



The effects of mowing and of spraying musk thistle on the biological control agent *Rhinocyllus conicus*
by Timothy John Miller

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in Agronomy

Montana State University

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Abstract:

Rhinocyllus conicus (Froelich), a phytophagous insect which feeds on musk thistle (*Carduus nutans* L.), has become established in the Gallatin Valley, Gallatin County, Montana. This study evaluates the effects of mowing and of spraying musk thistle on the weevil. Study sites, which contained four mowing treatments, four spray treatments and one control were established at Belgrade, Montana in 1976 and 1977 on field populations of musk thistle. Seedlings, rosettes and flowering musk thistle plants were sampled at various times in 1976 and 1977 and musk thistle seed heads were covered and evaluated for weevil survival and seed production. Spraying with 2,4-D amine May 10 or October 10 when musk thistle was in the seedling-rosette stage, eliminated all flowering plants. Spraying June 15 when musk thistle was in the bud stage reduced seed production to 2.7 seeds per head. Spraying July 1, July 15 or August 1 did not significantly reduce musk thistle seeds per head. Spray treatments at any date did not severely reduce *R. conicus* survival, however spraying in the spring or late fall was best because weevils were not in musk thistle flower heads at that time. Mowing was not found to be a good supplemental control because most weevils are killed as a result of the mowing, plants mowed early in the season grow back and mowing has a tendency to enhance seedling survival due to reduced plant competition.

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TABLE OF CONTENTS

	<u>Page</u>
VITA	ii
ACKNOWLEDGMENTS	iii
LIST OF TABLES	v
LIST OF FIGURES	viii
ABSTRACT	ix
INTRODUCTION	1
DESCRIPTION OF STUDY AREA	15
MATERIALS AND METHODS	17
RESULTS AND DISCUSSION	22
Growing Conditions	22
<u>Carduus nutans</u> Development	24
<u>Rhinocyllus conicus</u> Development	26
General Effects of Treatments	33
Effects of Treatment on <u>C. nutans</u> Plants	34
Effects of Treatment on <u>C. nutans</u> Seed Production	39
Effects of Treatment of <u>R. conicus</u> Survival	43
Effect of Treatment on Site III in 1977	48
Effect of Treatment on Primary, Secondary and Tertiary Heads	51
Germination of <u>C. nutans</u> Seeds	55
SUMMARY	60
LITERATURE CITED	63
APPENDIX	65

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. Monthly temperature and precipitation for 1976 and 1977 in Belgrade	23
2. <u>C. nutans</u> development and density and <u>R. conicus</u> density in 1976 and 1977	25
3. Correlation between head size and number of <u>R. conicus</u> for primary, secondary and tertiary heads on untreated plots	30
4. Correlation between <u>R. conicus</u> per head and seeds per head for primary and secondary heads on untreated plots	31
5. Effects of spraying with 2,4-D amine and of mowing on number of <u>C. nutans</u> seedlings in May surviving as rosettes in August, 1977	35
6. Effects of spraying with 2,4-D amine and of mowing on number of <u>C. nutans</u> on three dates in 1977	37
7. Effects of spraying with 2,4-D amine and of mowing in 1976 on number of flowering <u>C. nutans</u> in 1977	38
8. Effects of spraying with 2,4-D amine and of mowing on production of <u>C. nutans</u> seeds in 1977	41
9. Effects of spraying with 2,4-D amine and of mowing on percent survival of <u>R. conicus</u> in 1976	44
10. Effects of spraying with 2,4-D amine and of mowing on survival of <u>R. conicus</u> in 1977	45

LIST OF TABLES (cont.)

<u>Table</u>	<u>Page</u>
11. Effects of spraying with 2,4-D amine and of mowing on production of <u>C. nutans</u> seed and percent survival of <u>R. conicus</u> in 1977	47
12. Average number of <u>R. conicus</u> and seeds per <u>C. nutans</u> flowerhead from untreated plots at each site in 1977	49
13. Effects of spraying with 2,4-D amine and of mowing on production of <u>C. nutans</u> seed and survival of <u>R. conicus</u> at Site III in 1977	50
14. Effect of spraying with 2,4-D amine and of mowing on seed production from primary and secondary flower heads of <u>C. nutans</u> in 1977	52
15. Effects of spraying with 2,4-D amine and of mowing on <u>R. conicus</u> survival from primary flower heads of <u>C. nutans</u> in 1977	53
16. Effects of spraying with 2,4-D amine and of mowing on <u>R. conicus</u> survival from secondary flower heads of <u>C. nutans</u> in 1977	54
17. Effects of spraying with 2,4-D amine and of mowing on seed production of <u>C. nutans</u> and percent survival of <u>R. conicus</u> from tertiary heads in 1977	56
18. Effects of <u>R. conicus</u> plus spraying with 2,4-D amine and of <u>R. conicus</u> plus mowing on seed germination from individual <u>C. nutans</u> seed heads in 1977	57

LIST OF TABLES (cont.)

Appendix
TablePage

1. Effect of spraying with 2,4-D amine and of mowing on R. conicus survival from flower heads of C. nutans in 1976 68
2. Effects of spraying with 2,4-D amine and of mowing on R. conicus survival from flower heads of C. nutans in 1977 69
3. Effect of spraying with 2,4-D amine and of mowing on R. conicus survival from primary flower heads of C. nutans in 1977 70
4. Effects of spraying with 2,4-D amine and mowing on R. conicus survival from secondary flower heads of C. nutans in 1977 71
5. Effects of spraying with 2,4-D amine and of mowing on seed production from flower heads of C. nutans in 1977 72
6. Effects of spraying with 2,4-D amine and of mowing on seed production from primary flower heads of C. nutans in 1977 73
7. Effects of spraying with 2,4-D amine and of mowing on seed production from secondary flower heads of C. nutans in 1977 74

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. <u>C. nutans</u> A. Full grown rosette. B. Achene with pappus	3
2. <u>R. conicus</u> . A. Ventral view B. Side dorsal view C. Fifth instar larva	7
3. A. <u>C. nutans</u> seed head in full bloom showing adult <u>R. conicus</u> in receptable. B. <u>C. nutans</u> seed head showing cells from which adult <u>R. conicus</u> have emerged and intact pappus	9
4. <u>C. nutans</u> flowering plant showing primary flower head in full bloom (A), secondary flower head in early bloom stage (B), and tertiary flower head in bud stage (C)	13
5. Effects of spraying with 2,4-D amine and mowing on total number of <u>R. conicus</u> , number of live adult <u>R. conicus</u> and average number of <u>C. nutans</u> seed per head in 1977	42
6. Effect of spraying with 2,4-D amine on <u>C. nutans</u> seed germination. Seed from control plants on left and seed from plants sprayed July 1 on right	59

ABSTRACT

Rhinocyllus conicus (Froelich), a phytophagous insect which feeds on musk thistle (Carduus nutans L.), has become established in the Gallatin Valley, Gallatin County, Montana. This study evaluates the effects of mowing and of spraying musk thistle on the weevil. Study sites, which contained four mowing treatments, four spray treatments and one control were established at Belgrade, Montana in 1976 and 1977 on field populations of musk thistle. Seedlings, rosettes and flowering musk thistle plants were sampled at various times in 1976 and 1977 and musk thistle seed heads were covered and evaluated for weevil survival and seed production. Spraying with 2,4-D amine May 10 or October 10 when musk thistle was in the seedling-rosette stage, eliminated all flowering plants. Spraying June 15 when musk thistle was in the bud stage reduced seed production to 2.7 seeds per head. Spraying July 1, July 15 or August 1 did not significantly reduce musk thistle seeds per head. Spray treatments at any date did not severely reduce R. conicus survival, however spraying in the spring or late fall was best because weevils were not in musk thistle flower heads at that time. Mowing was not found to be a good supplemental control because most weevils are killed as a result of the mowing, plants mowed early in the season grow back and mowing has a tendency to enhance seedling survival due to reduced plant competition.

INTRODUCTION

Musk thistle (Carduus nutans L.) is a serious problem on overgrazed pastures, waste areas and recently disturbed sites. The problem is compounded on rangeland and pastures by livestock which feed around infestations reducing native plant competition.

Musk thistle is described as a biennial, winter annual or rarely an annual, reproducing entirely by seeds (McCarty et al., 1969). The stem is erect and branched and has spiny leaves running the length of the stem. These leaves are dark green, with light green midribs and are alternate, coarsely lobed with three to five points per lobe. Each lobe ends in a white or yellow spine (McCarty et al., 1969).

The flowers of the musk thistle plant are composite, large, flat, nodding, purple in color and are surrounded by large spiny bracts. The tap root is large, fleshy and hollow near the surface of the ground (McCarty et al., 1973).

The seed of musk thistle is contained in an achene measuring 4.5-5.0 mm with a deciduous pappus of numerous barbed capillary bristles 1 cm in length. The surface of a mature achene has shallow longitudinal furrows. Achene

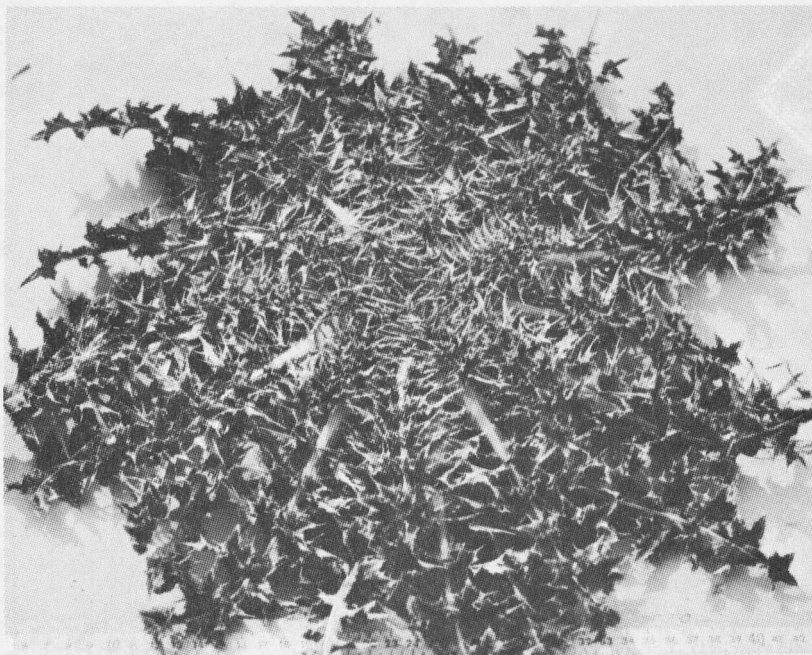
color is dull yellow to brown with the ridges generally lighter in color than the depressed areas (Isley, 1947) (Figure 1B).

