



Seed versus microsite limitation of Dalmatian toadflax (*Linaria genistifolia* ssp. *dalmatica*), extension of biological control agents for yellow toadflax (*Linaria vulgaris*), and a conceptual Dalmatian toadflax life history model

by Matthew James Donovan Grieshop

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Entomology

Montana State University

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Abstract:

Seed versus microsite limitation of Dalmatian toadflax was examined in order to establish whether or not the weed might be readily controlled by limiting its seed production. The extension objective of the thesis was done in order to facilitate both the establishment of natural enemies as well as producer understanding of the biological control process. Finally, a life history model was created as a means of better understanding Dalmatian toadflax population dynamics beyond seed versus microsite limitation.

Experimental methods included two years of repeated observations on plant quadrats at two field sites and partial addition series experiments. The observational field study examined treatments that added additional Dalmatian toadflax seeds to quadrats, excluded interspecific plant competition, and excluded insect herbivory from Dalmatian toadflax. Extension methods included attendance of regular meetings with the Blackfoot Challenge, release of natural enemies of yellow toadflax, and the creation of a brochure. The life history model was created using a pre-existing model as a framework and two simulations were run using data collected from the two field sites.

Dalmatian toadflax was determined to be more microsite than seed limited in dry rangeland conditions. Plant competition was identified as the major factor limiting seedling recruitment of new Dalmatian toadflax plants, while additional seeding and insect herbivory did not appear to affect seedling recruitment.

Extension objectives were met through producer cooperation and the creation of an eight page full-color brochure highlighting the biological control of yellow toadflax.

Model output suggested that Dalmatian toadflax density was increasing at one site and decreasing at the other. Model output was corroborated by independent plant-transect readings performed at both sites. A discussion of the implications of these results suggested that Dalmatian toadflax would probably be best managed using tactics that increase adult stem mortality as opposed to tactics which limit the number of seeds per adult stem. In the context of biological control, the results suggested that natural enemies of Dalmatian toadflax that attack reproductive structures were likely to be less effective than natural enemies that attack stem or root structures.

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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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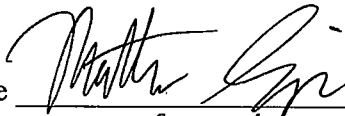
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## TABLE OF CONTENTS

1. INTRODUCTION.....	1
Seedling Recruitment in Dalmatian Toadflax.....	4
Producer Education through the Extension of Biological Control of Dalmatian Toadflax.....	5
Modeling Population Dynamics Of Dalmatian Toadflax.....	8
2. LITERATURE REVIEW.....	10
Dalmatian Toadflax Biology and Distribution.....	10
Seed Versus Microsite Limitation of Dalmatian Toadflax.....	12
3. MATERIALS AND METHODS.....	15
Field Study of Dalmatian Toadflax Seedling Recruitment and Mortality.....	15
Experimental Design.....	15
Site And Block Descriptions.....	15
Quadrat Frame Construction and Sampling Procedure.....	17
Overseeding Rate Calculation and Field Application.....	19
Plant Competition Exclusion Techniques.....	20
Natural Enemy Augmentation, Exclusion, and Presence Measurements.....	20
Analysis.....	22
Materials and Methods for the Partial Addition Series.....	24
Materials and Methods for the Phyto-toxicity Trial.....	26
Materials and Methods for the Seedling Emergence Trial.....	27
Materials and Methods for Soil Sample Processing/Seed Counting.....	29
Materials and Methods for the Extension Project.....	30
The Blackfoot Challenge.....	30
Materials and Methods for Boxcar Model Construction.....	33
4. RESULTS.....	36
Results for the Two Year Field Trial.....	36
Overall Trends/Data Summary.....	36
Mixed Model Repeated Measures.....	36
Model Validation.....	36
Total Seedling Counts.....	52

Cumulative Seedling Emergence .....	57
Cumulative Proportional Mortality .....	60
Seedheads per Stem .....	62
ANOVA's within Sampling Dates .....	65
Total Seedling Counts .....	65
Cumulative Seedling Emergence .....	69
Cumulative Proportional Mortality .....	72
Seedheads per Stem .....	76
Results for the Partial Addition Series Experiment .....	80
Results from the Orthene Phyto-toxicity Trial .....	91
Results for the Seed Emergence Trial .....	93
Results for Seedbank Analysis .....	95
Seed Production per Seed Capsule .....	99
Results of Insect Sweeps .....	99
Results of Extension .....	99
Results of the Boxcar Model .....	104
 5. DISCUSSION .....	 108
Field Trial .....	108
Discussion of the Partial Addition Series .....	111
Discussion of Model Output .....	114
Synergy of Experiments .....	118
 REFERENCES .....	 123
 APPENDIX .....	 129

## LIST OF TABLES

Table	Page
1. Validation and covariant parameters for the mixed model repeated measures of total seedling counts (Canyon Ferry 1997) .....	45
2. Validation and covariant parameters for the mixed model repeated measures of total seedling counts (Wyola 1997).....	45
3. Validation and covariant parameters for the mixed model repeated measures of total seedling counts (Canyon Ferry 1998) .....	46
4. Validation and covariant parameters for the mixed model repeated measures of total seedling counts (Wyola 1998).....	46
5. Validation and covariant parameters for the mixed model repeated measures of cumulative seedling emergence (Canyon Ferry 1997) .....	47
6. Validation and covariant parameters for the mixed model repeated measures of cumulative seedling emergence (Wyola 1997) .....	47
7. Validation and covariant parameters for the mixed model repeated measures of cumulative seedling emergence (Canyon Ferry 1998) .....	48
8. Validation and covariant parameters for the mixed model repeated measures of cumulative seedling emergence (Wyola 1998) .....	48
9. Validation and covariant parameters for the mixed model repeated measures of cumulative proportional seedling mortality (Canyon Ferry 1997).....	49

10. Validation and covariant parameters for the mixed model repeated measures of cumulative proportional seedling mortality (Wyola 1997).....	49
11. Validation and covariant parameters for the mixed model repeated measures of cumulative proportional seedling mortality (Canyon Ferry 1998).....	50
12. Validation and covariant parameters for the mixed model repeated measures of cumulative proportional seedling mortality (Wyola 1998).....	50
13. Validation and covariant parameters for the mixed model repeated measures of seedheads per stem (Canyon Ferry 1997).....	51
14. Validation and covariant parameters for the mixed model repeated measures of seedheads per stem (Wyola 1997).....	51
15. Validation and covariant parameters for the mixed model repeated measures of seedheads per stem (Canyon Ferry 1998).....	52
16. Validation and covariant parameters for the mixed model repeated measures of seedheads per stem (Wyola 1998).....	52
17. Mixed model repeated measures results for total seedling counts (Canyon Ferry 1997) .....	54
18. Mixed model repeated measures results for total seedling counts (Wyola 1997) .....	54
19. Significant t-test block comparisons for total seedling count mixed model repeated measures ( $\alpha = 0.05$ , Wyola1997).....	54
20. Significant t-test block-plant competition interaction comparisons for total seedling count mixed model repeated measures ( $\alpha = 0.05$ , Wyola1997).....	55
21. Significant t-test block-insecticide interaction comparisons for total seedling count mixed model repeated measures ( $\alpha = 0.05$ , Wyola1997).....	55

22. Mixed model repeated measures results for total seedling counts (Canyon Ferry 1998) .....	56
23. Significant t-test seeding-plant competition interaction comparisons for total seedling count mixed model repeated measures ( $\alpha = 0.05$ , Canyon Ferry 1998) .....	56
24. Significant t-test seeding-insecticide interaction comparisons for total seedling count mixed model repeated measures ( $\alpha = 0.05$ , Canyon Ferry 1998) .....	56
25. Mixed model repeated measures results for total seedling counts (Wyola 1998) .....	57
26. Mixed model repeated measures results for cumulative seedling emergence (Canyon Ferry 1997) .....	58
27. Mixed model repeated measures results for cumulative seedling emergence (Wyola 1997) .....	58
28. Mixed model repeated measures results for cumulative seedling emergence (Canyon Ferry 1998) .....	59
29. Significant t-test seeding-plant competition interaction comparisons for cumulative seedling emergence mixed model repeated measures ( $\alpha = 0.05$ , Canyon Ferry 1998) .....	59
30. Significant t-test seeding-insecticide interaction comparisons for cumulative seedling emergence mixed model repeated measures ( $\alpha = 0.05$ , Canyon Ferry 1998) .....	59
31. Mixed model repeated measures results for cumulative seedling emergence (Wyola 1998) .....	60
32. Mixed model repeated measures results for cumulative proportional seedling mortality (Canyon Ferry 1997) .....	60
33. Mixed model repeated measures results for cumulative proportional seedling mortality (Wyola 1997) .....	61
34. Mixed model repeated measures results for cumulative proportional seedling mortality (Canyon Ferry 1998) .....	61
35. Mixed model repeated measures results for cumulative proportional seedling mortality (Wyola 1998) .....	62

36. Mixed model repeated measures results for seedheads per stem (Canyon Ferry 1997) .....	63
37. Mixed model repeated measures results for seedheads per stem (Wyola 1997) .....	63
38. Significant t-test block-insecticide interaction comparisons for seedheads per stem mixed model repeated measures ( $\alpha = 0.05$ , Wyola 1997) .....	64
39. Significant t-test plant competition-insecticide interaction comparisons for seedheads per stem mixed model repeated measures ( $\alpha = 0.05$ , Wyola 1997) .....	64
40. Mixed model repeated measures results for seedheads per stem (Canyon Ferry 1998) .....	64
41. Mixed model repeated measures results for seedheads per stem (Wyola 1998) .....	65
42. P-values for within date ANOVA main effects and interactions for total seedling counts ( $\alpha = 0.05$ , Canyon Ferry 1997) .....	66
43. P-values for within date ANOVA main effects and interactions for total seedling counts ( $\alpha = 0.05$ , Wyola 1997) .....	67
44. P-values for within date ANOVA main effects and interactions for total seedling counts ( $\alpha = 0.05$ , Canyon Ferry 1998) .....	68
45. P-values for within date ANOVA main effects and interactions for total seedling counts ( $\alpha = 0.05$ , Wyola 1998) .....	69
46. P-values for within date ANOVA main effects and interactions for cumulative seedling emergence ( $\alpha = 0.05$ , Canyon Ferry 1997) .....	70
47. P-values for within date ANOVA main effects and interactions for cumulative seedling emergence ( $\alpha = 0.05$ , Wyola 1997) .....	70

48. P-values for within date ANOVA main effects and interactions for cumulative seedling emergence ( $\alpha = 0.05$ , Canyon Ferry 1998).....	71
49. P-values for within date ANOVA main effects and interactions for cumulative seedling emergence ( $\alpha = 0.05$ , Wyola 1998).....	72
50. P-values for within date ANOVA main effects and interactions for cumulative proportional seedling mortality ( $\alpha = 0.05$ , Canyon Ferry 1997) .....	73
51. P-values for within date ANOVA main effects and interactions for cumulative proportional seedling mortality ( $\alpha = 0.05$ , Wyola 1997) .....	74
52. P-values for within date ANOVA main effects and interactions for cumulative proportional seedling mortality ( $\alpha = 0.05$ , Canyon Ferry 1998) .....	75
53. P-values for within date ANOVA main effects and interactions for cumulative proportional seedling mortality ( $\alpha = 0.05$ , Wyola 1998) .....	76
54. P-values for within date ANOVA main effects and interactions for seedheads per stem ( $\alpha = 0.05$ , Canyon Ferry 1997) .....	77
55. P-values for within date ANOVA main effects and interactions for seedheads per stem ( $\alpha = 0.05$ , Wyola 1997).....	78
56. P-values for within date ANOVA main effects and interactions for seedheads per stem ( $\alpha = 0.05$ , Canyon Ferry 1998) .....	79
57. P-values for within date ANOVA main effects and interactions for seedheads per stem ( $\alpha = 0.05$ , Wyola 1998).....	80
58. ANOVA results for mean number of Dalmatian toadflax stems (Canyon Ferry 1998).....	84

59. ANOVA results for mean Dalmatian toadflax percent cover (Canyon Ferry 1998).....	84
60. ANOVA results for Dalmatian toadflax above-ground dry biomass (Canyon Ferry 1998).....	88
61. ANOVA results for mean number of Dalmatian toadflax stems (MSU Post Farm 1998).....	88
62. ANOVA results for mean Dalmatian toadflax percent cover (MSU Post Farm 1998).....	88
63. Student Neuman-Keuls multiple comparison for Dalmatian toadflax total percent cover by Dalmatian toadflax seeding level ( $\alpha = 0.05$ , MSU Post Farm 1998).....	89
64. ANOVA results for Dalmatian toadflax above-ground dry biomass (MSU Post Farm 1998).....	89
65. Student Neuman-Keuls multiple comparison of Dalmatian toadflax above-ground dry biomass by Dalmatian toadflax seeding level ( $\alpha = 0.05$ , MSU Post Farm 1998).....	89
66. ANOVA results for mean number of cheatgrass stems (Canyon Ferry 1998).....	91
67. Student Neuman-Keuls multiple comparison of mean number of cheatgrass stems by cheatgrass factor ( $\alpha = 0.05$ , Canyon Ferry 1998).....	91
68. ANOVA results for mean temperatures across replicates.....	93
69. ANOVA results for mean percent total emergence among seed sources.....	93
70. Student Neuman-Kuels multiple comparison for mean percent total emergence among seed sources ( $\alpha = 0.05$ ).....	95
71. ANOVA results of number of seeds obtained from A strata soil samples among blocks and overseeding treatments (Canyon Ferry 1998).....	95
72. ANOVA results of number of seeds obtained from B strata soil samples among blocks and overseeding treatments (Canyon Ferry 1998).....	98

73. ANOVA results of number of seeds obtained from A strata soil samples among blocks and overseeding treatments (Wyola 1998) .....	98
74. Student Neuman-Keuls multiple comparison of number of seeds among blocks of A strata soil samples ( $\alpha = 0.05$ , Wyola 1998).....	98
75. ANOVA results of number of seeds obtained from B strata soil samples among blocks and overseeding treatments (Wyola 1998) .....	98
76. Extension presentations given to the Blackfoot Challenge group (1997-1998).....	102
77. Parameters used in boxcar model simulations for the Canyon Ferry and Wyola research sites.....	106

## LIST OF FIGURES

Figure	Page
1. Quadrat frame diagram .....	18
2. Mean Total Dalmatian Toadflax Seedlings by Julian Date for the Eight Treatments Over Both Years (Canyon Ferry) .....	37
3. Mean Total Dalmatian Toadflax Seedlings by Julian Date for the Eight Treatments Over Both Years (Wyola) .....	38
4. Mean Dalmatian Toadflax Cumulative Seedling Germination by Julian Date for the Eight Treatments Over Both Years (Canyon Ferry) .....	39
5. Mean Dalmatian Toadflax Cumulative Seedling Germination by Julian Date for the Eight Treatments Over Both Years (Wyola) .....	40
6. Mean Dalmatian Toadflax Cumulative Proportional Seedling Mortality by Julian Date for the Eight Treatments Over Both Years (Canyon Ferry) .....	41
7. Mean Dalmatian Toadflax Cumulative Proportional Seedling Mortality by Julian Date for the Eight Treatments Over Both Years (Wyola) .....	42
8. Mean Dalmatian Toadflax Seedheads per Stem by Julian Date for the Eight Treatments Over Both Years (Canyon Ferry) .....	43
9. Mean Dalmatian Toadflax Seedheads per Stem by Julian Date for the Eight Treatments Over Both Years (Wyola) .....	44
10. Partial Addition Series; Mean Number of Dalmatian Toadflax Stems at the Canyon Ferry Site (1998) .....	81
11. Partial Addition Series; Dalmatian Toadflax Mean Percent Cover at the Canyon Ferry Site (1998) .....	82

12. Partial Addition Series; Mean Dalmatian Toadflax Above-Ground Dry Biomass at the Canyon Ferry Site (1998).....	83
13. Partial Addition Series; Mean Number of Dalmatian Toadflax Stems at the MSU Post Farm Site (1998).....	85
14. Partial Addition Series; Dalmatian Toadflax Mean Percent Cover at the MSU Post Farm Site (1998).....	86
15. Partial Addition Series; Mean Dalmatian Toadflax Above-Ground Dry Biomass at the MSU Post Farm Site (1998).....	87
16. Partial Addition Series; Mean Number of Cheatgrass Stems at the Canyon Ferry Site (1998).....	90
17. Average Maximum Stem Growth Between Control and Insecticide Treatments (n = 40).....	92
18. Average Total Flowers Between Control and Insecticide Treatments (n = 10).....	92
19. Percent Mean Seedlings Emerged.....	94
20. A and B Soil Strata Average # of Seeds per Block (n = 8) (Canyon Ferry 1988).....	96
21. A and B Soil Strata Average # of Seeds per Block (n = 8) (Wyola 1988).....	97
22. Seed per Seedhead Counts for Both Field Sites.....	100
23. Mean Number of <i>Brachypterolus pulicarius</i> Caught per 50 sweeps at Either Field Site (1998).....	101
24. Conceptual Model of the Dalmatian Toadflax System.....	105
25. Mean Stem Counts Over a 10 Generation Boxcar Model Run at Both Sites (n = 20).....	107
26. Mean Dalmatian Toadflax Stems per Daubenmire Frame (Wyola).....	116
27. Mean Dalmatian Toadflax Stems per Daubenmire Frame (Canyon Ferry).....	116

## ABSTRACT

Seed versus microsite limitation of Dalmatian toadflax was examined in order to establish whether or not the weed might be readily controlled by limiting its seed production. The extension objective of the thesis was done in order to facilitate both the establishment of natural enemies as well as producer understanding of the biological control process. Finally, a life history model was created as a means of better understanding Dalmatian toadflax population dynamics beyond seed versus microsite limitation.

Experimental methods included two years of repeated observations on plant quadrats at two field sites and partial addition series experiments. The observational field study examined treatments that added additional Dalmatian toadflax seeds to quadrats, excluded interspecific plant competition, and excluded insect herbivory from Dalmatian toadflax. Extension methods included attendance of regular meetings with the Blackfoot Challenge, release of natural enemies of yellow toadflax, and the creation of a brochure. The life history model was created using a pre-existing model as a framework and two simulations were run using data collected from the two field sites.

Dalmatian toadflax was determined to be more microsite than seed limited in dry rangeland conditions. Plant competition was identified as the major factor limiting seedling recruitment of new Dalmatian toadflax plants, while additional seeding and insect herbivory did not appear to affect seedling recruitment.

Extension objectives were met through producer cooperation and the creation of an eight page full-color brochure highlighting the biological control of yellow toadflax.

Model output suggested that Dalmatian toadflax density was increasing at one site and decreasing at the other. Model output was corroborated by independent plant-transect readings performed at both sites.

A discussion of the implications of these results suggested that Dalmatian toadflax would probably be best managed using tactics that increase adult stem mortality as opposed to tactics which limit the number of seeds per adult stem. In the context of biological control, the results suggested that natural enemies of Dalmatian toadflax that attack reproductive structures were likely to be less effective than natural enemies that attack stem or root structures.

## CHAPTER 1

## INTRODUCTION

Dalmatian toadflax, *Linaria genistifolia* ssp. *dalmatica* (Maire and Petitmengin Fam: Scrophulariaceae), has become a serious weed of recreation and rangelands in Montana and other Northwestern states (Nowierski 1995). Chemical management of the weed has had limited success and has generally not been cost effective (Lajeunesse et al. 1993). This is largely due to the fact that the weed prefers coarse, well-drained soils which do not permit systemic herbicides adequate time to act, nor provide an economic return high enough to pay for herbicides. Cultural control is also rarely feasible, since the weed has a deep taproot, excluding simple pulling or mowing as effective control techniques (Lajeunesse et al. 1993). In contrast to its tenacity in Western American rangelands, Dalmatian toadflax is not of significant economic importance in Eurasia, its point of origin, in part because it suffers from attack by a number of arthropods not found in the New World (Alex, 1962). This suggests that classical biological control of Dalmatian toadflax in North America should be a feasible weed management strategy (Nowierski 1995). Hence, biological control of the weed is being developed as an alternative toadflax management strategy to be used in conjunction with other weed management approaches.

The major questions of integrated weed management are how and when to implement management strategies in order to best manage weed populations. Invariably,

weed management strategies take the form of physical, chemical, or biological manipulation of the agroecosystem. Weeds tend to be highly adapted to disturbed systems and take ready advantage of resources freed by disruption of "normal" ecological function (Tilman 1997). Proper management should therefore provide a balanced disturbance that puts weeds at a disadvantage while it promotes desired species, so that they can exploit freed or floating resources. In order to accomplish this one needs to have an understanding of not only the weed's biology, but also its behavior as a population. More importantly its population interactions within the plant community should be well understood. All too frequently, we proceed in research as well as actual management practices without taking the population dynamics of the weed and plant community into account (Sheley 1996). If biological control is going to be a successful part of an integrated weed management program of Dalmatian toadflax the plant's ecology and response to management strategies need to be well understood.

Currently, seven species of herbivorous insects are approved for release by the USDA Animal Plant Health Inspection Service-Plant Protection and Quarantine (APHIS-PPQ) for the management of Dalmatian and yellow toadflax. The defoliating moth *Calophasia lunula* (Hufnagel) was the first agent to be released (1968), with varied success, mostly due to its susceptibility to cold and predation (Nowierski, 1995). In addition, two species of beetles accidentally introduced along with Dalmatian and yellow toadflax (*Linaria vulgaris* Miller) also have been approved for release (Hervey 1927). These include the ovary-feeding nitidulid, *Brachypterochus pulicarius* (L.), and the seed capsule feeding weevil, *Gymnetron antirrhini* (Paykul). Both beetles primarily feed on

yellow toadflax although they also have been shown to feed on Dalmatian toadflax (Lajeunesse, et al, 1993). More recently, two species of root boring moths, *Eteobalea intermediella* (Riedl) and *E. serratella* (Treitschke); two additional cuculionids, the stem galling weevil, *Mecinus janthinus* (Germar) and the root galling weevil, *Gymnetron linariae* (Panzer); and the Dalmatian toadflax-adapted strain of *Gymnetron antirrhini* have been approved for release.

Two of the seven approved biological control agents for Dalmatian toadflax directly affect seed production. Of these two, *Brachypterolus*, is also the most widely established of the approved natural enemies. In theory, the lowered level of seed production resulting from insect predation should lead to lowered seedling recruitment and an eventual reduction of the weed population, as older individuals die and are not replaced. In one scenario, seedling emergence microsites for Dalmatian toadflax are readily available and every seed removed from the environment is one less adult plant. In this scenario seed feeding natural enemies are well suited for biological control. However, in a second scenario, seed emergence microsites are scarce and already saturated by Dalmatian toadflax seeds. In this situation a seed feeding natural enemy will most likely not have much of an effect on an existing weed stand, since the reduced level of seed production will probably be enough to maintain the weed population. Given the incredible reproductive capacity of Dalmatian toadflax, and the fact that it can also reproduce vegetatively, it is not clear whether or not seed production is an appropriate target for its management.

My masters thesis focused on three main areas of Dalmatian toadflax ecology and management. The three objectives were as follows; 1) to examine seedling recruitment in existing Dalmatian toadflax stands in the context of seed and microsite limitation in the presence and absence of insect herbivory and interspecific plant competition; 2) to develop a producer-run yellow toadflax biological control program with the Blackfoot Challenge noxious weed program; and 3) to collect and quantify life history data in order to initiate the construction of a "boxcar" type mechanistic model of Dalmatian toadflax population dynamics. Life history data collected included seed production, presence of seed in the seedbank, and seedling recruitment.

#### Seedling Recruitment in Dalmatian Toadflax

Seedling recruitment in Dalmatian toadflax is a research topic that needs to be addressed in order to develop functional integrated management systems. Two of the seven biological control agents for Dalmatian toadflax directly affect seed production. If Dalmatian toadflax seedling recruitment is not directly limited by the amount of seed present in the environment, then biological control agents that focus on other elements of the plant's physiology and life history may be more appropriate for management of Dalmatian toadflax populations.

The first goal of this thesis was to evaluate Dalmatian toadflax seedling recruitment in its natural habitat and in the presence and absence of natural enemies and plant competition. Questions addressed in this study were: Is Dalmatian toadflax seedling recruitment limited by seed production?; does feeding by *Brachypterolus pulicarius* have a

negative effect on seedling recruitment?; and does interspecific competition by grass and forbs have a negative effect on seedling recruitment? I addressed these questions through a combination of studies at established toadflax sites as well as in a partial addition series experiment.

Hypotheses tested in this portion of the thesis are:

- 1:  $H_0$ : Additional seeding of existing stands of Dalmatian toadflax will not significantly increase seedling recruitment in the following year.
- 2:  $H_0$ : Insect herbivory by *Brachypterothus pulicarius* will not have a significant negative effect on seedling recruitment.
- 3:  $H_0$ : Interspecific plant competition will not have a negative effect on new seedling recruitment.

#### Producer Education through the Extension of Biological Control of Dalmatian Toadflax

The second objective of this thesis was to begin a producer-operated biological control program for yellow toadflax. The site for this program was the Blackfoot Valley utilizing the already existing Blackfoot Challenge group as the producer group.

Traditional extension from Land Grant Universities has followed a path similar to a patient-doctor relationship where the producer clientele asks a question and the university replies with an answer often researched without producer involvement. This approach, while well suited to past situations, is inflexible when presented with agroecological challenges specific to a particular region or ranch. Involving the producer in the research

and innovation of a new agricultural technology has the potential to incorporate the "later" stages of producer adaptation of the technologies into the earlier developmental phases of the technology (Hildebrand, 1988). In an idealized sense this would result in the producer performing his/her own experiments with scientific and technical support from the Land Grant University.

Biological control is the weed management technology involved in the extension component of my thesis. Like any ecologically based strategy of weed management, it requires that the specific environmental and ecological factors of a region or farm be understood in order to be successful.

Involving the producers at the beginning of a biological control of weeds program has two primary advantages. The first advantage is that producers with large infestations of the weed are in a perfect position to foster new natural enemy populations, eliminating the need for a weed garden or greenhouse rearing facilities. The second advantage is that once natural enemies are established at one or two weed sites on participating landowners' properties, they are easily spread to other weed sites through producer cooperation.

For the purposes of managing yellow toadflax in the Blackfoot Valley the three natural enemies selected were the defoliating moth, *Calophasia lunula*, the ovary feeding beetle, *Brachypterolus pulicarius*, and the stem boring weevil, *Mecinus janthinus*. The three natural enemies are appropriate agents from a biological control standpoint because they attack yellow and Dalmatian toadflax, and they impact different plant parts. *B. pulicarius* adults feed on plant meristematic tissue causing increased branching, while the larvae feed on plant pollen and ovaries, causing decreased fertilization and seed capsule

abortion. *Calophasia lunula* caterpillars defoliate toadflax plants decreasing the amount of resources the plant can put into growth and reproduction. *Mecinus janthinus* adults girdle plant stems in the process of oviposition, causing the terminal stem portion to wilt, while the larvae are stem and lateral shoot miners. Utilizing natural enemies with different types of impacts should lead to better management of toadflax than simply focusing on seed production or plant vigor alone.

*B. pulicarius* is adventive to North America and likely was introduced when Dalmatian and yellow toadflax plants were brought from Europe as ornamentals. This beetle species has become widely distributed in North America on yellow toadflax and is less commonly found on Dalmatian toadflax (Harris 1961). Reports of 74% to 90% reduction of viable seed in yellow toadflax have been reported as a result of feeding damage by *B. pulicarius* (Harris 1961, McClay 1992). *C. lunula* was the first toadflax natural enemy to be approved for release and has been established at a number of toadflax sites in the United States and Canada, West of the Continental Divide (Nowierski 1995). *M. janthinus* was approved for release within the last three years making the Blackfoot Challenge area one of the first release sites of this natural enemy in the United States.

The second and more traditional extension aspect of this thesis goal was producer education through presentations to the Blackfoot Challenge group and the production of simple supplementary extension materials. Presentations were performed in conjunction with the involvement of producers in the process of initiating and monitoring the establishment of natural enemies of yellow toadflax. A full color brochure style report was

produced and presented to the Blackfoot Challenge, highlighting the progress made over the two year period of study.

### Modeling Population Dynamics Of Dalmatian Toadflax

The final objective of this thesis was to begin the development of a population dynamics model of Dalmatian toadflax. Such models have been used extensively to describe the dynamics of plant populations and examine the intricacies of weed and management strategy interactions (Sheley 1994b, Lindquist 1995, Maxwell 1997). Boxcar type models are fairly simple models well suited to simulating weed population dynamics. The model consists of a set of "boxes", with each box containing a population value for a specific stage of the weed's life history. Between the boxes lie equations that process the value from the previous box, and transfer it to the next box. In this way, specific field data regarding a weed population can be plugged into the model and run through simulated generations to suggest likely weed population trends.

This style of model has good potential as a management tool, because the user can enter disturbance or mortality pressures representative of control methods, and get a prediction of what might result. In short, the model can help identify probable weak points in the weed 's life history. An added benefit to modeling range weed population dynamics is that smaller species-specific box car models can be incorporated into larger models that might be used to guide ecological succession on infested rangeland (Sheley 1996).

