Habitat manipulation in Australasia: recent biological control progress and prospects for adoption

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Abstract

We briefly review ways in which conservation biological control by habitat manipulation is used overseas as a 'low-tech' but ecologically-rational approach to pest management. Prospects for adoption in Australasia are illustrated by presentation of data from several recent studies which have taken place in a variety of annual and perennial crop systems in Australia and New Zealand. These have demonstrated the potential importance of neighbouring vegetation and the effects of within-paddock habitat diversification using paddock-margin plantings, within-crop strips, orchard understorey plantings and sequential harvesting of the crop itself. These studies show that certain types of vegetation adjacent to the crop can provide important resources for natural enemies. In contrast, most conventional crop systems are characterised by lower botanical diversity. This frequently disadvantages natural enemies which may require shelter, plant foods (nectar and pollen) and alternative hosts/prey. However, because of the relative paucity of research in this area, including into means of avoiding the non-crop vegetation benefiting pests, habitat manipulation approaches are rarely promoted in Australasia. Methods by which botanical diversity may be used to enhance natural enemies without benefiting pests are outlined. We stress the importance of laboratory and small-scale field studies (in addition to field trials) in understanding the biology of the arthropods involved. Remaining research challenges, and barriers to adoption are discussed and we propose the term, and practice of, 'integrated biological control'. This stresses the contribution which conservation biological control approaches may make to enhancing the efficacy of classical and inundative biological control.

Introduction

The use of biological control is receiving increasing international research and commercial attention as problems associated with pesticides have become more widely recognised. Much of this activity has taken the form of inoculative releases of exotic natural enemies, 'classical biological control', or mass releases of larger number of agents, 'inundative biological control'. The third broad approach, making better use of existing natural enemy fauna, 'conservation biological control', is relatively neglected (Dent 1995). This is despite many studies which have shown the potential for favouring predators and/or parasitoids by habitat manipulation (see recent review by Wratten and van Emden 1995).

Habitat manipulation researchers recognise several mechanisms by which natural enemies may be favoured by non-crop vegetation. The most important are provision of shelter (e.g. Thomas *et al.* 1992), plant foods such as nectar and pollen (e.g. Hickman and Wratten 1996), and alternative prey or hosts (e.g. Bugg *et al.* 1987). However, these studies, like most others which have used this approach, were conducted in North America or Western Europe and until very recently this approach has largely been neglected in Australasia.

In this contribution we provide a concise overview of several studies conducted in Australia and New Zealand in recent years. Our aim is two-fold. First, to illustrate the potential for habitat manipulation to contribute towards a more sustainable approach to pest management in the new millennium, and thereby stimulate greater research activity; and second, to critically consider the challenges which researchers will need to address, including the potentially counterproductive effects of habitat manipulation, if significant uptake by farmers is to be achieved.

Australasian progress

A crop monoculture constitutes a potentially high-quality and abundant resource for pests, which tend to be more abundant and damaging in such crops than in polycultures (Andow 1991). Although debate surrounds the extent to which the activity of natural enemies contributes to pest suppression in diverse vegetation, there is little doubt that predation and parasitism do make a significant contribution. A key tenet of habitat manipulation is, therefore, to strategically diversify the crop or its surroundings in order that key ecological resources are made available to natural enemies so that that their numerical and functional responses are optimised.

One means of achieving greater levels of diversity and providing resources to natural enemies is to manage the crop itself. In perennial forage crops such as lucerne, this approach may be achieved by sequential harvesting, which increases the continuity of availability of lucerne nectar and pollen for use by natural enemies. It also favours the many taxa of vagile natural enemies by providing a refuge available to individuals displaced by harvesting elsewhere in the paddock, whilst the act of harvesting is likely to kill many of the less vagile pests (e.g. lepidopteran larvae). Immature natural enemies are likely to suffer high mortality under both sequential, and conventional, harvesting strategies. Data from pilot trials in New South Wales (Hossain *et al*. 1997) in which replicated strips of lucerne measuring 20 m x 1 m were left uncut in a harvested crop on three occasions, and subsequently sampled using 30-s-long vacuum collections, show that such areas tend to support relatively high populations of the predatory red and blue beetle, *Dicranolaius bellulus* (Guérin-Méneville) (Coleoptera: Melyridae) (Table 1). In contrast, catches of *Helicoverpa* larvae were significantly lower in this treatment than in adjacent control plots which had been cut. Current larger scale work will determine the relative importance of *D. bellulus* and other natural enemies in such reductions in pest population using egg baiting techniques.