Musk thistle was noted in the east central states in the early 1900's (McCarty, 1964) and was first found in Montana near Woodman on the Lolo road, Missoula County in 1921 (MSU Herbarium). Since that time it has spread throughout western Montana, moved eastward to Gallatin and Park Counties and finally was discovered as far east as McCone County in 1957 (MSU Herbarium). Musk thistle is now found in 26 counties in Montana, infesting a total of 26,300 ha (Dunn, 1976).

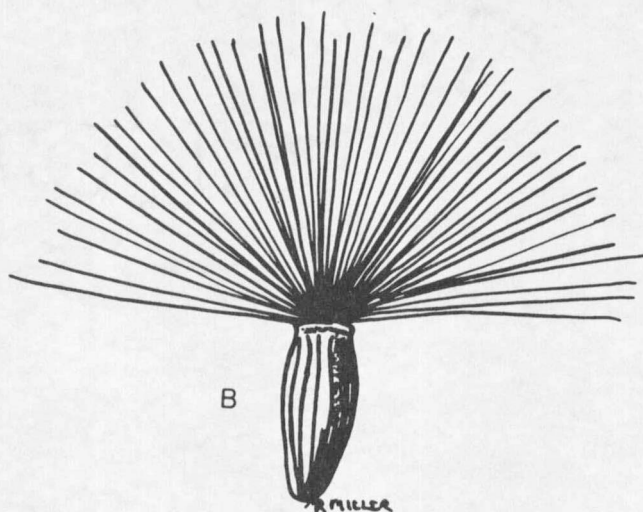
Musk thistle plants may produce from one to 100 or 200 seed heads per plant with an average of 1,000 seeds in the primary heads and as few as 25 seeds per head in some tertiary heads.

A typical plant in Montana bolts in late May from overwintering rosettes and begins to bloom in late June. Seeds disperse 8 to 10 days after a head is in full bloom and may be carried long distances by the action of the wind on the large pappus (McCarty et al., 1973).

Most seed germinates in the fall or spring but may germinate at any time when moisture is sufficient.



A



B

Figure 1. C. nutans A. Full grown rosette. B. Achene with pappus (x 10).

McCarty et al. (1969) reported no seed dormancy, but Lacefield and Gray (1964) working in Kentucky, found a minimum eight week dormancy period. McCarty et al. (1969) found that seeds placed between moistened paper towels in a temperature chamber achieved a maximum germination of 63% at 28°C, but when seeds were planted in a mixture of Sharpsburg silty clay loam and sand at a depth of 0.5 cm a maximum germination of 85% was achieved. McCarty et al. (1969) and Lacefield and Gray (1964) reported a field germination potential of 90-95% for musk thistle. McCarty concluded that light is not required for germination, that covering achenes with soil or other material appears to be necessary for high germination and that achenes require prolonged contact with moisture in order to germinate.

The musk thistle seedling rapidly develops into a rosette or vegetative stage which it maintains through the remainder of the first growing season, if it germinates in the spring or throughout the entire growing season if it germinates in the fall. These rosettes range from 4 or 5 to many cm in diameter (Figure 1A).

Feldman et al. (1967) found a negative correlation between musk thistle seedling establishment and amount of litter on the soil surface. In the same study more musk

thistle plants overwintered on plots grazed than on those protected from grazing.

Musk thistle can be controlled by chemicals. Feldman et al. (1967) working in Nebraska, found that herbicides applied to musk thistle during the rosette stage April 30, May 10, or October 14 gave best control. The most effective control at all dates was obtained with picloram (4-amino-3,5,6-trichloropicolinic acid). Dicamba (3,6-dichloro-o-anisic acid) at 2.2 kg/ha was effective at all spring dates. 2,4-D (2,4-dichlorophenoxy acetic acid) at 2.2 kg/ha resulted in excellent control when applied May 10 or October 14.

The herbicide 2,4-D is absorbed by the leaves or roots. Spraying established plants with 2,4-D is generally most effective in the fall since 2,4-D translocates within the phloem, moving with food material, and it is at this time that food material is moving most rapidly to the roots (Weed Sci. Soc. Am., 1974).

In 1975, McCarty and Hatting tested herbicides on musk thistle in the late bud, early bloom and late bloom stages. The most effective treatments at all three stages were dicamba at 0.56 kg/ha plus 2,4-D amine at 1.1 kg/ha, 2,4-D ester at 4.4 kg/ha or dicamba at 0.56 kg/ha.

Mowing also has been used as a control measure. According to McCarty and Hatting (1975) musk thistle mowed within two days after the first terminal heads in a population had bloomed eliminated the production of germinable seed. They further stated that a single mowing usually does not give satisfactory control due to wide differences in the maturity of plants in a field population.

The weevil, Rhinocyllus conicus Froelich (Coleoptera: Curculionidae) is distributed over southern and central Europe, parts of northern Africa and central Asia (Zwölfer, 1967). R. conicus is a phytophagous insect feeding on musk thistle and was introduced into the United States in 1969 by the USDA Biological Control of Weeds Laboratory, Albany, California as a potential biological control agent (Hodgson and Rees, 1976).

R. conicus overwinters as an adult (Figure 2A, B). It becomes active in the spring and engages in a period of feeding which is necessary for maturation of the ova (Zwölfer, 1967). The adult weevil feeds on the peripheral tissues of musk thistle--mainly the stem, peduncle, leaves and bracts. The damage caused by this feeding is not substantial.

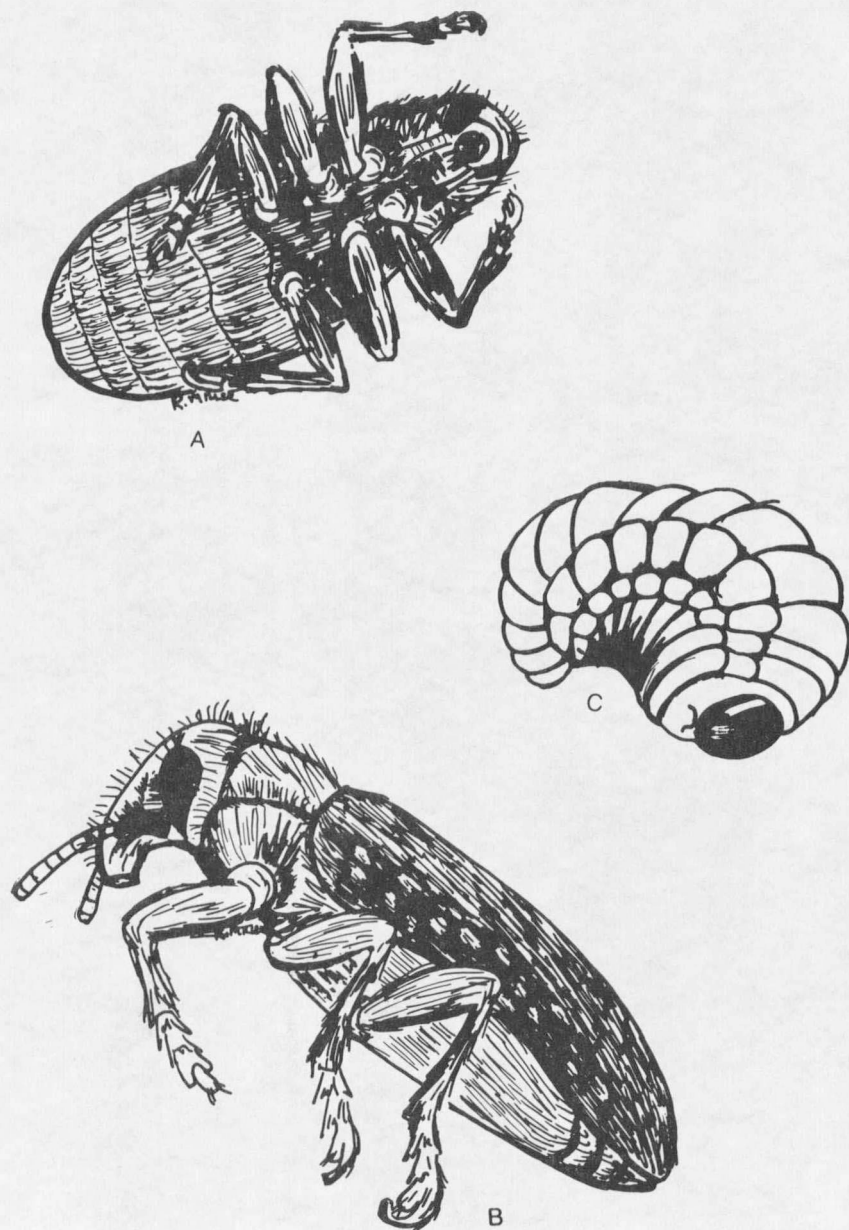


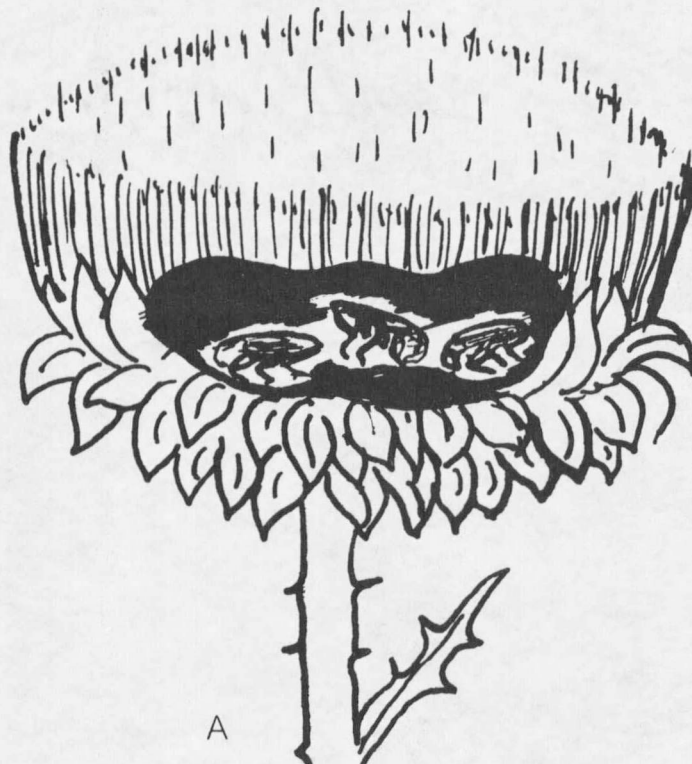
Figure 2. *R. conicus*. A. Ventral view (x 12),
B. Side dorsal view (x 15), C. Fifth
instar larva (x 10).

