Effects of stress inducing factors on musk thistle (Carduus nutans L.) including--grass competition, Rhinocyllus conicus Froel., terminal flower loss, and insecticides

by Daniel Robert Corr

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Entomology
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Abstract:
Musk thistle (Carduus nutans L.) is a common colonizer of overgrazed pastures within the Gallatin Valley despite the success of chemical and biological control measures. Research was undertaken to evaluate the thistle's response to relieved grazing and other stress inducing factors in 1985 and 1986.

Four individual sites within the Gallatin Valley were chosen because they had been continually overgrazed and had high levels of musk thistle infestation. Areas of approximately 1000 m2 were fenced to exclude grazing at each site. Individual plants were tagged and monitored both inside and outside these enclosures. Thistle damage by Rhinocyllus conicus Froel. increased as a result of relieved grazing. The types of seed heads attacked by the weevil was dependant upon thistle growth as affected by rainfall and temperature. During drier years (1985) thistles responded to increased plant competition by concentrating energy reserves within terminal and secondary seed heads. When rainfall was more plentiful (1986) stressed thistles produced more but smaller tertiary seed heads.

The major effect of relieved grazing on musk thistle was to reduce seedling numbers and eliminate microsites needed to promote rosette establishment.. Large musk thistles dropped more seeds to their base and rosettes preferred to establish around small-canopied adults.

A substantial number of tagged, field grown thistles lost their terminal seed heads during the summer of 1985. These thistles had significantly lower growth and reproduction especially under conditions of relieved grazing. Thistles grown in the greenhouse which lost their terminal flowers after full bloom had an increase in lateral branch production.

The insecticide, aldicarb, was applied to individual field grown thistles in an attempt to exclude weevils and. isolate the effects of plant competition. To assess the effects of insecticides on thistle growth and reproduction, thistle rosettes were collected in the field, potted, and placed in the greenhouse. Thistles were placed within blocks and divided into the following treatments: 1) control, 2) low aldicarb, 3) high aldicarb; 4) malathion, 5) low aldicarb plus malathion. Thistle growth was monitored and thistles were harvested and separated to determine vegetative and reproductive biomass.

Aldicarb application at recommended dosages produced no significant effects. Synergistic effects caused by the combination of aldicarb and malathion were significant, enhancing the growth and reproduction of musk thistle.

EFFECTS OF STRESS INDUCING FACTORS ON MUSK THISTLE (*CARDUUS NUTANS* L.) INCLUDING: GRASS COMPETITION, *RHINOCYLLUS CONICUS* FROEL., TERMINAL FLOWER LOSS, AND INSECTICIDES

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Musk thistle (Carduus nutans L.) is a common colonizer of overgrazed pastures within the Gallatin Valley despite the success of chemical and biological control measures. Research was undertaken to evaluate the thistle's response to relieved grazing and other stress inducing factors in 1985 and 1986.

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CHAPTER 1

LITERATURE REVIEW

Introduction

Carduus nutans L., commonly called musk thistle, is a spiny, unpalatable weed which has become widely established on western ranges. The thistle is either a winter annual or biennial and is found in overgrazed pastures, disturbed areas, and all types of land except deserts, dense forests, and newly cultivated lands (Rees, 1982). It is a prolific seed producer and can spread into both native ranges and irrigated pastures (Hull and Evans, 1973). A vigorous competitor, it reduces yields of other pasture species by competing for light, water, and nutrients (Boldt, 1979).

Musk thistle, like most weedy species of the genera *Carduus*, *Cirsium*, and *Silybum*, probably originated in southern Europe since so many endemic species are found there (Kasmi, 1964). It becomes economically important when introduced into new areas of similar climate that lack its original compliment of natural enemies (Schroeder, 1980).

This plant was introduced into the United States at least 100 years ago, but was not reported as a weed until the early 1940's (McCarty, 1978). Its earliest recorded appearance was in the state of Pennsylvania (Stuckey and Forsyth, 1971). At least 40 of the adjacent 48 states have recorded its presence, and 12% of these states rate their infestations as economically important (Dunn, 1976; Boldt and Kok, 1982). Harris (1984) observed that musk thistle densities of

150,000/ha ($15/m^2$) were sufficient to totally eliminate cattle grazing within a pasture.

A few endophagous insects, native to North America, are associated with musk thistle (e.g. Papaipema nebris Guenee, Platyptilia carduidactyla Riley, and Homoeosoma ellectellum Hulst). However, these lepidopteran insects have been rarely sampled and are therefore considered transient species which are of little help in controlling the thistle (Morihara and Balsbaugh, 1976).