To create a model for Dalmatian toadflax populations, data had to be collected for each stage in the plants life history. Seed production and dispersal, seed load in the soil,

seedling recruitment, and expected mortality data are all needed to create such a model (Radosevich, 1984). Some life history data for Dalmatian toadflax have been collected previously and include yearly emergence rates, seed production, early plant phenology, and yearly toadflax population monitoring at a number of research sites (Nowierski, Zeng, FitzGerald, unpublished data). Currently, detailed information is lacking on seed dispersal and seedling recruitment. I addressed these data gaps by taking measurements of the seed bank and setting up a series of permanent ground frame sites at two different locations. Later studies will need to address vegetative reproduction and adult plant mortality in order to complete the model.

## CHAPTER 2

## LITERATURE REVIEW

Dalmatian Toadflax Biology and Distribution

Dalmatian toadflax is a robust, broad-leaved, perennial herb native to the Mediterranean region, between the former Yugoslavia and Iran. The plant is characterized by glaucous green foliage, bright yellow snapdragon like flowers, and ovoid to nearly spherical fruit (Nowierski, 1995). Dalmatian toadflax stems are robust and woody at the base and are one to three feet tall. It has been cultivated as an ornamental plant in Europe for at least four centuries, and was introduced to the Americas by 1874 along with its close relative, yellow toadflax (*Linaria vulgaris*) (Alex, 1962). Since its introduction, Dalmatian toadflax has become a serious weed in rangelands in a number of Western States including, Montana, Wyoming, Washington, Oregon, Idaho, and California, mostly within the last 50 years (Nowierski, 1995).

Dalmatian toadflax seeds germinate in either the spring or fall, and first-year seedlings, if established, will flower and produce seed. Dalmatian toadflax blooms from June through September, with bumble bees and other robust insects serving as its primary pollinators. The weed releases seed by the end of August and dies back by the end of fall. Seeds are small, angular, possess irregular wings, and are primarily wind dispersed. Plants

put up new shoots and flower in the spring by using root reserves and non-stem rosettes (Lajeunesse et al. 1993).

The root system of Dalmatian toadflax includes a deep taproot with secondary lateral roots. The taproot can reach a depth of six feet or more, while lateral roots can extend up to ten feet away from the parent plant and are usually two to eight inches deep (Lajeunesse et al. 1993). The deep taproot of Dalmatian toadflax provides it with considerable energy reserves which allows rapid regrowth after herbivory. The lateral roots of the weed contain vegetative root buds, which are capable of producing flowering shoots, or if fragmented, a new plant.

Dalmatian toadflax has three main characteristics which make it a "problem weed".

1) It is a prolific seed producer and can reproduce vegetatively; 2) It prospers on coarse, well drained soils, especially on sites that have been recently disturbed and interspecific competition is low; and 3) it is unpalatable, if not toxic, to livestock.

Dalmatian toadflax has a very high sexual reproductive capacity. Under favorable conditions, a large plant is capable of producing 500,000 seeds per year. Furthermore, toadflax seeds can remain viable in soil for up to 10 years, allowing high levels of seed accumulation in the seedbank (Robocker 1970,1974). Dalmatian toadflax also reproduces vegetatively from secondary crown points located along the lateral root system, and the shoots produced from these lateral root-buds also may produce seed capsules (Nowierski 1995).

The soils favored by Dalmatian toadflax are coarse textured and best described as well drained and "poor". The weed can often be found on depleted rangelands and

recently disturbed sites. As a seedling, the weed is not a good moisture competitor compared to established grasses and herbs, but once established, toadflax can have a significant effect on the plant community surrounding it (Robocker 1974). As a result, Dalmatian toadflax is especially prevalent on rangelands with low interspecific competition (i.e., on sites with impoverished soils or sites that have been overgrazed).

Dalmatian toadflax may be toxic to livestock (Polunin 1969), although cattle and horses will reportedly graze on floral stocks. It is possible that the weed's seeds are dispersed, in part, through the feces of livestock and small rodents (Reed 1970). Possible toxicity of Dalmatian toadflax to livestock may result because the plants contain a gluoside antirrhinoside and the quinoline alkaloid, peganine (Polunin 1969). Beside of its possible toxic effects, the weed can significantly lower range quality by replacing higher quality forage species.

#### Seed Versus Microsite Limitation of Dalmatian Toadflax

The concept of seed limitation is that plant recruitment is limited by the amount of seed present in the environment. While this is usually true at some critical point, there are really two interdependent factors which may limit recruitment in plant populations. Both seed availability and the availability of microsites limit the recruitment of new plants into a population (Eriksson 1991). While recruitment is usually dependent on a combination of both of these factors, it is possible to determine which plays a bigger role in specific plant populations.

Insect herbivory tends to have a negative effect on the supply of seeds to the environment. Studies on the effects of inflorescence feeding insects on seedling recruitment of plants have shown that seed predation by insects can have a dramatic effect on seedling recruitment or little to no effect at all. Extensive experimentation by Louda et al (1990, 1995) in the Nebraska sand hills prairie has shown that recruitment of the Platt thistle, *Cirsium canescens*, (Nutt.) is severely limited by insect seed predators (Louda 1990, 1995). Seedling recruitment also was found to be limited by seed predation in the perennial shrub *Haploppappus squarrosus* (Hall) (Louda 1982), and in wild parsnip, *Pastinaca sativa* (L.) (Hendrix 1989). In contrast, for other plant species such as *Senecio jacoboea* (L.) and *Cytisus scoparius* (L.), seedling recruitment was not reduced by insect herbivory (Crawley 1989) or seed predation (Bossard and Rejmanek 1994).

Interspecific plant competition affects the availability of seedling emergence microsites, which in turn may effectively limit seedling recruitment. Putwain et al. (1968) showed that recruitment of *Rumex acetosella* (L.) in established grasslands was entirely dependent on reduced grass competition. Similarly, *Oputia Fragilis* (Haw.) has been shown to have a higher rate of recruitment when interspecific competition is excluded (Burger et al. 1995). In another study, initial recruitment of several biennial plant species was shown to be inversely correlated with levels of ground cover (Gross, 1982).

Given the prolific seed production of Dalmatian toadflax and its ability to reproduce vegetatively I propose that, in situations where seed predation is not a factor and plant competition is negligible, seedling recruitment of Dalmatian toadflax is not primarily limited by seed production. Whether or not it might be limited under high levels

of seed predation and/or plant competition is a more complex question. Given the poor competitive ability of Dalmatian toadflax seedlings for soil moisture, under competition from forbs and grasses it seems reasonable to expect seedling recruitment to be limited by micro-site availability (Robocker 1970, 1974).

In this study a combination of field observation studies and controlled field experiments were used to explore seed versus microsite limitations in Dalmatian toadflax. While field studies that add additional seeds to or remove insect predation or interspecific plant competition from pre-existing plant stands remain the most common methods of testing hypothesis regarding population dynamics of plant populations, controlled experiments may enable one to collect accurate data regarding the colonization of a disturbed habitat as a function of seeding rates. Examples of plant population dynamic studies that have involved alteration of standing plant populations through the addition or exclusion of seeds, predation, and interspecific competition include those of Louda (1982, 1991, 1995) and Crawley (1985, 1989). Partial addition series studies of *Bromus tectorum* (L.) and *Centaurea solstitialis* (L.) by Sheley and Larson (1994) and the invasiveness of biennial plants in unpopulated versus populated farmland (Gross, 1982), provide good examples of controlled field experiments.

## CHAPTER 3

## MATERIALS AND METHODS

Field Study of Dalmatian Toadflax Seedling Recruitment and MortalityExperimental Design

The field experimental design consisted of a fixed block, three factor design with eight treatments replicated across four blocks at two sites. The first factor consisted of overseeded or non-overseeded treatments, the second factor consisted of plant competition allowed or excluded, and the third factor consisted of natural enemies present or excluded. The two sites chosen for this study had received previous releases of *B. pulicarius*. Four blocks were established at the two research sites to block against obvious differences in vegetative cover. Each of the factor/treatment combinations was established once in each block through the use of permanent quadrats.

Site And Block Descriptions

The study took place during the 1997 and 1998 growing seasons. The two study sites were located at the Crow Reservation, 12 miles North of Wyola, Big Horn County, MT and adjacent to the Canyon Ferry Reservoir (about three quarters of a mile North of the dam) approximately ten miles SE of Helena, Broadwater County, MT. Sites were chosen because they reflected different habitat types infested with Dalmatian toadflax and

both sites had had previous releases of *B. pulicarius* for at least eight years. Each site consisted of four blocks with eight treatments representing eight possible combinations of experimental factors. Blocks were fixed previous to treatment assignment through the use of total plant cover measurements across a spatial gradient. The experiment was laid out in a randomized fashion across the fixed block design, with each treatment occurring once in each block.

The Wyola site had a higher density of Dalmatian toadflax plants than the Canyon Ferry site in addition to having a long history of cattle grazing. Cows, bulls, as well as some horses were present at the Wyola site during both study seasons. The area where the plots were laid out, and where toadflax density was highest was an old unfilled gravel pit. The soil tended to have a high clay content with rocks and gravel throughout. Blocking was laid out across a basin, up a north-facing slope, along the top of a slight hill, and then down a south-facing slope, with each described region receiving a single block of treatments. Other significant plants at the study site included cheatgrass (*Bromus tectorum* L.), yucca (*Yucca glauca* Nutt.), ragweed (*Ambrosia artemisiifolia* L.), western salsify (*Tragopogon dubius* Scop.), and yellow sweet clover (*Melilotus officinalis* (L) Lam).

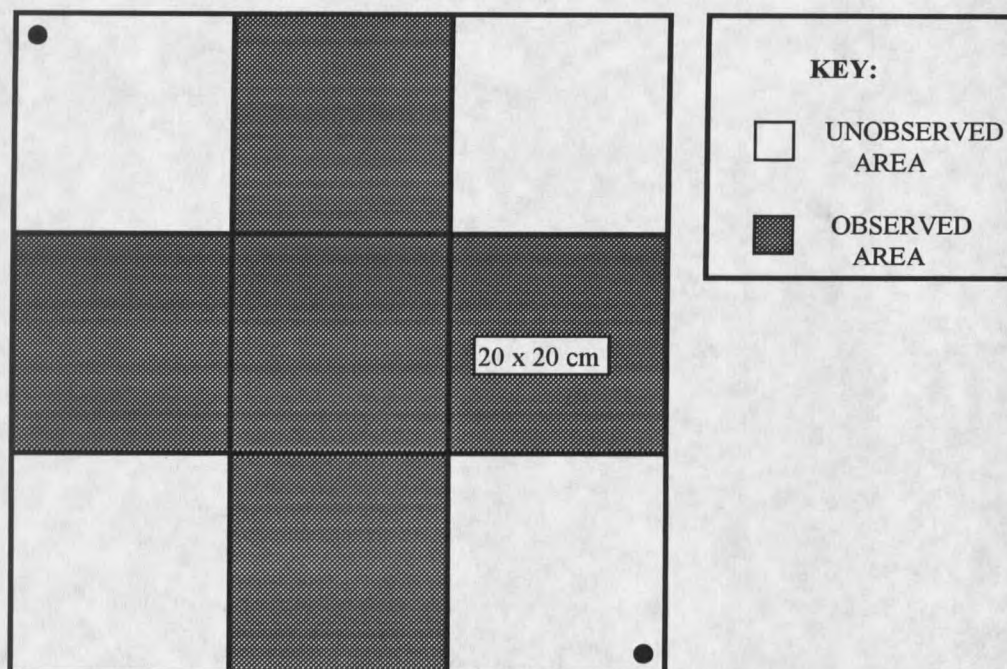
The site located at Canyon Ferry was markedly different than the Wyola site and consisted of a hillside adjacent to the BLM's Riverside Campground. Grazing pressure at the Canyon Ferry site did not compare to the Wyola site as it consisted of only occasional browsing by white-tail and mule deer. The soil at this site was rocky and gravelly with a lower clay content than that at the Wyola site. Environmental conditions were somewhat cooler than at the Wyola site with frequent thunderstorms. Blocking was laid across the

flat before a hillside and then in three progressively decreasing plant cover levels up the hillside. Each described region received a single block of treatments. Other significant plants at the study site included cheatgrass, prickly pear (*Opuntia polyacantha* Haw.), yellow sweet clover, leafy spurge (*Euphorbia esula* L.), and spotted knapweed (*Centaurea maculosa* Lam.).

#### Quadrat Frame Construction and Sampling Procedure

Seedling recruitment, plant cover data and seed production rates were collected using four blocks of eight 60 x 60 cm permanent quadrats at both sites. Thirty-two individual parent plants in four blocks of eight treatments per site, were randomly selected for the duration of the study. Plants selected for data collection were marked with two pieces of rebar at the NW and SE corners of the quadrat. A portable quadrat-frame consisting of a 60x60 cm square divided into nine 20x20 cm squares, was used to demarcate the observation arena. The frame had adjustable legs at each corner, which could extend to 30 cm in height to minimize plant disturbance during frame placement and removal. The frame consisted of 3.81 cm (1.5") PVC pipe, 0.315 cm (0.125") ready-bolt used make the smaller squares, and 0.635 cm (0.25") ready-bolt used for legs. The ready-bolt consisted of steel bars that were threaded along their entire length. A two-dimensional conceptual diagram of the quadrat frame can be seen below in Figure 1.

Figure 1. Quadrat frame diagram.



During data collection, the frame was oriented so that it lay between the rebar stakes, above and around a parent plant, so that the plant fit inside the inner frame, and a designated frame side faced north. Data was collected on a weekly basis during 1997 and on a seven to 14 day cycle in 1998. Data collected included seedling, stem, and seedhead counts as well as percent cover of Dalmatian toadflax, grasses, forbs, shrubs and bare ground in the 20x20 cm center square and the four quadrants located in each cardinal direction. The four quadrants and the one center square were averaged to generate whole quadrat weekly measurements. The previous sampling period's data was included on the current sampling period's data-sheet in order to increase accuracy of frame placement and minimize week to week bias in percent cover estimates.

Seedlings were sorted into three classes of counts in order to keep track of weekly mortality and emergence events. The first class consisted of seedlings with 1-2 nodes beyond the cotyledon, the second of seedlings 2-5 nodes beyond the cotyledon, and the third of seedlings with more than 5 nodes beyond the cotyledon. Stems were marked with plastic ties to maintain a census through time and to help orient the frame. Two colors of plastic ties were used, one for the center square and one for the cardinal direction squares. Finally, seed capsules were harvested from similar plants near each quadrat in 1997 and seeds counted in order to determine a realistic overseeding rate.

#### Overseeding Rate Calculation and Field Application

Experimental plots were supplementary seeded in order to address the question of whether or not seed abundance was the primary factor limiting Dalmatian toadflax seedling recruitment (Louda 1991, 1995, Crawley 1989). Overseeding rate was calculated by averaging the total number of seedheads for each quadrat at each site and multiplying the resulting mean by the mean number of seeds per head. The higher of the two site-means was taken and multiplied by a factor of two in order to generate an artificially high seeding rate of 92,192 seeds per quadrat which was applied to both sites in the Fall of 1997.

Overseeding took place following the completion of sampling on the last sampling date. Fall 1997 was selected as the overseeding time period so that seeds would be exposed to normal post-dispersal predation and mortality factors. Seeds were collected at the two sites in the weeks immediately prior to seeding and only seeds collected from a

given site were used in the experimental treatments for that site. Seeds were scattered by hand from approximately 20 cm above the soil surface, using the quadrat frame as a guide, in an alternating E to W, W to E zigzag running from the N to S sides of the quadrat frame.

#### Plant Competition Exclusion Techniques

Interspecific plant competition was excluded from half of the experimental quadrats in order to ascertain whether or not plant competition had an effect on Dalmatian toadflax seedling recruitment. Plant competition was excluded through a combination of careful pruning and herbicide application. After the quadrats had been mapped out and the frame set in place, Roundup<sup>®</sup> was applied at the lowest labeled rate around the outside of the quadrat through the use of a paintbrush, with care taken not to paint any toadflax plants. This was done only in the 1997 season when the quadrats were initially established. Plant species other than Dalmatian toadflax occurring within the frame were carefully removed by hand-pruners at the soil surface level. Pruning was done at every sampling period to minimize interspecific competition within the quadrat. Senescent toadflax stems from prior seasons were removed from all quadrats to facilitate frame placement.

#### Natural Enemy Augmentation, Exclusion, and Presence Measurements

Augmentative releases of *B. pulicarius* were made at each of the two research sites to supplement low populations of the beetle and enhance the anticipated negative effects of the beetle on the growth and reproduction of Dalmatian toadflax. Adult *B. pulicarius*, collected from British Columbia, were released at the two research sites during the weeks

of June 7, 1997 and June 10, 1998. Four hundred adult *B. pulicarius* were released in each beetle treatment plot during 1997 and 1998. Beetle excluded treatments received no beetles.

An insecticide treatment was applied to the beetle exclusion plots to eliminate the effects of *B. pulicarius* and other insect herbivores (Mills 1997). I selected Orthene Isotox<sup>®</sup> (Acephate) as my insecticide for natural enemy exclusion because it has a systemic residual action, demonstrates a low general phyto-toxicity, and has been used in similar experiments where it hasn't appeared to affect plant pollination rates (Louda, 1982, 1991, 1995). Orthene was applied at a rate of 15 ml pesticide per 350 ml. of water. Plants were sprayed using a hand-operated squirt bottle type sprayer, and applied from all sides of the plant to runoff. Plants in non-insecticide treatments were sprayed with water in an identical fashion. Pesticide was applied every 14 to 20 days, until plants senesced. A phyto-toxicity trial was run in the MSU Plant Growth Center during the winter of 1998-99 to quantify the effect of Orthene on Dalmatian toadflax growth and flower production.

During the 1998 growing season insect sweep samples were taken in an attempt to quantify the population of *B. pulicarius* at both sites. Sweeps were performed with a standard insect sweep net and consisted of four sets of 200 sweeps per block. A left to right to left zigzag was used while sweeping with the net held at 5-10 cm off the ground during each swing. Samples were taken back to the lab and kept in a freezer until they were processed.

### Analysis

Data were analyzed using a 2x2x4 factorial ANOVA for the 1997 data and a 2x2x2x4 factorial ANOVA for the 1998 data. ANOVA focused on four measurements related to seedling emergence, recruitment and production. The two ANOVA designs used in the analysis were a standard multi-factorial design used for data within sampling dates and a Repeated Measures with a partial covariance structure for the data among all dates. Both sites and years were analyzed separately, yielding four sets of analyses.

The four variables considered in the analyses were total seedling count, cumulative seedling emergence, proportional cumulative seedling mortality, and number of seedheads per stem. Data were transformed in order to meet normality requirements, with count data transformed using a square root transformation, cumulative seedling emergence transformed using a natural log transformation ( $\ln(x+1)$ ), and proportional cumulative seedling mortality transformed using an arcsine transformation. Proportional cumulative seedling mortality was calculated by summing seedling mortality to the current date and dividing it by the end cumulative seedling emergence for each experimental unit.

The SAS Statistical Package (SAS Institution 1997) was used for all data analyses using either the GLM or MIXED procedures. The GLM procedure was used for analysis of data by date and the MIXED procedure was used for repeated measures analysis of data over time. All ANOVA models were reduced to include only factor effects and two-way interaction effects with higher order interaction effects included in the overall MSE. F- statistics were calculated in this way after it was determined that there were no significant ( $P > 0.05$ ) three or more-way interactions. Significant two-way interactions

were analyzed using a t-test to compare each possible pairing of two-way factor combinations.

The MIXED procedure was used for the Repeated Measures because it allowed for partial covariance modeling between sampling dates allowing dependence over time to be accounted for (SAS Institute, 1997). Covariance structure was calculated using a spatial relationship algorithm based on a power function using time as the spacing coordinate.

The mixed model ANOVA had the following form:

$$Y_{ij} = \text{factors}_{ij} + \text{interactions}_{ij} + \rho_{ij} + \varepsilon_{ij}$$

Where  $y_{ij}$  is the response variable,  $\text{factors}_{ij}$  is variability accounted for by the factors,  $\text{interactions}_{ij}$  is the variability accounted for by factor interactions,  $\rho_{ij}$  is the variability accounted for by the covariance structure, and  $\varepsilon_{ij}$  is the response error. Covariance structure in the Mixed model repeated measures ANOVAs were calculated as a matrix of  $(\delta)^2 (\rho^{d_{ij}})$ , where  $(\delta)^2$  is the variance between correlated observations and  $(\rho^{d_{ij}})$  is the covariance with calculated decay, with  $d$  equal to distance between coordinates.

Covariance structures have been used increasingly in ANOVA designs where spatial factors violate assumptions of independence (Stroup 1994) (Zimmerman 1991). A typical covariance structure uses a decay function to correlate samples along a spatial gradient, with samples closest to one another most correlated and samples farthest away from each other least correlated. Similar techniques have been used to model dependence in repeated measures ANOVA using time as a decay coordinate (Potthoff 1964) (Jennrich

1986) (Lange 1987). I chose a power function to model covariance between sampling dates after comparison with seven other algorithms using Aikike's Information Criterion, Schwarz's Bayesian Criterion, and the Null model LRT Chi-square statistic testing significant effects on the repeated measures ANOVA model (SAS Institute 1997).

### Materials and Methods for the Partial Addition Series

A Partial addition series Dalmatian toadflax trial was performed between the Fall of 1997 and 1998 to supplement data collected from preexisting stands of Dalmatian toadflax. The trial consisted of four levels of Dalmatian toadflax and one level of cheatgrass seeding rates at two sites in a completely randomized design. Levels of seeding followed the logarithmic scale of 0x, 1x, 10x, 100x for Dalmatian toadflax and a fixed rate of either 0 or 1825 seeds per quadrat for cheatgrass. Dalmatian toadflax seeding rate (1000) was chosen to reflect extremes of seeding possibilities for Dalmatian toadflax while the cheatgrass rate was decided by personal recommendation (R. Sheley, Pers. Commun. 8/1997). The study sites chosen were at the MSU post farm, five miles west of Bozeman, Montana and at the Canyon Ferry field study area.

Before plots were established, both study areas were prepared by mowing, tilling, and grading. Staff at the MSU post-farm site mowed and tilled the study area, while at the Canyon ferry site, mowing and tilling were accomplished using a weed trimmer and a five horsepower rototiller. Both sites were graded through the use of a garden rake and a turf grass roller.

Plots were delineated at both areas in three 11 x 1 m strips with 1 m between each strip to accommodate sampling. Each strip contained eight 1 x 1 m areas each with 40 cm of buffer space between them. Plots were then centered within each square meter area and staked out in 60 x 60 cm squares to conform to a quadrat frame identical to the one used in the field trials. After plots were established, treatments were randomly assigned to the experiment.

Seeding took place with the quadrat frame in place as a guide. Seeding was done by hand, running from left to right over the soil area bounded by the frame with the hand positioned about 20 cm above the soil surface.

Plots were sampled and harvested in fall of 1998 after a full season of plant development. Sampling was accomplished by placing the 60 x 60 cm frame over the stakes of the plot and then placing a 20 x 50 cm Daubenmire frame within the square meter frame to reduce edge effects. The Daubenmire frame was placed randomly within the frame. Percent cover data, total stem count, and dry biomass measurements were taken for Dalmatian toadflax plus the one or two other dominant plant species and other grasses and forbs for each site. The other dominant species at the MSU Post-farm site were field pennycress, *Thlapsi arvensis* (L.), and redroot pigweed, *Amaranthus retroflexus* (S. Wats.), while at the Canyon Ferry site cheatgrass was the other dominant species. Aboveground plant material was harvested within the Daubenmire frame from each plot, dried in a temperature cabinet for one week, and then dry weights were determined for Dalmatian toadflax, grasses, and forbs.

Data from the trial were analyzed using 2 x 4 factorial ANOVA with cheatgrass seeding and Dalmatian toadflax seeding rates as the respective factors. Dependent variables considered in the analyses were Dalmatian toadflax density, arcsine transformed percent cover and dry weight of above ground plant material and competitor species percent cover, arcsine transformed percent cover and dry weight of above ground plant material. In addition total dry weight of above ground plant material was compared between sites with a student's t-test in order to test for differences in plant productivity between sites.

#### Materials and Methods for the Phyto-toxicity Trial

A phyto-toxicity trial was conducted on Dalmatian toadflax to confirm that there were no detrimental effects due to field applications of Orthene Isotox<sup>®</sup> to Dalmatian toadflax growth and floral development. The experiment was conducted in a greenhouse with a 12h light 12h dark photoperiod. The two treatments included an insecticide treatment and a control treatment. Both treatments consisted of 10 single Dalmatian toadflax plants in one quart pots. Plants used in this study were mature plants collected near Wyola, Montana in October 1998. Plants were placed in the greenhouse and allowed to acclimate. Only healthy plants, similar in stature and containing 6-12 stems were used in the study. Plants were watered every 2-3 days and received N-P-K fertilizer once on 12/10/98.

Plants involved in the insecticide treatment were treated with Orthene at a rate of 15 ml of chemical per 350 ml of tap-water corresponding to the field trial application rate and lowest labeled spray rate. Control plants were sprayed with tap-water. Plants were sprayed using a hand operated squirt bottle type sprayer every 20 days. Plants were sprayed from all sides until drops of insecticide or water were visible on foliage. Separate sprayers of identical make were used for insecticide and control treatments. Measurements were taken on a biweekly basis, and consisted of total number of stems, total number of flowers, as well as heights and flower counts for four randomly selected/marked stems per pot.

Data were analyzed using a t-test to compare peak total stem growth and total number of flowers per treatment.

#### Materials and Methods for the Seedling Emergence Trial

A seedling emergence study was performed in the Spring of 1999 to determine the viability of seed from the Wyola and Canyon Ferry sites during both the 1997 and 1998 seasons. Seeds used in the study were obtained from the two sites at the conclusion of the growing seasons during 1997 and 1998. Seed was harvested by shaking the senescent plants within an insect sweep net. Seed was stored in darkness at room temperature immediately after its collection. The seed emergence study was performed on a thermal-gradient bar located at the Biological Control of Rangeland Weeds Laboratory, MSU Bozeman.

The gradient bar consisted of four parallel aluminum plates that were normally heated at one end by a hot water bath unit and cooled at the opposite ends by a cold temperature isopropyl alcohol bath unit. However, in this study the hot and cold temperature bath were set to approximate a constant temperature of 18° C to maximize Dalmatian toadflax seedling emergence (Nowierski, FitzGerald, and Zeng unpublished data). The experimental design consisted of two replicates of each seedling population blocked four times on four thermal-gradient bars. Replicates were placed randomly within blocks. Each replicate consisted of 40 Dalmatian toadflax seeds on a 9 cm diameter seed emergence disk set directly on the gradient bar. Bars were covered with Plexiglas shields and disks moistened twice a day with distilled water in an attempt to keep water availability constant. Disks were kept in the same location on the bar throughout the study to try and minimize temperature variation within each replicate.

Seedlings were counted and removed on a daily basis until there were three days without emergence. Temperatures were taken for each replicate every three days in order to identify possible temperature effects between replicates. A thermocouple placed on the emergence disk was used to measure temperature. Temperature measurements were taken before seedlings were counted or the Plexiglas cover was removed from the thermal-gradient bar.

Data were analyzed using a 4 x 4 factorial ANOVA with blocks and seedling populations corresponding to the factors. Data were further used to quantify percent seed emergence in the boxcar model of Dalmatian toadflax seedling recruitment.

### Materials and Methods for Soil Sample Processing/Seed Counting

Soil samples were collected from field study sites with a shovel and partitioned into two 7.62 cm strata. Each quadrat in the field was sampled twice during the summer by taking samples approximately one meter away in a random direction, with the last sample extracted from within the quadrat itself. Samples were dried in paper bags at room temperature for approximately one week and then thoroughly mixed by hand. Sub-samples were then drawn from dried soil using a cylinder measuring 10.16 cm long with a 5.08 cm radius. Samples were placed in plastic bags and stored in a freezer until the next stage of processing.

Individual samples were mixed in 800 ml Mason jars with a 0.01g to 1 liter Calgon/distilled water solution in order to separate clay particles. Samples were soaked for one to two hours with occasional shaking, until the soil solution had a homogeneous appearance. Samples were then individually sieved through #10 and #60 soil screens with added water used to rinse soil through the screens. The #60 screen was chosen after establishing that toadflax seed would not pass through it. Both screens were thoroughly rinsed between samples. Once samples were rinsed, they were placed into individually-labeled petri dishes and placed in an incubator until dry. Dried soil samples were processed under a dissecting scope and toadflax seeds individually removed and counted.

## Materials and Methods for the Extension Project

### The Blackfoot Challenge

The extension objective of my thesis was carried out with cooperation from the Blackfoot Challenge in and around Ovando, Montana. The Blackfoot Challenge (BFC) was founded in 1991 by Blackfoot Valley landowners and was formally chartered in 1993 as a 501 (c)(3) nonprofit organization consisting of State, Federal, and Private land managers. Its original objectives were to protect rural lifestyles in the Blackfoot valley and to coordinate irrigation and river projects to protect the Blackfoot Valley's watershed. More recently, the BFC's strategic plan has expanded to consist of three program objectives including; 1) education, 2) weed management, and 3) native fisheries restoration (Blackfoot Challenge, 1999).

