Apion miniatum (Coleoptera: Apionidae) and the Control of Emex australis (Polygonaceae): Conflicts of Interest and Non Target Effects

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Abstract

The southern African plant, Emex australis Steinh., is a major weed of annual cropping systems across southern Australia. In Israel, larvae of Apion miniatum (Gyllenhal) develop in the stems, crown and roots, and the adults make small holes in leaves of E. spinosa (L.) Campd. The insect is considered a potential biological control agent for E. australis in Australia. Two contrasting conflicts of interest became apparent during host range tests and the application for release of this insect. First, the completion of host range tests depended on testing a possibly extinct species, Rumex drummondii Meissner. A survey lead to the re-discovery of the species and it was shown not to be threatened by the insect. The second issue became apparent during the review of the application to release the insect. Two native birds, Cacatua leadbeateri (Vigors) (Major Mitchell cockatoo), and Calyptorhynchus banksii samueli Mathews (inland subspecies of the red-tailed black cockatoo) eat the seeds of E. australis. The Major Mitchell cockatoo has a diverse diet of widely available plants and insects so it seems unlikely that lower densities of E. australis would affect this species. In contrast, populations of the red-tailed black cockatoo in grain growing regions feed almost exclusively on E. australis seed. The availability of water and E. australis seed due to farming activities has enabled the bird to spread south into grain growing regions where it had not previously been recorded. As it is a native species, legislation prohibits any threats to the bird throughout its distribution. Within the grain growing region, the birds consume only about 2% of the available surface seeds. Approval has been obtained for the release of Apion miniatum and future studies of the weed will include an assessment of any non-target impact on native Rumex species and cockatoo species.

Keywords: Emex australis, non target effects, host range tests, Apion miniatum, conflict of interest, Australia, annual crop systems

Sometimes opposition to using biological control against a weed can come from unexpected quarters, as in the following two examples. For many years the Australian Echium plantagineum L. (Boraginaceae) biological control project was delayed to enable a conflict of interest with beekeepers to be resolved (Cullen and Delfosse 1984). The use of saltcedar, Tamarix ramosissima Ledeb. for nesting sites by an endangered flycatcher
in USA is another example of conflict of interest that required resolution (Deloach et al. 1996). The assessment of potential indirect effects is now an important concern for all biological control projects.

Attempts to find biological control agents for use in Australia against the annual weed, _Emex australis_ Steinh. (Polygonaceae) (doublegee), have been ongoing since the 1950s. This southern African plant is a weed of cropping systems and pastures across southern Australia, in particular the northern grain producing region of Western Australia (WA) (Gilbey and Weiss 1980) (Figure 1). It has been estimated that 1.38 million ha in WA are heavily infested which costs agriculture $40 million per year. _E. australis_ has a long-lived seed bank and germination occurs from autumn to early winter (March to June). The rosette develops a strong taproot. Stems have indeterminate growth, producing spiny achenes at stem nodes. The plants senesce in October - November when the rains cease. Farming practices, rain fed agriculture with crop - pasture rotations, strongly favor the survival of the weed, and the persistence of the weed problem in agriculture has led to biological control being considered.

Apart from its reported use as a vegetable during the previous century (Gilbey and Weiss 1980), there appeared to be no conflicts of interest with the use of biological control against _E. australis_. _Emex_ species have no agricultural or ornamental uses and there are no native _Emex_ in Australia. Further more, within the same family (Polygonaceae), there are only two plant species of any economic value, rhubarb, _Rheum rhabarbrum_ L. and buckwheat, _Fagopyrum esculentum_ Moench. In the most closely related genus (_Rumex_), there are only seven native species (Rechinger 1984). Recent research on the biological control of _E. australis_ has focused on using _Emex_-specific insects from the native range of _E. spinosa_, a weed found in Australia of Mediterranean origins. This paper examines two conflicts of interest and possible non-target effects which arose during this work: the need to test a possibly extinct _Rumex_ species and the possible indirect effects that control of _E. australis_ would have on cockatoo species.