The growth and phenology of musk thistle is strongly influenced by environmental conditions. Thistles transplanted into pastures which had been denuded by herbicides had enhanced growth rates (Edmonds and Popay, 1983). North American thistles demonstrate a wide range of phenotypic plasticity having winter annual as well as spring and autumn biennial life cycles (Lee and Hamrick, 1983). Early autumn germination and establishment is necessary for winter annual behavior while late autumn or spring germination causes biennial cycling. In New Zealand, where annual cycling is common for musk thistle (Popay, et al., 1979), good rosette establishment is the key to winter annual cycling (Popay and Thompson, 1979). This type of life cycle was most prevalent when the thistle experienced low levels of competition in sparse vegetation (Popay and Thompson, 1980).

Methods of Musk Thistle Control

The use of the herbicide (2,4-dichlorophenoxy) acetic acid alkanolamine was the traditional chemical method of controlling musk thistle (Roeth, 1980). This herbicide was found to have its greatest effect when applied during the spring to pre-bolting rosettes (Roeth, 1980). Rotation of this herbicide with 3,6-dichloropicolinic acid was reported to be the most effective method for long term chemical control but the natural reoccupation of treated sites by perennial grasses was extremely slow (Reece, 1983). Applications of ammonium nitrate fertilizer at these same sites was found to increase thistles more than perennial grasses (Reece, 1983). Due to high application costs and the inconsistent affects of herbicides, biological control of this weed has been initiated.

Rhinocyllus conicus, a seed head inhabiting weevil and one of a number of phytophagous species attacking the flower heads of Carduus nutans in Europe, was reported to have excellent potential as a biological control agent (Zwolfer, 1980). This weevil has adapted, as a result of competition with other European insects, toward oviposition on a broad range of Carduus populations. This "compensation strategy" has helped the species spread over large bodies of thistle-infested land in Europe and North America as well (Zwolfer, 1980).

This weevil was released in California in 1969 as a biological control agent on milk thistle, Silybum marianum L. (Hawkes, et al., 1972). It overwintered and fed on thistle foliage for 2 to 3 weeks in the spring before oviposition on the lower surface of seed head bracts. Larvae burrowed into the seed head and damaged the receptacle of the flower. Only one generation per summer was observed and was reportedly due to early senescence of the thistle (Hawkes, et al., 1972).

In the Gallatin Valley of Montana, releases of R. conicus occurred gradually between 1969-73. In 1974 Rees reported that the weevil had established successfully over a broad range. Overcrowding within seed heads was reported and larvae feeding within the top of the thistle's stem resulted in abortion of terminal heads. Reduction in musk thistle seed production and seedling densities was reported by Rees in 1977. Populations are now often at saturation levels on some sites (Rees, 1980).

The weevil was released in Nebraska in 1972 where larval densities of 30 or more per seed head prevented seed development (McCarty, et al., 1981). Despite high weevil densities, a period of 7 to 10 years was required for the weevil to significantly reduce musk thistle populations (McCarty, et al., 1981).

Early establishment of R. conicus on musk thistle varied according to climate and weevil mortality rates. In Virginia, the first weevils introduced, suffered high mortality due to egg masses being damaged by wind and rain (Surles and Kok, 1976). Just six years later, the weevil had established well enough that high larval mortality and reduced adult size due to overcrowded conditions within flower heads was reported (Surles, et al., 1981). Weevil crowding caused complete abortion of thistle heads at high larval densities with subsequent death of the larvae (Dowd and Kok, 1981).

Releases of R. conicus in Canada in 1975 were very successful causing damage to 95% of thistles at release sites within three years following release. Eighty percent of the weevils eggs were found on the terminal head. A false, second weevil generation was described but this was due to the release of laboratory mated weevils in late August (Laing and Heels, 1978).

Problems Associated With Musk Thistle Control

Considerable hybridization occurs between species and subspecies in the Carduus nutans group and therefore their exact identification is difficult (Kazmi, 1964). Since the weevil R. conicus accepts all taxa within the group researchers have used C. nutans in a broad sense to represent all taxa in the group (McCarty, 1983). Differences between two species within the Carduus genus in terms of thistle growth and weevil attack were found to be insignificant in studies conducted in Montana (Rees, 1986).