Table 1. Vacuum catches of *Helicoverpa* larvae and the predatory red and blue beetle (*Dicranolaius bellulus*) in plots of cut and uncut lucerne in the Lachlan Valley, New South Wales (Hossain, Gurr and Wratten 1997).

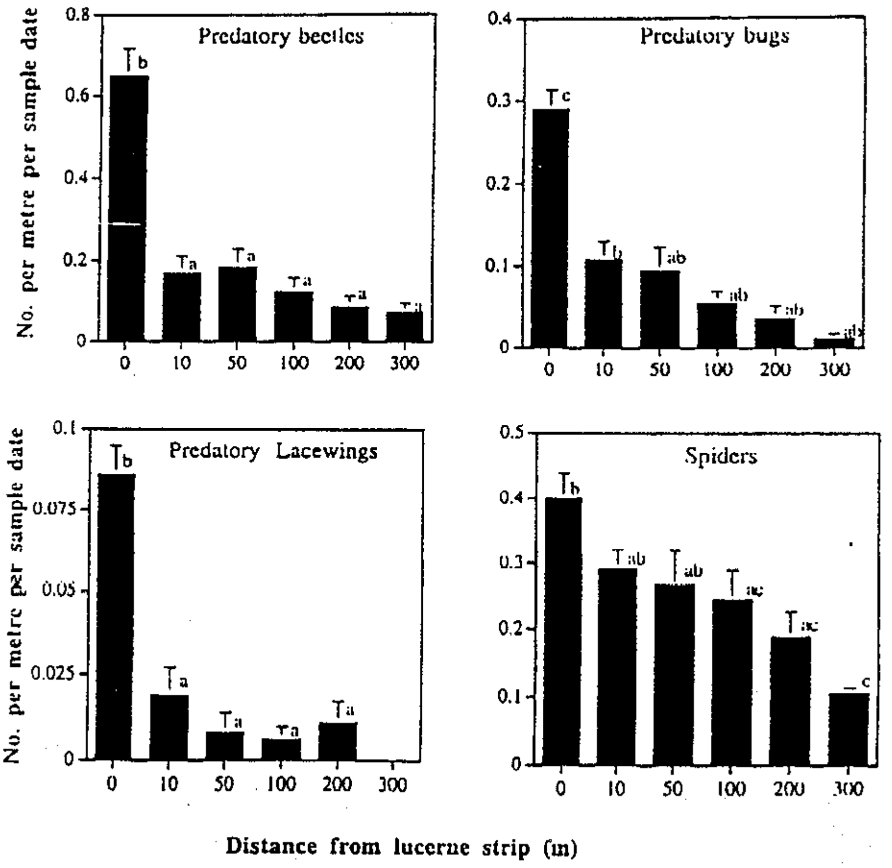
Sample Date•	***Dicranolaius bellulus****		***Helicoverpa* spp. larvae***	
	Uncut	**Cut**	**Uncut**	**Cut**
23 Dec '96	0.77a	0.23a	1.42a	2.02a
8 Jan. '97	2.45a	1.39a	1.59a	12.84b
2 Feb. '97	8.70a	0.99b	0.23a	0.19a
8 Feb. '97	3.77a	0.84b	0.36a	0.11a
23 Feb. '97	29.08a	0.65b	3.69a	0.0b
7 Mar. '97	10.44a	0.72b	0.36a	5.45b
11 Mar. '97	4.82a	0.32b	1.09a	17.31b

* Means within a date and taxon followed by differing letters are significantly different at $P < 0.05$ (analysis of variance of at least 7 replicates on each sample date.).

• Crop harvest dates on which new 'cut' and 'uncut' plots were created, were: 19 Dec '96, 22 Jan. '97 and 17 Feb. '97.