**Biological control program**

Surveys in Israel in 1988 (Scott unpublished) showed that the apionid weevil _Apion miniatum_ Germar (Coleoptera: Apionidae) was damaging on _E. spinosa_. The larvae of _A. miniatum_ develop in the stems, crown and roots, and the adults make small holes in leaves of _E. spinosa_. This insect was tested for host specificity during 1995 to 1997 then an application was made for its release. During the early part of this work we identified a potential conflict of interest that was not apparent in the earlier studies of potential biological control agents for _Emex_ species - that is, the need to include in host range tests, a possibly extinct native plant, _Rumex drummondii_ Meissner. This plant had not been collected for nearly 50 years and consequently it could be classified as a rare and endangered species under the WA legislation (Anon. 1993). However, as this species does not have showy flowers or other attributes attractive to the general plant collector, it could be reasonably argued that insufficient effort had been made to find the plant.

A systematic search was organized (Scott and Yeoh 1995) and the plant was eventually found in south west Australia to be locally abundant in highly disturbed habitats, including farmland. We were thus able to proceed with host range tests. The native _Rumex_, including _R. drummondii_, have crowns and roots that are too hard for the larvae to penetrate. We concluded that the native species are not suitable hosts (Scott and Yeoh unpublished) and that _A. miniatum_ would be safe for release in Australia.
Application made for the release of Apion miniatum

We applied to the Australian Quarantine and Inspection Service (AQIS) for a permit to release the insect. In this process, AQIS consults Federal and State Departments of Agriculture and the Environment (some 21 reviewers). We thought this would be a straightforward process. However approval of the release was delayed until we could give assurances that the introduction of the weevil would not endanger two native bird species in Western Australia, the Major Mitchell or pink cockatoo, (*Cacatua leadbeateri* (Vigors)) and the inland subspecies of the red-tailed black cockatoo (*Calyptorhynchus banksii samueli* Mathews). These birds include seeds of *E. australis* in their diet and a reduction of the abundance of the weed was seen as potentially threatening their populations. The cockatoos are protected under the Wildlife Conservation act (1950). The same Act stipulates that exotic animals cannot be released without a license issued by the WA Department of Conservation and Land Management. This is the first time that this procedure has been invoked.

**Major Mitchell cockatoo**

The Major Mitchell cockatoo is very widespread in Australia (Figure 2) with a distribution that is “locally common but generally scarce” (Storr 1967). The birds eat at least 28 different plant species in the WA grain growing region where *E. australis* density is high. Their diet includes a wide range of native vegetation, agricultural crops and their accompanying weeds together with insect larvae extracted from the stems of native trees and shrubs (Rowley and Chapman 1991, Johnstone and Storr 1998). Wheat, *Triticum aestivum*, doublegee, *E. australis* and pie-melons, *Citrullus lanatus*, were the three main foods eaten at all times of the year in various stages of ripeness (Rowley and Chapman 1991). Winter was the time when food was scarcest and cockatoos, including Major Mitchells, foraged on stubble for a range of seeds, including *E. australis*. There is no reference to Major Mitchell cockatoos being dependent on the availability of *E. australis* seed.

**Potential impact of biological control on the Major Mitchell cockatoo**

The Australian distributions of *E. australis* and the cockatoo overlap only in the northern grain growing region of WA: the bird is mainly found in desert regions (central Australia) whereas *E. australis* has a southern Australian, mainly Mediterranean climate, distribution (Figures 1 and 2 insert). Saunders *et al.* (1986) show that the distribution of the Major Mitchell cockatoo has retracted inland within the WA grain growing region. However this region may represent a marginal habitat for the bird (Rowley and Chapman 1991). “The areas that have been cleared for wheat farming were the outer, wetter margins of *C. leadbeateri* distribution and, as such, it was habitat probably not best suited to the species even before clearing took place” (Rowley and Chapman 1991, p. 253). Thus it appears that the bird is mostly found across Australia in areas where the weed is absent or in low abundance. Evidently, the Major Mitchell cockatoo does not consume *E. australis* seed over most of the bird’s Australian distribution.