The eggs are laid on the lower surface of the flower bracts. Each egg is individually covered with masticated plant material. These crusts are in the shape of a slightly flattened hemisphere and are yellow or brown in color measuring about 1.5 cm in diameter. As many as 528 egg crusts may be present per flower head (Rees, 1978). According to Surles and Kok (1976), the weevils prefer the bud stage of musk thistle over more advanced heads for oviposition.

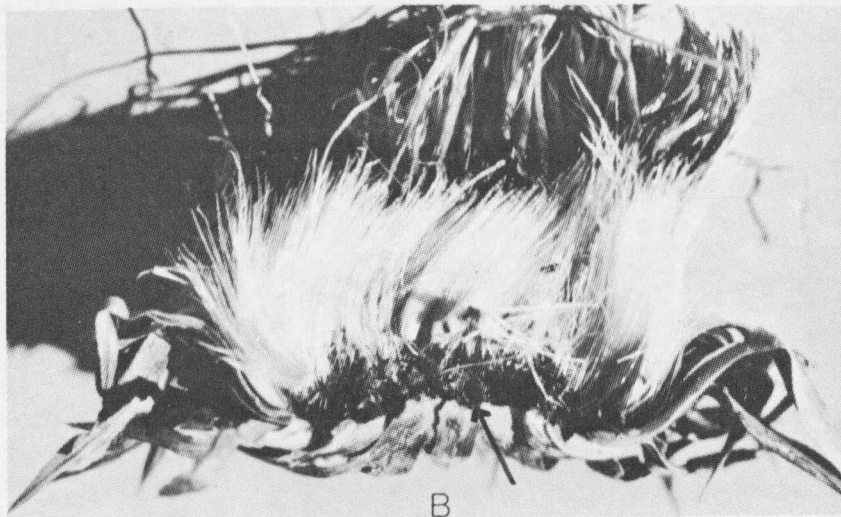
Hatching occurs 6 to 8 days after egg deposition and emerging larvae burrow through the bracts into the flower receptacle. The larvae feed within the receptacle and damage or destroy developing achenes. The larval stage lasts about 25-30 days (Figure 2C).

Pupation takes place within a cell formed by the larva pushing frass and feces together with its head. The pupal period lasts between 8 and 14 days. Young adults remain in pupal cells for several weeks before emerging, during which time the integument turns from light tan to brown (Figure 3A, B).

Adult R. conicus emerge through the pappus on the face of the seed head and search for overwintering sites. Overwintering adults have been found under the bark of



A



B

Figure 3. A. *C. nutans* seed head in full bloom showing adult *R. conicus* in receptacle. B. *C. nutans* seed head showing cells from which adult *R. conicus* have emerged and intact pappus (arrow).

trees, but are generally thought to spend the winter near or in the ground under debris, rocks or plant parts (Zwölfer, 1967). In a study on caged weevils, Kok (1976) found overwintering weevil mortality to be 52%. Preferred overwintering sites were the thistle plant, and its vicinity, cage corners and thistle heads placed in the cage.

Adult weevils are capable of flight, but only do so in the warmest hours of the day, mainly during periods of sunshine (Zwölfer, 1967). Rees (1978) estimates that the radius of R. conicus infestation has increased due to flying by 8 km each year in Montana.

R. conicus feeding and oviposition is limited to the genera Carduus, Cirsium, Silybum and Onopordum. A single case of 'slight and inconsistent' feeding has been observed on Centaurea nigrescens (Zwölfer, 1967).

Kok and Surles (1975) in Virginia reported the first successful control of musk thistle with R. conicus. In all but one of 11 research plots musk thistle density was reduced 90% or more. In a six year period both eggs and adults were detected 32 km from the original release site.

Between 1969 and 1973, a total of 2,940 adult R. conicus were released in the Gallatin Valley of Montana. Hodgson and Rees (1976) reported sites surveyed in 1974

had 63% of the musk thistle plants infested. This figure increased to 88% in 1975 and to 98% in 1976. Rees (1978) reported that R. conicus was present in musk thistle seed heads in an area of 1280 km² in 1974 and an area of 7,296 km² in 1977.

Surles et al. (1975) working in Virginia reported R. conicus egg to adult mortality of 68% with egg and early instar larval mortality accounting for 58%. Rees (1977) found R. conicus mortality from egg to adult of 23% in 1975; however in 1976 the figure jumped to 82%. He attributed the reduced survival to an increased weevil population with resulting egg deposition in excess of available receptacle sites. Rees (1978) reported egg and first instar larval mortality of 79%. Survival of second and later instar stages within the seed head was estimated to be 97% in 1977.

Musk thistle seed and seedling numbers have been reduced by R. conicus. Surles and Kok (1978) reported seed production losses from 60 randomly selected plants of 34.5% in 1973 and 36.3% in 1974 in spite of a large increase in musk thistle head number and size in 1974. Rees (1978) reported that fall seedling counts at 14 permanent sites for 1975, 1976 and 1977 were 20.2, 11.4 and 9.9 plants per m², respectively.

Germination of seed from R. conicus infested heads of musk thistle is low. Rees (1977) found 69% of the seed from noninfested flowers germinated, 45% from heads with four to six weevils and less than 2% from heads with nine or more.

Surles and Kok (1978) found that musk thistle seeds in Virginia gradually decreased in viability as the number of weevil pupation chambers increased. They also found that germination of seed from a particular head depended upon location of that head on the plant, i.e., primary, secondary or tertiary (Figure 4). Seed germination from noninfested tertiary heads, was much lower than from noninfested primary heads, but there was no difference between seed germination from primary and tertiary infested heads. They concluded that in plants which have been heavily parasitized by R. conicus, plant nutrients have been directed away from early developing heads into smaller tertiary heads, thereby producing seeds with increasing viability.

A successful biological control agent such as R. conicus will generally reduce a target species to a low level (Morris, 1959 and Flanders, 1971), but some type of integrated approach involving other control measures may be necessary to further reduce the economic impact of the species.

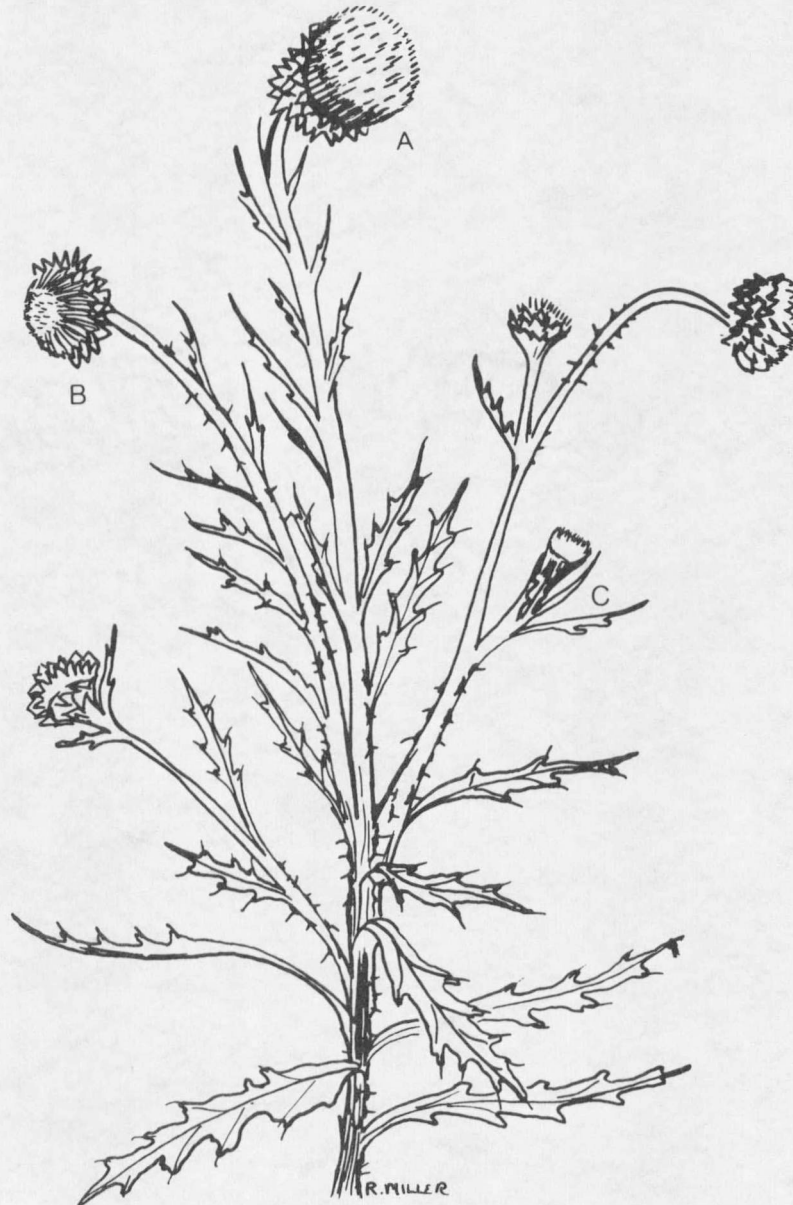


Figure 4. *C. nutans* flowering plant showing primary flower head in full bloom (A), secondary flower head in early bloom stage (B), and tertiary flower head in bud stage (C),

The research reported here was designed to evaluate the effects of mowing and of spraying musk thistle plants on the biological control agent, Rhinocyllus conicus and to evaluate the efficacy of mowing plus biological control and of spraying plus biological control in reducing the numbers of musk thistle to more manageable levels.