The education activities of the BFC are directed at a broad audience and address a wide range of Blackfoot Valley issues. The BFC has organized an ongoing weed education program for the last three years. Education activities have been developed for both adult and youth audiences and include weed management tours, presentations covering current developments in weed management technology, as well as a weed calendar contest in area schools. In addition to weed management education, the BFC sponsors workshops for Blackfoot valley school teachers through the Water Education for Teacher's project (WET). Topics covered in WET workshops include, riparian management, stream and mine restoration, wetlands preservation, and timber management.

Other BFC education projects address topics surrounding alternative ranch income, water quality issues, and native fishery restoration.

The second major objective of the BFC is the management of noxious weeds on a valley-wide basis. The Blackfoot Valley Cooperative Weed Management Program is directly related to the BFC and provides an innovative approach towards weed management. BFC activities in this area include financial support for roadside herbicide programs, the development of detailed, GIS-based weed maps of the Blackfoot valley, facilitation of cooperative weed management strategies among BFC members, as well as the implementation of integrated weed management practices including chemical control, biological control, grazing, and competitive seeding strategies.

The final major objective of the BFC is native fishery restoration. Primary emphasis is placed on the bull trout restoration plan, part of a statewide effort to recover bull trout populations. The BFC's goals for this objective are to enhance the quantity and quality of fish habitat through: 1) monitoring of the watershed; 2) information exchange between private landowners, sportsmen, and government agencies; 3) design and implementation of a cooperative watershed management program; 4) development of new habitat improvement techniques; and 5) assistance in the acquisition of additional funding for habitat improvement projects.

#### Extension Activities

My extension activities were directly related to the first and second BFC objectives and included presentation of information at producer meetings, cooperative release of

biological control agents of yellow toadflax, cooperative yearly monitoring of yellow toadflax sites, and the creation of an extension brochure highlighting progress made during the 1997-1998 period.

Meetings consisted of regular and special attendants of the Blackfoot Challenge in both indoor and outdoor presentations. Tours highlighting BFC projects were a regular part of each meeting, and in the case of yellow toadflax, consisted of discussions of the weed's history in North America, the natural enemies approved for yellow and Dalmatian toadflax biological control, and biological control strategies as part of an integrated weed management program.

Releases of natural enemies were conducted with the assistance of Jim Stone, current BFC chairman and Ovando rancher. Release sites were located on several producers' ranches with the understanding that natural enemies would be redistributed following their establishment. Natural enemies were released inside mesh insect cages measuring 3.05 m wide, 3.05 m long and 2.13 m tall. Release cages were used to protect natural enemies from predation and disturbance, as well as to restrain their mobility, in order to facilitate mating and reproduction. Release cages were provided for the Blackfoot Challenge as a future resource for producers participating in the biological control program.

In addition to natural enemy releases, cooperating producers were involved in the establishment of permanent plant-transects at each release site. Transects consisted of two 25 m strips marked with rebar stakes. A standard Daubenmire frame sample measuring 20 x 50 cm was read along each meter of the transects. Measurements included percent cover

readings for yellow toadflax, grasses, forbs, shrubs, and bare-ground, as well as total plant and stem counts of yellow toadflax. Transects were read in the Fall of 1997 and 1998 and will be continually monitored by both producers and university personnel as a means of tracking yellow toadflax populations at natural enemy release sites.

The brochure documenting the progress made in the biological control of yellow toadflax was written in the Spring of 1999 and will be presented to the BFC in the Fall of 1999. Topics covered by the brochure included objectives of the biological control project, a brief discussion of yellow toadflax life history, introductions to three of the toadflax natural enemies released in the Blackfoot Valley, a listing of natural enemy releases made over the 1997-1998 season, and contact information for interested BFC participants.

#### Materials and Methods for Boxcar Model Construction

The boxcar model constructed for Dalmatian toadflax was generated using the noxious weed population dynamics model framework designed by Maxwell and Sheley (1997). Model parameters were set through the use of field observations and some reasonable guesses for values not encompassed by this study. Data sets from both the Canyon Ferry and Wyola sites were used to calculate separate model parameters in order to generate projections for Dalmatian toadflax population trends at the respective sites. Models were run through a 10 generation cycle 20 times with means and standard errors computed for each generation.

Parameters estimated for the model included total seed produced per stem (spp), initial seedbank level per meter squared (SBf), spring seedling emergence proportion (grms), spring seedling mortality (sdms), juvenile recruitment into the next years stem population (flw), and the rate of mortality in adult stems (mpm). Parameters set through a best guess approach included rate of seed movement (mr), juvenile mortality (rm), fall to spring seedbank mortality (smf), and spring to fall seedbank mortality (sms). All estimated parameters were entered into the model as a normal distribution consisting of a mean and standard deviation. Data pertaining to the 1997 growing season were used to calculate model parameters since the 1998 rates of juvenile recruitment into adult stems and stem change between the 1998-99 seasons could not be calculated.

Total seed produced per stem was calculated by taking the average peak seed capsule per stem count for each site and multiplying it by the average seed produced per seed capsule measurement used in determining the field trial overseeding rate. Seedbank level per m<sup>2</sup> was calculated using A strata soil samples taken in 1998. Spring seedling emergence rate was calculated by taking the total average cumulative seedlings emerged per 20 x 20 cm quadrat per site, converting this to square meters and dividing the result by the seedbank measure times the seed emergence proportion determined in the laboratory emergence study. Spring seedling mortality was calculated as the overall site average of the cumulative proportional mortality measure in the field trial. The proportion of first year plants surviving to second year status (flw) was calculated as the average number of marked 1997 seedlings surviving to the 1998 season divided by the last date 1997 seedling counts. Rate of stem change was similarly calculated through the use of a proportion of

the site average of stems counted on the second sampling period in July 1997 by the average of stems counted on the second sampling period in July 1998. This last parameter was relegated to being a mortality measure with a range of zero to one, since vegetative recruitment was not quantified in the field experiments.

Parameters assigned model defaults included spring to fall seedbank mortality and fall to spring seedbank mortality, as sufficient data was not available to estimate these parameters. The rate of seed movement or seed emigration was set at 0.9 for both sites after considering the large amounts of seed produced per meter squared and the wind dispersal-adapted Dalmatian toadflax seeds. The rosette mortality factor was set at 1.0 since any juvenile plants that did not recruit into the adult stem population were considered to have perished. Fall season seedling emergence and mortality rates were left out of the model, as no data was available for these model parameters. Furthermore, low seedling vigor in the fall and a high probability of freezing probably minimize the chances for overwinter survival of fall germinating seedlings.

## CHAPTER 4

### RESULTS

#### Results for the Two Year Field Trial

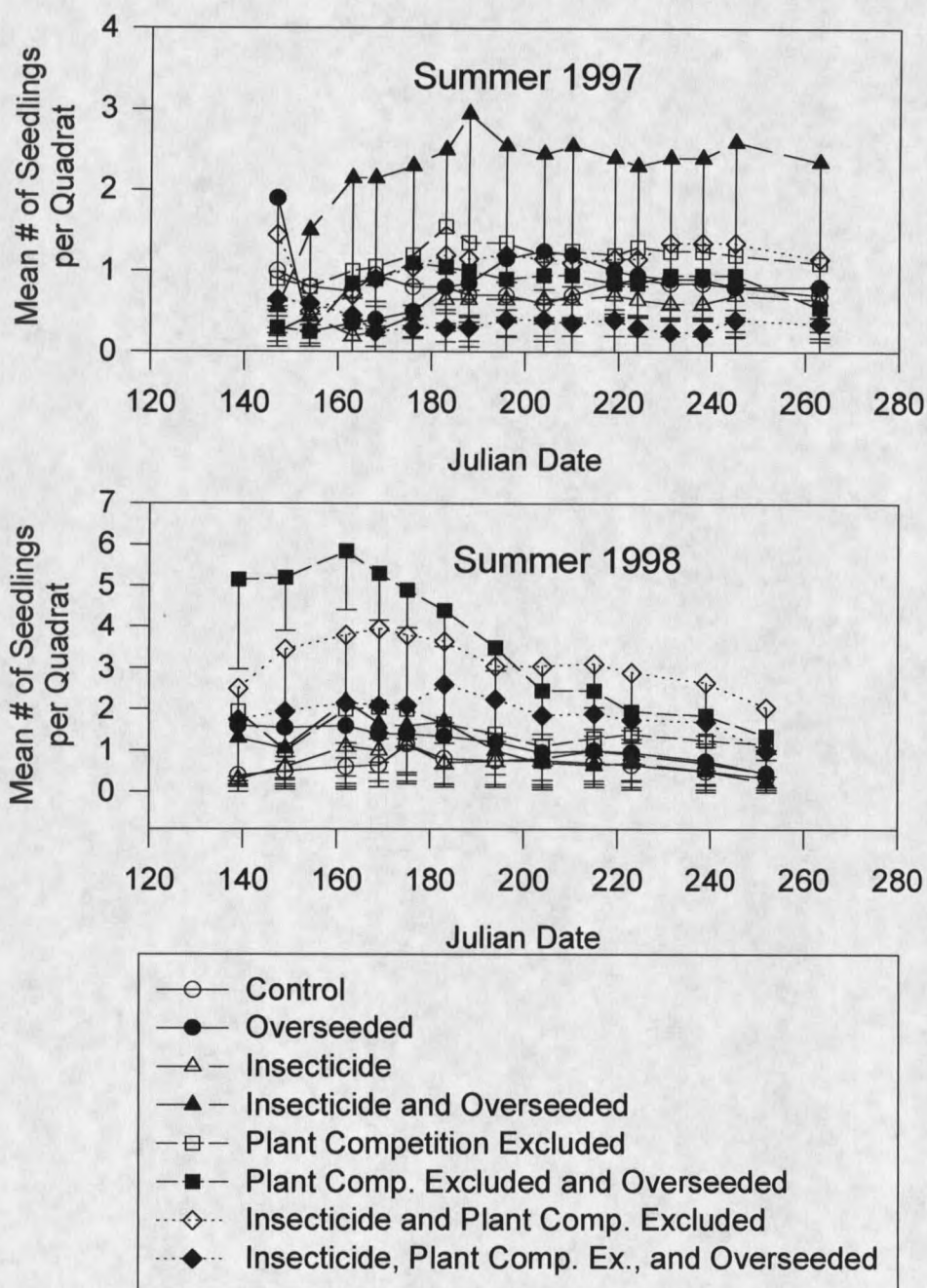
##### Overall Trends/Data Summary

Results from the 2 year field trial are presented in Figures 2-9. There was a general, but non-uniform tendency for treatments with plant competition exclusion to have higher total Dalmatian toadflax seedling counts and higher cumulative seedling emergence. However, the number of seed capsules per stem and cumulative percent mortality did not show such a trend.

##### Mixed Model Repeated Measures

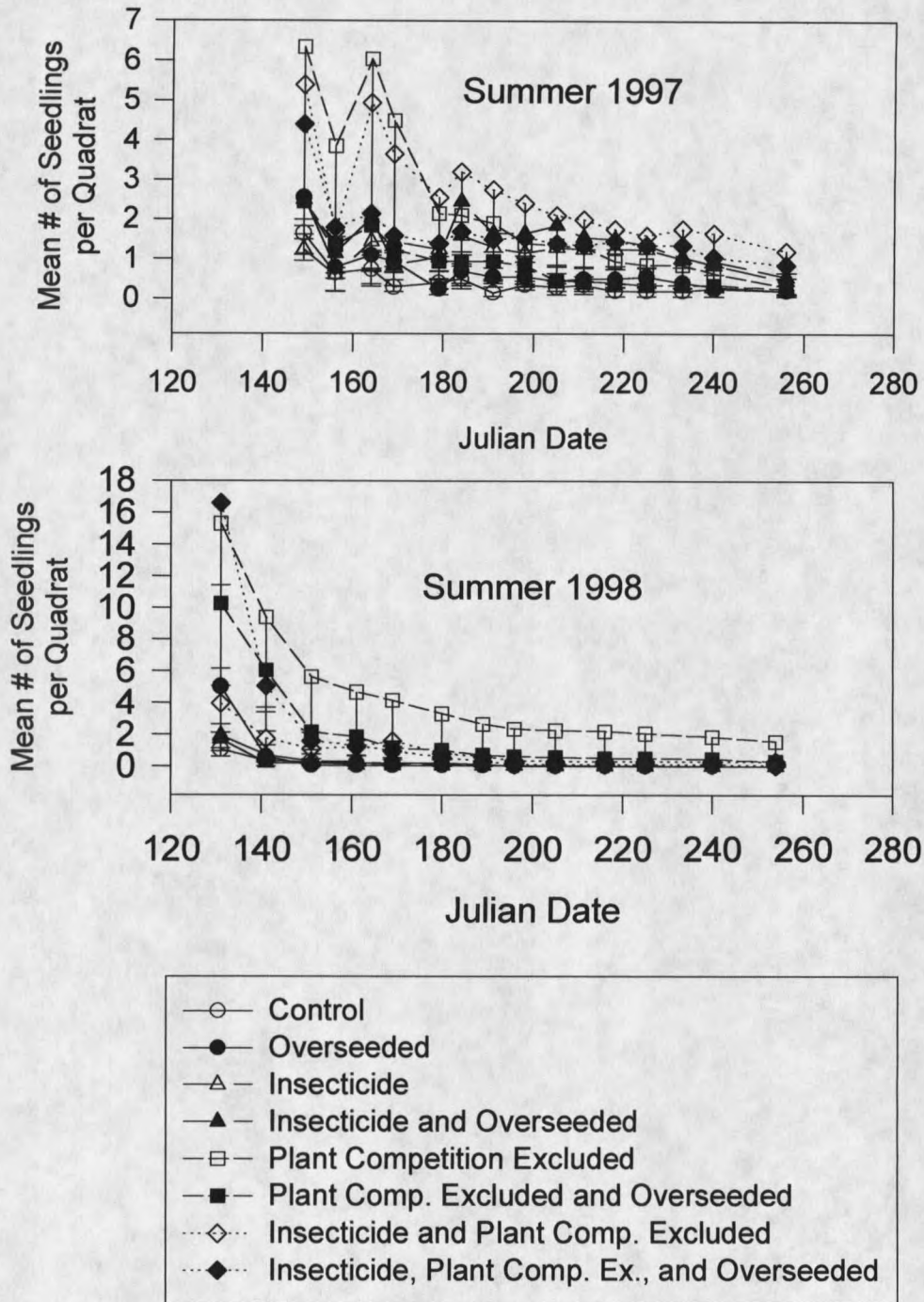
Model Validation All sixteen models showed a significant improvement over the null model without a covariance structure (Tables 1-16) with Chi-Squared P-values less than 0.00001. Likewise, the high positive Akaike's Information Criterion and Schwarz's Bayesian Criterion values for all measures of cumulative emergence and cumulative proportional mortality suggest that the models are well suited to the analysis. The low negative criterion values for total seedling count and seedheads per stem raised the question as to whether the mixed model is appropriate for analysis of these two variables. However, considering the highly significant null model Chi-Squared values and the fact

Figure 2. Mean<sup>1</sup> Total Dalmatian Toadflax Seedlings by Julian Date for the Eight Treatments Over Both Years (Canyon Ferry)



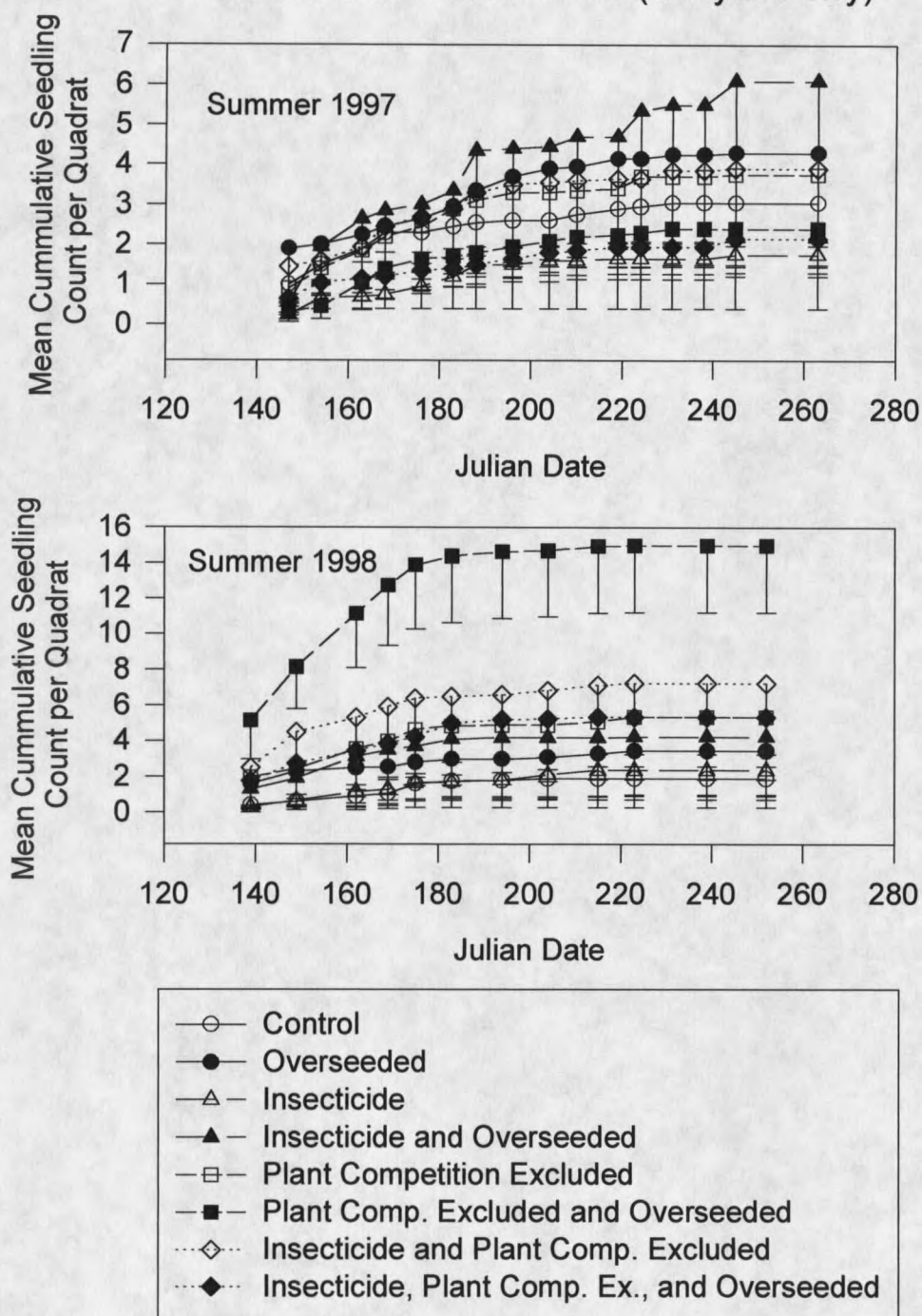
<sup>1</sup>: Mean of seedling counts from four blocks combined.

Figure 3. Mean<sup>1</sup> Total Dalmatian Toadflax Seedlings by Julian Date for the Eight Treatments Over Both Years (Wyola)



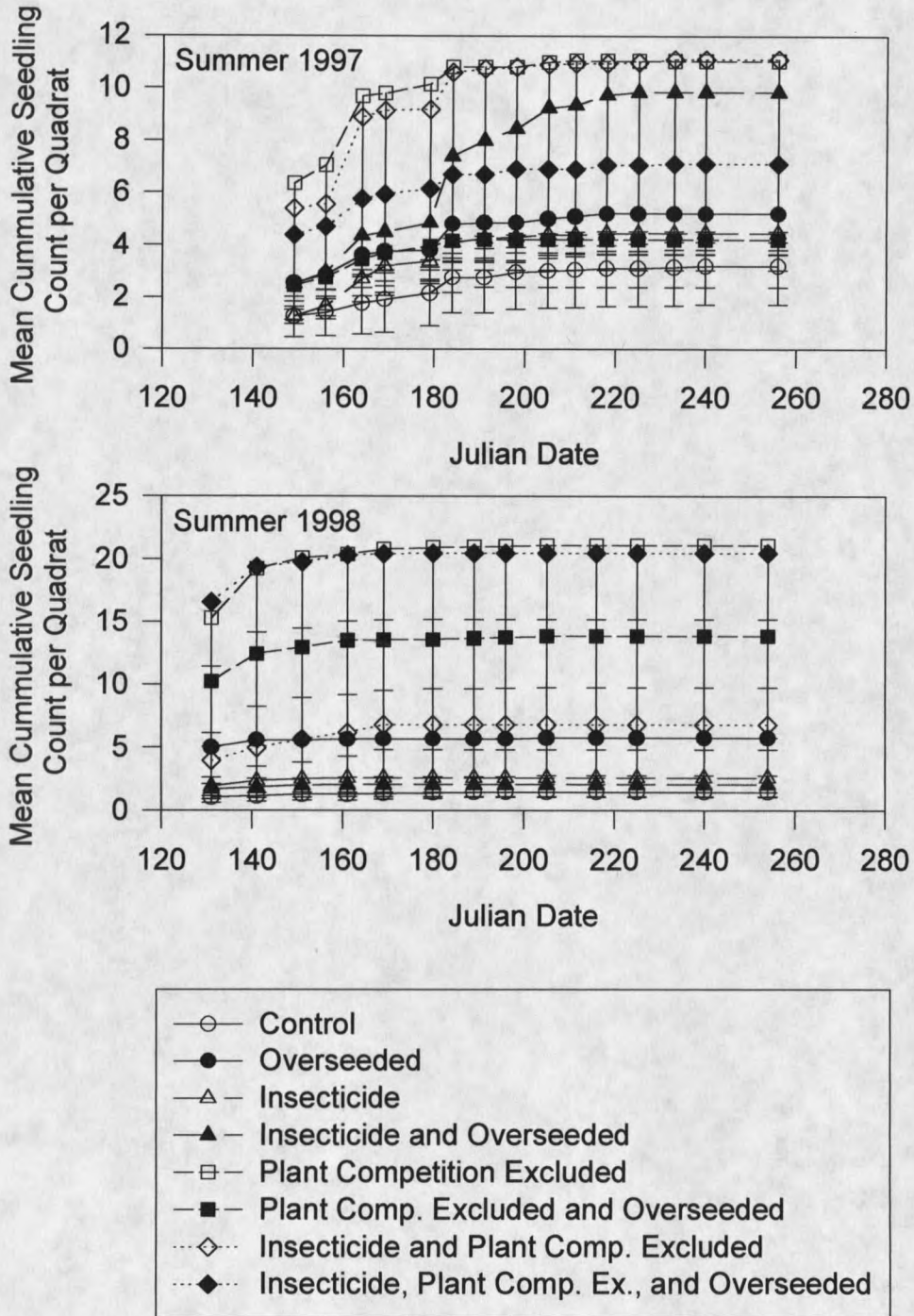
<sup>1</sup>: Mean of seedling counts from four blocks combined.

Figure 4. Mean<sup>1</sup> Dalmatian Toadflax Cumulative Seedling Germination by Julian Date for the Eight Treatments Over Both Years (Canyon Ferry)



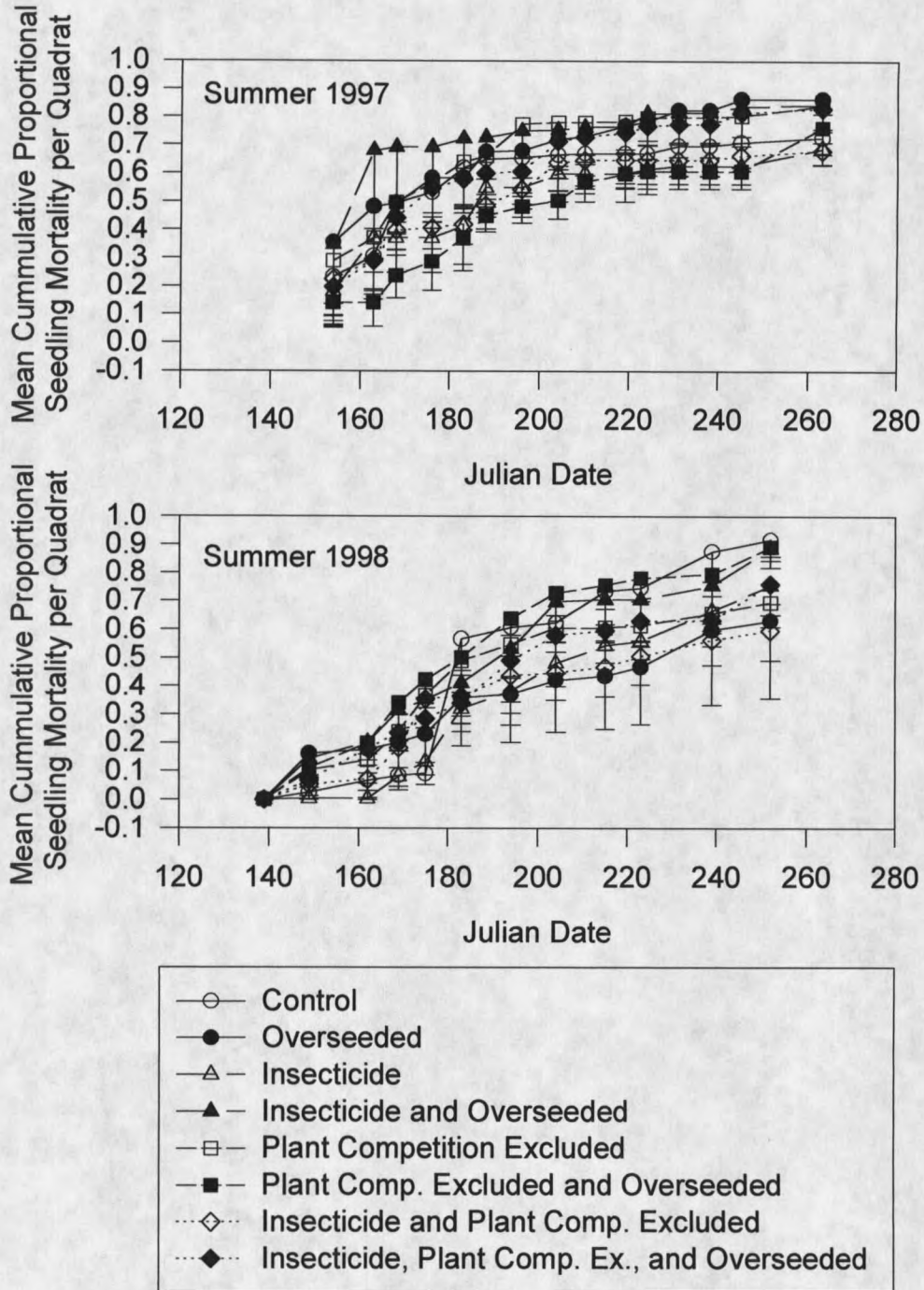
<sup>1</sup>: Mean of seedling germination counts from four blocks combined.