A characteristic of the biology of Major Mitchell cockatoos is that nesting pairs are widely spaced being separated by one to two kilometers, which prevents the birds from forming dense populations (at least 100 ha per pair). Major Mitchell cockatoos have specific nest site requirements (Rowley and Chapman 1991), but there appear to be adequate nest sites available (Saunders *et al.* 1982). Thus it appears that the density and reproduc-
tive success in the grain growing region is largely determined by the territorial behavior of the birds, a behavior likely to be more adapted in inland regions where native food may be in short supply compared to the WA grain growing region. Rowley and Chapman (1991, p. 241) state: “We feel that the spaced-out nesting locations are probably behavior remaining from pre-agricultural days, when the provisioning of nestlings would have depended upon the parent’s ability to forage from native plants near to the nest. Such plants tend to have relatively small crops and sparse distribution, so that a feeding territory around the nest could have been important”. Thus population numbers of Major Mitchell cockatoos in the grain growing region is largely a function of the effects of land clearing as birds displaced from nesting sites are unlikely to find another nest site nearby (Saunders et al. 1982). The wide range of food eaten and the large territories occupied by
nesting pairs of Major Mitchell cockatoo makes it very unlikely that the bird would be affected even by complete removal of *E. australis*.

**Red-tailed black cockatoo**

In Western Australia there are three subspecies of red-tailed black cockatoos. Only the subspecies *Calyptorhynchus banksii samueli*, the inland red-tail, was identified as a potentially threatened species because only this subspecies eats *E. australis* seeds (Johnstone and Storr 1998). The other subspecies are 1) *Calyptorhynchus banksii naso* Gould, the forest red-tail, which is found in the forested regions of south west Australia and eats seed of *Eucalyptus*, *Allocasuarina* and *Persoonia*, species native to this region (Saunders and Ingram 1995, Johnstone and Storr 1998) and 2) *Calyptorhynchus banksii macrorhynchus* Gould, the tropical red-tail, found in the Kimberleys (northern Western Australia) and Northern Territory (Ford 1980) which eats a wide range of native seeds (Johnstone and Storr 1998) (figure 3).

**Distribution of inland red-tailed black cockatoos**

Ford (1980) gives the most detailed distribution of inland red-tailed black cockatoos in WA. He originally described them as occurring from Narembeen in the south to Minilya River in the North. This area encompasses the northern part of the grain growing region and the pastoral country 200 km north of this region (Figure 3), Ford (1987) later included an additional population of red-tailed black cockatoo in the inland subspecies so that the current known distribution now extends over a considerable area of WA (figure 3). Johnstone and Storr (1998) also note that it is found in arid and semi-arid interior of eastern Australia, including populations found in central Australia, south-western Queensland and western New South Wales.

Ford (1980) states that before European colonization, the population of inland red-tailed black cockatoo in WA probably occurred no farther south than the Irwin River. The provision of water on farms has lead to its expansion southwards into the grain producing regions (Figure 3). The birds are able to move great distances, tagged birds having been

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**Fig. 3.** Distribution of red-tailed black cockatoos in Australia. The map is taken from Ford (1980). The distribution of the inland red-tailed black cockatoo incorporates Ford (1980 and 1987). The range extension south is based on Ford (1980).
sighted up to 150 km from their breeding area (CSIRO Division of Wildlife Research 1980). In the pastoral region of central WA the birds are associated with riverine woodland and mulga shrublands on wash plains (Saunders and Curry 1990). In the agricultural regions the bird is associated with eucalyptus woodlands, acacia scrub and farmlands (Saunders and Curry 1990, Johnstone and Storr 1998).