DESCRIPTION OF STUDY AREA

This study took place in and around the town of Belgrade, Gallatin County, Montana on field populations of musk thistle. Belgrade is located 15 km northwest of Bozeman, near the original release site of Rhinocyllus conicus in 1969 (Hodgson and Rees, 1976).

The soil at the study sites is Beaverton gravelly loam (Mont. Ag. Exp. Sta. and USDA-SCS, 1970). This soil is very dark in color and the gravelly to very gravelly loam surface layer is about 15 cm thick. The very gravelly loam subsoil is 11 to 23 cm thick and depth to loose sand and gravel varies from 25 to 38 cm. This type of soil is used mainly for pasture and wildlife.

There were three study sites in 1976 separated by 1.5 to 3 km. Site I, located in a field north of the Yellowstone Pine Lumber Company and south of the Burlington Northern right-of-way in Belgrade, is a disturbed area being used for refuse by the lumber company. Predominant vegetation at the start of the study in addition to musk thistle was tansy mustard (Descurainia sophia), downy brome grass (Bromus tectorum) and several perennial native grasses.

Site II was located north of the main airplane runway at Gallatin Field which is 3 km east of Belgrade. The site was established in an abandoned gravel pit, which is lower than the surrounding area. The vegetation at this site was primarily introduced wheat grasses (Agropyron spp.) and annual forbs.

Site III was located at the east end of the main runway at Gallatin Field in an abandoned farmstead. The vegetation at this site was mixed and ranged from introduced wheat grasses, to downy brome, to poison hemlock (Conium maculatum) and an assortment of small annual forbs.

New study sites separated by 3 to 10 km were selected in 1977 because 1976 sites still showed the effects of treatments. Site I was located north of the Yellowstone Pine Company and adjacent to site I in 1976. Site II was located 6 km west of Belgrade in an overgrazed pasture. The pasture was not grazed in the spring or summer, but was heavily grazed in the fall. The vegetation at this site was sparse native grasses and the topsoil is not more than 5 cm in depth. Site III was located north of the main runway at Gallatin Field and adjacent to site II in 1976. This area is described above.

MATERIALS AND METHODS

There were four mowing treatments, four spray treatments and one control arranged randomly within a block at each of the three sites. Each treatment plot measured 3 x 10 m and received only one treatment during the course of the study.

Spray treatments were made with 2,4-D amine at a rate of 2.2 kg/ha. The spray was applied from a boom with a CO₂ powered backpack sprayer in 224 liters of water per hectare.

Plots in 1976 were sprayed July 1, July 15, August 1 and October 10. One additional plot at each site was mowed and cleared to permit herbicide to contact the seedling and rosette musk thistle plants and then sprayed October 10.

Spray treatments in 1977 were made when musk thistle plants were in the rosette to early bolt stage, May 10; late bud stage, June 15; primary flower bloom stage; July 1; and seedling-rosette stage, October 10.

Mowing was accomplished using a Jari^R hand guided self-propelled sickle mower which cut off all plants approximately 4 cm above the soil line.

Plots in 1976 were mowed July 1, July 15 and August 1. Mowing treatments in 1977 were made when plants were in the late bud stage, June 15; primary flower bloom stage, July 1; secondary flower bloom stage, July 15; and tertiary flower bloom stage, August 1.

Flowering plant and seedling counts were made in the spring before treatments commenced, in August and in October after all treatments had been completed. Two square meters per treatment were counted in 1976. These areas were selected by running a transect lengthwise through the center of each plot and counting the third and eighth square meters. An additional square meter located midway between the third and eighth square meters was counted in 1977.

Musk thistle seedlings were classified as those in the cotyledon stage and those that had developed true leaves but were smaller than 2 cm in diameter. Rosettes were considered to be those plants larger than 2 cm and were divided by size in 5 cm increments.

Flowering musk thistle plants were separated by height in 5 cm increments in 1976. Plants were not separated by height in 1977 because they were not full grown when counted.

Flowering plants were selected in each treatment in 1976 and 1977 to evaluate R. conicus survival and seed production. Five plants were selected in 1976 in each treatment by running a transect lengthwise through the center of the treatment and marking the closest plant to the transect at two meter intervals starting with one meter. The marked plants were characterized (stage of growth, height, number of heads) prior to each treatment. Immediately following each treatment these plants were covered with a nylon mesh (6 x 6 strands per cm) bag to catch emerging adult weevils and dispersing seed.

Ten plants were selected in each treatment in 1977, using the same method, but marking the closest plant to the line at one meter intervals starting with one half meter. The primary flower head, the first two secondary heads and the first tertiary head on each plant were individually covered with 13 x 21 cm lightweight muslin bags 2 to 3 days after full bloom. (Secondary heads are those on branches originating from primary stems and tertiary heads are those on branches originating from secondary stems, Figure 4).

The method of recovering weevils and seeds was changed in 1977 to permit an evaluation of individual musk thistle flower heads.

The selected plants were left in the field until R. conicus had reached maturity and mature seed had dispersed. The plants were then brought into the laboratory where the heads were dissected. Data recorded from each head included number of seeds, head size, position of head (primary, secondary, tertiary), number and developmental stage of R. conicus and whether weevils were alive or dead.

Seed was collected from each plant in 1976 and from each head in 1977. The seed was partially cleaned by hand, followed by the use of an Oregon Continuous Air Blower. The seed blower was set (through trial and error) to remove light particles including shriveled and unfilled seed.

A nylon mesh (6 x 6 strands per cm) cage measuring 3 x 3 x 3 m was set up in late fall, 1976 at the Plant and Soil Science field laboratory 8 km west of Bozeman. Potential R. conicus overwintering sites of rock, sand, gravel, musk thistle rosettes, straw and boards were placed inside the cage along with 2,000 adult R. conicus for overwintering site and survival studies. The cage was examined periodically throughout the winter and in the spring of 1977 surviving weevils were captured with the use of an aspirator and counted.

Germination studies were carried out on seeds collected from treatments in 1977. The seeds were germinated in clear plastic boxes between paper towels moistened with 13 ml of a mixture of 100 $\mu\text{g/ml}$ KNO_3 and 0.02 molar gibberellic acid. The boxes were placed in the light at room temperature (ca 22°C) for 8 hours and in a dark germinator at 15°C for the remainder of the day. Additional moistening agent was added as necessary throughout the study. Seed from individual heads was germinated separately with three replications of each seed head. Each replication contained 50 seeds, if that number was available. When less than 150 seeds were produced, each replication included one-third of the total number of seeds.

Two thousand adult R. conicus were marked with a bright orange spot about 1 mm in diameter on either elytron in the fall of 1977 for further studies on overwintering sites. One thousand eight hundred of these weevils were released near site III in 1977. One hundred and fifty were placed in the previously described field cage and 50 were maintained in a refrigerator at 4°C along with 50 unmarked weevils to determine if there were any harmful effects from the paint.

RESULTS AND DISCUSSION

Growing Conditions.

Growing conditions varied considerably between 1976 and 1977 with 1976 more closely approximating the 30 year average (1941-1970) for temperature and 1977, the 30 year average for precipitation (Table 1). The growing season (April through August) in 1976 received 4.36 cm more precipitation than average. These same months in 1977 received 1.84 cm less moisture than the thirty year average. Most of the excess moisture in 1976 fell during the first part of the period with August receiving 1.65 cm less moisture than average. In contrast 1977 was fairly dry during the first part of the period with August recording 0.58 cm more moisture than the thirty year average.

The growing season on 1976 started out warmer than the 30 year average, but temperatures were near the average for the months of June, July and August. Temperatures in 1977 were near the 30 year average except for June which was a full 3.0°C warmer than average.

Table 1. Monthly temperature and precipitation for 1976 and 1977 in Belgrade.¹

	Temperature (°C)				Precipitation (cm)	
	Av. max.	Av. min.	Monthly average	Departure ²	Total precip.	Departure ²
1976						
Jan	-0.8	-12.0	- 6.4	2.3	0.56	-1.12
Feb	3.6	- 8.4	- 2.5	2.5	0.79	-0.25
Mar	3.6	-10.6	- 3.6	-1.4	1.37	-0.84
Apr	12.6	- 1.3	5.7	0.6	6.20	3.25
May	20.3	3.3	11.8	1.4	3.71	-1.63
Jun	21.9	6.0	13.9	-0.4	8.81	2.03
Jul	28.9	9.8	19.4	0.2	5.16	2.36
Aug	27.0	8.6	17.8	-0.5	1.27	-1.65
Sept	22.1	4.5	13.3	0.9	4.17	0.64
Oct	13.7	- 2.7	5.5	-1.4	2.72	0.18
Nov	7.7	- 7.8	- 0.1	0.7	0.46	-1.60
Dec	3.6	- 9.9	- 3.2	2.7	0.28	-1.23
1977						
Jan	-3.4	-17.2	-10.2	-1.6	1.70	0.03
Feb	5.9	- 8.6	- 1.3	4.1	0.22	-0.81
Mar	4.0	- 7.6	- 1.8	0.4	3.94	1.73
Apr	16.5	- 0.4	8.1	2.9	0.89	-2.06
May	16.7	3.1	9.9	-0.5	6.50	1.17
Jun	25.4	9.2	17.3	3.0	5.89	-0.89
Jul	28.7	9.4	19.1	-0.1	2.16	-0.64
Aug	26.4	8.8	17.6	-0.7	3.51	0.58
Sep	20.4	4.4	12.4	0.1	7.62	4.09

¹NOAA, Environmental Data Service, Asheville, N.C., 1976 and 1977. Climatological Data -- Montana.

²Departure from 30 year average (1941-70).

Carduus nutans Development.

When the study began in the middle of June, 1976, the first heads on musk thistle plants were in the late bud stage. These heads bloomed towards the end of June and seeds began to disperse on July 9. Plants continued to produce buds and bloom through the middle of August.