The relatively broad host range of R. conicus and its ability to attack native thistles has caused some concern among researchers (Turner, et al., 1987). There seems to be a possibility that the seed head weevil may damage populations of native thistles where musk thistle densities are low (Zwolfer and Preiss, 1983). Turner et al. (1987) recorded emergence of adult R. conicus from 12 species of native, non-target Cirsium thistles in California. Rees (1977) has also reported the utilization of native thistles (Cirsium arvense (L.) Scop., C. vulgare (Savi) Tenore, and C. undulatum (Nutt.) Spreng.) by R. conicus, however damage to the non-target thistles was found to be minimal. The lack of significant weevil damage to native thistles was reported to be primarily due to a lack of synchrony between thistle bud production and high spring weevil emergence (Rees, 1979). Under different environmental conditions the results have been different as French strains of this weevil, have been found to show a preference for Cirsium vulgare over Carduus nutans in Europe (Zwolfer and Preiss, 1983).

McCarty and Lamp (1982) reported that the plant persisted on disturbed sites due to residual seed production by unattacked lateral heads.

The continued persistence of musk thistle has prompted the introduction of another thistle feeding weevil, Trichosirocalus horridus (Panz.). This weevil was imported to the U.S. from Italy in 1974 and has established in Virginia (Kok and Trumble, 1979). This beetle emerges earlier in the season than R. conicus, feeds on the rosette stage of the plant, and disrupts apical dominance. T. horridus will hopefully complement the effects of R. conicus, but establishment has been slow.

The success of R. conicus as a biological control agent led to efforts to integrate herbicide applications with weevil attack. At recommended doses, applications of 2,4-D to adult female weevils showed no significant increase in mortality (Trumble and Kok, 1980). However, damage to adult musk thistle plants from 2,4-D applications during the spring caused near total mortality of larva within developing heads (Rees, 1977). Rees recommended that 2,4-D be applied during the fall after weevil oviposition and development has been completed.

Carduus nutans may retard natural succession of native grassland species (Higgins and Baker, 1982). Musk thistle is unpalatable to most herbivores and thus it remains on disturbed sites for an extended period of time (McCambridge, et al., 1982). The thistle has a tendency to remain on overgrazed sites despite successful chemical and biological efforts to control it.

CHAPTER 2

EFFECTS OF RELIEVED GRAZING AND *RHINOCYLLUS CONICUS* FROEL. ON MUSK THISTLE

Introduction

Nonconventional management strategies for controlling musk thistle have focused on the importance of fostering good stands of competing grasses to stress the thistle and prevent seed set. Rotational grazing and fencing of drought stricken pastures has been recommended to help hasten the decline of thistle populations (Koller, 1979; Hartridge, 1979). Popay and Thompson (1980) reported that increased plant competition in pastures resulted in reduced seed germination and high mortality of mature thistles in New Zealand. Rapid reductions in thistle populations on ungrazed weevil release sites in Kansas (Horber, 1980) have demonstrated the success of integrating weevil releases and grazing management.

Given adequate moisture, weevils tend to develop best in thistles growing in fertile soil, but can also develop in plants growing in poor soil (Dowd and Kok, 1983). A four year study of nutrient poor, disturbed sites in Canada revealed that a reduction in seed production caused by *R. conicus* in combination with reduced soil disturbance eliminated musk thistle on these sites (Harris, 1984). Elimination of grazing reduced, by 50%, the time necessary for thistle control using the weevil alone (Harris, 1984). Tall fescue (*Festuca arundinacea* Schreb.) in combination with *R. conicus* caused a reduction in thistle growth and seed production on cultivated plots as compared to the effects of the weevil alone (Kok, et al., 1986).

Rees (1979) found that reductions in musk thistle populations within the Gallatin Valley were steady over the first four years following initial weevil releases and that populations of R. conicus had extended beyond the valley. Despite well established populations of R. conicus in the Gallatin valley and other areas, isolated infestations of the thistle have persisted on disturbed or overgrazed lands.

The mating period of the weevil has been reported to fluctuate. A 28 day mating period in 1976 was followed by a 16 day mating period in 1977 (Rees, 1979). Since musk thistle phenology varies with varying environmental conditions (Lee and Hamrick, 1983; Smith, et al., 1984) and R. conicus prefers the bud stage of musk thistle for oviposition (Surles and Kok, 1976) the relief of grazing may cause variation in the synchrony between weevil and thistle.

The purpose of this study was to determine the effects of R. conicus and relieved grazing on the dynamics of musk thistle in uncultivated, natural pasture in foothill grasslands of Montana.

Methods and Materials

Study sites

Four grazed pastures having substantial musk thistle infestations were chosen for this study. All sites were in the Gallatin Valley of Montana. In the summer of 1985, an ca. 1000 m^2 area was fenced off to remove grazing at each site. Three sites were fenced in mid-June of 1985. Site no. 1, the "Belgrade" site, was located near Belgrade, MT.