**Food of inland red-tailed black cockatoos**

Native vegetation is the dominant plant life form over at least the northern two thirds of the WA distribution of the inland red-tailed black cockatoo (Figure 3). Unfortunately, there are few observations of the native food of this bird. Seeding *Banskia* and *Grevillea* species are cited as a food source in Johnstone and Storr (1998) and based on the morphology of the birds bill, Ford (1980) presumes that in the absence of *Emex*, the inland red-tailed black cockatoo feed on small fruits of other plants such as acacias, grevillea and native grasses. Rowley *et al.* (1989) state: “The red-tailed black cockatoo with its large bill is a very versatile species. In its pristine environment this bird feeds extensively on several native species some of which produce seeds with hard spiny cases, such as *Sclerolaema* spp. With the advent of agriculture and its accompanying weeds, red-tails have turned their attention to the invasive emex and appear to exist on an almost exclusive diet of this.”

This explanation seems reasonable. Fruits of *Sclerolaema* spp. (Chenopodiaceae), bear a strong resemblance to the achenes of *Emex* species. Many *Sclerolaema* species are found in pastoral areas within the distribution of the inland red-tailed black cockatoo (Wilson 1984). Thus the bird would have been pre-adapted to manipulating and efficiently opening hard, dry spiny fruits. *E. australis* fruits and seed are larger than those of *Sclerolaema* species and consequently the birds may find them strongly attractive.

The only detailed published data on feeding by inland red-tailed black cockatoo is from agricultural regions and is reported in Saunders *et al.* (1986): “Of 237 observations of feeding flocks, 219 were seen feeding on doublegee. The remainder were seen on other agricultural weeds (*Saffron Thistle, Carthamus lanatus* 2: wild radish, *Rhapanus raphanistrum* 1; wild melon 5; native vegetation (*Acacia acuminata* 1; *A. costata* 1; *Grevillea paniculata* 4; *Hakea recurva* 2); and insect larvae (2). Analysis of the crop contents of 16 dead birds from the same region showed the same dependence on doublegee. All 16 contained doublegee seed and there was wild radish seed in one and wild turnip, *Brassica tournefortii*, in another.”

**Potential impact of biological control on the inland subspecies of red-tailed black cockatoo**

The apparent dependence of the inland subspecies of the red-tailed black cockatoo on seed of *E. australis* presents a far more serious question for biological control than that of the Major Mitchell cockatoo. It is only in the southern extension of its range that native vegetation has largely been removed and where alternative food might be in short supply. It is therefore only in this region that the potential impact of the biological control of *Emex australis* on the inland subspecies of red-tailed black cockatoo needs be addressed.

**Amount of seed eaten**

Inland red-tailed black cockatoo are remarkably efficient at extracting seed from the spiny fruit of *E. australis*. Each bird requires no more than 3500 seeds per day (Saunders et al. 1986).
et al. 1986) (this implies they consume 70 g dry weight of seed per day (approximately 20 mg dry weight per seed based on Scott and Shivas (1998)) and consume 1,277,500 seeds per year). Adult birds weigh 565 - 730 g (Johnstone and Storr 1998). The birds eat both fresh and dry seed, which means that they can consume seed all year round whereas the plant produces seed only in winter and spring.

It is difficult to estimate the average population density of the inland red-tailed black cockatoo within the grain producing region, the average foraging area of individual birds and the minimum area requirement to feed a bird. The birds are reported as being uncommon to common “south of the mulga-eucalyptus line” and most plentiful in the northern and north-eastern grain growing region (Johnstone and Storr 1998). They feed in flocks of 100 to 250 birds and flocks of over 2,000 birds have been observed (Saunders 1977). In a 15 ha plot containing native trees with hollows suitable for nest sites, the cockatoos used 16 tree hollows as nest sites (Saunders et al. 1982). Nesting adults do not appear to be territorial, apart from at the nest site and there appeared to be adequate nest sites available. It is estimated that 94% of the native vegetation has been cleared from this region (Saunders and Rebeira 1991) so the 15 ha plot represents a typical small island of suitable nesting trees. Tentatively, these areas imply that each nesting bird requires at least 6 - 7 ha. (15 ha = 7% of area occupied by 16x2 birds, without population increase). In reality, the area available for each bird would be more because not all the native vegetation would contain suitable nest hollows.