Plants in 1977 began to bolt around the middle of May with some buds produced by the first part of June. These buds were in full bloom by the end of June and seed dispersal began July 6. Plants which did not dry up with the high temperatures in June continued to flower until the middle of September.

Plants selected for seed production and R. conicus survival studies in 1976 averaged 96 cm in height and 9.3 main stem flowers per plant (Table 2). Individual plants were not measured in 1977, but appeared to be smaller with fewer buds, probably due to higher temperatures and decreased moisture during the growing season.

Musk thistle seed heads from untreated plots dissected in 1976 were larger than those dissected in 1977. All heads from each selected plant in 1976 averaged 2.15 cm in diameter while the four selected heads from each plant in 1977 averaged 1.96 cm (Table 2).

Table 2. C. nutans development and density and R. conicus density in 1976 and 1977.

Item	1976			1977		
	N	$\bar{X}$	SD	N	$\bar{X}$	SD
<u>C. nutans</u>						
Head Size (cm)						
All	125	2.15	0.62	94	1.84	1.96
Primary				33	2.14	4.56
Secondary				51	1.88	5.33
Tertiary				10	1.69	2.29
Flowering Plants						
Density (m^2)	30	10.7	9.3	18	6.3	6.6
Height (cm)	30	96.0	31.6			
Flowers/Plant	30	8.3	7.7			
<u>R. conicus</u>						
Total density per <u>C. nutans</u> head ¹	125	9.0	- ²	88	11.6	13.0
Larval density per <u>C. nutans</u> head in June				41	38.7	31.8

¹Includes dead larvae, pupae, and adults and live adults.

²R. conicus numbers in individual heads were not counted.

Plants in both 1976 and 1977 generally produced one central stem with branching from that stem; however some plants on site III in 1976 produced up to 11 primary stems. These stems all came from the base of the plant and some plants produced over 200 flowering heads. Growing conditions apparently were more favorable at this site and we believe that an unexplained injury to the growing point produced the profuse branching.

Musk thistle flowering plant densities averaged 10.7 plants/m² in 1976 with sites ranging from 6.4 to 10.6. The average in 1977 was 6.3 and ranged from 4.3 to 10.4 plants per m² (Table 2).

Rhinocyllus conicus Development.

R. conicus was in the late larval stage when the study began. Weevils began pupating July 4 and the first adults were observed July 19. They began to emerge from musk thistle flower heads July 26.

The first overwintering adults in 1977 were observed May 2. Mating and egg deposition began May 6. Larvae were first seen in the receptacle June 7 and the first pupae were observed July 8. Some musk thistle plants had mature adult R. conicus in the flower heads by July 14 and the weevils began emerging July 19.

Overwintering adults were still mating in large numbers and depositing eggs July 1. After this date their numbers declined rapidly with the last overwintering adults seen July 25. During July the overwintering adult weevils could only be found on musk thistle regrowth from mowed plots, suggesting a preference for new growth.

New generation R. conicus adults can be differentiated from overwintering adults by color. Adults emerging from seed heads are brown in color with lighter brown mottling on the elytra. Overwintering adults get progressively darker throughout the season until they are almost black before they die.

Only an occasional adult R. conicus was seen after emergence from the flower head. It is thought that they immediately seek an overwintering site (Zwölfer, 1967).

Average R. conicus density (including dead larvae, pupae, and adults and live adults) was 9.0 weevils per head for all heads from each plant in 1976 and 11.6 weevils per head for the four selected heads on each plant in 1977 (Table 2). Weevil densities at the three sites ranged from 1.2 to 11.4 insects per head in 1976 and from 3.2 to 20.1 insects per head in 1977.

Weevils were also counted in primary heads June 21, 1977 when these heads were in full bloom. Numbers of live larvae averaged 38.7 per head and ranged from 18.0 to 62.7 insects per head among the sites (Table 2). Apparently many larvae die when they are extremely small (first and second instar larvae), dry up and are not found when all heads are dissected in the fall.

R. conicus also has a high egg to larval mortality. Surles et al. (1975) reported egg and early instar larval mortality of 58%. Rees (1978) found egg and first instar larval mortality of 82% in 1976 and 79% in 1977.

Kok and Surles (1976) reported that a musk thistle seed head with a high number of R. conicus will generally dry and die prematurely without producing seed. They found that 50 or more larvae were necessary. Our study produced similar findings with such heads appearing as if they had dried up when in full bloom with the pappus remaining intact. The number of weevils necessary depended upon head size and stage of head development.

Seed heads were also found to die prematurely because of larvae within the stem. Rees (1977) reported that prior to 1976 in the Gallatin Valley larvae rarely were found in the stem, but in 1976 feeding within the stem often caused

death of the flower above it. According to Rees, weevils oviposited on the stems because of a shortage of oviposition sites on the flower heads. In the present study it was observed that flower heads died prematurely if a number of weevils were found in the peduncle. The seed head in this case may die during any stage of growth and often did so in the bud stage.

There appears to be a correlation between musk thistle head size and number of weevils per head from untreated plots (Table 3). Correlation coefficients were calculated on individual sites because of a wide variation in R. conicus infestation among the sites. Correlation coefficients of .84 and .73 for primary and secondary heads were found where R. conicus infestation was high on site III.

Secondary heads from sites I and II also had significant correlations between weevils per head and head size with correlation coefficients of .75 and .52, respectively.

Number of weevils per head and seeds per head showed only a small degree of correlation (Table 4) with all correlation coefficients less than .50. Lack of greater correlation is probably due to the variation in head size and in weevil infestation.

Table 3. Correlation between head size and number of R. conicus for primary, secondary and tertiary heads on untreated plots.

Site	$\bar{x}$ Head Size	$\bar{x}$ Weevils/hd	x-y Pairs	r
<u>Primary Heads</u>				
I	2.12	9.05	20	.29
II	2.01	2.73	19	.11
III	2.28	27.95	20	.84*
<u>Secondary Heads</u>				
I	1.66	3.45	29	.75*
II	1.72	3.15	26	.52*
III	2.18	24.23	39	.73*
<u>Tertiary Heads</u>				
III	1.69	2.50	15	.46

$\bar{x}$ = estimate of the mean.

r = correlation coefficient

* = significant at the 5% level.

Table 4. Correlation between R. conicus per head and seeds per head for primary and secondary heads on untreated plots.

Site	$\bar{x}$ Weevils/hd	$\bar{x}$ Seeds/hd	x-y Pairs	r
<u>All Heads</u>				
I	5.41	106.7	46	-.41*
II	3.22	110.2	46	-.30*
<u>Primary Heads</u>				
I	9.16	74.3	19	-.38
II	2.78	154.1	18	-.44
<u>Secondary Heads</u>				
I	3.57	116.4	28	-.31
II	3.39	96.2	23	-.24

$\bar{x}$ = estimate of the mean.

r = correlation coefficient.

* = significant at the 5% level.

A total of 660 weevils survived the winter out of the 2,000 placed inside the cage at the field laboratory. A survival rate of only 33% may have resulted from the insect confinement and storage for approximately one month before being released and because there was limited snow cover within the cage.

Only a few of the weevils could be found inside the cage during the winter months. The most favored overwintering sites were between the boards and just under the soil along the edges of the cage.

Weevils marked with orange paint were field released September 13, 1977, a sunny day with a maximum temperature of 27°C. Approximately one fourth of the 1,800 released, immediately took to flight with the prevailing wind. The remainder crawled out of the container and into the grass and trash on top of the ground. Several marked weevils were found under musk thistle rosettes during late fall, 1977. From May 4-9, 1978, one hundred twenty-five marked weevils were collected from two musk thistle rosettes no farther than 30 cm from the release site. No further recovery of these marked weevils was made even though several thousand weevils from the surrounding area were

collected during the annual Biological Weed Control Workshop held in Bozeman May 23.

It is apparent that these weevils spent the winter in or under these rosettes. It is not nearly so certain that this was their preferred overwintering site. It is possible that when the insects were released it was too late for them to search for a more favorable overwintering site.

General Effects of Treatments

Musk thistle plants sprayed May 10 were in the cotyledon and rosette stages. The cotyledon seedlings died within a few days. Larger seedlings and rosettes dried more gradually, but eventually died.

Plants sprayed June 15 showed grossly curled and twisted stems and greatly reduced budding with most of the existing buds dying.

Plants sprayed July 1, and later, showed a curling in the area of the peduncle and reduced budding, but no other visible injury.

Musk thistle plants mowed early produced a regrowth of generally five stems from the stump of the mowed plant. Mowing destroys the apical bud (meristem) and allows the lateral buds to produce stems. Mowing early will greatly

increase the number of primary heads and also may permit many flower heads to escape the period of most severe weevil infestation. Regrowth plants generally do not reach the same height as those which have not been mowed.

Plants mowed June 15 developed an average of 6.7 stems per m^2 on the regrowth. Based on five stems per plant, 1.3 plants/ m^2 showed regrowth. Flower heads on the regrowth began to bloom two weeks after mowing.

Plants mowed July 1 also grew back, but to a lesser degree than those mowed earlier with only 1.9 stems/ m^2 .

Regrowth on plots mowed July 15 was negligible and was nonexistent when the mowing was delayed until August 1.

Effects of Treatment on C. nutans Plants

There is a large natural mortality among musk thistle seedlings. Only 9.5% of the total seedlings in May, 1977 were present as rosettes in August, on untreated plots (Table 5). During this period cotyledon plants passed into the early rosette stage and young rosettes gained vegetative growth. A further reduction in survival is indicated by the number of flowering plants in 1977 produced from rosettes present in 1976 on untreated plots (Table 7). The

Table 5. Effects of spraying with 2,4-D amine and of mowing on number of *C. nutans* seedlings in May surviving as rosettes in August, 1977.

Treatment	Seedling Density May ¹ (plants/m ²)	Percent Seedling ₂ Survival ²
Control	40.5	9.5 ab ³
Spray		
May 10	59.4	11.0 ab
June 15	70.9	0.3 b
July 1	55.2	3.3 bc
Oct. 10 ⁴	129.8	0.7 b
Mow		
June 15	68.1	16.0 a
July 1	63.8	9.3 ab
July 15	56.1	13.3 ac
Aug. 1	98.1	7.0 ab

¹The average of three square meters counted on each of the three sites.

