of goats and cattle gave worthwhile results, though in very steep country considerable time was required to manage the cattle effectively. Otherwise, the trampling effect of the cattle on the weed was decreased.

Competitive native plants

In natural ecosystems, the role of competitive native plants has not been evaluated, practically or experimentally, despite it being a potentially important aspect of integrated control of St. John's wort on land not subject to grazing by domestic stock. Davey (1919) suggested that the deep-rooted, summer-growing native grass *Themeda australis* (syn. *T. triandra*) was one species able to suppress growth of St. John's wort. With St. John's wort now a major weed of roadsides in national parks, on water catchments and on public land generally, perhaps it is timely to look again at the ability of native perennial species to compete with plants of St. John's wort.

Biological control

Attempts at biological control of St. John's wort in Australia can be considered in a number of phases, as outlined by Briese (1997b) in his review. The most recent of these has been concerned with attempting to reduce the overall vigour of the weed in a systematic manner so as to reduce its capacity to regenerate after damage, whether caused by grazing, herbicides or the beetle *Chrysolina quadrigemina.* The two most recently established agents are examples of species with the potential to achieve such a reduction. The aphid, *Aphis chloris*, has not maintained high populations consistently enough to damage a significant proportion of St. John's wort populations over a long enough period, but the mite, *Aculus hyperici*, is showing substantial impact in several areas. Whilst the observed rate of natural spread of 1 km per annum is significant, it is still important to establish the mite as widely as possible as soon as possible in order to fully exploit its potential. It is therefore important to continue to develop the networks established for distribution of the mite (Mahr *et al.* 1997) Any further need for biological control will depend very much on the eventual effectiveness of *A. hyperici*, including the influence of variation in the weed, so it is vital that the impact of this mite is carefully evaluated.

It seems that in grazing situations in particular, *A. hyperici* may weaken the weed sufficiently for competitive species to be effective and the combination of biological control and competition may produce satisfactory control. In natural ecosystems however, the potential for finding and manipulating competitive native species is untested and the effectiveness of the mite on its own is unknown as yet. There therefore remains a bigger question over the possibility of control in such natural systems.

Apart from the possible need to consider additional populations of *A. hyperici*, better adapted to resistant forms of the weed, other possibilities for future study include further introductions of the root-boring beetle *Agrilus hyperici*, a little known sesiid moth whose larvae also bore into the root, the pathogen *Colletotrichum gloeosporioides* from Canada and the *Hypericum* rust *Melampsora hypericorum*. Some effects of *C. gloeosporioides* have been examined in quarantine in Victoria

(McLaren *et al.* 1997) and can certainly be damaging, but the pathogen has the potential to damage some non-target species under particular conditions and its host specificity may not be sufficient to satisfy requirements for release. An accidentally introduced strain of *M. hypericorum* has been devastatingly effective on the related weed tutsan, *Hypericum androsaemum*, in Victoria and the species has been recorded on St. John's wort in Europe, but was only ever found once during extensive surveys of the weed in Europe.

Discussions on priorities

The papers presented provided a base for subsequent group discussions aimed at identifying:

- gaps in our knowledge of particular areas of weed biology and current management practices,
- future research directions that would provide the knowledge required,
- the feasibility of integration of the various management strategies,
- any drawbacks associated with integration,
- methodologies that might allow evaluation of the interaction and integration of control methods.

The product of these discussions was a list of 26 proposals for different research topics (Table 1). During the final session, workshop participants were given the opportunity to rate each proposal according to their attractiveness (to what extent the results would improve weed management) and their feasibility (the probability of actually achieving the results). Proposals were rated as low, medium or high for each category. The results were then averaged and graphed (feasibility vs attractiveness) to produce a picture of the combined view of workshop participants (Figure 1). This graph was not seen as an end in itself, but served as a tool for discussing the merits of the 26 proposals, and generating a series of recommendations for future research on the integrated management of St. John's wort.

It was clear that extension, education and training are, and will continue to be, important in order that land managers can understand the various possibilities for effective management of the weed. High priorities were given to the development of guidelines and the production of handbooks for management of the weed and the development of accessible information networks to train land managers and extension workers. It was also felt that given that grazing management could play a significant role, more work was worthwhile in order to give better guidance, as was research on the integration of grazing with biological control. Grazing management could be improved if information were available on variability in the levels of the toxin, hypericin, both between plant forms and at different stages of the plant's life cycle, and these were considered attractive areas for research. In particular, it was felt that further research should be directed at measuring the interactions between biological control agents and the use of herbicides and different grazing strategies. Whilst herbicide use was often not a favoured option, some work to determine the possibility of more economic application of herbicides was considered worthwhile.