Figure 5. Mean<sup>1</sup> Dalmatian Toadflax Cumulative Seedling Germination by Julian Date for the Eight Treatments Over Both Years (Wyola)



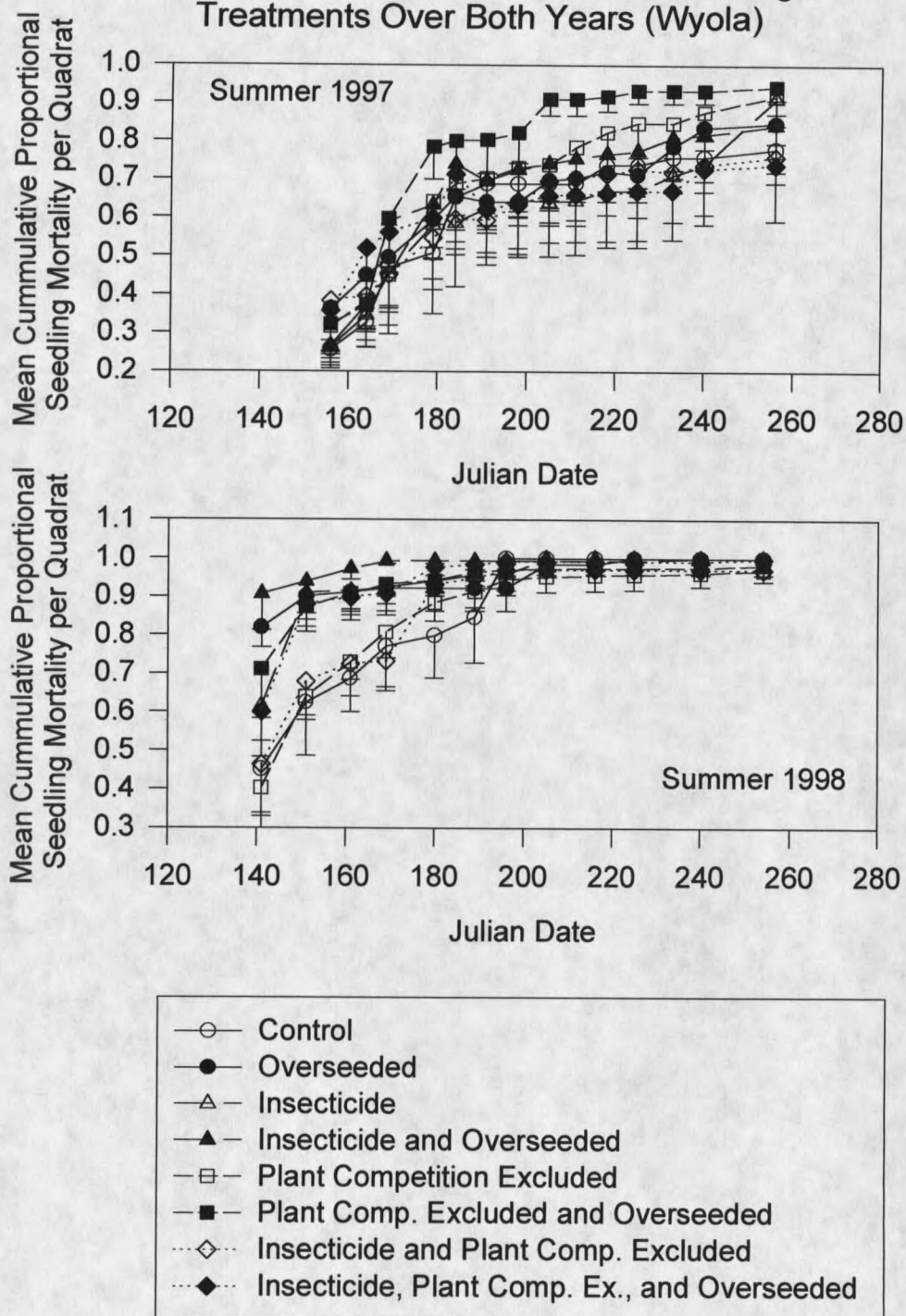
<sup>1</sup>: Mean of seedling germination counts from four blocks combined.

Figure 6. Mean<sup>1</sup> Dalmatian Toadflax Cumulative Proportional Seedling Mortality by Julian Date for the Eight Treatments Over Both Years (Canyon Ferry)



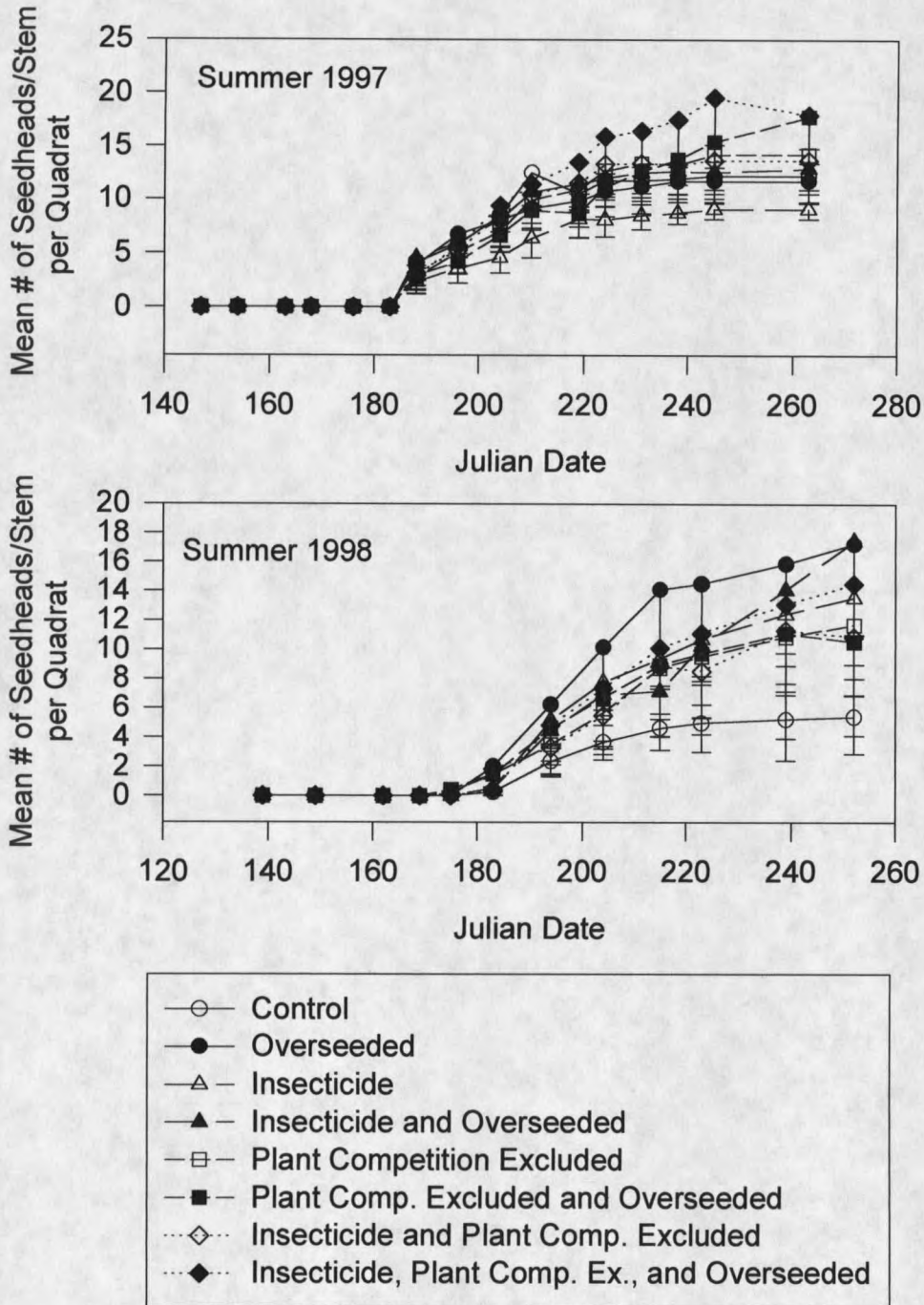
<sup>1</sup>: Mean of seedling mortality counts from four blocks combined.

Figure 7. Mean<sup>1</sup> Dalmatian Toadflax Cumulative Proportional Seedling Mortality by Julian Date for the Eight Treatments Over Both Years (Wyola)



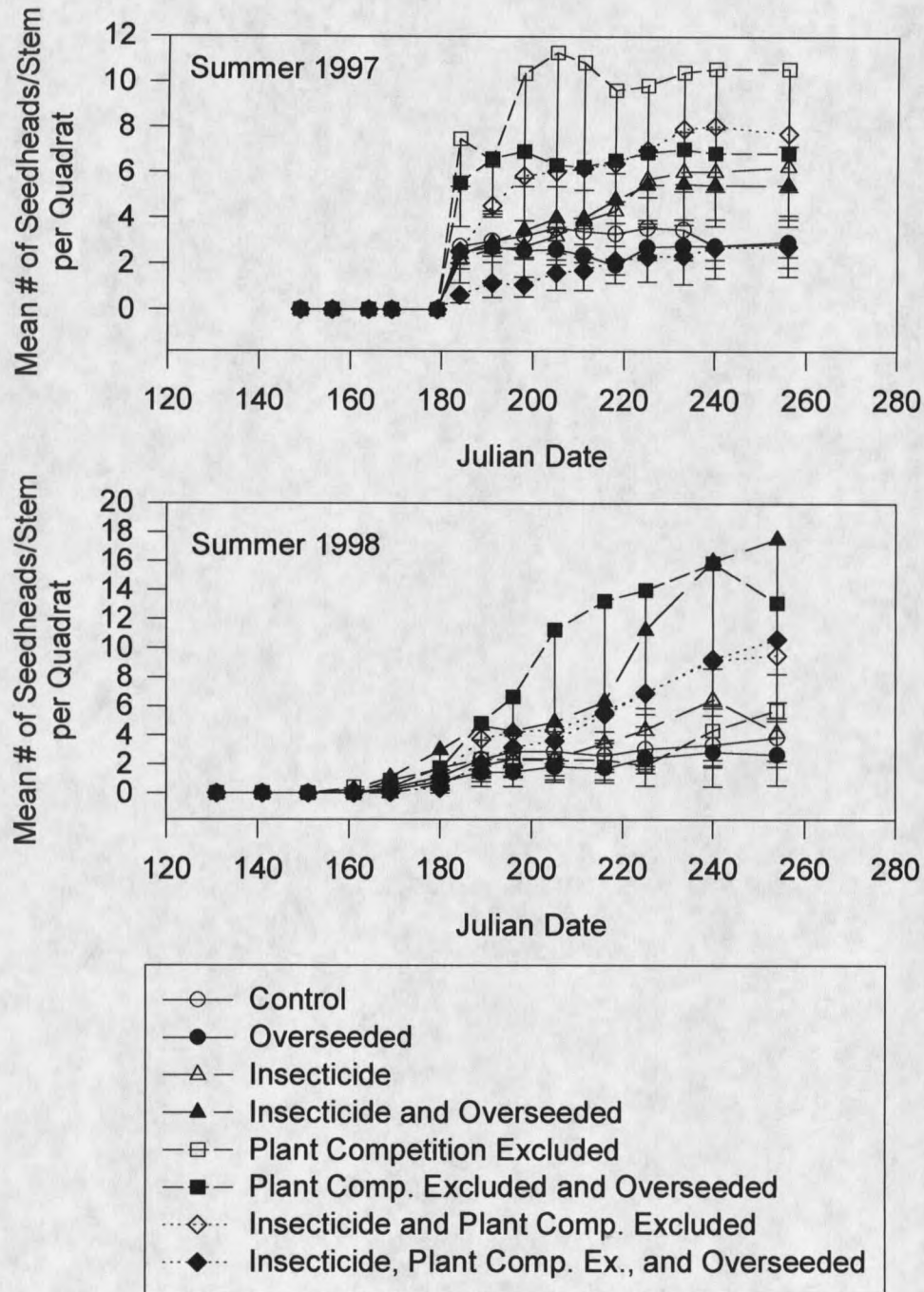
<sup>1</sup>: Mean of seedling mortality counts from four blocks combined.

Figure 8. Mean<sup>1</sup> Dalmatian Toadflax Seedheads per Stem by Julian Date for the Eight Treatments Over Both Years (Canyon Ferry)



<sup>1</sup>: Mean of seedhead per stem counts from four blocks combined.

Figure 9. Mean<sup>1</sup> Dalmatian Toadflax Seedheads per Stem by Julian Date for the Eight Treatments Over Both Years (Wyola)



<sup>1</sup>: Mean of seedhead per stem counts from four blocks combined.

that the covariance structure selected was among the best algorithms tried suggests that the models are acceptable.

Table 1. Validation and covariant parameters for the mixed model repeated measures of total seedling counts (Canyon Ferry 1997).

Description	Value	Block	Covariant Variance	Covariant Value
Observations	472.0000	1	0.1469	0.9772
Akaike's Information Criterion	-79.8647	2	0.2010	0.9724
Schwarz's Bayesian Criterion	-96.3809	3	0.7763	0.9918
Null Model LRT Chi-Square	612.9247	4	0.1571	0.9329
Null Model LRT DF	7.0000			
Null Model LRT P-Value	0.0000			

Data were normalized using a square root transformation.

Table 2. Validation and covariant parameters for the mixed model repeated measures of total seedling counts (Wyola 1997).

Description	Value	Block	Covariant Variance	Covariant Value
Observations	472.0000	1	1.6939	0.9901
Akaike's Information Criterion	-210.5960	2	0.2527	0.9298
Schwarz's Bayesian Criterion	-227.1120	3	0.4049	0.9858
Null Model LRT Chi-Square	493.2725	4	0.1636	0.9497
Null Model LRT DF	7.0000			
Null Model LRT P-Value	0.0000			

Data were normalized using a square root transformation.

Table 3. Validation and covariant parameters for the mixed model repeated measures of total seedling counts (Canyon Ferry 1998).

Description	Value	Block	Covariant Variance	Covariant Value
Observations	384.0000	1	0.1347	0.9818
Akaike's Information Criterion	-19.4111	2	0.2669	0.9881
Schwarz's Bayesian Criterion	-35.0107	3	1.4410	0.9970
Null Model LRT Chi-Square	626.4811	4	0.6279	0.9964
Null Model LRT DF	7.0000			
Null Model LRT P-Value	0.0000			

Data were normalized using a square root transformation.

Table 4. Validation and covariant parameters for the mixed model repeated measures of total seedling counts (Wyola 1998).

Description	Value	Block	Covariant Variance	Covariant Value
Observations	416.0000	1	2.7491	0.9962
Akaike's Information Criterion	-249.9280	2	2.6072	0.9965
Schwarz's Bayesian Criterion	-265.8640	3	1.7424	0.9960
Null Model LRT Chi-Square	498.1688	4	3.8106	0.9976
Null Model LRT DF	7.0000			
Null Model LRT P-Value	0.0000			

Data were normalized using a square root transformation.

Table 5. Validation and covariant parameters for the mixed model repeated measures of cumulative seedling emergence (Canyon Ferry 1997).

Description	Value	Block	Covariant Variance	Covariant Value
Observations	472.0000	1	0.2840	0.9966
Akaike's Information Criterion	285.0536	2	0.4170	0.9959
Schwarz's Bayesian Criterion	268.5374	3	0.9457	0.9982
Null Model LRT Chi-Square	1272.0910	4	0.1028	0.9983
Null Model LRT DF	7.0000			
Null Model LRT P-Value	0.0000			

Data were normalized using a LN transformation.

Table 6. Validation and covariant parameters for the mixed model repeated measures of cumulative seedling emergence (Wyola 1997).

Description	Value	Block	Covariant Variance	Covariant Value
Observations	472.0000	1	0.9727	0.9993
Akaike's Information Criterion	267.0460	2	0.5885	0.9978
Schwarz's Bayesian Criterion	250.5298	3	0.5539	0.9980
Null Model LRT Chi-Square	1408.0460	4	0.2361	0.9954
Null Model LRT DF	7.0000			
Null Model LRT P-Value	0.0000			

Data were normalized using a LN transformation.

Table 7. Validation and covariant parameters for the mixed model repeated measures of cumulative seedling emergence (Canyon Ferry 1998).

Description	Value	Block	Covariant Variance	Covariant Value
Observations	384.0000	1	0.4172	0.9978
Akaike's Information Criterion	167.3990	2	0.3733	0.9986
Schwarz's Bayesian Criterion	151.7994	3	1.9971	0.9995
Null Model LRT Chi-Square	1096.6310	4	1.3251	0.9988
Null Model LRT DF	7.0000			
Null Model LRT P-Value	0.0000			

Data were normalized using a LN transformation.

Table 8. Validation and covariant parameters for the mixed model repeated measures of cumulative seedling emergence (Wyola 1998).

Description	Value	Block	Covariant Variance	Covariant Value
Observations	416.0000	1	1.0210	0.9999
Akaike's Information Criterion	527.4568	2	2.3955	0.9999
Schwarz's Bayesian Criterion	511.5210	3	0.2525	0.9995
Null Model LRT Chi-Square	1969.1760	4	0.5771	0.9996
Null Model LRT DF	7.0000			
Null Model LRT P-Value	0.0000			

Data were normalized using a LN transformation.

Table 9. Validation and covariant parameters for the mixed model repeated measures of cumulative proportional seedling mortality (Canyon Ferry 1997).

Description	Value	Block	Covariant Variance	Covariant Value
Observations	425.0000	1	0.3349	0.9931
Akaike's Information Criterion	258.4784	2	0.3992	0.9935
Schwarz's Bayesian Criterion	242.3943	3	0.1399	0.9976
Null Model LRT Chi-Square	983.2404	4	0.3450	0.9993
Null Model LRT DF	7.0000			
Null Model LRT P-Value	0.0000			

Data were normalized using an arcsine transformation.

Table 10. Validation and covariant parameters for the mixed model repeated measures of cumulative proportional seedling mortality (Wyola 1997).

Description	Value	Block	Covariant Variance	Covariant Value
Observations	426.0000	1	0.4200	0.9957
Akaike's Information Criterion	159.2277	2	0.1518	0.9882
Schwarz's Bayesian Criterion	143.1339	3	0.2665	0.9960
Null Model LRT Chi-Square	621.2563	4	0.1208	0.9830
Null Model LRT DF	7.0000			
Null Model LRT P-Value	0.0000			

Data were normalized using an arcsine transformation.

Table 11. Validation and covariant parameters for the mixed model repeated measures of cumulative proportional seedling mortality (Canyon Ferry 1998).

Description	Value	Block	Covariant Variance	Covariant Value
Observations	324.0000	1	0.6572	0.9982
Akaike's Information Criterion	98.5229	2	0.6038	0.9954
Schwarz's Bayesian Criterion	83.6417	3	0.7137	0.9985
Null Model LRT Chi-Square	554.2348	4	0.6822	0.9988
Null Model LRT DF	7.0000			
Null Model LRT P-Value	0.0000			

Data were normalized using an arcsine transformation.

Table 12. Validation and covariant parameters for the mixed model repeated measures of cumulative proportional seedling mortality (Wyola 1998).

Description	Value	Block	Covariant Variance	Covariant Value
Observations	384.0000	1	0.2025	0.9939
Akaike's Information Criterion	77.0121	2	0.4091	0.9928
Schwarz's Bayesian Criterion	61.4125	3	0.3198	0.9949
Null Model LRT Chi-Square	443.6928	4	0.2360	0.9943
Null Model LRT DF	7.0000			
Null Model LRT P-Value	0.0000			

Data were normalized using an arcsine transformation.

Table 13. Validation and covariant parameters for the mixed model repeated measures of seedheads per stem (Canyon Ferry 1997).

Description	Value	Block	Covariant Variance	Covariant Value
Observations	288.0000	1	3.9417	0.9949
Akaike's Information Criterion	-197.8370	2	1.0924	0.9855
Schwarz's Bayesian Criterion	-212.3040	3	0.8113	0.9921
Null Model LRT Chi-Square	398.7061	4	1.1898	0.9928
Null Model LRT DF	7.0000			
Null Model LRT P-Value	0.0000			

Data were normalized using a square root transformation.

Table 14. Validation and covariant parameters for the mixed model repeated measures of seedheads per stem (Wyola 1997).

Description	Value	Block	Covariant Variance	Covariant Value
Observations	320.0000	1	0.7435	0.9919
Akaike's Information Criterion	-32.2435	2	0.5266	0.9954
Schwarz's Bayesian Criterion	-32.2435	3	0.5266	0.9954
Null Model LRT Chi-Square	651.4489	4	1.1594	0.9950
Null Model LRT DF	7.0000			
Null Model LRT P-Value	0.0000			

Data were normalized using a square root transformation.

Table 15. Validation and covariant parameters for the mixed model repeated measures of seedheads per stem (Canyon Ferry 1998).

Description	Value	Block	Covariant Variance	Covariant Value
Observations	256.0000	1	8.6732	0.9959
Akaike's Information Criterion	-289.5190	2	4.5762	0.9947
Schwarz's Bayesian Criterion	-303.3910	3	2.3599	0.9946
Null Model LRT Chi-Square	332.5301	4	6.7022	0.9948
Null Model LRT DF	7.0000			
Null Model LRT P-Value	0.0000			

Data were normalized using a square root transformation.

Table 16. Validation and covariant parameters for the mixed model repeated measures of seedheads per stem (Wyola 1998).

Description	Value	Block	Covariant Variance	Covariant Value
Observations	320.0000	1	6.9263	0.9976
Akaike's Information Criterion	-270.9600	2	3.3586	0.9952
Schwarz's Bayesian Criterion	-285.7890	3	2.1958	0.9961
Null Model LRT Chi-Square	546.1212	4	5.7502	0.9968
Null Model LRT DF	7.0000			
Null Model LRT P-Value	0.0000			

Data were normalized using a square root transformation.

Total Seedling Counts The mixed model repeated measures ANOVA results for total seed counts for both sites and years have been presented in Tables 26-31. Significant block effects for total seedling counts were obtained for the Canyon Ferry and Wyola sites in 1997 ( $P = 0.023$ ; Table 17 and  $P = 0.0317$ ; Table 18 respectively). Likewise, significant plant competition-insecticide interactions were detected at the Canyon Ferry site in 1997

( $P = 0.032$ ; Table 17) and significant block-plant competition and block-insecticide interactions were detected at the Wyola site in 1997 ( $P = 0.001$ ,  $P = 0.028$  respectively; Table 18). Significant plant competition effects as well as seeding-plant competition and seeding-insecticide interactions were detected at the Canyon Ferry site in 1998 ( $P = 0.027$ ,  $P = 0.005$ ,  $P = 0.003$ , respectively; Table 22). However no significant effects or interactions were detected at the Wyola site in 1999 ( $P > 0.05$ ; Table 25).

The significant plant competition-insecticide interaction obtained from Canyon Ferry in 1997 did not yield significant comparisons so it was concluded that this interaction was probably the result of block variability. The block-plant competition and block-insecticide interactions obtained at Wyola in 1997 were also probably due to block variability as evidenced by the significant differences between blocks 2 and 3 and blocks 3 and 4 ( $P = 0.016$ ,  $P = 0.010$ , respectively Tables 19-21). Significant seeding-plant competition interactions at Canyon Ferry in 1998 yielded a higher value for total seedling counts in comparisons of overseeded with plant competition excluded treatments versus treatments that were overseeded, excluded from plant competition, or maintained without overseeding or plant competition exclusion at ( $P = 0.002$ ,  $P = 0.029$ ,  $P = .033$ , respectively; Table 23). This interaction term provided further support for the significant plant competition main factor results. The significant seeding-insecticide interaction at Canyon Ferry in 1998 yielded only one significant least square means comparison, indicating a higher total seedling count for overseeded treatments without insecticide application versus treatments that were not overseeded or sprayed with insecticide ( $P = 0.025$ ; Table 24).

Table 17. Mixed model repeated measures results for total seedling counts (Canyon Ferry 1997).

Source	NDF	DDF	F Value	Pr = F
Block	3	16	3.99	<b>0.0232</b>
Plant Competition	1	16	0.04	0.8497
Insecticide	1	16	0.05	0.8319
Block * Plant Competition	3	16	1.07	0.3842
Block * Insecticide	3	16	1.02	0.4076
Plant Competition * Insecticide	1	16	5.38	<b>0.0317</b>

Data were normalized using a square root transformation.  
 Bold face text indicates a significant P-value ( $\alpha = 0.05$ ).

Table 18. Mixed model repeated measures results for total seedling counts (Wyola 1997).

Source	NDF	DDF	F Value	Pr = F
Block	3	16	3.82	<b>0.0269</b>
Plant Competition	1	16	2.34	0.1427
Insecticide	1	16	1.21	0.2860
Block * Plant Competition	3	16	8.22	<b>0.0010</b>
Block * Insecticide	3	16	3.76	<b>0.0283</b>
Plant competition * Insecticide	1	16	2.95	0.1019

Data were normalized using a square root transformation.  
 Bold face text indicates a significant P-value ( $\alpha = 0.05$ ).

Table 19. Significant t-test block comparisons for total seedling count mixed model repeated measures ( $\alpha = 0.05$ , Wyola1997).

Block	Least Squares Mean	Block	Least Squares Mean	Difference Between LS Means	DF	"t" Value	P-value
2	0.657	3	1.156	-0.499	19	-2.65	0.016
3	1.156	4	0.622	0.534	19	2.88	0.010

Table 20. Significant t-test block-plant competition interaction comparisons for total seedling count mixed model repeated measures ( $\alpha = 0.05$ , Wyola1997).

Block	Plant Competition (+/-)	Least Squares Mean	Block	Plant Competition (+/-)	Least Squares Mean	Difference Between LS Means	DF	"t" Value	P-value
1	-	1.919	2	-	0.371	1.548	19	2.88	0.010
1	-	1.919	4	+	0.393	1.527	19	2.85	0.010
2	-	0.371	2	+	0.943	-0.572	19	-3.51	0.002
2	-	0.371	3	-	1.267	-0.896	19	-3.37	0.003
2	-	0.371	3	+	1.045	-0.674	19	-2.53	0.020
2	-	0.371	4	-	0.851	-0.480	19	-3.08	0.006
2	+	0.943	4	+	0.393	0.550	19	3.53	0.002
3	-	1.267	4	+	0.393	0.874	19	3.34	0.004
4	-	0.851	4	+	0.393	0.149	19	3.08	0.006

Table 21. Significant t-test block-insecticide interaction comparisons for total seedling count mixed model repeated measures ( $\alpha = 0.05$ , Wyola1997).

Block	Insecticide (+/-)	Least Squares Mean	Block	Insecticide (+/-)	Least Squares Mean	Difference Between LS Means	DF	"t" Value	P-value
1	+	1.613	2	-	0.428	1.185	19	2.20	0.040
1	+	1.613	4	+	0.489	1.123	19	2.10	0.050
2	+	0.886	2	-	0.428	0.458	19	2.81	0.011
2	+	0.886	4	+	0.489	0.397	19	2.55	0.020
2	-	0.428	3	+	1.238	-0.810	19	-3.05	0.007
2	-	0.428	3	-	1.074	-0.646	19	-2.43	0.025
2	-	0.428	4	-	0.755	-0.327	19	-2.09	0.050
3	+	1.238	4	+	0.489	0.749	19	2.86	0.010
3	-	1.074	4	+	0.489	0.585	19	2.23	0.038

Table 22. Mixed model repeated measures results for total seedling counts (Canyon Ferry 1998).

Source	NDF	DDF	F Value	Pr = F
Block	3	13	2.71	0.0879
Seeding	1	13	0.75	0.4024
Plant Competition	1	13	6.21	<b>0.0270</b>
Insecticide	1	13	0.00	0.9803
Block * Seeding	3	13	0.11	0.9523
Block * Plant Competition	3	13	1.23	0.3371
Block * Insecticide	3	13	0.23	0.8709
Seeding * Plant Competition	1	13	11.56	<b>0.0047</b>
Seeding * Insecticide	1	13	12.80	<b>0.0034</b>
Plant Competition * Insecticide	1	13	3.00	0.1069

Data were normalized using a square root transformation.  
 Bold face text indicates a significant P-value ( $\alpha = 0.05$ ).

Table 23. Significant t-test seeding-plant competition interaction comparisons for total seedling count mixed model repeated measures ( $\alpha = 0.05$ , Canyon Ferry 1998).

Seeding (+/-)	Plant Competition (+/-)	Least Squares Mean	Seeding (+/-)	Plant Competition (+/-)	Least Squares Mean	Difference Between LS Means	DF	"t" Value	P-value
-	-	0.817	+	-	1.522	-0.705	13	-2.45	0.029
-	+	0.687	+	-	1.522	-0.835	13	-2.37	0.033
+	-	1.522	+	+	0.413	1.109	13	3.86	0.002

Table 24. Significant t-test seeding-insecticide interaction comparisons for total seedling count mixed model repeated measures ( $\alpha = 0.05$ , Canyon Ferry 1998).

Seeding (+/-)	Insecticide (+/-)	Least Squares Mean	Seeding (+/-)	Insecticide (+/-)	Least Squares Mean	Difference Between LS Means	DF	"t" Value	P-value
-	-	0.497	+	-	1.228	-0.730	13	-2.54	0.025

Table 25. Mixed model repeated measures results for total seedling counts (Wyola 1998).

Source	NDF	DDF	F Value	Pr = F
Block	3	13	0.37	0.7785
Seeding	1	13	0.09	0.7685
Plant Competition	1	13	3.26	0.0940
Insecticide	1	13	0.09	0.7656
Block * Seeding	3	13	0.10	0.9574
Block * Plant Competition	3	13	0.41	0.7463
Block * Insecticide	3	13	0.30	0.8224
Seeding * Plant Competition	1	13	0.02	0.9013
Seeding * Insecticide	1	13	0.08	0.7777
Plant Competition * Insecticide	1	13	0.00	0.9851

Data were normalized using a square root transformation.

Bold face text indicates a significant P-value ( $\alpha = 0.05$ ).

Cumulative Seedling Emergence The mixed model repeated measures ANOVA results for cumulative seedling emergence for both sites and years have been presented in Tables 26-31. Significant block effects were detected for cumulative seedling emergence for the Canyon Ferry and Wyola sites in 1997 ( $P < 0.05$ , Table 26, and  $P = 0.03$ , Table 27, respectively). All other factors were not found to be significant ( $P > 0.05$ ). Significant seeding-plant competition and seeding-insecticide interactions for cumulative seedling emergence were obtained for the Canyon Ferry site in 1998 ( $P = 0.036$  and  $P < 0.05$ , respectively; Table 28). Plant competition was the only factor that significantly affected cumulative seedling emergence at the Wyola site in 1998 ( $P = 0.006$ ; Table 31).

