EFFECTIVENESS OF *RHINOCYLLUS CONICUS* AS A BIOLOGICAL CONTROL AGENT FOR NODDING THISTLE, *CARDUUS NUTANS*, IN AUSTRALIA

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Summary. Data are presented from Glencoe, NSW, on the phenology of flowering of nodding thistle, *Carduus nutans*, and the effectiveness of the biocontrol agent, *Rhinocyllus conicus*. The period of activity of the weevil is restricted to the first two months of the plant's flowering period, which often extends for a further three months. A reduction of seeding by 37.5% was recorded in 1991-1992. Although the activity of this weevil will help to reduce the high seed bank levels found in Australia, it seems unlikely that *R. conicus* on its own will control nodding thistle in Australia.

INTRODUCTION

Nodding thistle, *Carduus nutans*, naturally occurs in Europe, Siberia, Asia Minor and North Africa. It has become a weed in North and South America, New Zealand and Australia. Here it is a noxious weed that is widely distributed in the tableland regions of NSW, and sporadically present in elevated regions of southern Queensland, Victoria and Tasmania. Single infestations have been eradicated from South and Western Australia. Biological control of nodding thistle has been undertaken in Canada, USA, Argentina and New Zealand using the receptacle weevil, *Rhinocyllus conicus*, from the mid 1960's onwards (2). Releases of this weevil were first made in Australia in 1988 in the northern, central and southern tablelands of NSW, where the weevil is now established (11). This paper discusses seed destruction attributed to this weevil at Glencoe, NSW, and the effectiveness of the weevil in relation to the phenology of the thistle.

Biology of the weevil. The adult weevil is about 6 mm long, and emerges from diapause in mid spring, when it starts to feed on nodding thistle rosette leaves. Damage from this feeding is minimal. The female lays eggs on the first green flower buds (greens), which are usually heavily overloaded with eggs, such that although seed set is low, not many larvae survive to adulthood, due to overcrowding. The eggs are laid on the bracts surrounding the capitulum. Upon hatching the larvae burrow down into the receptacle, which they proceed to mine and prevent seed in the area above the damage from developing. Late instar larvae construct hard, black pupation cells inside the receptacle. The adult weevil emerges between 5-7 weeks after the eggs are laid, and seeks overwintering sites in the leaf litter. There is only one main generation a year. However, a very small proportion of the first adults to develop in the summer produce a second generation. Each female lays about 200 eggs, over a 6-8 week period (3).

Biology of the thistle. Nodding thistle biology has recently been reviewed by Popay and Medd (6). Only a brief outline is presented here with emphasis on the relevant aspects for biocontrol purposes. The seed bank in Australia can be as high as 12000/m^2, with the annual seed rain as high as 40000/m^2 (Woodburn and Cullen, unpublished data). In Europe the seed bank is very low, less than 60/m^2, with a seed rain of less than 250/m^2 (4). Seedlings quickly form prostrate rosettes, that can grow to over a meter in diameter. After vernalisation terminal capitula are formed, firstly on the main stem, and successively on the lower branches. The plant dies when seeding has finished.

METHODS

Assessment of seed rain. An unfenced experimental plot (25x25 m) was established at Glencoe in 1988 at the time of release of the weevil, in which ten randomly placed 0.25 m^2 permanent quadrats were positioned. In spring of each year the number of plants likely to flower was counted, and if more than 20 such plants were present, flowering data were recorded from them. In years when the number of flowering plants was low on the quadrats, or the quadrats were not characteristic of the plot as a whole, an area of the plot was randomly chosen, and its size increased until the number of flowering plants was sufficient to represent the plot as a whole.

Every fortnight throughout the season the diameter of each flowering capitulum on each plant selected as described above was recorded. The flowering stage was chosen because previous work on plant phenology had shown that 1): the flowering period of each capitulum was less than a fortnight, and hence it would only be measured once, and 2): the proportion of capitula passing from buds to matures during this interval is known, and hence a correction can be made for it (Woodburn and Cullen, unpublished data). A relationship between capitulum diameter of the flowering stage and seed production (Woodburn and Cullen, unpublished data) was used to predict the expected number of seed in each capitulum, and hence the expected seed rain/m^2 for each fortnight and cumulatively for each season.

Assessment of weevil damage. Samples of 50 randomly collected capitula, that had stopped producing flowers but had not started to shed seed, were collected at the same fortnightly intervals as above. At the beginning and end of the season when capitula were scarce, the area sampled was several hectares, but for most of the season the collection was made over less than a hectare. In the laboratory, the diameter of each capitula was measured, and counts were made of the numbers of eggs, larvae, pupae and/or adult weevils present. The number of mature seed set was also recorded. A modified relationship between the mature capitulum diameter and seed production was used to predict the expected number of seed in each capitulum. The effect of the weevil for each infested capitula was calculated as the difference between the observed and expected seed total. The impact in each sampling period was calculated from the proportion of heads attacked, and seeds destroyed, in each sample. These values were used to scale the expected seed rain/m^2, obtained from the fortnightly measurement of flowering capitula on the experimental plots, to produce the actual seed rain.

RESULTS AND DISCUSSION

R. conicus became established at Glencoe during the first year, 1988-89, and successfully overwintered (11), but numbers were not large enough for any impact on seed production to be assessed during 1989-90. The thistle population was monitored, however, and the results concerning the reproductive effort are presented in Table 1. Although the first formed capitula were the largest and therefore produced the most seed, these heads contribute very little to the overall seed rain, the bulk of which comes from large numbers of medium sized heads produced in mid season (Table 1).