For biological control, it was important to obtain as much benefit as possible from the agents present and the major need was to concentrate on the current redistribution project for *Aculus hyperici*, and to accurately evaluate its effectiveness in different environments. An allied priority was to determine the distribution of forms of the weed that show resistance to mite attack. In this regard, an understanding of the breeding system and genetic variation of St. John's wort were felt to be crucial and linked to the possibility of obtaining other populations of the mite. The fortuitous attack of the rust fungus, *M. hyperici*, on tutsan in southern Victoria presented an opportunity to contribute to both the benefits and science of biological control by re-releasing it at strategic unattacked sites and carefully studying the epidemiology of rust infection.

Modelling of the population dynamics of the plant under a range of habitats and different stress conditions was viewed as an attractive means of detecting 'weaknesses' in the weed's life-system and thereby refining strategies for its management under different patterns of land-use. Finally, in view of the concern over

Table 1. List of individual proposals to improve the control of St. John's wort and achieve integrated management.

No.	Research recommendation
1	Quantitative plant ecology under different environments/stresses (modelling)
2	Competitive differences between types of St. John's wort
3	Effectiveness of aerial application of Starane® + effects on native vegetation
4	Update distribution of St. John's wort (including biotypes) in Australia, especially public lands
5	Determine biotype herbicide tolerance
6	Strategic and economic application of herbicides
7	Exploration for clearwing moth (attacks roots) in Europe
8	Exploration for *Melampsora* rust on St. John's wort in Europe
9	Detailed assessment of *Aculus* mite impact in different habitats
10	Exploration for new strains of the mite
11	Survey for native pathogens on St. John's wort in Australia
12	Attempt to re-establish the root-borer *Agrilus* in Australia
13	Introduce *Melampsora* rust on tutsan infestations in New South Wales forests
14	Investigate the role of fire in the management of St. John's wort
15	Develop accessible information networks and materials on St. John's wort management
16	Develop whole catchment/landscape management plans
17	Integration of biocontrol agents with grazing management/tolerance
18	Maximize impact of *Chrysolina* and mites
19	Measure hypericin levels throughout the year
20	Determine levels of stock grazing on wort control
21	Determine pasture species replacements and fertilization rates
22	Measure interactions between herbicides and biocontrol agents
23	Quantify impact of wort on biodiversity and its social value
24	Investigate integrated control strategies for public lands
25	Develop guidelines and handbooks for management/training
26	Revegetation with competitive native species

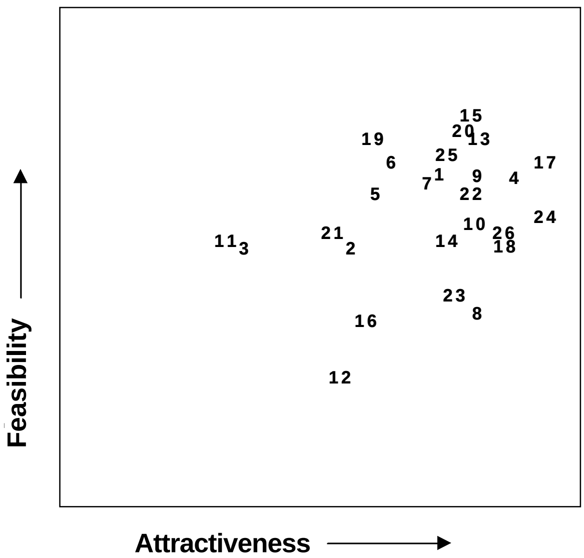

Figure. 1. Relative attractiveness and feasibility of research proposals.

management of St. John's wort on public lands, there is an urgent need to determine more accurately the distribution of the weed in these areas and its impact on local biodiversity. Despite the potential difficulties, it was considered that there is an urgent need to develop appropriate management strategies for infestations of the weed in natural environments, which take into account current practices in natural areas, such as prescribed fire regimes, and the need to find competitive native species to prevent reinfestation.

Conclusions

It was apparent from the presentations and the discussions that there are the means, or at least the potential, to solve management problems with St. John's wort in many of the agricultural situations where it is still a significant weed. Its economic impact can be assessed and costs and benefits of control evaluated. Competitive pastures and stock management following herbicide application, or more probably, in conjunction with biological control by the mite *A. hyperici*, could possibly see a decline in the importance of St. John's wort, providing resistance in the weed can be managed and overcome. In natural ecosystems and public lands however, the situation is different. The impact of St. John's wort on biodiversity and conservation values is not known and nor is the potential of native species as effective competitors. How dependent management of St. John's wort will be on manipulation of such species will in turn be linked to the effectiveness of *A. hyperici* as an agent in such ecosystems, which has yet to be evaluated.

These considerations raise some very clear questions to be answered. The CRC program has the potential to resolve them and there is therefore some confidence that in the life of this CRC, St. John's wort is one weed where effective management is an achievable aim on privately-owned grazed land. It is important to remember, however, that control of St. John's wort will always depend on adequate dissemination of the knowledge about how to manage this weed and therefore education and extension have to be an integral part of any future control program.

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