Significant seeding-plant competition interactions at Canyon Ferry in 1998 yielded a higher value for cumulative seedling emergence counts in comparisons of overseeded with plant competition excluded treatments versus treatments that were overseeded, excluded from plant competition, or maintained without overseeding or plant competition

exclusion ( $P = 0.041$ ,  $P = 0.029$ ,  $P = .050$ , respectively; Table 29). These results provided further support the significant plant competition main factor results. Significant seeding-insecticide interaction at Canyon Ferry in 1998 yielded only one significant least square means comparison, indicating a higher cumulative seedling emergence count for overseeded treatments with insecticide application versus treatments that were not overseeded or sprayed with insecticide ( $P = 0.049$ ; Table 30).

Table 26. Mixed model repeated measures results for cumulative seedling emergence (Canyon Ferry 1997).

Source	NDF	DDF	F Value	Pr = F
Block	3	16	3.14	<b>0.0495</b>
Plant Competition	1	16	0.00-	0.9515
Insecticide	1	16	0.43	0.5184
Block * Plant Competition	3	16	0.29	0.8288
Block * Insecticide	3	16	0.22	0.8792
Plant Competition * Insecticide	1	16	0.19	0.0901

Data were normalized using a LN transformation.  
 Bold face text indicates a significant P-value ( $\alpha = 0.05$ ).

Table 27. Mixed model repeated measures results for cumulative seedling emergence (Wyola 1997).

Source	NDF	DDF	F Value	Pr = F
Block	3	16	3.65	<b>0.0312</b>
Plant Competition	1	16	1.17	0.2927
Insecticide	1	16	0.38	0.5459
Block * Plant Competition	3	16	1.76	0.1890
Block * Insecticide	3	16	0.61	0.6146
Plant competition * Insecticide	1	16	0.66	0.4266

Data were normalized using a LN transformation.  
 Bold face text indicates a significant P-value ( $\alpha = 0.05$ ).

Table 28. Mixed model repeated measures results for cumulative seedling emergence (Canyon Ferry 1998).

Source	NDF	DDF	F Value	Pr = F
Block	3	13	2.10	0.1497
Seeding	1	13	1.15	0.3030
Plant Competition	1	13	3.72	0.0760
Insecticide	1	13	0.06	0.8092
Block * seeding	3	13	0.07	0.9752
Block * Plant Competition	3	13	0.56	0.6480
Block * Insecticide	3	13	0.11	0.9532
Seeding * Plant Competition	1	13	5.45	<b>0.0362</b>
Seeding * Insecticide	1	13	4.67	<b>0.0499</b>
Plant Competition * Insecticide	1	13	2.44	0.1419

Data were normalized using a LN transformation.  
 Bold face text indicates a significant P-value ( $\alpha = 0.05$ ).

Table 29. Significant t-test seeding-plant competition interaction comparisons for cumulative seedling emergence mixed model repeated measures ( $\alpha = 0.05$ , Canyon Ferry 1998).

Seeding (+/-)	Plant Competition (+/-)	Least Squares Mean	Seeding (+/-)	Plant Competition (+/-)	Least Squares Mean	Difference Between LS Means	DF	"t" Value	P-value
-	-	0.862	+	-	1.864	-1.002	13	-2.27	0.041
-	+	0.817	+	-	1.864	-1.047	13	-2.12	0.050
+	-	1.864	+	+	0.564	1.301	13	2.95	0.011

Table 30. Significant t-test seeding-insecticide interaction comparisons for cumulative seedling emergence mixed model repeated measures ( $\alpha = 0.05$ , Canyon Ferry 1998).

Seeding (+/-)	Insecticide (+/-)	Least Squares Mean	Seeding (+/-)	Insecticide (+/-)	Least Squares Mean	Difference Between LS Means	DF	"t" Value	P-value
-	-	0.592	+	-	1.548	-0.955	13	-2.17	0.049

Table 31. Mixed model repeated measures results for cumulative seedling emergence (Wyola 1998).

Source	NDF	DDF	F Value	Pr = F
Block	3	13	1.19	0.3507
Seeding	1	13	1.01	0.3343
Plant Competition	1	13	10.61	<b>0.0062</b>
Insecticide	1	13	0.02	0.8901
Block * Seeding	3	13	0.31	0.8209
Block * Plant Competition	3	13	0.95	0.4471
Block * Insecticide	3	13	0.66	0.5934
Seeding * Plant Competition	1	13	1.72	0.2128
Seeding * Insecticide	1	13	0.58	0.4592
Plant Competition * Insecticide	1	13	0.00	0.9475

Data were normalized using a LN transformation.  
 Bold face text indicates a significant P-value ( $\alpha = 0.05$ ).

Cumulative Proportional Mortality The mixed model repeated measures ANOVA results for cumulative proportional mortality for both sites and years have been presented in Tables 32-35. No significant effects or interactions were detected at the Canyon Ferry nor the Wyola sites in neither 1997 or 1998 for cumulative proportional mortality.

Table 32. Mixed model repeated measures results for cumulative proportional seedling mortality (Canyon Ferry 1997).

Source	NDF	DDF	F Value	Pr = F
Block	3	16	0.87	0.4725
Plant Competition	1	16	0.08	0.7806
Insecticide	1	16	0.08	0.7792
Block * Plant Competition	3	16	0.04	0.9894
Block * Insecticide	3	16	0.23	0.8747
Plant competition * Insecticide	1	16	0.03	0.8652

Data were normalized using an arcsine transformation.  
 Bold face text indicates a significant P-value ( $\alpha = 0.05$ ).

Table 33. Mixed model repeated measures results for cumulative proportional seedling mortality (Wyola 1997).

Source	NDF	DDF	F Value	Pr = F
Block	3	16	1.09	0.3779
Plant Competition	1	16	0.02	0.8939
Insecticide	1	16	0.44	0.5160
Block * Plant Competition	3	16	1.31	0.3011
Block * Insecticide	3	16	0.05	0.9867
Plant competition * Insecticide	1	16	1.39	0.2540

Data were normalized using an arcsine transformation.  
**Bold face text indicates a significant P-value ( $\alpha = 0.05$ ).**

Table 34. Mixed model repeated measures results for cumulative proportional seedling mortality (Canyon Ferry 1998).

Source	NDF	DDF	F Value	Pr = F
Block	3	13	0.04	0.9890
Seeding	1	13	0.00	0.9841
Plant Competition	1	13	0.04	0.8457
Insecticide	1	13	0.11	0.7511
Block * Seeding	3	13	0.04	0.9903
Block * Plant Competition	3	13	0.11	0.9527
Block * Insecticide	3	13	0.03	0.9909
Seeding * Plant Competition	1	13	0.25	0.6289
Seeding * Insecticide	1	13	0.05	0.8275
Plant Competition * Insecticide	1	13	0.00	0.9895

Data were normalized using an arcsine transformation.  
**Bold face text indicates a significant P-value ( $\alpha = 0.05$ ).**

Table 35. Mixed model repeated measures results for cumulative proportional seedling mortality (Wyola 1998).

Source	NDF	DDF	F Value	Pr = F
Block	3	13	0.18	0.9063
Seeding	1	13	1.76	0.2070
Plant Competition	1	13	1.14	0.3052
Insecticide	1	13	0.15	0.7013
Block * Seeding	3	13	0.08	0.9684
Block * Plant Competition	3	13	0.16	0.9246
Block * Insecticide	3	13	0.17	0.9176
Seeding * Plant Competition	1	13	0.01	0.9440
Seeding * Insecticide	1	13	0.00	0.9667
Plant Competition * Insecticide	1	13	0.25	0.6223

Data were normalized using an arcsine transformation.  
**Bold face text indicates a significant P-value ( $\alpha = 0.05$ ).**

**Seedheads per Stem** The mixed model repeated measures ANOVA results for seedheads per stem for both sites and years are presented in Tables 36-42. Block-insecticide and plant competition-insecticide interactions at Wyola in 1997 were the only significant results detected for seedheads per stem ( $P = 0.023$ ,  $P = 0.039$ , respectively; Table 37). Comparisons of block-insecticide combinations for seedheads per stem counts at Wyola in 1997 suggest that blocking effects may have caused the interaction since three out of the five significant comparisons show block 1 as having a significantly lower seedheads per stem mean than the other three blocks (Table 38). However, two of the significant block-insecticide comparisons at Wyola in 1997 yielded higher values for insecticide treatments versus insecticide free treatments within the same block ( $P = 0.033$ ,  $P = 0.017$ ; Table 38) suggesting that there may have been an increase in seedheads per stem associated with insecticide treatment. Comparisons of plant competition-insecticide combinations at Wyola in 1997 show that plant competition alone yielded a higher

seedheads per stem value than plant competition exclusion with insecticide application or where neither treatment was performed ( $P = 0.045$ ,  $P = 0.029$ , respectively; Table 39), suggesting that plant competition exclusion may have increased seedhead production.

Table 36. Mixed model repeated measures results for seedheads per stem (Canyon Ferry 1997).

Source	NDF	DDF	F Value	Pr = F
Block	3	16	1.29	0.3069
Plant Competition	1	16	0.12	0.7365
Insecticide	1	16	0.03	0.8583
Block * Plant Competition	3	16	0.16	0.9235
Block * Insecticide	3	16	0.14	0.9372
Plant competition * Insecticide	1	16	0.37	0.5502

Data were normalized using a square root transformation.  
 Bold face text indicates a significant P-value ( $\alpha = 0.05$ ).

Table 37. Mixed model repeated measures results for seedheads per stem (Wyola 1997).

Source	NDF	DDF	F Value	Pr = F
Block	3	16	1.58	0.2277
Plant Competition	1	16	1.35	0.2599
Insecticide	1	16	0.74	0.3989
Block * Plant Competition	3	16	0.43	0.7359
Block * Insecticide	3	16	3.98	<b>0.0233</b>
Plant competition * Insecticide	1	16	4.89	<b>0.0394</b>

Data were normalized using a square root transformation.  
 Bold face text indicates a significant P-value ( $\alpha = 0.05$ ).

Table 38. Significant t-test block-insecticide interaction comparisons for seedheads per stem mixed model repeated measures ( $\alpha = 0.05$ , Wyola 1997).

Block	Insecticide (+/-)	Least Squares Mean	Block	Insecticide (+/-)	Least Squares Mean	Difference Between LS Means	DF	"t" Value	P-value
1	+	2.019	1	-	0.788	1.231	19	2.30	0.033
1	-	0.788	2	-	2.435	-1.646	19	-3.25	0.004
1	-	0.788	3	-	2.435	-1.646	19	-3.25	0.004
1	-	0.788	4	-	2.429	-1.365	19	-2.19	0.041
2	+	1.478	2	-	2.435	-0.957	19	-2.63	0.017

Table 39. Significant t-test plant competition-insecticide interaction comparisons for seedheads per stem mixed model repeated measures ( $\alpha = 0.05$ , Wyola 1997).

Plant Competition (+/-)	Insecticide (+/-)	Least Squares Mean	Plant Competition (+/-)	Insecticide (+/-)	Least Squares Mean	Difference Between LS Means	DF	"t" Value	P-value
-	+	1.651	-	-	2.474	-0.823	19	-2.15	0.045
-	-	2.474	+	-	1.569	0.906	19	2.37	0.029

Table 40. Mixed model repeated measures results for seedheads per stem (Canyon Ferry 1998).

Source	NDF	DDF	F Value	Pr = F
Block	3	13	0.60	0.6281
Seeding	1	13	0.31	0.5890
Plant Competition	1	13	0.00	0.9897
Insecticide	1	13	0.07	0.7968
Block * Seeding	3	13	0.06	0.9799
Block * Plant Competition	3	13	0.19	0.9028
Block * Insecticide	3	13	0.00	0.9599
Seeding * Plant Competition	1	13	0.01	0.9263
Seeding * Insecticide	1	13	0.03	0.8649
Plant Competition * Insecticide	1	13	0.01	0.9313

Data were normalized using a square root transformation.  
 Bold face text indicates a significant P-value ( $\alpha = 0.05$ ).

Table 41. Mixed model repeated measures results for seedheads per stem (Wyola 1998).

Source	NDF	DDF	F Value	Pr = F
Block	3	13	0.24	0.8658
Seeding	1	13	0.19	0.6705
Plant Competition	1	13	0.05	0.8265
Insecticide	1	13	0.46	0.5113
Block * Seeding	3	13	0.07	0.9762
Block * Plant Competition	3	13	0.42	0.7438
Block * Insecticide	3	13	0.10	0.9603
Seeding * Plant Competition	1	13	0.06	0.8144
Seeding * Insecticide	1	13	0.08	0.7841
Plant Competition * Insecticide	1	13	0.00	0.9959

Data were normalized using a square root transformation.  
**Bold face text indicates a significant P-value ( $\alpha = 0.05$ ).**

#### ANOVA's within Sampling Dates

Total Seedling Counts P-values for main effects and two-way interactions for the total seedling counts within date ANOVAs have been presented in Tables 42-45.

Significant block effects for total seedling counts were obtained at the Canyon Ferry site in 14 out of 15 sampling dates in 1997 ( $p < 0.05$ ; Table 42). Significant blocking effects for total seedling counts at Wyola were obtained at 6 of a possible 15 dates in 1997. Other significant effects for total seedling counts at Wyola in 1997 included 2 of 15 dates with significant plant competition effects, and 5 of 15 dates with significant block-plant competition interactions ( $p < 0.05$ ; Table 43). Significant blocking effects at Canyon Ferry for total seedling counts were detected in 10 of 12 dates in 1998, with 11 of 12 dates also having significant plant competition effects ( $p < 0.05$ ; Table 44). Significant factors of total seedling counts at Wyola in 1998 consisted of 2 of 13 dates with significant blocking

effects, 1 of 13 dates with significant seeding effects, and 13 of 13 dates with significant plant competition effects ( $p < 0.05$ ; Table 45).

Table 42. P-values for within date ANOVA main effects and interactions for total seedling counts ( $\alpha = 0.05$ , Canyon Ferry 1997).

Julian Date	147	154	163	168	176	183	188	196	204	210	219	224	231	245	263
Block	<b>0.000</b>	<b>0.028</b>	<b>0.041</b>	<b>0.075</b>	<b>0.011</b>	<b>0.040</b>	<b>0.008</b>	<b>0.015</b>	<b>0.012</b>	<b>0.018</b>	<b>0.048</b>	<b>0.029</b>	<b>0.022</b>	<b>0.012</b>	<b>0.019</b>
Plant	0.996	0.990	0.662	0.578	0.556	0.734	0.858	0.899	0.921	0.915	0.986	0.949	0.859	0.826	0.932
Competition															
Insecticide	0.495	0.614	0.549	0.501	0.721	0.702	0.903	0.860	0.804	0.817	0.808	0.807	0.812	0.996	0.831
Block *	0.693	0.865	0.703	0.635	0.781	0.807	0.880	0.975	0.952	0.941	0.905	0.949	0.940	0.784	0.749
Plant															
Competition															
Block *	0.215	0.941	0.953	0.869	0.751	0.889	0.897	0.990	0.992	0.953	0.907	0.956	0.899	0.789	0.838
Insecticide															
Plant	<b>0.022</b>	0.854	0.836	0.718	0.679	0.83	0.506	0.936	0.881	0.933	0.712	0.984	0.989	0.868	0.940
Competition															
* Insecticide															

Data were normalized using a square root transformation.

Bold face text indicates a significant P-value.

Table 43. P-values for within date ANOVA main effects and interactions for total seedling counts ( $\alpha = 0.05$ , Wyola 1997).

Julian Date	149	156	164	169	179	184	191	198	205	211	218	225	233	240	256
Block	<b>0.002</b>	<b>0.003</b>	<b>0.001</b>	<b>0.003</b>	<b>0.023</b>	0.233	0.269	0.386	0.499	0.443	0.411	0.333	0.263	0.143	<b>0.033</b>
Plant	0.093	0.058	0.065	0.097	<b>0.034</b>	0.248	0.077	0.132	0.255	0.305	0.415	0.383	0.130	0.113	<b>0.033</b>
Competition															
Insecticide	0.913	0.461	0.884	0.292	0.287	0.246	0.094	0.095	0.076	0.068	<b>0.030</b>	<b>0.020</b>	<b>0.025</b>	<b>0.022</b>	<b>0.008</b>
Block * Plant	<b>0.044</b>	<b>0.027</b>	0.077	<b>0.017</b>	<b>0.027</b>	<b>0.011</b>	<b>0.035</b>	<b>0.016</b>	<b>0.031</b>	<b>0.013</b>	<b>0.024</b>	<b>0.032</b>	<b>0.049</b>	<b>0.030</b>	<b>0.014</b>
Competition															
Block *	0.765	0.608	0.638	0.929	0.120	0.280	0.368	0.352	0.332	0.266	0.175	0.175	0.139	0.215	0.095
Insecticide															
Plant	0.735	0.403	0.366	0.718	0.568	0.957	0.662	0.947	0.700	0.873	0.911	0.736	0.482	0.567	0.095
Competition *															
Insecticide															

Data were normalized using a square root transformation.  
 Bold face text indicates a significant P-value.

Table 44. P-values for within date ANOVA main effects and interactions for total seedling counts ( $\alpha = 0.05$ , Canyon Ferry 1998).

Julian Date	139	149	162	169	175	183	194	204	215	223	239	252
Block	<b>0.009</b>	<b>0.021</b>	<b>0.006</b>	<b>0.030</b>	<b>0.009</b>	<b>0.011</b>	<b>0.022</b>	<b>0.017</b>	<b>0.046</b>	<b>0.043</b>	0.053	0.067
Seeding	0.154	0.215	0.293	0.432	0.486	0.210	0.315	0.566	0.762	0.877	0.801	0.875
Plant	0.096	<b>0.020</b>	<b>0.026</b>	<b>0.019</b>	<b>0.033</b>	<b>0.014</b>	<b>0.014</b>	<b>0.020</b>	<b>0.017</b>	<b>0.024</b>	<b>0.010</b>	<b>0.005</b>
Competition												
Insecticide	0.440	0.959	0.722	0.770	0.953	0.621	0.596	0.315	0.371	0.347	0.278	0.360
Block * Seeding	0.936	0.798	0.776	0.945	0.924	0.940	0.966	0.943	0.892	0.919	0.972	0.967
Block * Plant	0.316	0.542	0.596	0.615	0.486	0.414	0.332	0.466	0.503	0.346	0.239	0.204
Competition												
Block *	0.987	0.816	0.950	0.806	0.786	0.700	0.790	0.623	0.778	0.879	0.931	0.843
Insecticide												
Seeding * Plant	0.642	0.307	0.375	0.472	0.288	0.430	0.333	0.326	0.409	0.626	0.549	0.695
Competition												
Seeding *	0.273	0.107	0.107	0.146	0.152	0.215	0.145	0.098	0.117	0.182	0.184	0.128
Insecticide												
Plant	0.534	0.775	0.441	0.568	0.661	0.873	0.963	0.582	0.788	0.824	0.891	0.871
Competition *												
Insecticide												

Data were normalized using a square root transformation.

Bold face text indicates a significant P-value.

Table 45. P-values for within date ANOVA main effects and interactions for total seedling counts ( $\alpha = 0.05$ , Wyola 1998).

Julian Date	131	141	151	161	169	180	189	196	205	216	225	240	254
Block	0.446	0.169	<b>0.036</b>	<b>0.009</b>	<b>0.044</b>	0.239	0.220	0.137	0.091	0.075	0.118	0.070	0.069
Seeding	0.252	0.863	0.202	0.113	<b>0.046</b>	0.178	0.179	0.353	0.465	0.459	0.368	0.278	0.281
Plant Competition	<b>0.007</b>	<b>0.001</b>	<b>0.001</b>	<b>0.001</b>	<b>0.001</b>	<b>0.019</b>	<b>0.014</b>	<b>0.017</b>	<b>0.013</b>	<b>0.014</b>	<b>0.009</b>	<b>0.006</b>	<b>0.010</b>
Insecticide	0.712	0.417	0.258	0.273	0.408	0.220	0.253	0.291	0.224	0.249	0.327	0.293	0.431
Block * Seeding	0.863	0.696	0.416	0.540	0.340	0.380	0.376	0.32*9	0.422	0.426	0.306	0.322	0.260
Block * Plant Competition	0.336	0.198	0.141	0.098	0.053	0.213	0.076	0.086	0.148	0.123	0.074	0.070	0.069
Block * Insecticide	0.405	0.373	0.368	0.450	0.851	0.534	0.189	0.203	0.111	0.092	0.145	0.120	0.170
Seeding * Plant Competition	0.752	0.685	0.757	0.650	0.311	0.582	0.287	0.217	0.170	0.162	0.215	0.278	0.281
Seeding * Insecticide	0.473	0.547	0.190	0.348	0.529	0.745	0.752	0.964	0.886	0.890	0.778	0.968	0.837
Plant Competition * Insecticide	0.946	0.559	0.221	0.246	0.589	0.368	0.391	0.174	0.224	0.249	0.188	0.293	0.431

Data were normalized using a square root transformation.  
 Bold face text indicates a significant P-value.

Cumulative Seedling Emergence P-values for main effects and two-way interaction for the cumulative seedling emergence within date ANOVAs have been presented in Tables 46-49. Significant blocking effects for cumulative seedling emergence were obtained at all 15 dates at the Canyon Ferry site in 1997 ( $P < 0.05$ ; Table 46). Wyola had 11 out of a possible 15 possible dates with significant blocking effects and 10 of 15 dates with significant blocking-plant competition interactions in 1997 ( $p < 0.05$ ; Table 47). Significant blocking and plant competition effects for cumulative seedling emergence were obtained for 12 out of 12 dates at Canyon Ferry ( $p < 0.05$ ; Table 48). Finally, significant

plant competition effects were obtained for 13 of 13 dates at Wyola 1998 ( $p < 0.05$ ; Table 49).

Table 46. P-values for within date ANOVA main effects and interactions for cumulative seedling emergence ( $\alpha = 0.05$ , Canyon Ferry 1997).

Julian Date	147	154	163	168	176	183	188	196	204	210	219	224	231	245	263
Block	<b>0.001</b>	<b>0.003</b>	<b>0.003</b>	<b>0.004</b>	<b>0.003</b>	<b>0.004</b>	<b>0.004</b>	<b>0.005</b>	<b>0.004</b>	<b>0.004</b>	<b>0.009</b>	<b>0.005</b>	<b>0.005</b>	<b>0.005</b>	<b>0.005</b>
Plant	0.914	0.638	0.872	0.613	0.743	0.831	0.940	0.852	0.821	0.805	0.735	0.879	0.884	0.876	0.876
Competition															
Insecticide	0.376	0.834	0.465	0.491	0.343	0.361	0.499	0.442	0.426	0.405	0.506	0.378	0.356	0.435	0.435
Block * Plant	0.630	0.813	0.744	0.785	0.757	0.705	0.782	0.883	0.893	0.923	0.917	0.929	0.916	0.900	0.900
Competition															
Block *	0.478	0.817	0.959	0.923	0.930	0.951	0.900	0.957	0.946	0.956	0.860	0.943	0.909	0.905	0.905
Insecticide															
Plant	<b>0.020</b>	0.198	0.309	0.451	0.278	0.359	0.481	0.379	0.383	0.371	0.656	0.379	0.362	0.367	0.367
Competition															
* Insecticide															

Data were normalized using a LN transformation.  
 Bold face text indicates a significant P-value.

Table 47. P-values for within date ANOVA main effects and interactions for cumulative seedling emergence ( $\alpha = 0.05$ , Wyola 1997).

Julian Date	149	156	164	169	179	184	191	198	205	211	218	225	233	240	256
Block	<b>0.008</b>	<b>0.017</b>	<b>0.010</b>	<b>0.035</b>	<b>0.009</b>	<b>0.027</b>	<b>0.036</b>	<b>0.042</b>	<b>0.045</b>	<b>0.047</b>	<b>0.049</b>	0.050	0.052	0.052	0.052
Plant	0.110	0.098	0.147	0.249	0.159	0.341	0.374	0.394	0.401	0.416	0.437	0.425	0.419	0.424	0.424
Competition															
Insecticide	0.709	0.762	0.394	0.259	0.387	0.426	0.370	0.362	0.386	0.400	0.399	0.384	0.378	0.383	0.383
Block * Plant	0.060	0.052	0.092	0.052	0.055	<b>0.041</b>	<b>0.045</b>	<b>0.045</b>	<b>0.044</b>	<b>0.043</b>	<b>0.041</b>	<b>0.042</b>	<b>0.042</b>	<b>0.041</b>	<b>0.041</b>
Competition															
Block *	0.577	0.642	0.647	0.721	0.555	0.545	0.593	0.605	0.603	0.597	0.599	0.596	0.607	0.607	0.607
Insecticide															
Plant	0.968	0.684	0.622	0.986	0.520	0.658	0.625	0.666	0.621	0.631	0.644	0.657	0.678	0.684	0.684
Competition *															
Insecticide															

Data were normalized using a LN transformation.  
 Bold face text indicates a significant P-value.

Table 48. P-values for within date ANOVA main effects and interactions for cumulative seedling emergence ( $\alpha = 0.05$ , Canyon Ferry 1998).

Julian Date	139	149	162	169	175	183	194	204	215	223	239	252
Block	<b>0.005</b>	<b>0.012</b>	<b>0.010</b>	<b>0.020</b>	<b>0.014</b>	<b>0.014</b>	<b>0.017</b>	<b>0.024</b>	<b>0.029</b>	<b>0.029</b>	<b>0.030</b>	<b>0.030</b>
Seeding	0.123	0.123	0.151	0.180	0.241	0.206	0.212	0.258	0.293	0.299	0.299	0.299
Plant	<b>0.071</b>	<b>0.029</b>	<b>0.023</b>	<b>0.017</b>	<b>0.019</b>	<b>0.015</b>	<b>0.015</b>	<b>0.020</b>	<b>0.021</b>	<b>0.021</b>	<b>0.021</b>	<b>0.021</b>
Competition												
Insecticide	0.415	0.636	0.862	0.930	0.852	0.929	0.976	0.957	0.928	0.943	0.943	0.943
Block *	0.877	0.873	0.892	0.940	0.929	0.943	0.949	0.944	0.936	0.940	0.940	0.940
Seeding												
Block * Plant	0.325	0.587	0.650	0.683	0.620	0.597	0.618	0.686	0.719	0.705	0.705	0.705
Competition												
Block *	0.986	0.932	0.946	0.892	0.816	0.790	0.828	0.868	0.883	0.875	0.875	0.875
Insecticide												
Seeding *	0.682	0.433	0.314	0.359	0.257	0.228	0.215	0.207	0.211	0.228	0.228	0.228
Plant												
Competition												
Seeding *	0.290	0.198	0.190	0.197	0.197	0.257	0.259	0.246	0.236	0.246	0.246	0.246
Insecticide												
Plant	0.513	0.538	0.400	0.413	0.387	0.427	0.440	0.447	0.435	0.425	0.425	0.425
Competition												
* Insecticide												

Data were normalized using a LN transformation.

Bold face text indicates a significant P-value.

Table 49. P-values for within date ANOVA main effects and interactions for cumulative seedling emergence ( $\alpha = 0.05$ , Wyola 1998).

Julian Date	131	141	151	161	169	180	189	196	205	216	225	240	254
Block	0.553	0.529	0.506	0.481	0.489	0.499	0.505	0.505	0.498	0.498	0.498	0.498	0.498
Seeding	0.239	0.324	0.384	0.405	0.442	0.453	0.463	0.463	0.459	0.459	0.459	0.459	0.459
Plant Competition	<b>0.009</b>	<b>0.007</b>	<b>0.006</b>	<b>0.005</b>	<b>0.005</b>	<b>0.005</b>	<b>0.005</b>	<b>0.005</b>	<b>0.005</b>	<b>0.005</b>	<b>0.005</b>	<b>0.005</b>	<b>0.005</b>
Insecticide	0.851	0.904	0.917	0.958	0.971	0.954	0.939	0.937	0.929	0.929	0.929	0.929	0.929
Block * Seeding	0.895	0.917	0.918	0.923	0.923	0.927	0.932	0.933	0.937	0.937	0.937	0.937	0.937
Block * Plant Competition	0.463	0.467	0.453	0.419	0.428	0.430	0.427	0.428	0.434	0.434	0.434	0.434	0.434
Block * Insecticide	0.601	0.668	0.718	0.724	0.760	0.772	0.782	0.781	0.777	0.777	0.777	0.777	0.777
Seeding * Plant Competition	0.803	0.887	0.926	0.965	0.970	0.984	0.998	0.997	0.992	0.992	0.992	0.992	0.992
Seeding * Insecticide	0.660	0.700	0.676	0.706	0.748	0.733	0.722	0.722	0.728	0.728	0.728	0.728	0.728
Plant Competition * Insecticide	0.825	0.789	0.774	0.748	0.671	0.662	0.654	0.655	0.652	0.652	0.652	0.652	0.652

Data were normalized using a LN transformation.  
 Bold face text indicates a significant P-value.