Other studies have also recognised the potential of lucerne to support natural enemy populations. Walker (1997) found that lucerne supported at least as many natural enemies of cotton pests as any of the 27 vegetation types sampled (Table 2). More importantly, because of its perenniality and prolonged period of active growth when irrigated, it supported high populations throughout the year, whereas most other crops held significant numbers of natural enemies for only short periods before they either senesced or were harvested. This was in broad agreement with earlier comparisons of natural enemy densities in lucerne and cotton (Mensah 1996). In more recent work, Mensah (1998), has attempted to exploit the favourability of lucerne to confer a benefit to cotton. Growing lucerne strips within cotton paddocks was found to profoundly influence the spatial distribution of four taxa of entomophagous arthropods within the adjacent cotton (Fig. 1). This suggests scope for increasing the densities of natural enemies within cotton crops by planting lucerne strips at intervals within cotton paddocks. Within such a system, dispersal of natural enemies into the adjacent cotton could be encouraged by applying the attractant, Envirofeast®, to the cotton (Mensah 1997), or by cutting the lucerne. Either action could be timed to occur when monitoring showed that key pests, such as *Helicoverpa* spp., required control within the cotton; and slashing could be used to kill potential cotton pests, such as *Creontiades dilutus* (Stål) (Hemiptera: Miridae), whilst present in the lucerne in the nymphal stage (Mensah and Khan 1997).

Figure 1. Densities of entomophagous taxa over a range of distances from a 12 m wide lucerne strip bordering a cotton crop. (Means are of vacuum catches over 20 m of row on four occasions between 2 Nov. 1993 and 2 Jan. 1994. Differing letters indicate differences significant at $P < 0.05$, Tukey-Kramer multiple comparisons test. Bars are standard errors.) (Source: RK Mensah, 1998. Habitat diversity: Implications for the conservation of and use of predatory insects of *Helicoverpa* spp. in cotton systems in Australia. International Journal of Pest Management (In press).



One disadvantage of this habitat manipulation approach is the proportion of land taken out of production, even if, as suggested by Mensah and Harris (1998), the lucerne is harvested as hay to partly offset the lost production of the primary crop. Consequently other studies have sought to make use of the unproductive field margins which are not normally planted with the crop. Recent work by Baggen and Gurr (1997) employed borage, *Borago officinalis* L. (Boraginaceae) as a source of nectar for *Copidosoma koehleri* Blanchard (Hymenoptera: Encyrtidae), a parasitoid of the potato moth, *Phthorimaea operculella* (Zell.) (Lepidoptera: Gelechiidae). Borage seeds were sown along one half of one edge of a commercial potato crop on the Central Tablelands of New South Wales. Subsequent measurements showed that the level of parasitism in the vicinity of the borage was significantly ($P < 0.001$) greater than elsewhere within the crop (Fig. 2).

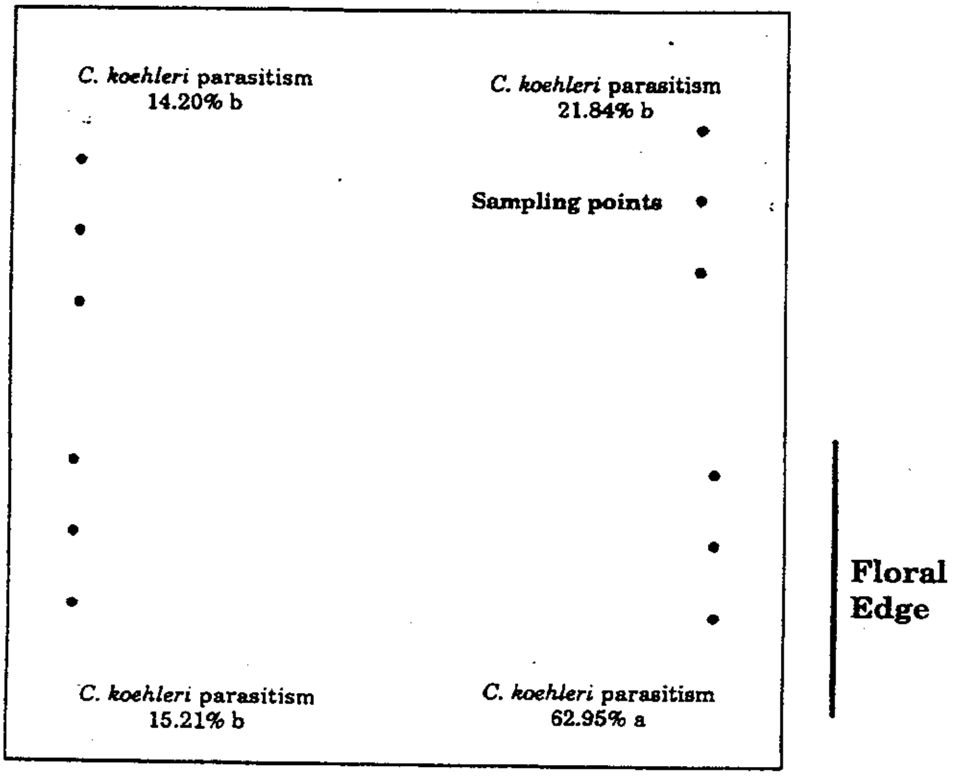
Table 2. Catches of key predators of cotton pests in vacuum samples from crop and non-crop habitats in the Namoi Valley, New South Wales, between January 1996 and March 1997. (Walker 1997).