(NE1/16 of NE1/8 of NW1/4 of Section 7, R4E T1S) at an elevation of 4400 ft. Site no. 2, the "Amsterdam" site, was located near Amsterdam, MT (NW1/16 of NW1/8 of SE1/4 of Section 33, R3E T1S), elevation 4600 ft.. Site no. 3, the "Bozeman" site, was located near Bozeman, MT (SE1/16 of NW1/8 of NW1/4 of Section 5, R6E T2S), elevation 4760 ft.. This site was further divided according to slope into a wetter "swale" area and a drier "ridge" area. Site no. 4, the "Four Corners" site, was located near Four Corners, MT (NE1/16 of SE1/8 of NE1/4 of Section 14, R4E T2S) at an elevation of 4720 ft. and was not fenced until late August of 1985.

Initial plant coverage

Twenty 2 dm x 5 dm frames placed along two randomly chosen transects (both within and outside the fenced areas) were used to determine the initial plant composition, plant coverage, and frequency in late July of 1985.

Standing crop

In the fall of 1985, samples were clipped from six rectangular 1/2 m^2 frames placed along random transects both within and outside the fenced areas at all sites. All plant material within these frames was clipped, separated into plant type categories, bagged, dried for 10 days at 35° C, and weighed. This procedure was repeated with 15 frames per transect on three of the five sites in the fall of 1986.

1985 thistle growth and weevil effects

In late June of 1985, four randomly chosen, 25 m transect lines were run at both the Belgrade and Amsterdam sites. Two of these transects were within the fenced area and two were outside. The Bozeman site had four subsites: ridge enclosed, ridge open, swale enclosed, swale open. Each was sampled via quadrats placed along two 25 m transects. Samples to assess thistle growth and weevil effects were not taken at the Four Corners site.

Twenty adult musk thistle plants along each transect were flagged at approximately 1 m intervals. Alternate thistles along these transects were treated with the systemic insecticide aldicarb at a rate of 10 Kg/A or 0.233 gm/plant to eliminate weevil damage. These sites were visited at weekly intervals throughout the summer to monitor aspects of thistle growth.

Treated and untreated plants were clipped at the base and plant parts were separated into three categories: 1) terminal seed head, 2) lateral seed heads, 3) vegetative stems and lateral branches. These were bagged, dried for 10 days at 35° C and weighed. Seed heads were later dismantled and the number of cells produced by weevil pupation as well as the number of mature seeds remaining were determined.

1986 thistle growth and weevil effects

Transects established in 1985 were revisited in early May of 1986. In addition, a fifth set of transect lines were established at the Four Corners site. Twenty musk thistle rosettes were flagged at 1 m intervals along all transects. Upon bolting and appearance of the terminal bud, aldicarb was again applied to alternate plants along all transects. The sites were visited weekly to monitor both the growth of tagged thistles and the general rate of weevil development within random untagged thistles.

Harvest of seed heads began in early August at all sites. When weevil damaged seed heads were determined to contain fully developed adults and prior to weevil emergence they were harvested, separated into three categories: 1) terminal head; 2) secondary lateral heads; 3) tertiary lateral heads, and bagged. When undamaged seed heads were determined to be fully mature and prior to seed release they were harvested and separated as to categories above.

In late August of 1986, all plants at each site were clipped at the base and plant parts were separated into the following categories: 1) remaining tertiary seed heads and 2) vegetative stems and laterals. These were bagged and, along with previously collected seed heads, dried for 10 days at 35°C and weighed. Seed heads were later dismantled and the number of adult weevils and mature seeds determined.

Statistical analysis

Multifactor analysis of variance was used to determine differences among treatments at a significance level of 0.05. Additional mean comparisons were obtained by using a Tukey's Studentized Range test, also at a significance level of 0.05. Significant interactions between treatments were further analyzed by comparing graphs produced from individual treatment combination means (Neter, et al., 1985).

Results and Discussion

Initial coverage

Grasses provided the highest percent coverage at all sites. The perennial grass, Poa pratensis L., was dominant at four of five plots while the annual, Bromus tectorum L., dominated the Belgrade site (Table 1). The presence of B. tectorum indicated that the Belgrade site had a history of overgrazing (McCambridge, et al., 1982).

The Belgrade site and the Bozeman ridge site had the lowest initial total grass coverage (Table 1). Prior to fencing, both sites had greater grass coverage in the ungrazed areas than in the grazed areas (Belgrade site, $P < 0.05$; Bozeman site, $P < 0.01$). There was also lower Carduus nutans coverage in these ungrazed areas ($P < 0.05$, Table 1). Since high grass coverage tends to inhibit musk thistle infestations (Edmonds and Popay, 1983), it appeared that the grazed areas on these two sites may have been preferentially used by cattle prior to fencing. This should be taken into consideration when interpreting standing crop comparisons below.