²The mean of number of rosettes in August divided by the number of seedlings in June from each site.

³Means followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range.

⁴Seedling counts for this treatment were made in October, 1976 and June, 1977.

high mortality is thought to be due to moisture stress and plant competition.

On the basis of seedling survival spraying June 15 and October 10 were the most satisfactory treatments (Table 5). Survival percentages of less than 1% probably represent those plants which were protected from herbicide injury by a canopy of other plants. This explanation can also account for the 3.3% survival from the July 1 spraying. Spraying May 10 was not effective because many seeds germinated after the treatment was made.

Mowing is not an effective way to reduce musk thistle first year plants. In fact, these results indicate a tendency for mowing to enhance seedling survival (Table 5). This enhanced survival is probably due to reduced plant competition.

In contrast to the decrease observed from May to August, the number of C. nutans first year plants increased from August through October, due to germination of new seed (Table 6).

There was a wide variation in the effect of 1976 treatments on the number of flowering plants in the same plots in 1977 (Table 7). Generally spraying reduced plant numbers and mowing did not change or increased plant numbers.

Table 6. Effects of spraying with 2,4-D amine and of mowing on number of C. nutans on three dates in 1977.

Treatment	Total Seedlings			Rosettes			Rosettes		
	May (m ²)			August (m ²)			October (m ²)		
	N	$\bar{X}$	SD	N	$\bar{X}$	SD	N	$\bar{X}$	SD
Control	9	49.1	22.8	9	4.8	3.6	9	22.2	15.1
Spray									
May 10	9	68.1	47.7	9	3.7	5.1	9	22.1	22.0
June 15	9	63.8	37.9	9	0.2	0.4	9	21.7	11.2
July 1	9	55.1	23.4	9	1.2	2.3	9	56.8	87.8
Mow									
June 15	9	59.4	42.2	9	8.0	5.1	9	31.2	21.0
July 1	9	69.3	74.2	9	5.6	5.3	9	15.4	12.8
July 15	9	65.0	44.2	9	6.0	6.0	9	24.7	20.7
Aug. 1	9	35.8	33.9	9	1.7	1.7	9	24.4	33.3

N = Number of square meters counted per treatment.

$\bar{X}$ = Estimate of the mean.

SD = Standard Deviation.

Table 7. Effects of spraying with 2,4-D amine and of mowing in 1976 on number of flowering C. nutans in 1977.

Treatment	Rosettes, June 1976 (m ²)			Flowering Plants June, 1977 (m ²)		
	N	$\bar{X}$	SD	N	$\bar{X}$	SD
Control	6	4.8	3.3	6	3.2	1.0
Spray						
July 1	6	7.8	8.5	6	1.7	2.3
July 15	6	2.0	2.8	6	2.2	4.4
Aug. 1	6	8.8	9.1	6	0.8	1.3
Oct. 10	6	9.2	7.5	6	0.2	0.4
Mow						
July 1	6	0.5	0.8	6	2.0	2.7
July 15	6	2.2	1.7	6	3.8	2.9
Aug. 1	6	1.7	1.8	6	1.7	3.1
Mow + Spray						
Oct. 10	6	4.5	7.8	6	0.0	0.0

N = Number of square meters counted per treatment.

$\bar{X}$ = Estimate of the mean.

SD = Standard Deviation.

Spraying July 1, August 1 or October 10 reduced numbers of flowering plants while spraying October 10, after removing topgrowth, completely eliminated flowering plants. The flowering plants present in 1977 following the July 15 spraying were all found on one site and suggest that the spray treatment was not effectively carried out on this plot.

Mowing tended to increase the number of flowering musk thistle plants in 1977 from rosettes counted in June, 1976 (Table 7). Apparently mowing reduced competition and allowed more plants to survive.

Effect of Treatment on *C. nutans* Seed Production.

Seed counts from selected plants in 1976 were not reliable. Plants were covered to collect seed and adult *R. conicus* immediately after a particular treatment had been made. When these treatments were made early in the season, i.e., July 1, normal pollination could not occur on many heads and seeds did not fill. When these treatments were made late in the season, i.e., August 1, much of the seed had already dispersed.

Generally in 1976, seed was produced on the controls but not on plots mowed July 1 or July 15. Seed was produced

from plants mowed August 1, however most of this seed had dispersed before the bags were put on.

Seed was produced on most sprayed plots, but the July 1 spraying produced less seed than the control in 1976.

The 84 flowers examined from the untreated plots in 1977 produced an average of 78.9 seeds. Flowers on all treated plots produced fewer seeds (Table 8, Figure 5, Appendix Table 5), but the differences were significant at the 5% level of probability for only three spray and one mowing dates. Spraying July 1 was too late to reduce seed production. Regrowth from plants mowed June 15 produced as many seeds as those that were not mowed until July 15 or later.

Spraying May 10, June 15 or October 10 or mowing July 1 were most effective in reducing seeds per musk thistle head in 1977. Spraying May 10 or October 10 or mowing July 1 completely eliminated seed production, while spraying June 15 reduced seed production to an average of only 2.7 seeds per head.

Table 8. Effects of spraying with 2,4-D amine and of mowing on production of C. nutans seeds in 1977.

Treatment	Number of Heads	Average Number of Seeds per Head
Control	84	78.9 b ¹
Spray		
May 10	0	0.0 a
June 15	51	2.7 a
July 1	89	57.7 ab
Oct. 10 ²	0	0.0 a
Mow		
June 15 ³	43	57.0 ab
July 1	48	0.0 a
July 15	71	49.3 ab
Aug. 1	84	50.3 ab

¹Means followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range.

²Sprayed October 10, 1976.

³Heads and seed from regrowth.

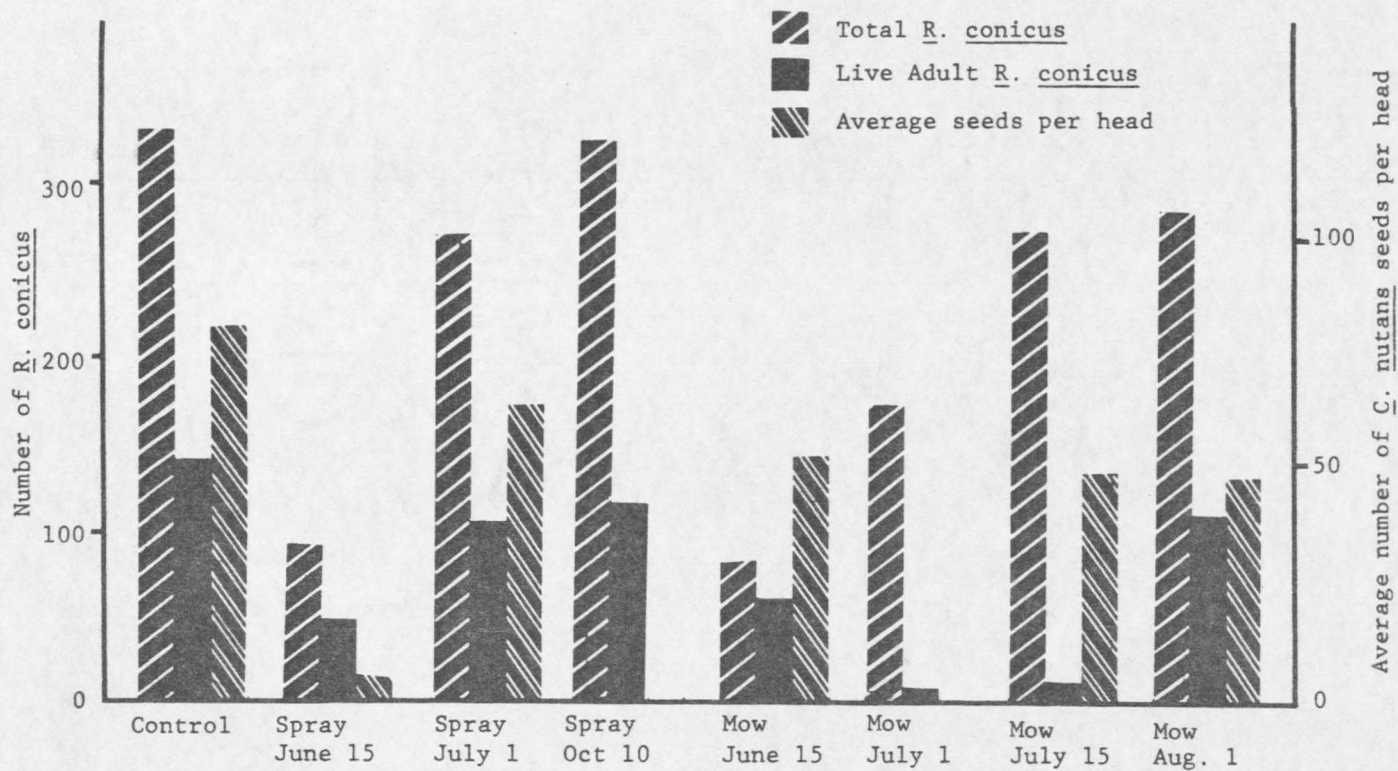


Figure 5. Effects of spraying with 2,4-D amine and of mowing on total number of R. conicus, number of live adult R. conicus and average number of C. nutans seed per head in 1977.

Effect of Treatment on
R. conicus Survival.

R. conicus survival from larvae to adult in 1976 was 90.7% on untreated plots (Table 9, Appendix Table 2). Mowing July 1 killed all weevils before they reached maturity. Mowing July 15 was only slightly less injurious to the weevils. The other mow treatment and all spray treatments indicate decreased R. conicus survival, but not significantly so.

Survival of R. conicus in 1977 was much lower than in 1976 with only 50% survival on untreated plots (Table 10, Figure 5, Appendix Table 2). However, the different survival percentages for the two years are not comparable, since entire plants were reported in 1976 and only four heads on each plant in 1977. The results do follow the same general pattern in that spray treatments made during the bud and flowering stages of C. nutans development did not seriously affect R. conicus survival.

Mowing is more injurious to R. conicus survival than spraying. Only the first and the last mowing dates did not severely reduce R. conicus survival. The June 15 mowing represents weevil survival entirely from regrowth of the mowed plants and many R. conicus larvae too small to count

Table 9. Effects of spraying with 2,4-D amine and of mowing on percent survival of R. conicus in 1976.