Habitat	Vegetation sampled	No. sample sites	No. times sampled	No. Months sampled[2]	No. predator taxa caught[3]
Field Crop	Lucerne	5	32	15	16
	Maize	7	33	9	16
	Peanuts	5	27	10	15
	Potatoes	5	16	6	15
	Wheat	7	23	4	15
	Grain sorghum	10	22	7	14
	Faba beans	5	27	6	14
	Forage sorghum	5	12	6	13
	Soy beans	5	20	3	13
	Sunflowers	5	20	7	12
	Mung beans	7	12	5	11
	Cow peas	3	8	5	10
	Oats	3	7	5	10
	Safflower	2	4	2	10
	Adzuki beans	1	4	3	9
	Field peas	2	9	4	8
Pasture/ Stock routes	Burr medic	3	5	4	11
	Mixed grass spp	1	5	3	10
	Turnip weed	4	5	4	9
	Yellowvine	6	9	3	8
	Common nardoo	1	2	2	1
Roadside vegetation/ field borders	Paterson's curse	3	6	3	13
	Ann. sunflower	3	13	6	11
	Wild parsnip	4	13	5	10
	Paper daisy	3	4	4	2
	Sticky beak	1	2	1	2
Riparian	Mixed herbaceous spp	1	5	4	12

[1] Samples consisted of three or five 10 m transects of vegetation per sampling occasion.
[2] Sampling period extended until harvest or senescence of vegetation.
[3] Predator taxa counted: *Oechalia schellenbergii* ((Guérin-Méneville), Hemiptera: Pentatomidae), *Cermatulus nasalis* ((Westwood), Hemiptera: Pentatomidae), *Orius* spp. (Hemiptera: Anthocoridae), *Geocoris lubra* (Kirkaldy, Hemiptera: Lygaeidae), *Deraeocoris signatus* ((Distant), Hemiptera:

Miridae), *Nabis* sp. (Hemiptera: Nabidae), *Dicranolaius bellulus* ((Guérin-Méneville), Coleoptera: Melyridae), *Coccinella transversalis* (Fabricus, Coleoptera: Coccinellidae), *Harmonia octomaculata* ((Fabricus), Coleoptera: Coccinellidae), *Micraspis frenata* ((Erichson), Coleoptera: Coccinellidae), *Diomus notescens* ((Blackburn), Coleoptera: Coccinellidae), *Stethorus* spp. (Coleoptera: Coccinellidae), *Anthicus* spp. (Coleoptera: Anthicidae), *Mallada* spp. (Neuroptera: Chrysopidae), *Micromus tasmaniae* (Walker, Neuroptera:Hemerobiida), Syrphidae and Araneida.

Figure 2. Rate of parasitism in potato moth larvae recovered from various positions from within a habitat manipulation field experiment using borage to constitute a 'floral edge' (Baggen and Gurr 1997). (Means are of larvae recovered from three sample points, each of 15 m of potato crop row, for each of the four positions. Differing letters indicate differences significant at $P < 0.05$.)