As with any plant population, the seed population of *E. australis* is highly variable (Table 1). An assumption of 1000 seeds per m² produced each year, based on the observations in Table 1, equates to 10 million seeds per ha whereas one bird requires 1.3 million seeds per year. At a density of one bird per 6 ha this implies that the birds consume about 2% of available seed.

Scott and Shivas (1998) examined the effect of fungicides and pesticides on seed production in *E. australis*. The objective was to determine the background level of seed reduction due to biotic means before the introduction of biological control agents. The 0.5 x 1.0 m plots were weeded to remove competition from other plant species. Consequently the number of seed (up to 17,460 m⁻²) was exceptionally high and possibly attractive to cockatoos since the plots at harvest contained fruits damaged in the manner characteristic of cockatoos. The species involved is unknown, although inland red-tail black cockatoos were observed in the region during the study period. Because the birds extract seeds from the fruit which is discarded, it was possible to estimate the percentage of seed eaten by collecting all the current season fruits in a plot (Figure 4). The number of seeds consumed ranged from zero to almost 40% per plot. There did not appear to be a relationship with seed density and the feeding was highly patchy with the overall yearly percentage of fresh seeds consumed being 5.4%.

**Breeding by the inland red-tailed black cockatoo**

One potentially negative impact on cockatoo reproduction and hence density may come from the use of *E. australis* as the sole source of food. Inland red-tailed black cockatoos breed in spring and much less frequently in autumn, in contrast to other cockatoos which only breed in spring (Saunders 1977). The availability of *E. australis* seed may enable the birds to breed twice (Smith and Saunders 1986). In spring, the eggs are laid from August through to early October and the fledglings leave the nest in late November through to late January (Smith and Saunders 1986). When the fledglings leave the nest
there are abundant fresh, dry seed available. However, the published records of breeding in inland red-tailed black cockatoo are from the southern edge of its range and maybe sub-optimal for climatic and other reasons (Smith and Saunders 1986, Saunders et al. 1986).

**Quality of *E. australis* seed**

Inland red-tailed black cockatoo has low hatching success and the lowest productivity (0.3) of cockatoo species in the northern grain growing region (Smith and Saunders 1986). The reasons for this high infertility and nestling mortality are unknown, but a possibility is that toxins within *E. australis* seed may be responsible (Smith and Saunders 1986, Saunders et al. 1986).

Extensive surveys on both *E. australis* and *E. spinosa* in North and South Africa and