Treatment	Number of Heads	Total <u>R. conicus</u> ¹	Percent <u>R. conicus</u> Survival ²
Control	126	1128	90.7 a ³
Spray			
July 1	92	1415	71.3 a
July 15	113	1114	83.3 a
Aug. 1	92	500	78.3 a
Mow			
July 1	45	564	0.0 b
July 15	72	809	11.0 b
Aug. 1	247	1674	59.3 a

¹Includes dead larvae, pupae, adults and live adults.

²The mean of live adult weevils divided by total weevils from each site.

³Means followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range.

Table 10. Effects of spraying with 2,4-D amine and of mowing on survival of R. conicus in 1977.

Treatment	Number of Heads	Total <u>R. conicus</u> ¹	Percent <u>R. conicus</u> Survival ²
Control	84	1039	50.0 b ³
Spray			
May 10 ⁴	-	-	-
June 15	51	267	64.0 b
July 1	89	804	47.7 b
Oct. 10 ⁴	-	-	-
Mow			
June 15 ⁵	43	249	65.7 b
July 1	48	518	0.7 a
July 15	71	828	1.3 a
Aug. 1	84	861	37.7 ab

¹Includes dead larvae, pupae, adults and live adults.

²The mean of live adult weevils divided by total weevils from each site.

³Means followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range.

⁴Weevils were not in musk thistle heads at the time of treatment.

⁵Weevil survival from regrowth.

were killed when the mowing was made. These numbers were very likely similar to those from the June 15 spraying. The comparatively high survival of R. conicus on the June 15 mowing regrowth is a reflection of weevil density. Since these heads came on later in the season they were not as heavily infested and consequently there is a higher survival.

The high survival percentage from the June 15 spray treatment was accompanied by a reduced number of total R. conicus indicating reduced egg deposition, egg hatchability, or low first and second instar larval survival following the spray treatment. Weevils were not produced on plots sprayed May 10, since all second year plants were killed by the treatment. It is probably accurate to say that there was no adverse effect on survival of R. conicus from the treatment, since the weevils which would have oviposited on these plants, moved to other plants.

Considering both seeds per head and R. conicus survival it is apparent that only spraying May 10, June 15 or October 10 satisfactorily reduce seed production without damaging the survival of R. conicus (Table 11 and Figure 5).

Table 11. Effects of spraying with 2,4-D amine and of mowing on production of C. nutans seed and percent survival of R. conicus in 1977.

Treatment	Average Number of Seeds per Head	Percent <u>R.</u> <u>conicus</u> Survival ¹
Control	79.3 b ²	50.0 a ²
Spray		
May 10	0.0	- ³
June 15	2.7 a	64.0 a
July 1	57.7 ab	47.7 a
Oct. 10	0.0 a	- ³
Mow		
June 15 ⁴	57.0 ab	65.7 a
July 1	0.0 a	0.7 b
July 15	49.3 ab	1.3 b
Aug. 1	50.3 ab	37.7 ab

¹The mean of live adult weevils divided by total weevils from each site.

²Means followed by the same letter in each column are not significantly different at the 5% level according to Duncan's Multiple Range.

³Weevils were not in heads at the time of treatment.

⁴Seeds and weevils from regrowth.

Effect of Treatment on Site III
in 1977.

There is a negative correlation between R. conicus per flower head and seeds per flower head of C. nutans among the three sites in 1977 (Table 12). Site III with its high number of R. conicus (20.1 per head) and low average numbers of seeds (26 per head) is unique and warrants a closer look.

R. conicus numbers were high enough at site III to eliminate seed from primary and secondary flower heads. Mowing August 1 at site III eliminated most seed from tertiary heads and those heads which would have been produced later on. There was no musk thistle regrowth from this treatment. The mowing was done late enough so that 36% of the weevils survived compared to 39% on the control of this site (Table 13).

The data in Table 13 further suggests that where R. conicus numbers are high and conditions are such that very few tertiary and later heads are produced, seed production will be low.

Table 12. Average number of R. conicus and seeds per C. nutans flowerhead from untreated plots at each site in 1977.

Site	Average <u>R. conicus</u> per Head	Average Seeds per Head
I	6.3	98
II	3.1	114
III	20.1	26

$r = -.999.$

Table 13. Effects of spraying with 2,4-D amine and of mowing on production of C. nutans seed and survival of R. conicus at Site III in 1977.

Treatment	Average Number of Seeds per Head	Percent <u>R.</u> <u>conicus</u> Survival ¹
Control	26	39
Spray		
May 10	0	- 2
June 15	0	35
July 1	11	36
Oct. 10	0	- 2
Mow		
June 15 ³	82	77
July 1	0	2
July 15	0	4
Aug. 1	6	36

¹Live adult weevils divided by total weevils.

²Weevils were not in heads at time of treatment.

³Seeds and weevil survival from regrowth.

Effect of Treatment on Primary,
Secondary and Tertiary Heads

Primary and secondary seed heads responded differently to treatment (Table 14, Appendix Tables 6 and 7). Spraying July 1 reduced seed production in secondary heads by a third compared to the control, while primary head seed production stayed the same. Mowing June 15, July 1 or July 15 greatly reduced seed production from secondary heads, while seed production from primary heads was reduced only slightly.

R. conicus infestation in primary heads averaged 13.5 and in secondary heads 11.5 in 1977 on untreated plots. Weevil survival was generally higher in secondary heads, as might be expected, since secondary heads come on later in the season and are not infested as heavily (Tables 15 and 16, Appendix Tables 3 and 4). Mowing August 1 decreased R. conicus survival in secondary heads but not in primary heads. Weevils were more mature in primary heads and were therefore more able to survive the mowing treatment.

Spraying June 15 increased weevil survival in primary heads while lowering it in secondary heads. Evidently buds sprayed on June 15 had not been heavily infested by the weevils and the effects of the spray on the plant caused

Table 14. Effect of spraying with 2,4-D amine and of mowing on seed production from primary and secondary flower heads on C. nutans in 1977.

Treatment	Primary		Secondary	
	Number of Heads	Ave. Seeds per Head ¹	Number of Heads	Ave. Seeds per Head ¹
Control	29	73	48	66
Spray				
May 10	0	0	0	0
June 15	22	0	18	0
July 1	31	74	48	46
Oct. 10 ²	0	0	0	0
Mow				
June 15 ³	28	64	11	26
July 1	30	0	18	9
July 15	30	62	40	36
Aug. 1	29	54	47	44

¹The mean of average seeds per head from each site.

²Sprayed October 10, 1976.

³Heads and seed from regrowth.

Table 15. Effects of spraying with 2,4-D amine and of mowing on R. conicus survival from primary flower heads of C. nutans in 1977.

Treatment	Number of Heads	Total <u>R. conicus</u> ¹	Percent <u>R. conicus</u> Survival ²
Control	29	392	41.0 ab ³
Spray			
May 10 ⁴	-	-	-
June 15	22	167	60.3 a
July 1	31	286	32.0 ab
Oct. 10 ⁴	-	-	-
Mow			
June 15 ⁵	28	153	65.7 a
July 1	30	329	1.0 b
July 15	30	299	0.0 b
Aug. 1	29	382	40.3 ab

¹Includes dead larvae, dead pupae, dead adults and live adults.

²The mean of live adult weevils divided by total weevils from each site.

³Means followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range.

⁴Weevils were not in musk thistle heads at time of treatment.

⁵R. conicus survival from regrowth.

Table 16. Effects of spraying with 2,4-D amine and of mowing on R. conicus survival from secondary flower heads of C. nutans in 1977.

Treatment	Number of Heads	Total <u>R. conicus</u> ¹	Percent <u>R. conicus</u> Survival ²
Control	48	554	66.3 b ³
Spray			
May 10 ⁴	-	-	-
June 15	18	100	49.7 bc
July 1	48	385	57.7 b
Oct. 10 ⁴	-	-	-
Mow			
June 15 ⁵	11	79	72.0 b
July 1	18	188	0.3 a
July 15	40	508	0.3 a
Aug. 1	47	409	27.7 c

¹Includes dead larvae, pupae, adults and live adults.

²The mean of live adult weevils divided by total weevils from each site.

³Means followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range.

⁴Weevils were not in heads at the time of treatment.

⁵R. conicus survival from regrowth.

a reduction of future R. conicus infestation. Low density of R. conicus per seed head means high weevil survival. The secondary buds were still quite small at the time of the treatment and were largely killed by the spray.

Tertiary heads in 1977 were not produced at sites I and II, probably due to more adverse growing conditions than at site III. The effect of treatment further eliminated tertiary heads from the June 15, July 1 and July 15 mowings and from the May 10 and June 15 sprayings. Seed production and R. conicus survival on the remaining treatments were quite variable. Both spraying July 1 and mowing August 1 reduced seed production. Even though the number of flower heads examined is small, the increased R. conicus survival from spraying July 1 seems significant (Table 17).

Germination of C. nutans Seeds.

Germination of seed was highly variable with no clear cut trends in relation to number of R. conicus present or method of treatment. Germination of seed from individual heads ranged from 0 to 99% (Table 18). Generally seed from heads with no R. conicus present gave better germination than seeds from heads with weevils.

Table 17. Effects of spraying with 2,4-D amine and of mowing on seed production of C. nutans and percent survival of R. conicus from tertiary heads in 1977.

Treatment	Number of Heads	Average Seeds per Head ¹	Total <u>R. conicus</u> ²	Percent <u>R. conicus</u> Survival ³
Control	6	160	19	34
Spray				
July 1	7	17	52	65
Mow				
Aug. 1	9	25	70	27

¹The mean of average seeds per head from each site.

²Includes dead larvae, pupae, adults and live adults.

³The mean of live adult weevils divided by total weevils from each site.

Table 18. Effects of *R. conicus* plus spraying with 2,4-D amine and of *R. conicus* plus mowing on seed germination from individual *C. nutans* seed heads in 1977.