Other work has taken place in perennial tree crops where there has typically been a history of high levels of agrochemical inputs (Gurr *et al.* 1996), including broad-spectrum insecticides and herbicides. The former directly limit the activity of most natural enemies, while the latter minimise the contribution of non-crop plants to their survival and activity. Integrated pest management in orchards has tended to address particular pest groups (e.g. mites or lepidopterans) and typically has not considered the consequences of actions for all biological components of the orchard system (Wratten *et al.*, this volume). The rapid increase in research on, and promotion of, integrated fruit production (IFP) in New Zealand pip-fruit orchards, however, with its abstinence of use of broad-spectrum organophosphorus insecticides, the adoption of less disruptive compounds (such as the insect growth regulator tebufenozide), and the consideration of the orchard as an ecosystem, gives biological control and its enhancement by understorey management, new potential. In New Zealand IFP is actively promoted by ENZA (Bachelor *et al.* 1997) because of overseas market demand for apples produced in this more sustainable way. ENZA has reviewed recent progress in each component of IFP in New Zealand and has identified understorey management as requiring much more research to formulate clear recommendations for what species to plant, and to quantify the benefits and how these may be maximised by optimal management.

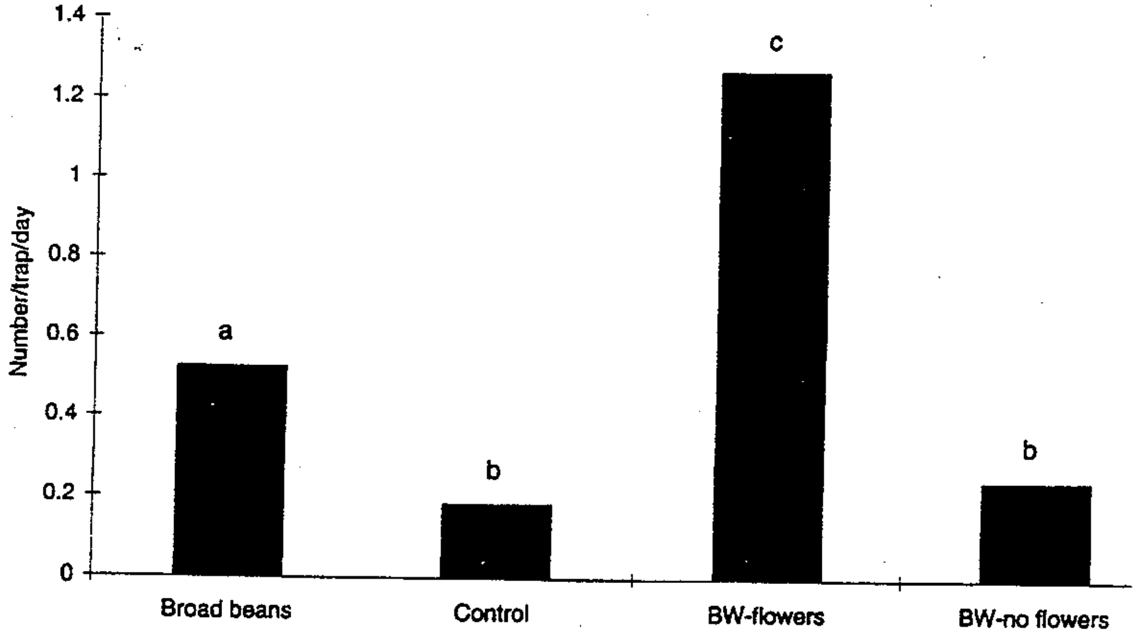
At Lincoln University, work in collaboration with HortResearch is evaluating understorey management options which promote biological control of leafroller (Lepidoptera: Tortricidae) pests via enhancement of the numbers and activity of *Dolichogenidea tasmanica* Cameron (Hymenoptera: Braconidae). In recent work this has been the commonest leafroller parasitoid in the orchards of the Canterbury Plains (Stephens *et al.*, unpublished). Buckwheat, *Fagopyron esculentum* Moench (Hydrophyllaceae), was used in experimental apple orchard understorey plots as it was shown to be agronomically well suited to the Canterbury summer conditions (Bowie *et al.* 1995) and also was attractive to beneficial insects with short mouthparts because of its shallow corollae giving easy access to its pollen and nectar (Lövei *et al.* 1993). Further, the very large gene pool of this species offers good scope to select cultivars suited to particular agronomic and climatic conditions. However, because buckwheat is a short-lived annual, unless sequential sowings are made, or fresh flowering is promoted by cutting, nectar and pollen are available only for a short period of the leafrollers' abundance period. Exploiting extra-floral nectaries, such as those found on the stipules of many legumes is a possible solution. Broad beans, *Vicia faba* L.(Fabaceae), produce nectar from extra-floral nectaries from a very young stage of growth and throughput the plant's long growing season.