Cumulative Proportional Mortality P-values for main effects and two-way interaction for cumulative proportional seedling mortality within date ANOVAs have been presented in Tables 50-53. Significant blocking effects for cumulative proportional mortality were obtained for only 1 of 14 dates at the Canyon Ferry site in 1997 ( $P < 0.05$ ; Table 50). Significant blocking effects for cumulative proportional mortality were obtained for 11 of 14 dates, significant insecticide effects were obtained in 5 of 14 dates, significant block-plant competition interactions were found in 13 of 14 dates, and a significant insecticide-plant competition interaction was obtained for 1 of 14 dates at Wyola in 1997

( $P < 0.05$ ; Table 51). A significant blocking effect for cumulative proportional mortality was obtained for 1 of 11 dates and significant seeding and plant competition effects were obtained for 1 of 11 dates at Canyon Ferry in 1998 ( $P < 0.05$ ; Table 52). Significant seeding effects on cumulative proportional mortality were obtained in 5 of 12 dates, significant plant competition effects were obtained for 6 of 12 dates, and a significant block-insecticide interaction was obtained for 1 of 11 dates at Wyola in 1998 ( $P < 0.05$ ; Table 53).

Table 50. P-values for within date ANOVA main effects and interactions for cumulative proportional seedling mortality ( $\alpha = 0.05$ ; Canyon Ferry 1997).

Julian Date	154	163	168	176	183	188	196	204	210	219	224	231	245	263
Block	<b>0.001</b>	0.066	0.836	0.182	0.381	0.275	0.358	0.445	0.385	0.714	0.523	0.524	0.554	0.636
Plant	0.640	0.179	0.284	0.431	0.402	0.294	0.495	0.613	0.683	0.696	0.639	0.509	0.576	0.918
Competition														
Insecticide	0.686	0.563	0.522	0.884	0.869	0.888	0.731	0.978	0.923	0.830	0.887	0.801	0.932	0.624
Block * Plant	0.955	0.958	0.961	0.985	0.992	0.975	0.998	0.962	0.975	0.834	0.933	0.891	0.711	0.804
Competition														
Block *	0.989	0.776	0.438	0.829	0.840	0.922	0.831	0.165	0.716	0.424	0.641	0.566	0.353	0.190
Insecticide														
Plant	0.894	0.462	0.927	0.888	0.864	0.861	0.720	0.956	0.938	0.908	0.913	0.987	0.677	0.882
Competition *														
Insecticide														

Data were normalized using an arcsine transformation.

Bold face text indicates a significant P-value.

Table 51. P-values for within date ANOVA main effects and interactions for cumulative proportional seedling mortality ( $\alpha = 0.05$ , Wyola 1997).

Julian Date	156	164	169	179	184	191	198	205	211	218	225	233	240	256
Block	0.074	0.307	0.452	<b>0.016</b>	<b>0.039</b>	<b>0.005</b>	<b>0.002</b>	<b>0.002</b>	<b>0.002</b>	<b>0.002</b>	<b>0.002</b>	<b>0.001</b>	<b>0.006</b>	<b>0.014</b>
Plant	0.336	0.718	0.931	0.081	0.646	0.509	0.622	0.953	0.660	0.694	0.520	0.926	0.865	0.676
Competition														
Insecticide	0.812	0.953	0.668	0.316	0.312	0.136	0.165	0.097	<b>0.046</b>	<b>0.026</b>	<b>0.025</b>	<b>0.013</b>	<b>0.025</b>	0.123
Block * Plant	<b>0.008</b>	<b>0.025</b>	<b>0.025</b>	<b>0.013</b>	<b>0.011</b>	<b>0.012</b>	<b>0.012</b>	<b>0.025</b>	<b>0.006</b>	<b>0.011</b>	<b>0.018</b>	<b>0.033</b>	<b>0.027</b>	0.277
Competition														
Block *	0.444	0.721	0.884	0.594	0.378	0.673	0.687	0.741	0.563	0.548	0.669	0.457	0.699	0.743
Insecticide														
Plant	0.196	0.178	0.730	0.297	0.508	0.326	0.235	0.241	0.109	0.083	0.061	0.049	0.093	<b>0.011</b>
Competition *														
Insecticide														

Data were normalized using an arcsine transformation.

Bold face text indicates a significant P-value.

Table 52. P-values for within date ANOVA main effects and interactions for cumulative proportional seedling mortality ( $\alpha = 0.05$ , Canyon Ferry 1998).

Julian Date	149	162	169	175	183	194	204	215	223	239	252
Block	0.100	0.056	<b>0.026</b>	0.296	0.829	0.764	0.861	0.666	0.682	0.333	0.755
Seeding	0.127	<b>0.018</b>	<b>0.021</b>	0.342	0.479	0.670	0.599	0.815	0.846	0.564	0.989
Plant Competition	0.908	0.426	0.050	<b>0.023</b>	0.999	0.644	0.905	0.842	0.721	0.395	0.439
Insecticide	0.570	0.598	0.689	0.879	0.249	0.414	0.506	0.424	0.429	0.190	0.319
Block * Seeding	0.727	0.600	0.660	0.738	0.583	0.631	0.775	0.786	0.771	0.761	0.787
Block * Plant Competition	0.165	0.338	0.284	0.777	0.858	0.808	0.992	0.889	0.827	0.220	0.316
Block * Insecticide	0.883	0.970	0.270	0.842	0.688	0.585	0.553	0.563	0.581	0.508	0.816
Seeding * Plant Competition	0.185	0.441	0.302	0.262	0.517	0.452	0.290	0.206	0.190	0.150	0.1833
Seeding * Insecticide	0.524	0.301	0.590	0.939	0.549	0.446	0.526	0.477	0.567	0.473	0.443
Plant Competition * Insecticide	0.538	0.634	0.124	0.285	0.855	0.859	0.683	0.759	0.858	0.711	0.952

Data were normalized using an arcsine transformation.

Bold face text indicates a significant P-value.

Table 53. P-values for within date ANOVA main effects and interactions for cumulative proportional seedling mortality ( $\alpha = 0.05$ , Wyola 1998).

Julian Date	141	151	161	169	180	189	196	205	216	225	240	254
Block	0.369	0.385	0.302	0.505	0.748	0.828	0.192	0.185	0.125	0.366	0.164	0.177
Seeding	<b>0.001</b>	<b>0.013</b>	<b>0.007</b>	<b>0.014</b>	0.102	0.219	0.937	0.861	0.944	0.582	0.371	0.262
Plant	<b>0.032</b>	0.135	0.139	0.087	0.958	0.939	0.546	<b>0.028</b>	<b>0.029</b>	<b>0.010</b>	<b>0.003</b>	<b>0.006</b>
Competition												
Insecticide	0.367	0.165	0.154	0.428	0.106	0.167	0.519	0.478	0.560	0.931	0.753	0.831
Block *	0.324	0.519	0.479	0.269	0.644	0.498	0.824	0.685	0.635	0.445	0.475	0.518
Seeding												
Block * Plant	0.463	0.893	0.985	0.549	0.578	0.471	0.419	0.440	0.305	0.124	0.164	0.177
Competition												
Block *	0.145	0.981	0.956	0.695	0.765	0.550	0.361	0.066	<b>0.044</b>	0.159	0.119	0.186
Insecticide												
Seeding *	0.296	0.730	0.823	0.702	0.892	0.730	0.225	0.113	0.116	0.250	0.371	0.262
Plant												
Competition												
Seeding *	.0646	0.371	0.474	0.971	0.998	0.986	0.155	0.489	0.398	0.691	0.399	0.232
Insecticide												
Plant	0.107	0.267	0.161	0.142	0.611	0.543	0.832	0.706	0.820	0.479	0.753	0.831
Competition												
* Insecticide												

Data were normalized using an arcsine transformation.

Bold face text indicates a significant P-value.

Seedheads per Stem P-values for main effects and two-way interaction for seedheads per stem within date ANOVAs have been presented in Tables 54-57. Significant blocking effects for seedheads per stem were obtained on 5 of 9 dates and significant plant competition effects were obtained on 2 of 9 dates at Canyon Ferry in 1997 ( $P < 0.05$ ; Table 54). Significant blocking effects for seedheads per stem were obtained on 4 of 10 dates, a significant insecticide effect was obtained on 1 of 10 dates, and significant block-insecticide interactions were obtained on 9 of 10 dates at Wyola in 1997 ( $P < 0.05$ ; Table 55). Significant blocking effects for seedheads per stem were obtained on 5 of 8 dates,

significant seeding effects were obtained on 1 of 8 dates, and significant block-plant competition interactions were obtained in 4 of 8 dates at Canyon Ferry in 1998 ( $P < 0.05$ ; Table 56). A significant seeding effect was found on 1 of 10 dates at Wyola in 1998 ( $P < 0.05$ ; Table 57).

Table 54. P-values for within date ANOVA main effects and interactions for seedheads per stem ( $\alpha = 0.05$ , Canyon Ferry 1997).

Julian Date	188	196	204	210	219	224	231	245	263
Block	<b>0.001</b>	<b>0.001</b>	<b>0.002</b>	0.066	0.948	0.080	0.071	<b>0.035</b>	<b>0.021</b>
Plant	0.190	0.584	0.536	0.704	0.726	0.149	0.108	<b>0.034</b>	<b>0.021</b>
Competition									
Insecticide	0.597	0.401	0.621	0.682	0.764	0.713	0.787	0.904	0.793
Block * Plant	0.785	0.850	0.548	0.564	0.565	0.208	0.177	0.194	0.100
Competition									
Block * Insecticide	0.858	0.436	0.399	0.493	0.889	0.645	0.517	0.475	0.123
Plant	0.389	0.100	0.067	0.258	0.284	0.182	0.311	0.382	0.658
Competition * Insecticide									

Data were normalized using a square root transformation.  
**Bold face text indicates a significant P-value.**

Table 55. P-values for within date ANOVA main effects and interactions for seedheads per stem ( $\alpha = 0.05$ , Wyola 1997).

Julian Date	184	191	198	205	211	218	225	233	240	256
Block	0.789	0.709	0.404	0.312	0.223	0.061	<b>0.030</b>	<b>0.032</b>	<b>0.040</b>	<b>0.028</b>
Plant	0.195	0.160	0.124	0.114	0.153	0.231	0.362	0.322	0.216	0.248
Competition										
Insecticide	<b>0.001</b>	0.071	0.167	0.230	0.418	0.883	0.803	0.705	0.562	0.584
Block * Plant	0.451	0.901	0.690	0.725	0.929	0.646	0.779	0.738	0.774	0.722
Competition										
Block *	<b>0.014</b>	<b>0.027</b>	<b>0.049</b>	<b>0.016</b>	0.050	<b>0.027</b>	<b>0.024</b>	<b>0.027</b>	<b>0.029</b>	<b>0.030</b>
Insecticide										
Plant	<b>0.006</b>	0.084	0.114	0.080	0.087	0.119	0.096	0.114	0.104	0.095
Competition										
* Insecticide										

Data were normalized using a square root transformation.

Bold face text indicates a significant P-value.

Table 56. P-values for within date ANOVA main effects and interactions for seedheads per stem ( $\alpha = 0.05$ , Canyon Ferry 1998).

Julian Date	175	183	194	204	215	223	239	252
Block	0.399	0.231	0.187	<b>0.034</b>	<b>0.048</b>	<b>0.024</b>	<b>0.004</b>	<b>0.005</b>
Seeding	0.807	0.353	0.252	0.088	0.158	0.111	0.061	<b>0.049</b>
Plant Competition	0.137	0.602	0.971	0.988	0.699	0.960	0.959	0.557
Insecticide	0.460	0.514	0.831	0.811	0.956	0.662	0.284	0.196
Block * Seeding	0.750	0.588	0.937	0.617	0.464	0.2785	0.244	0.333
Block * Plant Competition	0.399	0.774	0.230	<b>0.012</b>	0.054	<b>0.044</b>	<b>0.025</b>	<b>0.036</b>
Block * Insecticide	0.871	0.816	0.516	0.345	0.469	0.428	0.213	0.269
Seeding * Plant Competition	0.807	0.320	0.788	0.917	0.770	0.848	0.544	0.406
Seeding * Insecticide	0.574	0.186	0.662	0.394	0.273	0.295	0.250	0.498
Plant Competition * Insecticide	0.460	0.876	0.977	0.736	0.505	0.878	0.991	0.887

Data were normalized using a square root transformation.

Bold face text indicates a significant P-value.

Table 57. P-values for within date ANOVA main effects and interactions for seedheads per stem ( $\alpha = 0.05$ , Wyola 1998).

Julian Date	161	169	180	189	196	205	216	225	240	254
Block	0.716	0.919	0.932	0.945	0.873	0.918	0.665	0.522	0.442	0.396
Seeding	0.526	0.292	0.843	0.711	0.873	0.560	0.445	0.314	0.342	0.382
Plant	0.853	0.891	0.519	0.707	0.557	0.582	0.446	0.713	0.774	0.714
Competition										
Insecticide	0.870	0.637	0.939	0.557	0.520	0.600	0.330	0.207	0.165	0.198
Block *	0.263	0.786	0.998	0.890	0.654	0.865	0.798	0.944	0.913	0.892
Seeding										
Block * Plant	0.310	0.082	<b>0.049</b>	0.115	0.114	0.184	0.226	0.280	0.525	0.623
Competition										
Block *	0.309	0.059	0.209	0.794	0.842	0.882	0.845	0.788	0.933	0.877
Insecticide										
Seeding *	0.181	0.576	0.151	0.737	0.685	0.679	0.677	0.845	0.932	0.798
Plant										
Competition										
Seeding *	0.187	0.426	0.322	0.601	0.837	0.951	0.796	0.881	0.998	0.661
Insecticide										
Plant	0.370	0.410	0.313	0.631	0.755	0.694	0.692	0.725	0.644	0.848
Competition										
* Insecticide										

Data were normalized using a square root transformation.

Bold face text indicates a significant P-value.

### Results for the Partial Addition Series Experiment

The two sites involved in the partial addition series Dalmatian toadflax experiment yielded very different results, although blocking was never a significant factor. The experimental study at the Canyon Ferry site did not yield any significant differences ( $P > 0.05$ ; Tables 58-60, Figures 10-12) in Dalmatian toadflax total stem counts, percent cover, or dry biomass for any combination of factors. Likewise, Dalmatian toadflax total stem count was nearly significant between seedling levels at the MSU Post Farm site

Figure 10. Partial Addition Series; Mean Number of Dalmatian Toadflax Stems at the Canyon Ferry Site (1998)

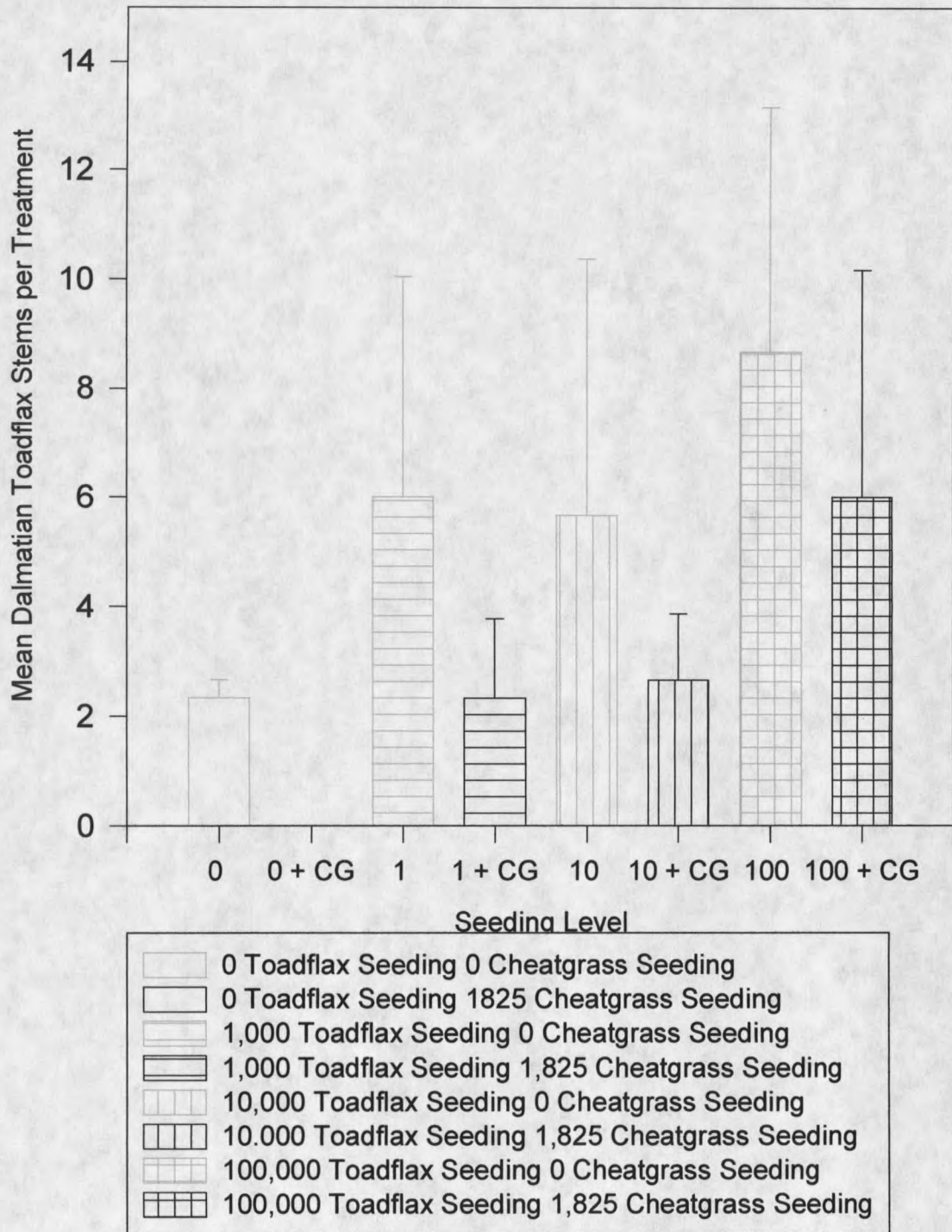


Figure 11. Partial Addition Series; Dalmatian Toadflax Mean Percent Cover at the Canyon Ferry Site (1998)

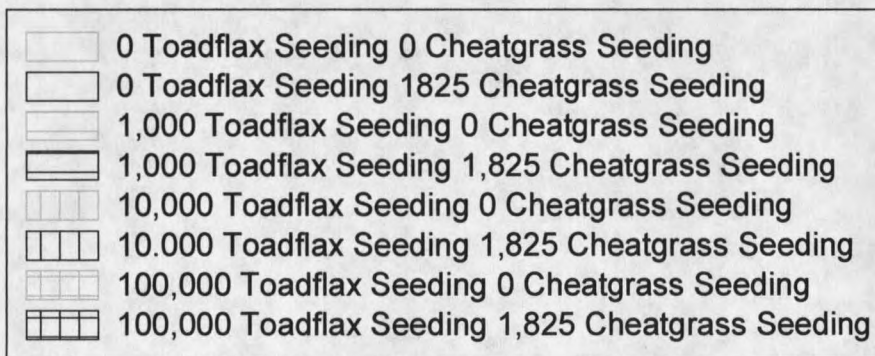
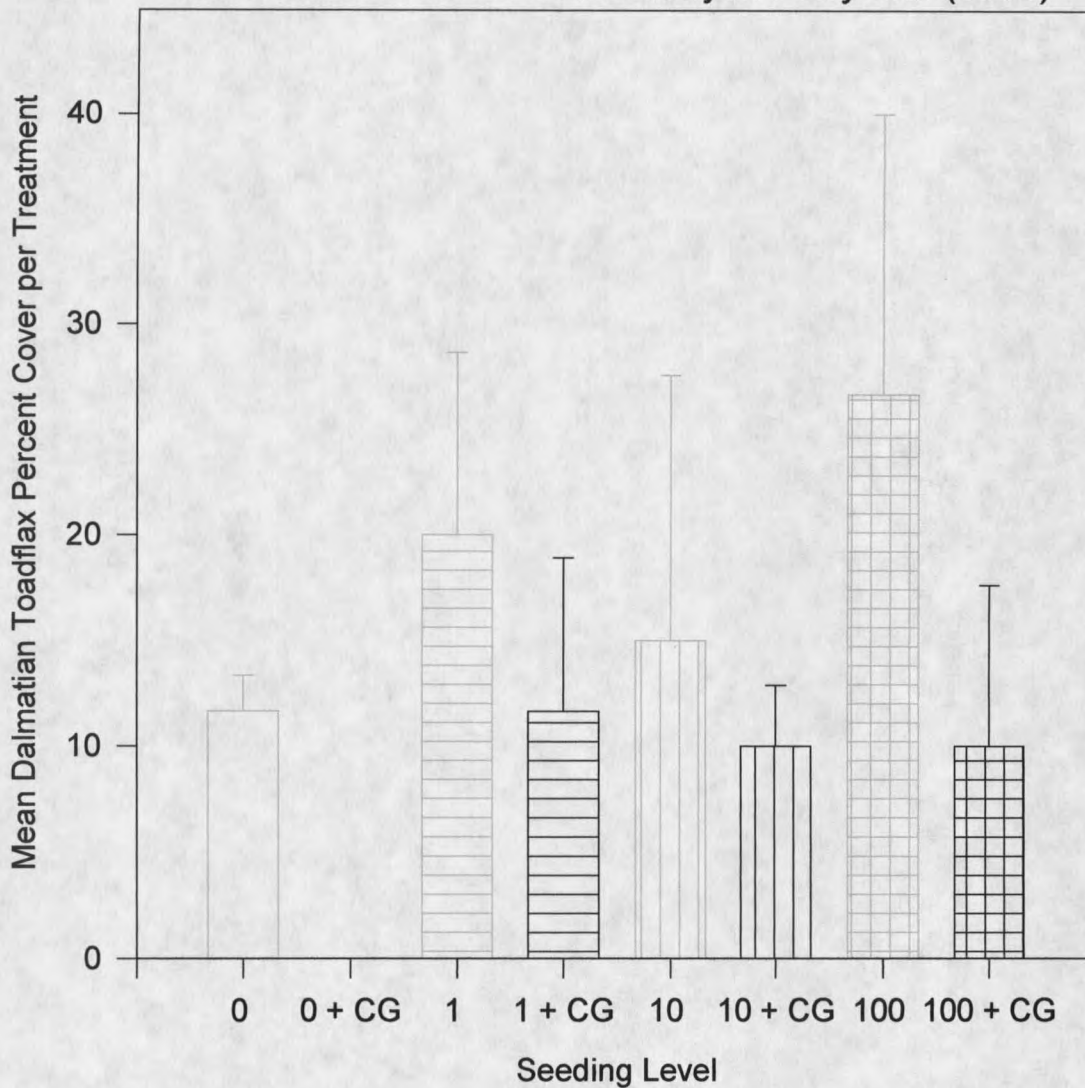
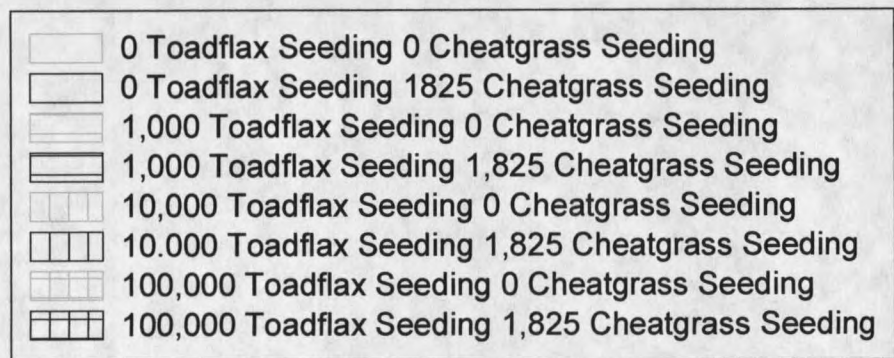
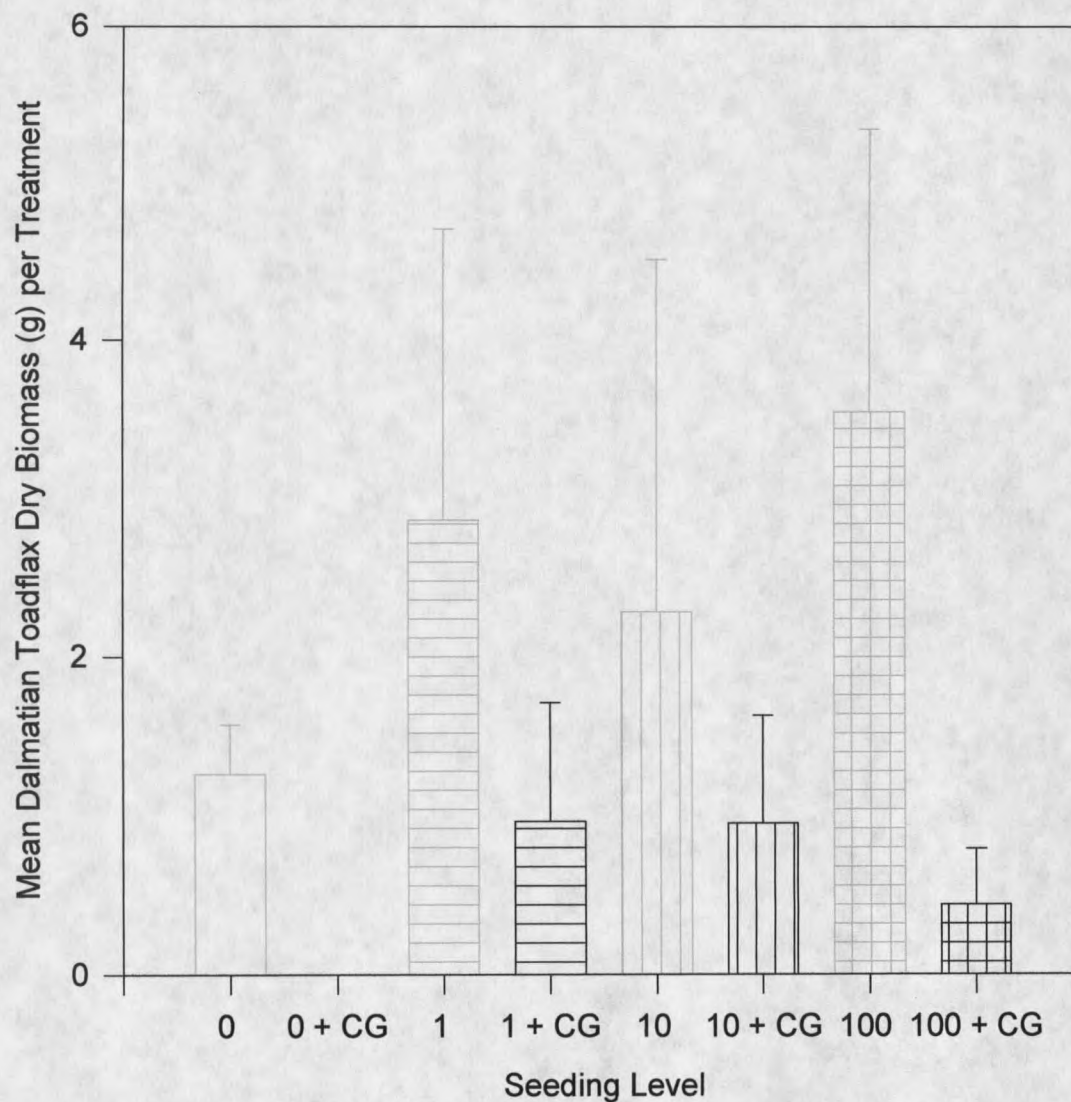


Figure 12. Partial Addition Series; Mean Dalmatian Toadflax Above-Ground Dry Biomass at the Canyon Ferry Site (1998)



( $P = 0.05$ ; Table 61, Figure 13). However, significant seeding rate effects were obtained at the MSU Post Farm site for percent Dalmatian toadflax cover ( $P = 0.02$ ; Tables 62 and 63, Figure 14) and Dalmatian toadflax dry biomass ( $P = 0.03$ ; Tables 64 and 65, Figure 15).

Table 58. ANOVA results for mean number of Dalmatian toadflax stems (Canyon Ferry 1998).