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**Table 1.**

The number of *Emex australis* seeds recorded in various studies in Western Australia.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Density m⁻²</th>
<th>Location and Year</th>
<th>Literature source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viable seeds at start of growing season</td>
<td>1245 ± 130 (SE)</td>
<td>Wongan Hills</td>
<td>Panetta and Randall 1993a</td>
</tr>
<tr>
<td>Seeds produced in a first year of pasture following a crop</td>
<td>5500</td>
<td></td>
<td>Gilbey and Lightfoot 1979</td>
</tr>
<tr>
<td>Seed production in controls</td>
<td>2808, 2389, 1543</td>
<td>Wongan Hills, 1988, 1989, 1990</td>
<td>Panetta and Randall 1993b</td>
</tr>
<tr>
<td>Seed production in herbicide treated plots</td>
<td>3549 to 426</td>
<td>Wongan Hills, 1988, 1989, 1990</td>
<td>Panetta and Randall 1993b</td>
</tr>
<tr>
<td>Seeds in soil after pasture</td>
<td>2373</td>
<td>Avondale RS</td>
<td>Gilbey 1977</td>
</tr>
<tr>
<td>Seeds in soil after pasture</td>
<td>1062</td>
<td>Wongan Hills RS</td>
<td>Gilbey 1977</td>
</tr>
<tr>
<td>Seeds in soil after pasture</td>
<td>1431</td>
<td>Chapman RS</td>
<td>Gilbey 1977</td>
</tr>
<tr>
<td>Seeds after crop</td>
<td>94</td>
<td>Avondale RS</td>
<td>Gilbey 1977</td>
</tr>
<tr>
<td>Seeds after crop</td>
<td>433</td>
<td>Wongan Hills RS</td>
<td>Gilbey 1977</td>
</tr>
<tr>
<td>Seeds after crop</td>
<td>261</td>
<td>Chapman RS</td>
<td>Gilbey 1977</td>
</tr>
<tr>
<td>From soil following a year of pasture</td>
<td>up to 10,000</td>
<td>Wongan Hills RS</td>
<td>Gilbey 1996</td>
</tr>
<tr>
<td>Fungicide and pesticide treated plots</td>
<td>up to 17,460</td>
<td>Watheroo 1992</td>
<td>Scott and Shivas 1998</td>
</tr>
</tbody>
</table>
the Middle East have failed to find insects that attack the seed (Scott and Way 1990, Scott and Sagliocco unpublished). In South Africa, no birds utilize the seed within the achene, although there are many seed feeding birds in the region (finches, sparrows, weavers, widowbirds, bishopbirds, firefinches, waxbills, mannikin, whydahs, widowfinches, canaries and buntings). Parrots are absent in the Western Cape, the main E. australis area (Newman 1983). Ostriches will however eat the achene whole. Thus in its natural distribution E. australis is an unexploited food source for birds or invertebrates, for unknown reasons.

The seed has never been analyzed for its chemical constituents so it is not known if there are toxic chemicals involved. A similar sized seed from the closely related buckwheat (Fagopyrum esculentum) is eaten by humans. If large amounts are eaten, buckwheat poisoning, or fagopyrism, a photo-sensitization disease can develop (De Jong 1972).

Up to 30% of E. australis seeds in WA are infested with the host-specific fungus Phomopsis emicis (Shivas and Scott 1994, Shivas et al. 1994b). The fungus was considered for use as a mycoherbicide until it was found to produce Phomopsin A, a powerful mammalian poison (Shivas et al. 1994a). The effect on birds is unknown, however the fungus is very widespread on E. australis (Shivas et al. 1994b) and birds solely eating E. australis seed would come in contact with the fungus. Thus it is possible that quality of E. australis seed, in particular toxins, could be affecting reproduction in the inland red-tailed black cockatoo.

**Population regulation of the inland red-tailed black cockatoo**

Populations of inland red-tailed black cockatoo do not appear to be regulated by the availability of E. australis seed, which is extremely abundant. Saunders et al. (1982) maintain that the availability of tree hollows for nesting sites is unlikely to be limiting, as only about half the potential nesting sites were used at their study site. Water is unlikely to be limiting since it is now readily available in agricultural areas. Many factors, both biological and inorganic are involved in the regulation of populations so it is difficult to
identify a single factor. In addition, the bird in the grain growing region is at the southern edge of its natural range, where habitats are likely to be sub-optimal. The only factor identified so far that could be involved in population regulation is the quality of the food, as pointed out by Smith and Saunders (1986) and Saunders et al. (1986).

**Release of Apion miniatum authorized**

Saunders and Ingram (1995) state that “control of doublegee will see the loss of this bird from those areas it has invaded”. However, biological control does not work if the plant is completely removed - the biological control agent needs the plant present for future generations. The main distribution of the inland red-tailed black cockatoo is in the central WA pastoral country where *E. australis* is at low densities and where the agent is unlikely to survive. The overlap of the bird’s distribution with areas of dense *E. australis* only occurs in agricultural regions. This overlap has developed in the recent (150 years) extension of the birds’ original range.