To test the effects of these plants, replicated plots of broad bean and buckwheat were sown below apples at Lincoln University in the 1996/97 season. A third treatment consisted of buckwheat from which flower buds were removed as they appeared. This treatment offered shelter to *D. tasmanica* adults but no access to nectar or pollen. Between January and April 1997, *D. tasmanica* adults were captured on sticky yellow traps above these plots and from control plots with bare ground. Trapping was repeated on four occasions. After five trapping periods all plants were removed by cultivation, returning these plots to the same state as the control. A repeated-measures analysis of variance showed that flowering buckwheat and broad beans gave higher *D. tasmanica* catches than other treatments (Irvin, unpublished) (Fig. 3). This pattern was consistent for the first five sample dates with no significant effect of buckwheat without flowers, strongly indicating that floral and extra-floral resources were responsible for the parasitoid's population/activity enhancement. When all plants were removed, parasitoid catches reverted to background levels. On some dates, parasitism rates of leafroller larvae released onto the trees above the plots were also enhanced in some flowering plots.

Future challenges

The above studies show clear scope to profoundly influence the abundance, activity and spatial distribution of natural enemies by relatively simple manipulations of crop habitats. However, if this progress is to be translated into widespread adoption and marked reductions in insecticide applications, problems of both a scientific and non-scientific nature will need to be addressed. An important scientific problem will be our imperfect understanding of the ecology of pests and their natural enemies and this implies scope for pests to benefit from habitat manipulation initiatives. For example, the US work by Bugg *et al.* (1987) showed that the common knotweed, *Polygonum aviculare* L. (Polygonaceae), provides such a favourable habitat for natural enemies that their tendency to leave and forage in adjacent crops was questionable. Possibly, under these circumstances, displacement of natural enemies into the crop could be encouraged by cutting the weed in a manner similar to that proposed for lucerne strips within cotton crops (see above). Other potential problems associated with habitat manipulation have been shown by recent New Zealand work with orchard understoreys. In one study, the greatest enhancement of natural enemies in the vicinity of buckwheat plots was for *Anacharis* sp. (Hymenoptera: Figitidae), a parasitoid of the predatory brown lacewing, *Micromus tasmaniae* Walker (Stephens *et al.*, unpublished data). Catches of the parasitoid were greater in plots planted with buckwheat than in the control over most of the period after flowering of the buckwheat commenced (Fig. 4). Fortunately in this instance *M. tasmaniae* is not an important predator of pests in the New Zealand apple orchard ecosystem but the potential for negative effects in other systems is clear, and there is a need to proceed with caution when developing habitat manipulation strategies.

Figure 3. Catches of the leafroller parasitoid *Dolichogenidea tasmanica* on yellow sticky traps above each of four understorey treatments in an apple orchard on the Canterbury Plains, New Zealand (Irvin, unpublished data). (Columns with differing letters differ significantly ($P < 0.05$)).



An additional potential problem, as well as a means of avoiding it, has been shown by Baggen and Gurr (1998). In their work with *C. koehleri* it was shown that floral nectar could enhance its longevity and fecundity in the laboratory and this in turn increased levels of field parasitism of *P. operculella*. Unfortunately, the benefit of this was partially offset by moths feeding on the nectar of the coriander, *Coriandrum sativum* L. (Umbelliferae), plants used. However, further work showed that borage, whilst conferring a significantly greater longevity than coriander for *C. koehleri*, did not appear to be fed upon by *P. operculella*, its longevity being no greater than when allowed water only (Table 3). This selective floral resource was identified only by laboratory screening, which is not generally done when selecting plant species for use in habitat manipulation initiatives. Future attempts will need to address plant choice more carefully, considering a broader range of criteria, and Gurr *et al.* (1998) suggest a decision-making framework by which this may be achieved.

Figure 4. Catches of *Anacharis* sp., a predator of the predatory brown lacewing (*Micronus tasmaniae*) in orchard plots sown with buckwheat or treated with herbicide (control). (Stephens *et al.*, unpublished data).