Source	DF	Type III SS	Mean Square	F Value	Pr = F
Block	2	102.08	51.04	2.31	0.18
DT Seeding Rate	3	114.13	38.04	1.72	0.26
CG Seeding	1	51.04	51.04	2.31	0.18
Block*DT	3	1.46	0.48	0.02	1.00
Block*CG	6	207.25	34.54	1.57	0.30
DT*CG	2	35.58	17.79	0.81	0.49

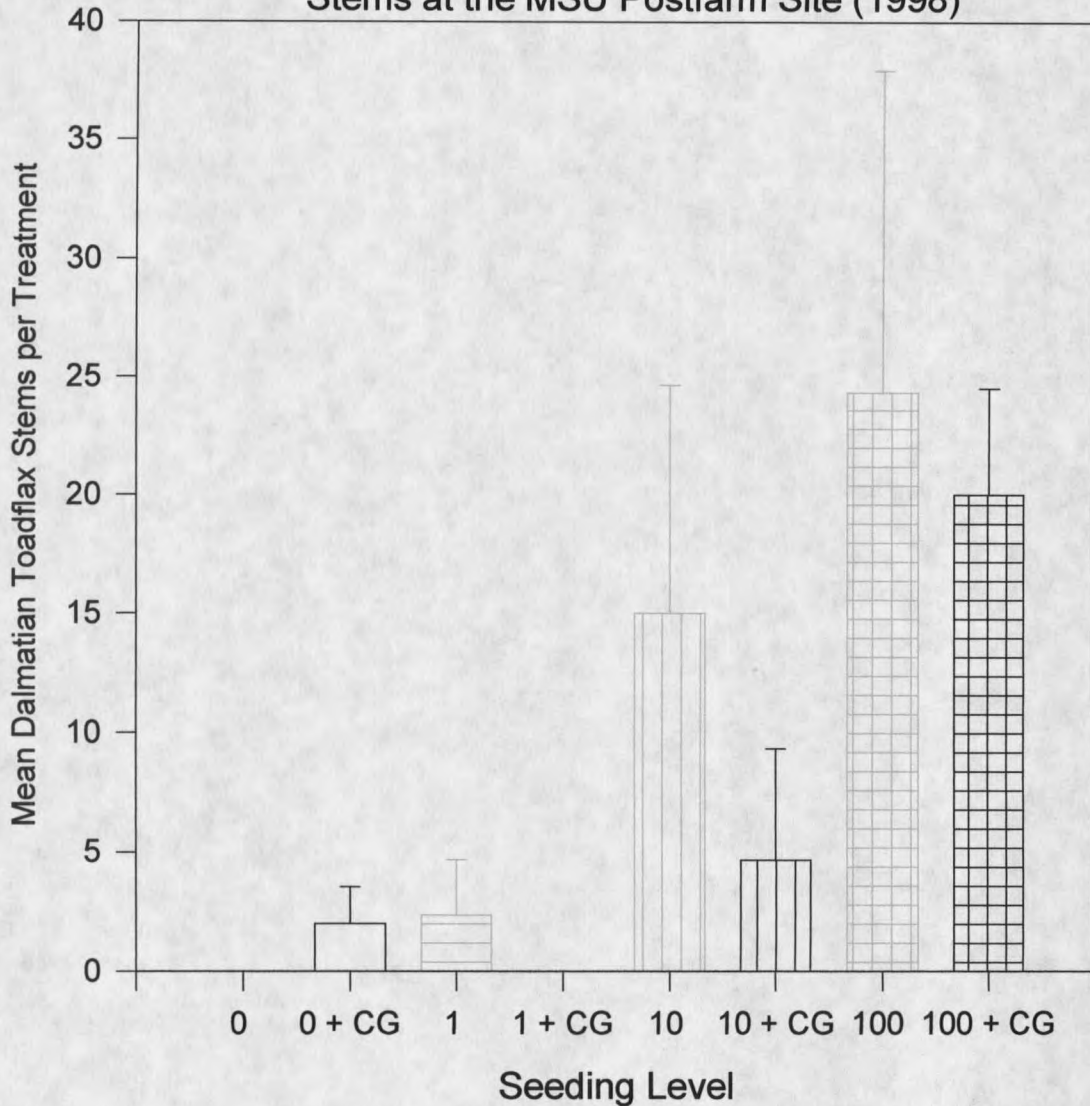
Bold face text indicates a significant P-value.

Table 59. ANOVA results for mean Dalmatian toadflax percent cover (Canyon Ferry 1998).

Source	DF	Type III SS	Mean Square	F Value	Pr = F
Block	2	0.05	0.02	1.56	0.28
DT Seeding Rate	3	0.06	0.02	1.17	0.40
CG Seeding	1	0.07	0.07	4.34	0.08
Block*DT	3	0.01	0.00	0.25	0.86
Block*CG	6	0.18	0.03	1.84	0.24
DT*CG	2	0.02	0.01	0.48	0.64

Bold face text indicates a significant P-value.  
Data were transformed using an arcsine transformation.

Figure 13. Partial Addition Series; Mean Dalmatian Toadflax Stems at the MSU Postfarm Site (1998)



- 0 Toadflax Seeding 0 Cheatgrass Seeding
- 0 Toadflax Seeding 1825 Cheatgrass Seeding
- 1,000 Toadflax Seeding 0 Cheatgrass Seeding
- 1,000 Toadflax Seeding 1,825 Cheatgrass Seeding
- 10,000 Toadflax Seeding 0 Cheatgrass Seeding
- 10,000 Toadflax Seeding 1,825 Cheatgrass Seeding
- 100,000 Toadflax Seeding 0 Cheatgrass Seeding
- 100,000 Toadflax Seeding 1,825 Cheatgrass Seeding

Figure 14. Partial Addition Series; Dalmatian Toadflax Mean Percent Cover at the Post Farm Site (1998)

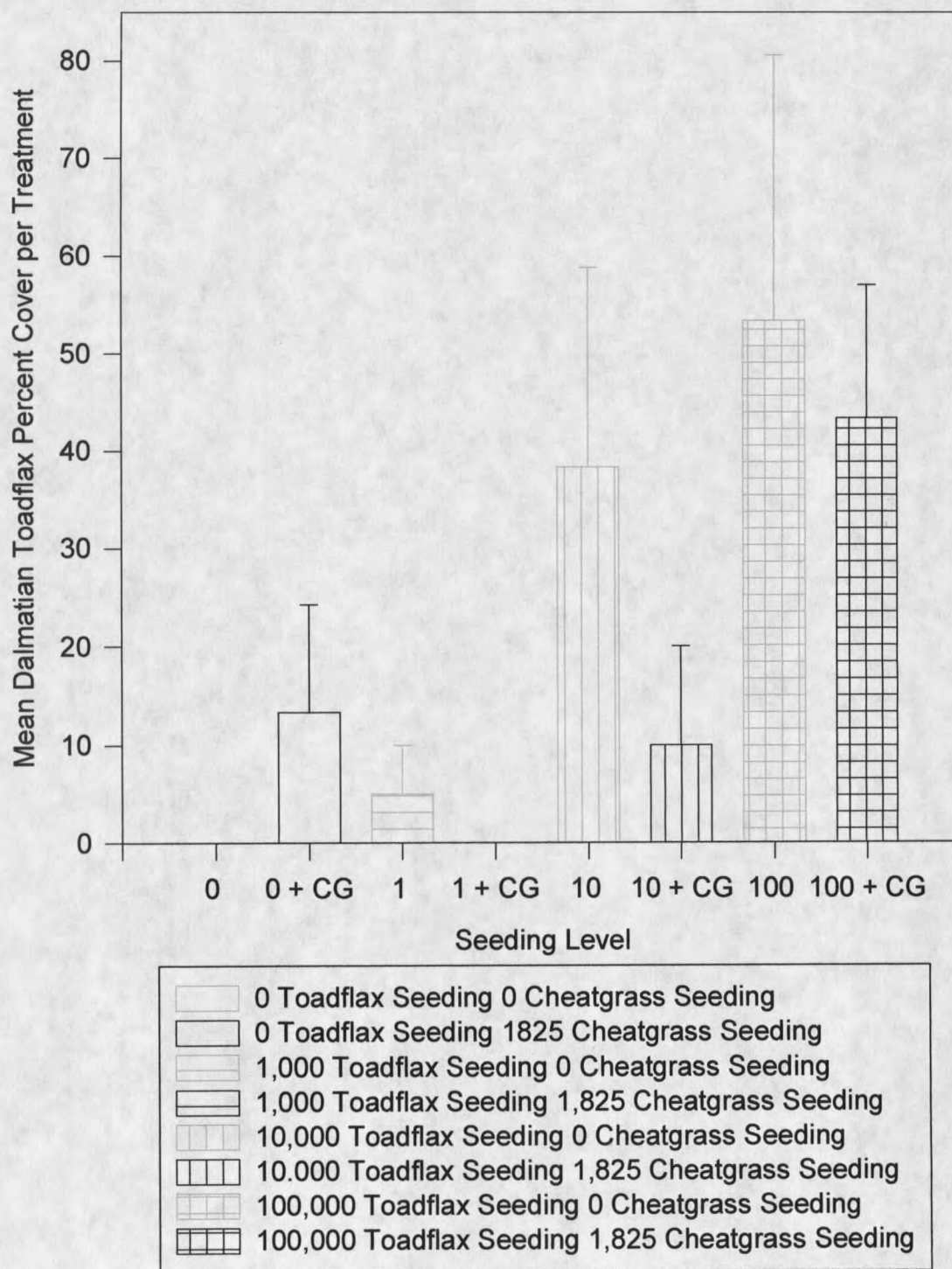


Figure 15. Partial Addition Series; Mean Dalmatian Toadflax Above-Ground Dry Biomass at the Post Farm Site (1998)

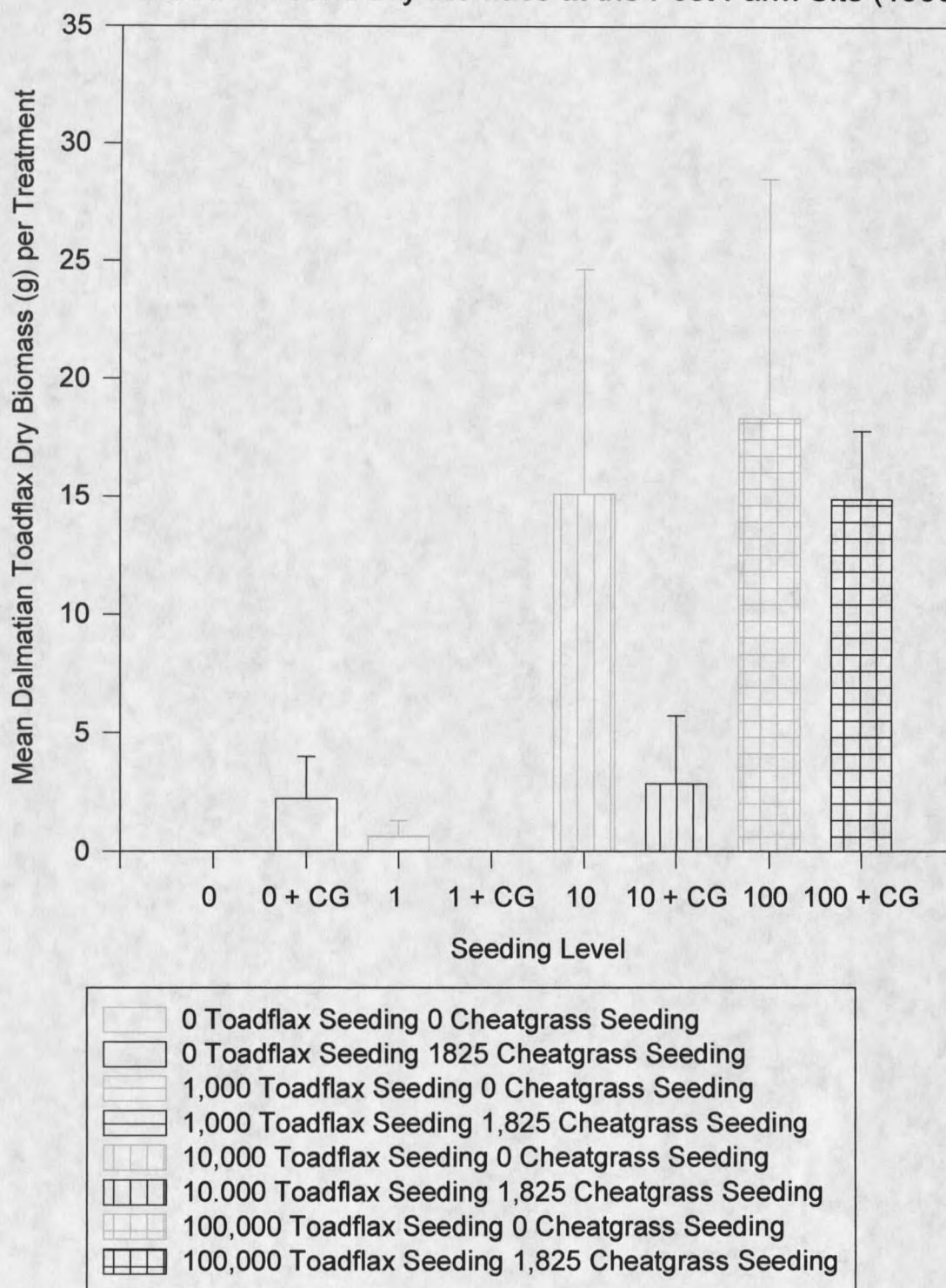


Table 60. ANOVA results for Dalmatian toadflax above-ground dry biomass (Canyon Ferry 1998).

Source	DF	Type III SS	Mean Square	F Value	Pr = F
Block	2	13.23	6.61	1.35	0.33
DT Seeding Rate	3	7.07	2.36	0.48	0.71
CG Seeding	1	21.64	21.64	4.42	0.08
Block*DT	3	3.29	1.10	0.22	0.88
Block*CG	6	29.76	4.96	1.01	0.49
DT*CG	2	04.57	2.29	0.47	0.65

Bold face text indicates a significant P-value.

Table 61. ANOVA results for mean number of Dalmatian toadflax stems (MSU Post Farm 1998).

Source	DF	Type III SS	Mean Square	F Value	Pr = F
Block	2	278.58	139.29	1.17	0.37
DT Seeding Rate	3	1791.46	597.15	5.00	0.05
CG Seeding	1	84.38	84.38	0.71	0.43
Block*DT	3	118.13	39.38	0.33	0.80
Block*CG	6	343.42	57.24	0.48	0.80
DT*CG	2	627.75	313.88	2.63	0.15

Bold face text indicates a significant P-value.

Table 62. ANOVA results for mean Dalmatian toadflax percent cover (MSU Post Farm 1998).

Source	DF	Type III SS	Mean Square	F Value	Pr = F
Block	2	0.23	0.11	2.64	0.15
DT Seeding Rate	3	1.02	0.34	7.87	<b>0.02</b>
CG Seeding	1	0.06	0.06	1.37	0.28
Block*DT	3	0.16	0.05	1.26	0.37
Block*CG	6	0.43	0.07	1.67	0.27
DT*CG	2	0.35	0.17	4.08	0.08

Bold face text indicates a significant P-value.  
Data were transformed using an arcsine transformation.

Table 63. Student Neuman-Keuls multiple comparison for Dalmatian toadflax total percent cover by Dalmatian toadflax seeding level ( $\alpha = 0.05$ , MSU Post Farm 1998).

SNK Grouping	Mean	N	Toadflax Seeding Level
A	22.17	6	100,000
AB	9.83	6	10,000
B	1.17	6	1,000
B	1.00	6	0

Groupings with the same letter are not significantly different

Table 64. ANOVA results for Dalmatian toadflax above-ground dry biomass (MSU Post Farm 1998).

Source	DF	Type III SS	Mean Square	F Value	Pr = F
Block	2	0197.86	98.93	1.60	0.28
DT Seeding Rate	3	1049.39	349.80	5.67	<b>0.03</b>
CG Seeding	1	74.31	074.31	1.21	0.31
Block*DT	3	175.35	58.45	0.95	0.47
Block*CG	6	294.85	49.14	0.80	0.60
DT*CG	2	426.31	213.15	3.46	0.10

Bold face text indicates a significant P-value.

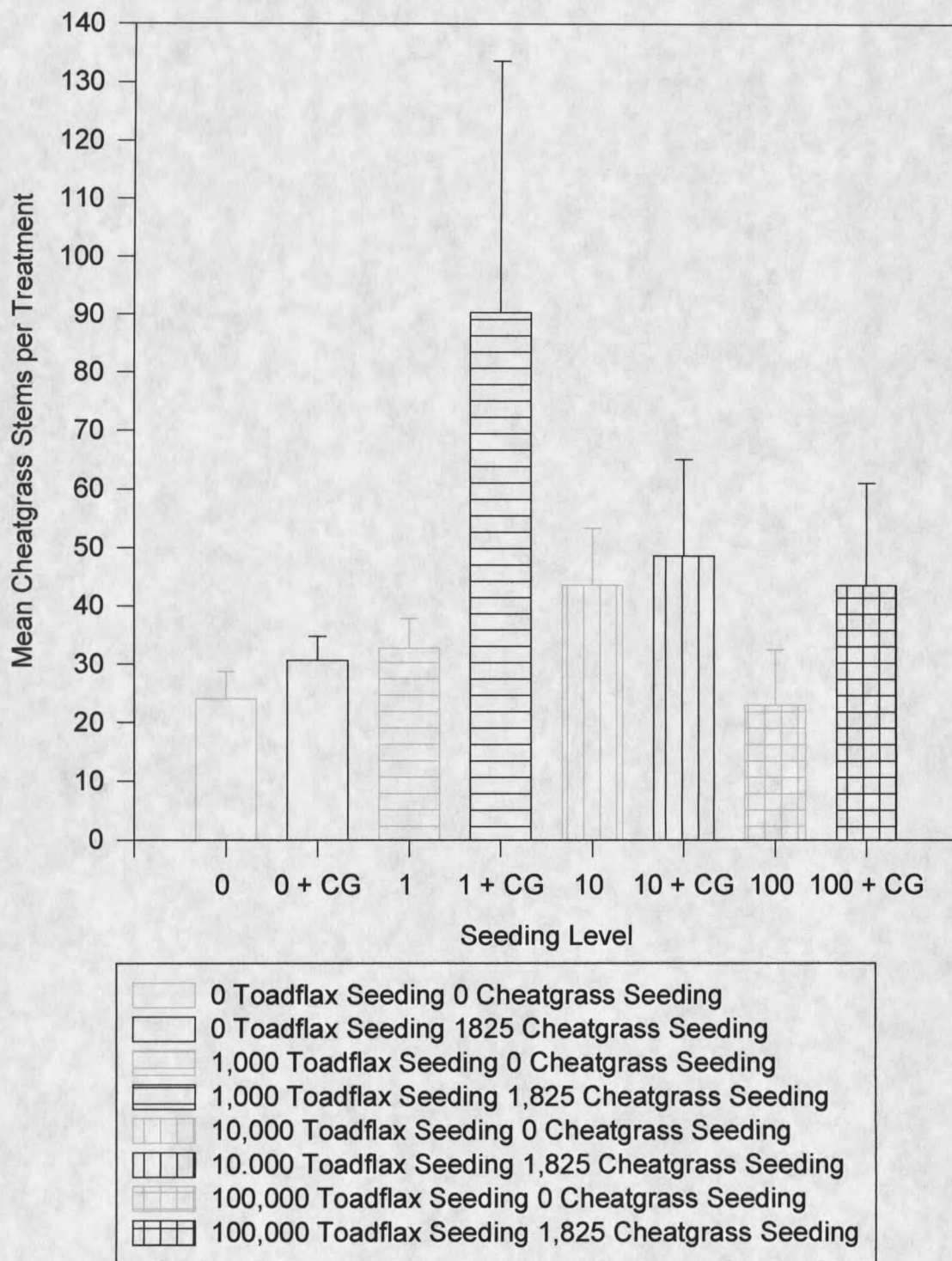
Table 65. Student Neuman-Keuls multiple comparison of Dalmatian toadflax above-ground dry biomass by Dalmatian toadflax seeding level ( $\alpha = 0.05$ , MSU Post Farm 1998).

SNK Grouping	Mean	N	Toadflax Seeding Level
A	16.60	6	100,000
AB	8.97	6	10,000
B	1.11	6	1,000
B	0.33	6	0

Groupings With The Same Letter Are Not Significantly Different

Cheatgrass was present in all quadrats at the Canyon Ferry site and seeded quadrats had a significantly higher level of grass stems with respect to cheatgrass seeding levels ( $P = 0.04$ ; Tables 66 and 67, Figure 16). No cheatgrass stems were observed on the

Figure 16. Partial Addition Series; Mean Number of Cheatgrass Stems at the Canyon Ferry Site (1998)



Post Farm site in any of the quadrats; instead common crop weeds were observed, the most numerous being redroot pigweed and field pennycress. A significant difference in total above ground plant dry biomass was found between the two sites (student's two-tailed t; assuming unequal variance ;  $t = 2.0638$ ,  $df = 24$ ,  $P = 0.0001$ ).

Table 66. ANOVA results for mean number of cheatgrass stems (Canyon Ferry 1998).

Source	DF	Type III SS	Mean Square	F Value	Pr = F
Block	2	4461.5800	2230.79	4.72	0.0590
DT Seeding Rate	3	4126.8300	1375.61	2.91	0.1231
CG Seeding	1	3037.5000	3037.50	6.42	<b>0.0400</b>
Block*DT	3	2695.5000	898.50	1.90	0.2300
Block*CG	6	5348.4167	891.40	1.89	0.2299
DT*CG	2	3564.7500	1782.38	3.77	0.2307

Bold face text indicates a significant P-value.

Table 67. Student Neuman-Keuls multiple comparison of mean number of cheatgrass stems by cheatgrass factor ( $\alpha = 0.05$ , Canyon Ferry 1998).

SNK Grouping	Mean	N	Cheatgrass Level
A	53.33	12	W/ Cheatgrass
B	30.83	12	W/O Cheatgrass

Groupings with the same letter are not significantly different

#### Results from the Orthene Phyto-toxicity Trial

Treatment of toadflax plants with Orthene significantly increased maximum stem growth by 34% ( $t = -2.134$ ,  $df = 76$ ,  $P = 0.0361$ ) compared to control plants which were treated with water (Figure 17). Orthene treatment also increased total flower production by approximately 37%, although this difference was not significant ( $t = -0.3689$ ,  $df = 18$ ,  $P = 0.717$ ; Figure 18).

Figure 17. Average Maximum Stem Growth Between Control and Insecticide Treatments (n=40).

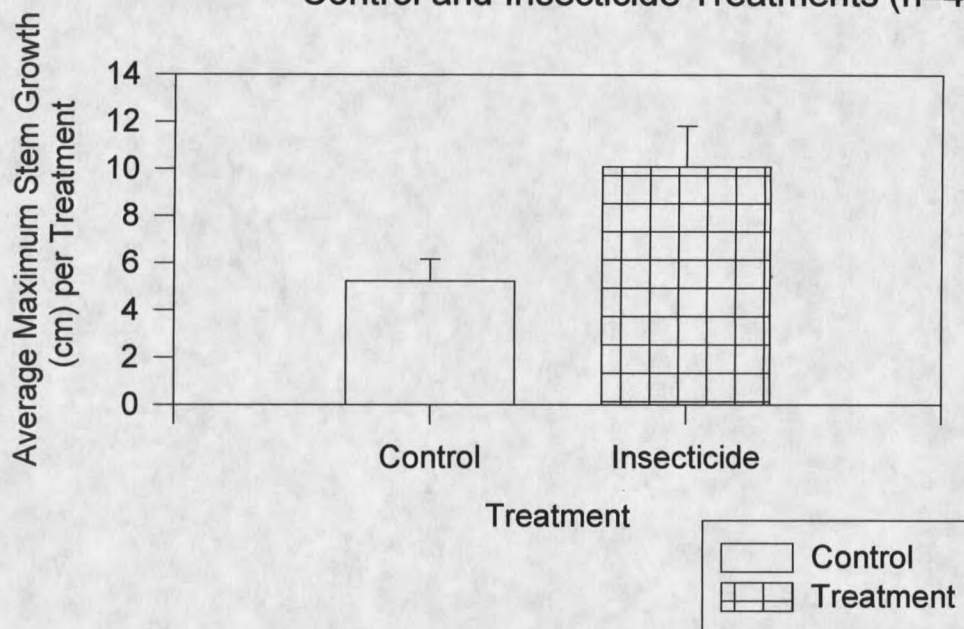
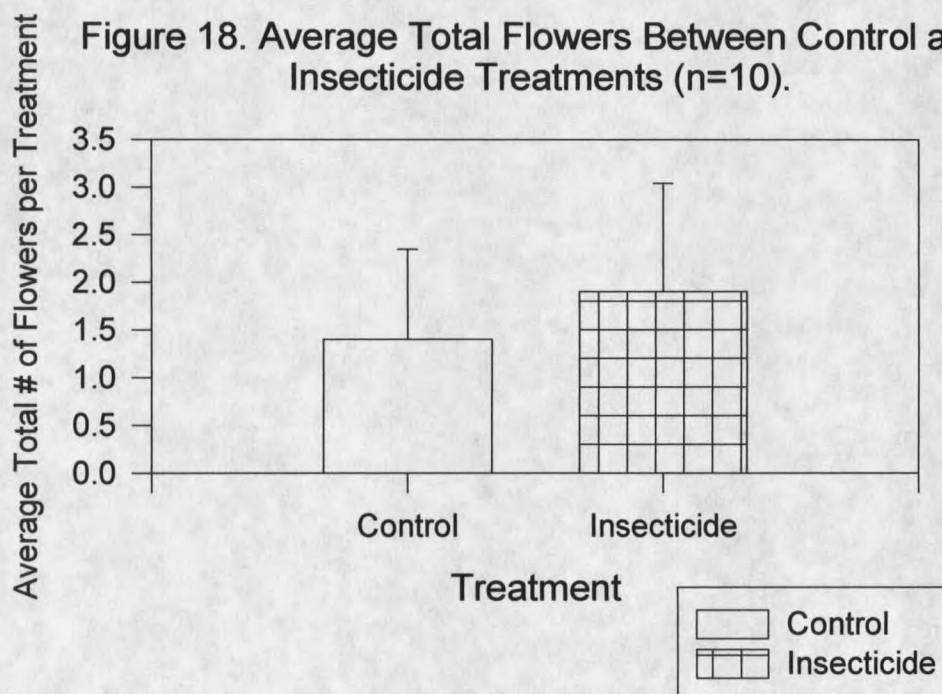


Figure 18. Average Total Flowers Between Control and Insecticide Treatments (n=10).



Results for the Seed Emergence Trial

The results of the seed emergence trials are presented in figure 19. Mean temperatures recorded across replicates for the seed emergence trials were statistically similar ( $P = 0.963$ ; Table 68). Mean percent emergence for seed collected from Wyola 1997 ( $0.71 \pm 0.05$ ), Wyola 1998 ( $0.66 \pm 0.05$ ), and Canyon Ferry ( $0.69 \pm 0.04$ ) were statistically similar ( $P > 0.05$ ). However mean percent emergence was statistically lower for Canyon Ferry 1998 seed ( $0.28 \pm 0.05$ ) compared to the other three seed sources ( $P = 0.0001$ ; Tables 69 and 70).

Table 68. ANOVA results for mean temperatures across replicates.

Source	DF	Type III SS	Mean Square	F Value	Pr = F
Bar	3	0.231319	0.077106	0.09	0.9632
Seed Source	3	1.321875	0.440625	0.53	0.6698
Bar * Seed Source	9	6.005417	0.667269	0.80	0.6231

Table 69. ANOVA results for mean percent total emergence among seed sources.

Source	DF	Type III SS	Mean Square	F Value	Pr = F
Bar	3	0.1201375	0.0400458	1.09	0.3814
Seed Source	3	1.4728712	0.4909571	13.37	0.0001
Bar * Seed Source	9	0.2128986	0.0236554	0.64	0.7447

Data were normalized using an arcsine transformation.

Figure 19. Percent Mean Seedlings Emerged

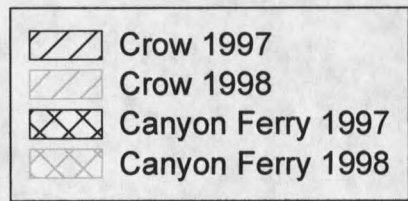
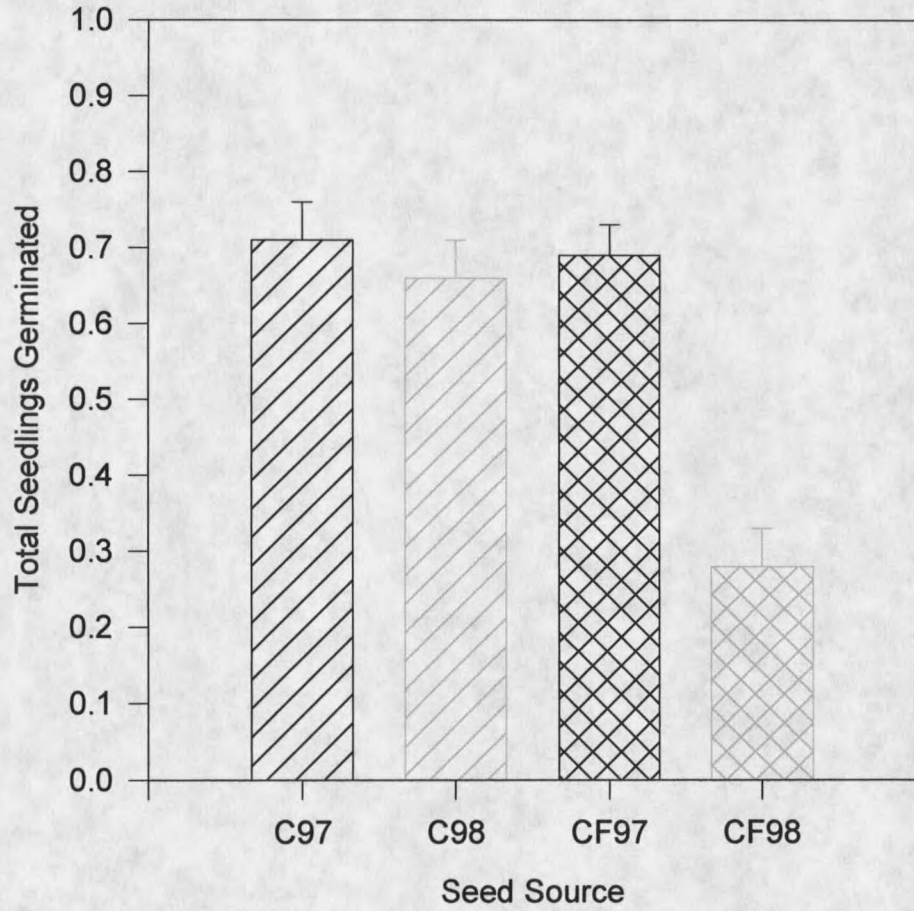


Table 70. Student Neuman-Kuels multiple comparison for mean percent total emergence among seed sources ( $\alpha = 0.05$ ).