Treatment	Head Size	Total <i>R. conicus</i> ¹	Seeds ²	Mean Percent Germination ³
Control	1.7	0	50	96
	1.4	0	30	90
	1.9	1	30	99
	1.5	1	50	80
	1.7	2	50	98
	1.5	3	35	70
	1.8	4	50	51
	2.0	7	50	91
	2.5	9	50	42
	2.1	10	20	58
Spray July 1	1.7	1	20	3
	2.0	2	30	82
	1.8	3	50	5
	3.1	4	50	17
	2.1	4	50	71
	2.2	4	25	43
	1.5	5	40	54
	2.1	6	25	80
	1.9	7	40	6
	2.3	8	30	62
	2.3	13	35	42
Mow July 15	1.5	0	50	17
	1.8	1	40	0
	1.6	3	30	27
	1.9	5	30	55
	1.8	5	20	68
	2.3	5	10	53
	2.0	6	30	70
	2.1	8	30	84
	2.1	9	40	71
	2.0	10	25	63
	2.0	10	10	45
Mow August 1	1.8	0	35	86
	2.1	5	20	18
	2.2	7	40	42
	2.0	8	10	77

¹Includes dead larvae, pupae, and adults and live adults.

²Number of seeds in each replication.

³Based on 3 replications of each seed head.

Seeds from plants sprayed July 1 produced a characteristic club shaped radicle and shoot upon germination (Figure 6). It is doubtful that these seedlings could produce plants.

No corroborating evidence was found to support previous findings that seed germination is severely reduced by the presence of R. conicus. It must be emphasized that only plump seed was used for the germination studies and that possibly not enough seed was germinated to come up with conclusive results.



Figure 6. Effect of spraying with 2,4-D amine on *C. nutans* seed germination. Seed from control plants on left and seed from plants sprayed July 1 on right.

SUMMARY

This study was designed to evaluate the effects of spraying with 2,4-D amine and of mowing musk thistle plants on the continued success and establishment of Rhinocyllus conicus and to propose a control program involving R. conicus plus spraying and R. conicus plus mowing. The major findings are:

A. C. nutans

- 1) There is a high natural mortality among musk thistle seedlings. Only 9.5% of the total seedlings in May, 1977, were found as rosettes in August, 1977.
- 2) Mowing musk thistle plants and vegetation during the early part of the growing season has a tendency to enhance seedling survival, probably due to reduced plant competition.
- 3) Musk thistle is best controlled with 2,4-D amine in the seedling-rosette stage in the spring or late fall or in the early bolt to late bud stage, before June 15.

- 4) Musk thistle plants mowed early (June 15 or July 1) will generally grow back allowing new buds to escape the most severe R. conicus infestation.
- 5) Musk thistle plants mowed late (August 1) will produce seed on primary and secondary heads, but not on most tertiary and later heads. There is generally no regrowth when plants are mowed late in the season.
- 6) Musk thistle has been found to require a huge seed load in the soil to compete effectively with surrounding vegetation. Additional work should be done to determine how much seed reduction is necessary to lower musk thistle infestations to more tolerable levels.

B. R. conicus

- 1) Spraying musk thistle plants with 2,4-D amine at any time, does not severely reduce R. conicus survival, but spraying in the spring or late fall is probably best since the weevils are not in seed heads at this time.

- 2) Mowing musk thistle plants when weevils are inside flower heads generally kills all weevils except those which are in or past the early adult stage.
- 3) Mowing when tertiary musk thistle heads are in full bloom combined with high R. conicus infestation per seed head may satisfactorily control musk thistle without significantly reducing the survival of R. conicus.
- 4) Number of R. conicus per musk thistle seed head had little effect on the viability of plump well formed seed.

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APPENDIX

Table 1. Effect of spraying with 2,4-D amine and of mowing on R. conicus survival from flower heads of C. nutans in 1976.

Treatment	Site I			Site II			Site III		
	Total ¹	Live	% Surv.	Total ¹	Live	% Surv.	Total ¹	Live	% Surv.
	<u>R. conicus</u>	Adult Weevils		<u>R. conicus</u>	Adult Weevils		<u>R. conicus</u>	Adult Weevils	
Control	16	16	100	204	193	95	908	707	78
Spray									
July 1	136	102	75	220	138	63	1059	808	76
July 15	151	134	89	365	326	89	598	429	72
Aug. 1	5	4	80	126	94	74	369	297	81
Mow									
July 1	21	0	0	91	0	0	452	0	0
July 15	10	0	0	242	44	18	557	66	12
Aug. 1	41	24	59	259	157	61	1347	820	60

¹Includes dead larvae, pupae and adults and live adults.

Table 2. Effects of spraying with 2,4-D amine and of mowing on R. conicus survival from flower heads of C. nutans in 1977.

Treatment	Site I			Site II			Site III		
	Total ¹	Live	% Surv.	Total ¹	Live	% Surv.	Total ¹	Live	% Surv.
	<u>R. conicus</u>	Adult Weevils		<u>R. conicus</u>	Adult Weevils		<u>R. conicus</u>	Adult Weevils	
Control	144	83	57	124	42	56	771	235	37
Spray									
May 10 ²	-	-	-	-	-	-	-	-	-
June 15	195	111	57	4	4	100	68	24	35
July 1	130	54	42	60	39	65	614	220	36
Oct. 10 ²	-	-	-	-	-	-	-	-	-
Mow									
June 15 ³	14	14	100	20	4	20	215	165	77
July 1	60	0	0	38	0	0	420	8	2
July 15	81	0	0	69	0	0	678	30	4
Aug. 1	140	54	39	56	21	38	665	240	36

¹Includes dead larvae, pupae and adults and live adults.

²Weevils were not in musk thistle heads at the time of treatment.

³R. conicus from regrowth.

Table 3. Effect of spraying with 2,4-D amine and of mowing on R. conicus survival from primary flower heads on C. nutans in 1977.

Treatment	Site I			Site II			Site III		
	Total ¹ R. <u>conicus</u>	Live Adult Weevils	% Surv.	Total ¹ R. <u>conicus</u>	Live Adult Weevils	% Surv.	Total ¹ R. <u>conicus</u>	Live Adult Weevils	% Surv.
Control	90	44	48	24	12	51	278	67	24
Spray May 10 ²	-	-	-	-	-	-	-	-	-
June 15	124	72	58	4	4	100	39	9	23
July 1	72	18	25	20	7	35	194	69	36
Oct. 10 ²	-	-	-	-	-	-	-	-	-
Mow June 15 ³	14	14	100	20	4	20	119	92	77
July 1	55	0	0	37	0	0	237	7	3
July 15	65	0	0	52	0	0	182	0	0
Aug. 1	92	48	52	32	12	38	258	79	31

¹Includes dead larvae, pupae and adults and live adults.

²Weevils were not in musk thistle heads at the time of treatment.

³R. conicus from regrowth.

Table 4. Effects of spraying with 2,4-D amine and of mowing on R. conicus survival from secondary flower heads of C. nutans in 1977.

Treatment	Site I			Site II			Site III		
	Total ¹ R. <u>conicus</u>	Live Adult Weevils	% Surv.	Total ¹ R. <u>conicus</u>	Live Adult Weevils	% Surv.	Total ¹ R. <u>conicus</u>	Live Adult Weevils	% Surv.
Control	50	38	75	32	25	79	472	272	45
Spray May 10 ²	-	-	-	-	-	-	-	-	-
June 15 ³	71	32	45	-	-	-	28	15	54
July 1	53	32	60	25	20	80	307	101	33
Oct. 10 ²	-	-	-	-	-	-	-	-	-
Mow June 15 ⁴	-	-	-	-	-	-	79	57	72
July 1	5	0	0	0	0	0	183	1	1
July 15	16	0	0	13	0	0	479	5	1
Aug. 1	48	6	12	24	7	29	337	142	42

¹Includes dead larvae, pupae and adults and live adults.

²Weevils were not in musk thistle heads at the time of treatment.

³The treatment eliminated secondary heads on Site II.

⁴R. conicus numbers from regrowth.

Table 5. Effects of spraying with 2,4-D amine and of mowing on seed production from flower heads of C. nutans in 1977.

Treatment	Site I		Site II		Site III	
	Average Seeds/hd	No. of Heads	Average Seeds/hd	No. of Heads	Average Seeds/hd	No. of Heads
Control	98	25	113	23	26	37
Spray						
May 10	0	0	0	0	0	0
June 15	8	34	0	3	0	14
July 1	113	26	49	26	11	37
Oct. 10 ¹	0	0	0	0	0	0
Mow						
June 15 ²	16	2	73	11	82	30
July 1	0	14	0	14	0	20
July 15	61	20	87	20	0	31
Aug. 1	31	22	114	25	6	39

¹Sprayed October 10, 1976.

²Seeds and heads from regrowth.

Table 6. Effects of spraying with 2,4-D amine and of mowing on seed production from primary flower heads of C. nutans in 1977.

Treatment	Site I		Site II		Site III	
	Average Seeds/hd	No. of Heads	Average Seeds/hd	No. of Heads	Average Seeds/hd	No. of Heads
Control	70	10	149	9	0	10
Spray						
May 10	0	0	0	0	0	0
June 15	0	10	0	3	0	9
July 1	120	10	69	10	34	11
Oct. 10 ¹	0	0	0	0	0	0
Mow						
June 15 ²	16	2	73	11	104	15
July 1	0	10	0	10	0	10
July 15	77	10	110	10	0	10
Aug. 1	27	9	134	10	0	10

¹Sprayed October 10, 1976.

²Seeds and heads from regrowth.

Table 7. Effects of spraying with 2,4-D amine and of mowing on seed production from secondary flower heads of C. nutans in 1977.

Treatment	Site I		Site II		Site III	
	Average Seeds/hd	No. of Heads	Average Seeds/hd	No. of Heads	Average Seeds/hd	No. of Heads
Control	112	15	85	14	0	20
Spray						
May 10	0	0	0	0	0	0
June 15	8	13	0	0	0	5
July 1	94	16	45	12	0	20
Oct. 10 ¹	0	0	0	0	0	0
Mow						
June 15	0	0	0	0	78	11
July 1	0	4	0	4	0	10
July 15	45	10	64	10	1	20
Aug. 1	32	13	100	14	1	20

¹Sprayed October 10, 1976.

²Seeds and heads from regrowth.

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