The other three sites showed no initial difference in grass coverage between grazed and ungrazed areas. There were, however, significant but inconsistent differences in initial musk thistle coverage ($P < 0.05$, Table 1).

At the Amsterdam site the ungrazed area had lower total coverage due to litter than did the grazed area as well as the lowest thistle coverage. Musk thistle seeds have been shown to retain germinability for extended periods if covered by litter (Popay and Thompson, 1979; Burnside, et al., 1981). Hamrick and Lee (1987) found increased germination of musk thistle seeds due to reduced evaporation from low levels of litter.

Unlike the other three sites, the ungrazed areas of the Bozeman swale site and the Four Corners site had higher initial musk thistle coverage than grazed areas ($P < 0.05$, Table 1). Ungrazed areas on these sites had a significantly higher total forb coverage also ($P < 0.05$, Table 1). The ungrazed Four Corners site had 5.9% total forb coverage with 5.8% C. nutans while the ungrazed Bozeman swale site had 19.5% total forb coverage with only 3% being C. nutans (Table 1). The fenced area at the Four Corners site was located next to a commonly used feeding and watering area. Therefore, greater disturbance in this area accounted for its greater C. nutans coverage. In contrast, the ungrazed portion of the Bozeman swale site appeared to favor all forb species, a component of which was musk thistle.

The initial differences in coverage at these sites can be used to explain other results obtained during this study.

1985 standing crop

Comparisons based on standing crop data for the summer of 1985 were restricted to three of the five sites studied. The Four Corners site was eliminated due to late fencing which prevented any grazing comparisons at this site. The Belgrade site had extensive damage to musk thistle and other forb species due to ground squirrel feeding activity. These sites were also eliminated from thistle growth and weevil effect studies done during the summer of 1985.

Table 1. 1985 vegetation composition in grazed and ungrazed musk thistle sites in Montana. Centered dots indicate the species did not occur at that site. See Appendix for scientific and common names corresponding to plant species codes.

	Belgrade				Four Corners				Amsterdam			
	Grazed		Ungrazed		Grazed		Ungrazed		Grazed		Ungrazed	
	Mean % Cover ± SD (% Frequency)											
Total Grass	28.1a		50.5b		63.3b		64.4b		57.3b		58.1b	
Agrsmi	4.9 ± 4.3	(87)	1.4 ± 1.8	(60)	• •	•	• •	•	10.5 ± 6.2	(100)	23.1 ± 7.0	(100)
Broine	• •	•	• •	•	24.7 ± 6.7	(100)	23.3 ± 7.4	(100)	• •	•	• •	•
Brotec	22.9 ±11.6	(100)	29.2 ±10.4	(100)	• •	•	• •	•	• •	•	• •	•
Carste	0.1 ± 0.4	(3)	0.4 ± 0.7	(27)	• •	•	• •	•	• •	•	• •	•
Carpra	• •	•	• •	•	• •	•	• •	•	0.7 ± 2.8	(8)	0.0 ± 0.0	(0)
Dacglo	• •	•	• •	•	• •	•	• •	•	• •	•	• •	•
Koecri	0.1 ± 0.4	(7)	0.0 ± 0.1	(3)	• •	•	• •	•	• •	•	• •	•
Stivir	• •	•	• •	•	• •	•	• •	•	0.2 ± 0.6	(10)	0.0 ± 0.2	(3)
Poapra	0.2 ± 4.4	(100)	19.5 ±13.4	(97)	39.6 ± 9.5	(100)	41.1 ± 9.3	(100)	45.9 ±14.2	(100)	35.0 ± 9.3	(100)
Bare Ground	10.1 ± 8.7	(73)	9.5 ±11.1	(43)	24.6 ± 9.8	(100)	16.9 ± 7.8	(98)	7.9 ± 7.0	(80)	14.6 ± 9.2	(88)
Litter	20.1 ± 9.7a	(100)	23.1 ± 7.8a	(100)	10.9 ± 5.2a	(100)	15.6 ± 8.6a	(100)	30.4 ±11.6b	(100)	17.8 ± 8.5a	(100)
Cryptogams	30.1 ± 9.1	(100)	17.9 ±10.9	(100)	9.8 ± 6.8	(90)	10.7 ± 9.3	(83)	2.0 ± 4.0	(35)	9.3 ± 8.5	(85)