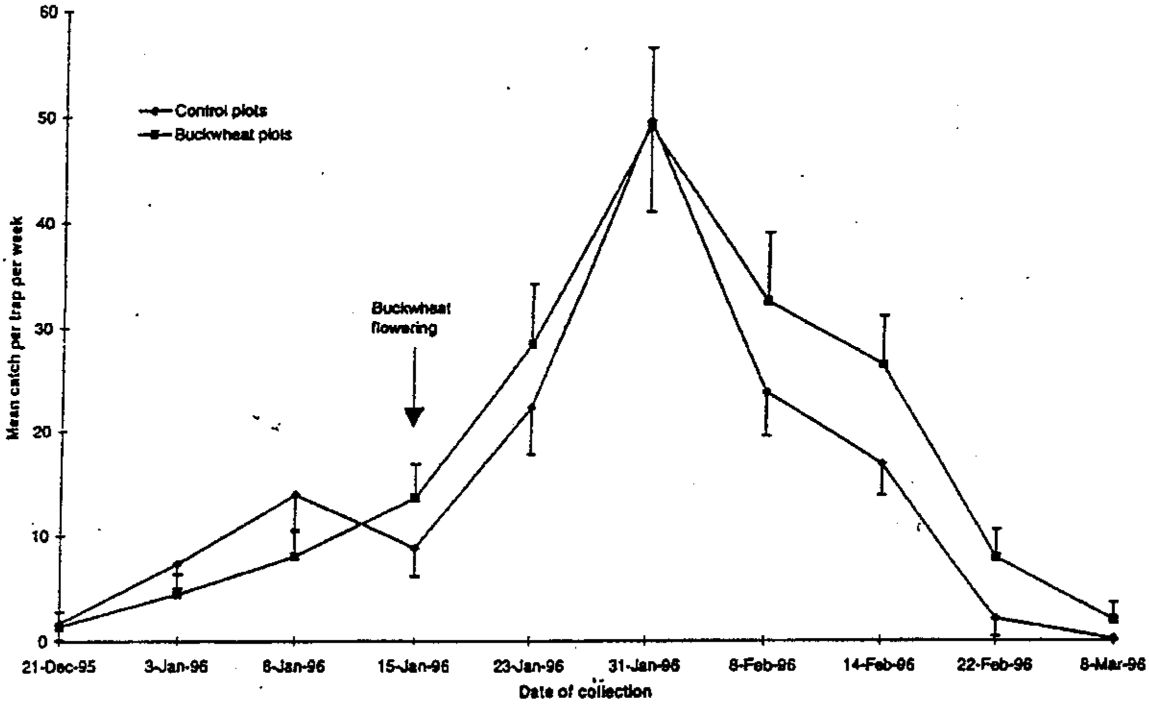


Table 3: The longevity of potato moth (*Phthorimaea operculella*) and its parasitoid *Copidosoma koehleri* when adults exposed to flowers of a range of plant species (Source: Baggen LR, Gurr GM. 1998. The influence of food on *Copidosoma koehleri*, and the use of flowering plants as a habitat management tool to enhance biological control of potato moth, *Phthorimaea operculella*. Biological Control. 11: 9-17.)

Flower provision*	**Adult longevity (days)#**	
	P. operculella	***C. koehleri***
Coriander	13.43a	9.84b
Borage	8.76b	11.96a
Control (water only)	7.76b	5.26c

* Examples only, > 7 treatments per experiment.
#Means within a column followed by differing letters are significantly different ($P = 0.05$)

Because of potential problems such as these, the promotion of habitat manipulation approaches which use a mixture of several plant species is of some concern. Bugg and Waddington (1994) detailed seven proprietary 'insectary seed mixes' for sale in California. It is unlikely that each of the plant species contained in these has been screened for potential negative effects, as described above, and pest damage could be exacerbated by their use. Though Boller (1992) showed that increasing floral diversity in European vineyards increases the numbers of natural enemy species, whilst numbers of pests remained relatively stable, this survey did not indicate the population levels of pests nor degree of pest damage. Diversity *per se* may, therefore, lead to unexpected and unwelcome results. We suggest that a more targeted approach to habitat manipulation is required if deleterious effects are to be avoided and the whole conservation biological control approach becomes discredited by the naive attempts. This demands that key pests and their natural enemies are intensively studied so that means are found to selectively favour the later by a manipulation of the habitat which is as inexpensive and agronomically tractable as possible. To achieve this it is important that more research is conducted on the mechanisms by which a selective benefit may be extended to key natural enemies. Potentially, pests may be prevented pests from feeding by mechanisms which include: repellency or lack of apparency of whole plants, inflorescence architecture which makes nectaries/anthers inaccessible, distasteful or non-nutritious nectar/pollen, and inflorescences which are closed at times when pests are active.