In 1990-91 *R. conicus* attacked over 70% of the first heads produced in late November and early December (Table 2), averaging 19.4 and 8.1 eggs/attacked head respectively. The number of heads attacked dropped markedly from then, as did the number of eggs/head, until late in the season when there is evidence of the activity of a second generation. The reduction in seed set from the random samples was considerable in those heads attacked in November (73.5%) and moderate in those from April (21.4%). These peaks of activity, which represent the tail ends of the distribution of the production of capitula, had no impact on the estimated seasonal reduction in seed rain (16%), since none of the very small number of flowers present at these times occurred contributing to the density estimates of seeds/m^2 for the site.

Table 1. Phenology of flowering of nodding thistle at Glencoe, NSW during 1989-90

Date	22.11.89	13.12.89	27.12.89	9.1.90	30.1.90	7.2.90	21.2.90	7.3.90	Sum
Mean size of capitula ± s.e.	35	28 ± 1.3	24.5 ± 0.6	19.4 ± 0.4	15.4 ± 0.5	13.7 ± 0.4	14.8 ± 1.2	17.4 ± 0.6	
No. of capitula/m^2	0.6	3.4	10.9	24	16	6.9	5.1	7.4	74.3
No. of seed/m^2	309.9	1246.4	3101	4585.8	2104.3	741.3	646.3	1286.9	14021.9

Table 2. Proportion of capitula attacked by *R. conicus* at Glencoe, NSW during 1990-91

Date	22.11.90	12.12.90	24.12.91	4.1.91	18.1.91	29.1.91	12.2.91	26.2.91	12.3.91	3.4.91
Proportion attacked	0.71	0.77	0.13	n/a[a]	0.04	0.06	0.04	0.12	0.1	0.22

[a] no sample taken.

In the following season, 1991-92, *R. conicus* activity commenced in early November and continued until May, although flowering on the experimental plot did not commence until mid December and ceased in mid April (Table 3). For nearly 2 months at the beginning of the season the majority of all capitula were attacked, and most of the seeds were destroyed. As in the previous year, the seed destruction documented in the first two samples had little impact on the estimated overall seed rain as they formed an insignificant proportion. There was only slight evidence of the activity of a second generation at the end of the season. This can be attributed to low larval survival in samples collected before the end of December. From then on numbers of eggs/infested head dropped to a level where survival from egg to adult approached expected levels of around 50%. The overall effect of *R. conicus* activity for 1991-92 was a reduction of 35.7% in the total seed rain.

Table 3. Pattern of capitula disTribution, *R. conicus* !ctivity and seed destruction at Glencoe, NSW during 1991-92.

Date (d.m)	5.11	30.11	10.12	17.12	31.12	14.1	28.1	11.2	7.3	24.3	12.4	16.5
no. heads/m^2[a]			0.03	0.16	0.47	1.22	1.28	0.75	0.50	1.22	0.25	
prop of sample inf.[b]	1.0	1.0	1.0	1.0	0.98	0.35	0.44	0.11	0.02	0.02	0.0	0.02
eggs/inf. head	108.1	77.5	77.6	47.8	18.3	25.9	26.2	3.6	2.0	1.0	0.0	1.0
prop. seed destroyed	1.0	1.0	1.0	0.98	0.98	0.48	0.26	0.06	0.01	0.003	0.0	0.005
actual seed set/m^2			0	1.5	3.0	165.2	229.0	138.9	79.5	176.7	26.4	
expected seed set/m^2			9.9	65.5	143.0	318.8	307.5	148.0	80.1	177.3	26.4	

[a] includes only capitula flowering on the experimental plot
[b] prop. = proportion, inf. = infested

The maximum level of seed loss recorded in Canada, 15 years after release of the weevil, was 50% (3). This was sufficient to control nodding thistle populations (3). In New Zealand, after a similar time lapse, the maximum level recorded was 40%, which was insufficient to control the thistle (4). Although the data reported here were collected only 3-4 years after release, it is unlikely that the level of reduction will continue to rise substantially. There are already high levels of attack and large numbers of insects/head resulting in nigh on total seed destruction for most of the period over which the weevil is active. The peak of capitulum production, however, escapes attack (Table 3). Nodding thistle in Australia and New Zealand grows more vigorously than it does in the northern hemisphere, which is in part a reflection of the longer growing season in the southern hemisphere. In 1988-89 plants at Glencoe produced an average of 14.2 capitula (range 1-60) over a 4 month period; at Kybeyan, NSW, 23.3 capitula were produced (range 1-87) over a 5 month period (Woodburn and Cullen, unpublished data). In Europe, plants averaged 6.4 capitula (4) over a 3 month period (A.W. Sheppard, unpublished data), and in Virginia, USA, the average number of green bud stage was estimated at 7.0, also over a three month period (5). In Europe attack by the weevil is restricted to the first two of the three month long flowering period, during which time 90% of the annual seed rain is produced (A.W. Sheppard, unpublished data), with a similar situation occurring in North America (5). In Australia the activity of the weevil is restricted to the first portion of the reproductive stage of the thistle, with the bulk of seeding occurring after weevil activity has ceased (Table 3). Although *R. conicus* has an impact on seed reduction, and will help to decrease the very high level of seeds in the seed bank (11) when compared to levels in European banks (7), it seems most unlikely that it will achieve control of nodding thistle here on its own. In order to augment the seed destruction already caused by the weevil, the seed fly, *Urophora solstitialis*, was released in 1991 (9). This fly, which due to its ability to undergo a second generation is potentially capable of reducing seeding in all capitula produced, is now established (10).

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