A central issue to the cockatoo question was to know the impact of *A. miniatum* on seed production. However, studies of the impact are not possible since this is a “new association”, the insect being from Israel and the weed from southern Africa.

The principal strategy of the current biological control project against *E. australis* is to provide stress on the plant so that seed dormancy is reduced (Scott and Yeoh 1996). It is recognized that it will be very difficult to significantly reduce seed abundance by biological control means although it is hoped that this will occur. The plant is ephemeral with a long lived seed bank that responds to high levels of ecosystem disturbance, all factors making biological control with insects difficult. Seed dormancy in *E. australis* appears related to the degree of stress experienced by the plant as it is growing. High levels of stress causing reduced growth, leads to reduced seed dormancy, but not necessarily less seed. Reduced dormancy means that the farmer can manage *E. australis* infestations more readily, by spraying during the crop phase of the pasture/crop rotation. It is foreseen that biological control will work in an integrated setting, but possibly not by itself. Thus, in non agricultural situations and non managed farmlands, it is likely that *E. australis* populations will not be reduced by biological control to the same degree as in managed farmland.

The conservation authorities accepted the above arguments and authorization to release the insect was obtained in late 1996. While Western Australia, like other Australian States, has an Act of parliament, which regulates biological control (Biological Control Act 1986, see Cullen and Delfosse 1984 for an example of the legislation), recourse to the Act was not required in this situation.

**Releases of *Apion miniatum*: current situation**

Only a limited number of field releases (6) of *A. miniatum* were made in Australia last year. Although the insects breed well during the season (up to 50 times increase in population size), the initial numbers of insects released (2 insect pairs/m² and 32 pairs/site) were not high enough to inflict any measurable impact on seed production (an overall average of 3300 seeds/m² produced).

However studies in the laboratory in Perth where different densities of insects were released onto 16 caged doublegee plants have given encouraging results. At the highest density (16 pairs of insects) seeding was reduced by 34% on average compared with caged plants with no added insects.
Large numbers of *A. miniatum* were mass reared in field cages during the past year so that much larger field releases have been made this year (up to 2000 insects/site). It is anticipated that, with high release numbers, an impact on seed production will be detectable during the current season.

**Further research**  
More information is needed on the native foods of the cockatoo and the behavior of the bird in throughout its range. It will be important to assess the toxicity of the seed of *E. australis*. Monitoring of the amount of seed eaten by the cockatoos before and during the biological control project should be included as part of the assessment process. Research directed towards the conservation of the inland subspecies will, if it results in an increase in cockatoo populations, help the overall objective of biological control, since the birds also contribute to seed destruction.

**Conclusion**  
The review process in Australia is effective in allowing a thorough coverage of all possible impacts of a biological control release. Apparently no other bird species are associated with *E. australis*. It is in the interests of biological control to keep the red-tailed black cockatoo as part of the grain growing region environment. Perhaps the planting of native species, *Sclerolaema* spp. or others that are suitable native food will diversify the diet and improve the breeding of the cockatoo. Provision of nest sites might be another strategy. However more information is needed on the bird in its native habitat. Clearly a reduction in *E. australis* density will not threaten the survival of the inland red-tailed black cockatoo. In the southern part of the range of the inland red-tailed black cockatoo population numbers are not currently limited by the abundance of *E. australis* seed, but something else, possibly the quality of seed. Reduction in *E. australis* numbers by biological control could favor the populations of the inland red-tailed black cockatoo by encouraging diversification of food intake and reducing pesticide use on farms. Biological control will have a greater or lesser impact on the weed, depending on the situation. It is likely that this variation will ensure that the inland red-tailed black cockatoo will continue to feed on *E. australis* seed and, in part, contribute to the control desired for this important agricultural weed. The use of a “new association” made it impossible to have any measurements of the impact of the insect on the plant in its natural habitat. With the current concern over non target effects, this presents a serious constraint that needs consideration in biological control projects.

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**References**  