An additional scientific problem associated with research in this area is the 'replication versus plot size' issue (Brown 1989). The problem is well illustrated in the orchard-based work of Irvin (reviewed above) for it is possible that inter-plot interference would have exaggerated the treatment effects by the parasitoid being attracted from control plots to those where nectar was available. Conversely, the presence of plots of nectar-producing plants within the experimental area may have increased the local population of the parasitoid leading to catches which were higher than they otherwise would have been, even in the control plots. Resolving such issues will require that better techniques are developed for tracking the movement of small insects and that research programs include experiments which use a range of scales. The work by Baggen and Gurr, for example has used replicated small flight cage experiments in the laboratory, replicated large flight cage experiments in the field and small scale field trials in addition to evaluations in commercial crops. The former have utility in determining the mechanisms and extent of the benefit of a range of candidate treatments before moving to a larger scale to quantify the 'real world' benefits.

Addressing such scientific issues will also require that non-scientific issues are dealt with. The major problem of this type is that habitat manipulation is hampered by the relatively poor scope for recouping R&D investment under the protection of patents. The plants and planting patterns used in habitat manipulation are rarely 'owned' commercially. Because of this lack of ownership, commercial funding is more difficult to secure than for research into novel pesticides, resistant seed stock or even inundative biological control agents which are all more product-based. Funding by governments and not-for-profit organisations is a means by which some habitat manipulation work may be carried out, particularly if the short-term outcomes are embedded within an attempt to better understand the ecology of insect-plant and tri-trophic relationships. However the decline in publicly funded research and the growth of a user-pays philosophy in Australasia suggests that despite certain exceptions (see acknowledgement) other sources of funding may need to be explored. Growers' organisations such as ENZA (see above) or food companies with a clear commitment to low-pesticide, sustainable food production are possible sources and, in New Zealand, Heinz-Wattie are active in this area (Wratten *et al.*, unpub. data).

Conclusion

For classical biological control attempts against insects in which this was the sole control measure taken, a 'substantial success' rate of forty percent has been cited (Wagge and Greathead 1988). Often the released agents either do not establish or the efficacy/impact on the target pest is too low. How then to increase the success rate? Pre-release work in these cases is usually thorough in terms of quarantine, target specificity, and potential impact on the target, but the agents' requirements beyond those associated with its host/prey are rarely considered. Many agroecosystems have low botanical diversity and it seems that many future releases of biological control ag[illegible] will be doomed to failure unless the release is integrated with changed cropping management practices which enhance the survival and activity of the released agent. We view this interface of classical and conservation biological control as an important future area for research. Scope also exists to maximise the impact of inundative biological control by integrating it with conservation biological control methods such as providing nectiferous plants. For example, in Australia, biological control of lightbrown apple moth (*Epiphyas postvittana* Walker (Lepidoptera: Tortricidae)) by the parasitoid *Trichogramma carverae* Oatman and Pinto (Hymenoptera: Trichogrammatidae) is now being promoted. However, the lifespan of this agent is very short unless allowed to feed on nectar, sources of which are few in many vineyards because of herbicidal and mechanical weed control. Scope therefore exists to develop vineyard cover crops which will enhance the longevity of inundative biological control agents and thereby maximise the economic return on the outlay they constitute.

Integrated biological control, in which the agents' resource requirements are identified, carefully researched and then provided as part of the inoculative or inundative release strategy, need to be promoted. If this happens, then the separation of 'classical', 'inundative' and 'conservation' biological control will largely disappear. We suggest that this would be to the benefit of end users in Australasia and elsewhere. It would also benefit the discipline of biological control as more collaborative work rises above the reductionism of traditional methodological divisions and approaches the common task as one set within agroecosystems where an integrated or holistic approach is most likely to be successful.

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