SNK Grouping	Mean	N	Seed Source
A	0.80860	8	Wyola1997
A	0.77352	8	Canyon Ferry 1997
A	0.73741	8	Wyola1998
B	0.28114	8	Canyon Ferry 1998

Data were normalized using an arcsine transformation.  
Groupings with the same letter are not significantly different (.05 level)

### Results for Seedbank Analysis

Overseeding did not significantly affect the number of toadflax seed obtained from either A or B strata at either site, although mean numbers of seed were higher in overseeded blocks (Tables 71-75, Figures 20 and 21). No differences in the number of seed were found among blocks and seeding treatments for either A or B strata at the Canyon Ferry site in 1998 ( $P > 0.05$ ; Tables 71 and 72). A significant difference was detected in A strata seed samples among blocks at the Wyola site ( $P = 0.0053$ ; Tables 73-75), however no differences in seed levels were found among blocks from strata A ( $P > 0.05$ ).

Table 71. ANOVA results of number of seeds obtained from A strata soil samples among blocks and overseeding treatments (Canyon Ferry 1998).

Source	DF	Type III SS	Mean Square	F Value	Pr = F
Block	3	87.98213	29.32738	1.82	0.171
Seeding	1	8.42471	8.42471	0.52	0.477
Block * Seeding	3	0.39610	0.13203	1.03	0.396

Figure 20. A and B Soil Strata Average # of Seeds per Block (n=8)(Canyon Ferry 1998).

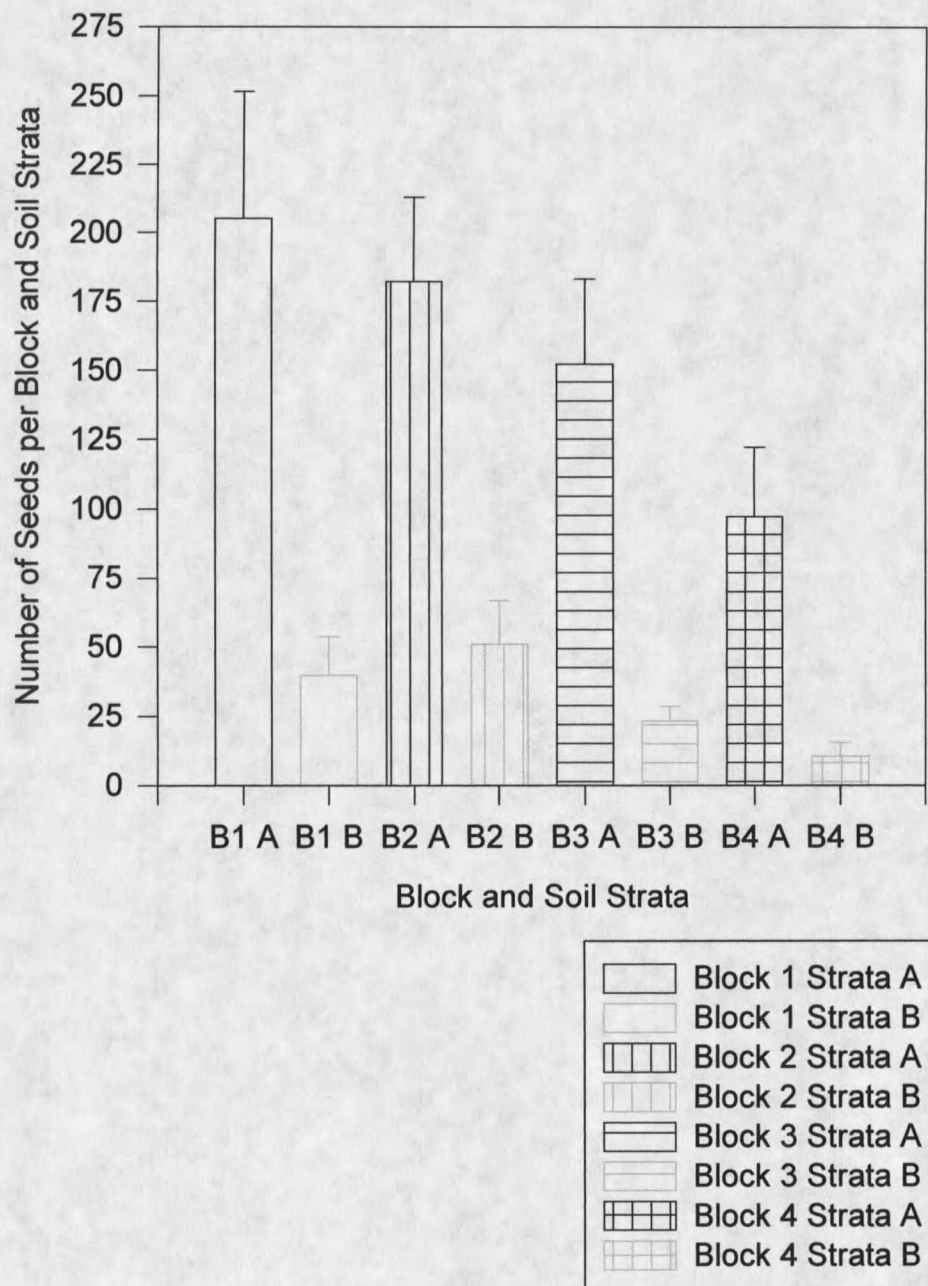


Figure 21. A and B Soil Strata Average # of Seeds per Block (n=8)(Wyola 1998).

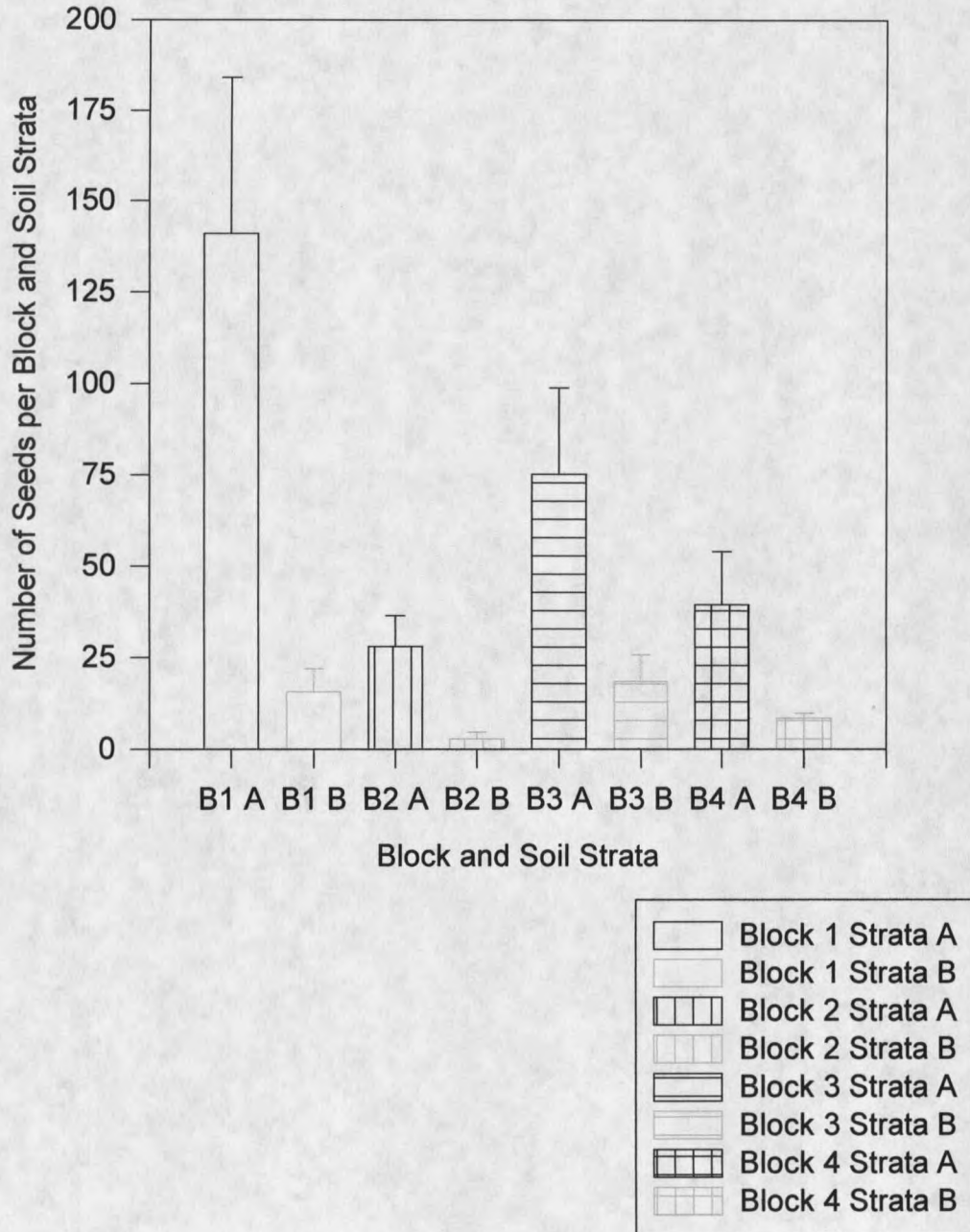


Table 72. ANOVA results of number of seeds obtained from B strata soil samples among blocks and overseeding treatments (Canyon Ferry 1998).

Source	DF	Type III SS	Mean Square	F Value	Pr = F
Block	3	53.85438	17.95146	2.47	0.0860
Seeding	1	14.64919	14.64919	2.02	0.1683
Block * Seeding	3	16.26270	5.42090	0.75	0.5348

Table 73. ANOVA results of number of seeds obtained from A strata soil samples among blocks and overseeding treatments (Wyola 1998).

Source	DF	Type III SS	Mean Square	F Value	Pr = F
Block	3	185.81730	61.93910	5.45	0.0053
Seeding	1	37.02478	37.02478	3.26	0.0837
Block * Seeding	3	5.14152	1.71384	0.15	0.9282

Table 74. Student Neuman-Keuls multiple comparison of number of seeds among blocks of A strata soil samples ( $\alpha = 0.05$ , Wyola 1998).

SNK Grouping	Mean	N	Block
A	11.040	8	1
BA	8.114	8	3
B	5.776	8	4
B	4.786	8	2

Groupings with the same letter are not significantly different

Table 75. ANOVA results of number of seeds obtained from B strata soil samples among blocks and overseeding treatments (Wyola 1998).

Source	DF	Type III SS	Mean Square	F Value	Pr = F
Block	3	32.312540	10.77085	2.92	0.0544
Seeding	1	1.132586	1.132586	0.31	0.5843
Block * Seeding	3	5.160921	1.720307	0.47	0.7079

### Seed Production per Seed Capsule

The average number of seed per seed capsule multiplied by the number of seed capsules per unit area were used to calculate the 1997 overseeding rate for the two sites. In addition, this information was used to estimate the amount of seed produced per stem for the boxcar models for either site. Seed capsules at the Canyon Ferry site had a mean of 243 (SE = 10.44) seeds per seed capsule (n = 11) (Figure 22). Wyola seed capsules had an mean of 178.3 (SE = 6.77) seeds per seed capsule (n = 16) (Figure 22). A significant difference was detected between sites using a students t-test assuming unequal variance ( $t = -5.3571$ ,  $df = 20$ ,  $P = 0.0001$ ).

### Results of Insect Sweeps

Sweeping indicated that *B. pulicarius* was not abundant at either study site. Canyon Ferry had an order of magnitude more beetles than Wyola, but neither site averaged even one beetle per sweep (Figure 23).

### Results of Extension

The primary component of extension work performed between 1997 and 1998 consisted of presentations focusing on the available biological control agents for yellow

Figure 22. Seed per Seedhead Counts for Both Field Sites

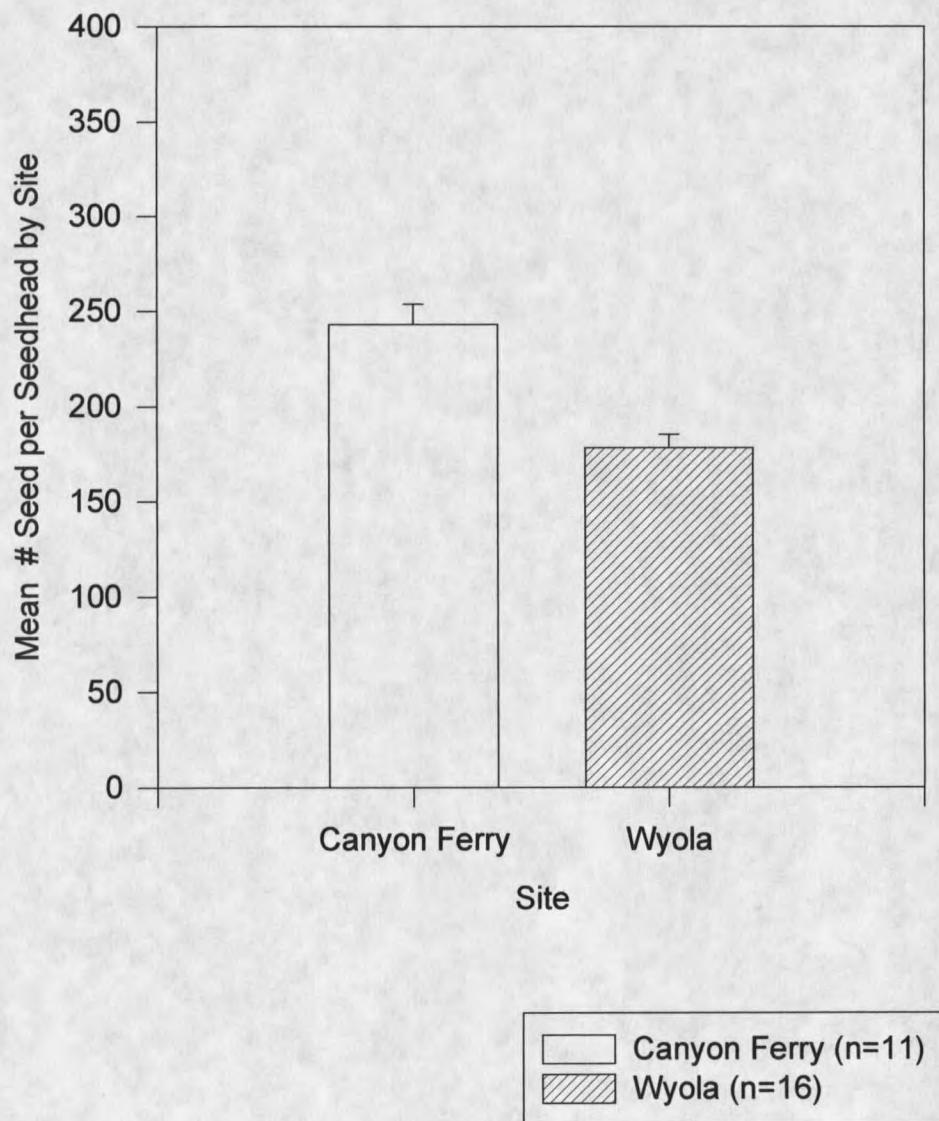
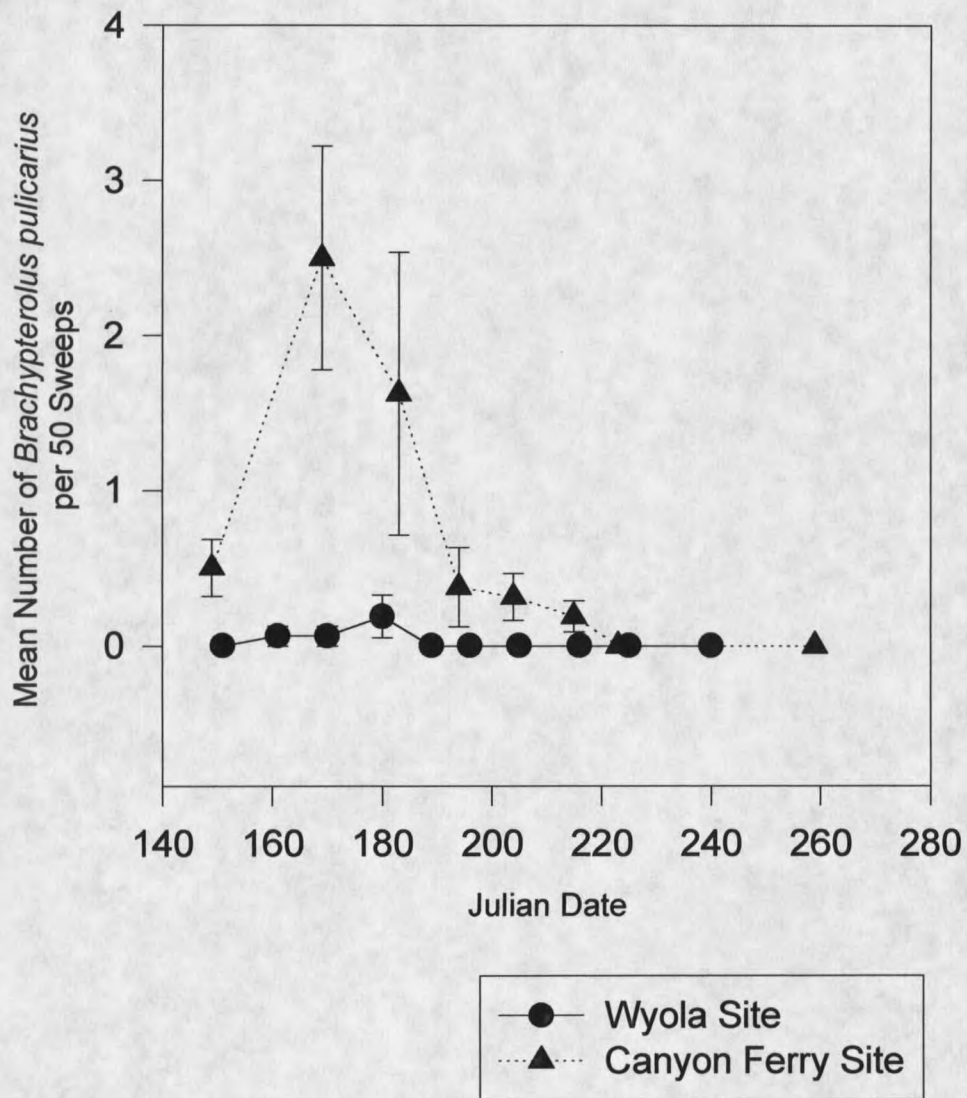


Figure 23. Mean Number *Brachypterosolus pulicarius* Caught per 50 Sweeps at Either Field Site (1998).



toadflax. Six presentations were given over the summers of 1997 and 1998 during field tours sponsored by the BFC (Table 76).

Table 76. Extension presentations given to the Blackfoot Challenge group (1997-1998).

Date	Activity
6/12/97	Attended the biannual Blackfoot Challenge Weed tour and presented information on yellow toadflax biological control agents.
7/11/97	Released <i>Mecinus janthinus</i> on a BFC cooperators ranch.
8/14/97	Attended the biannual BFC weed tour and presented information on integrating biological control with other weed management strategies.
8/27/97	Released <i>Eteobalea serratella</i> eggs on a BFC cooperators ranch, found evidence of <i>Mecinus janthinus</i> from earlier release date.
6/10/98	Attended the biannual BFC Weed tour and presented information on yellow toadflax plant life history.
8/21/98	Gave a presentation on biological control of range weeds to the WET educator group associated with the BFC.
9/12/98	Evaluated <i>Mecinus janthinus</i> site with BFC cooperators.

Biological control presentations given to the BFC group focused on the introduction and/or distribution of several biological control agents of yellow and Dalmatian toadflax. These included the flower feeding beetle, *Brachypterochus pulicarius*, the foliage feeding moth, *Calophasia humula*, the root feeding moths, *Eteobalea serratella* and *E. intermediella*, and the stem boring weevil, *Mecinus janthinus*. In addition, individual cooperators were involved in the establishment and vegetative monitoring of permanent plant-transects at the yellow toadflax sites to evaluate the long term impact of the biological control agents.

Releases of natural enemies were conducted with the active cooperation of land owners. Direct involvement of cooperators in the release of biological control agents provided cooperator education regarding procedures involved in the release process. Once

natural enemy populations have reached an acceptable level of establishment at the original release sites, cooperators should be able to redistribute insects to other yellow toadflax infestations utilizing the basic release techniques demonstrated during initial releases. *E. serratella*, *E. intermediella*, and *M. janthinus* were released on two yellow toadflax infestations on one cooperator's ranch using a caged release strategy, while *B. pulicarius* and *C. lunula* were free released by multiple cooperators. Permanent transects were established at each release site and baseline data collected in order to monitor the impact of natural enemies on yellow toadflax.

During the summer of 1997 multiple releases were made of *M. janthinus*, *C. lunula*, *B. pulicarius*, *E. serratella*, and *E. intermediella*. In 1998 emphasis was placed on the release of the stem boring weevil, *M. janthinus*. At the conclusion of the two year period, *M. janthinus* had overwintered at one yellow toadflax site and *C. lunula* had successfully established at two yellow toadflax sites.

In addition to presentations and cooperative field work, an eight panel, full color pamphlet was published during the Spring of 1999 (Appendix A). The objective of the pamphlet was to present the progress made in the 1997-1998 insect releases as well as notes on the biology of yellow toadflax and the natural enemies released. Pamphlets will accompany a closing presentation in the early fall of 1999.

Extension of new technologies to a producer clientele is one of the primary directives of any land grant institution. All too often, extension is left out of research programs, excluding the producer clientele from the development of technologies earmarked for their benefit. As land grant universities approach the next century it

becomes increasingly important that they integrate producer needs, opinions, and ideas into agricultural research. While the major portion of this thesis focuses on research conducted within the traditional scientific framework, extension of the developing biological control technologies encompassed by work with the BFC made up an equally important contribution to my education as an agricultural scientist.

#### Results of the Boxcar Model

Boxcar model parameters differed greatly between the two sites leading to very different results in model output. The model framework used is nearly identical to the Noxious Weed Model of Maxwell and Sheley (1997) with the exception of the Fall emergence and seedling mortality boxes, which have been removed (Figure 24). Model parameters for the respective sites are presented in Table 77. Simulations were run without utilizing the density dependence component of the model. Results of the model simulations from the two sites indicate that Dalmatian toadflax population level seems to be increasing at the Canyon Ferry site while it appears to be in a state of decline at the Wyola site (Figure 25).

**Figure 24. Conceptual Model of the Dalmatian Toadflax System.**

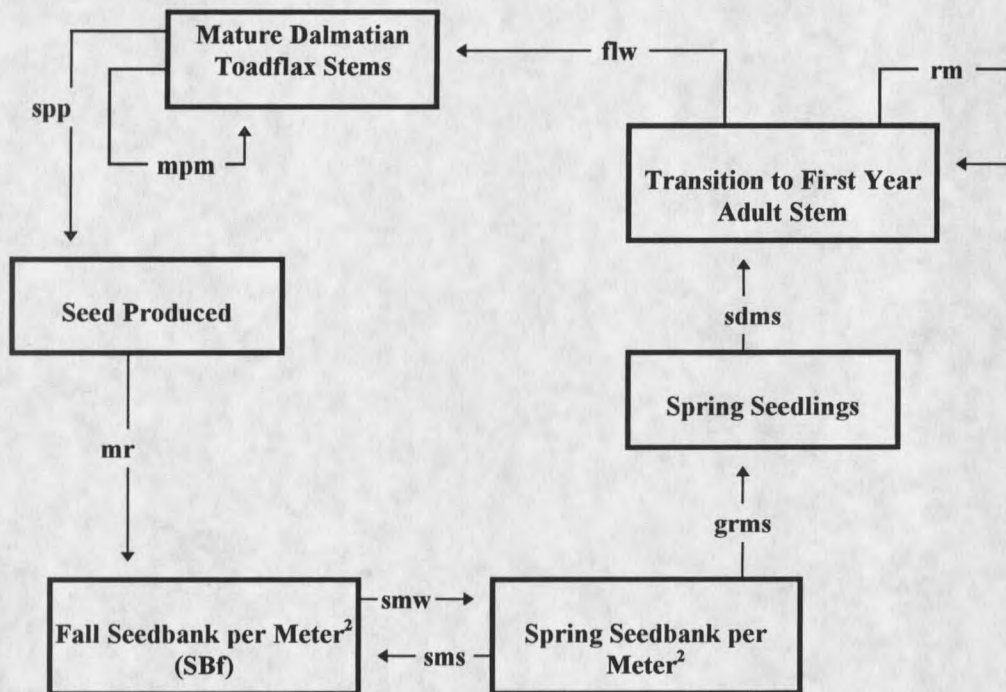
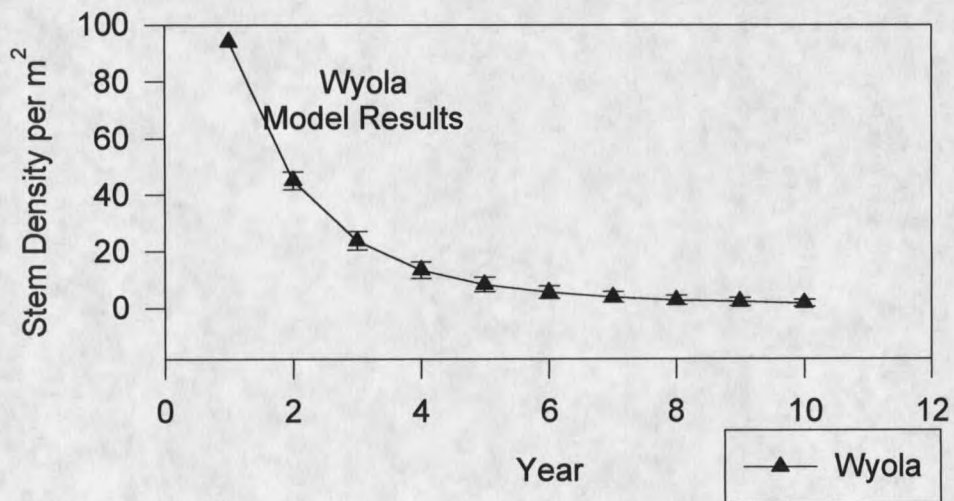
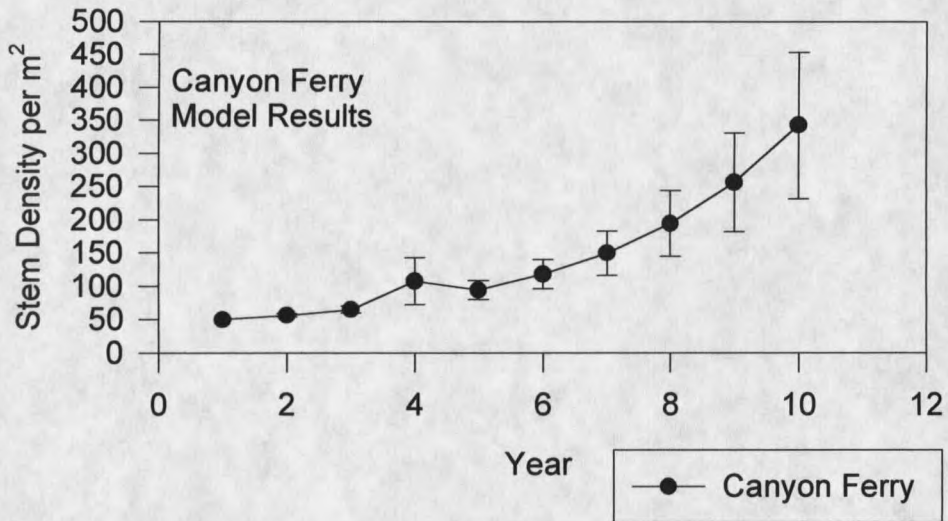


Table 77. Parameters used in boxcar model simulations for the Canyon Ferry and Wyola research sites.

Model Parameter	Canyon Ferry Site		Wyola Site	
	Parameter Value	Parameter Standard Deviation	Parameter Value	Parameter Standard Deviation
Starting Seed Bank (Seeds m <sup>2</sup> ) (SBf)	19631.180	12422.320	8738.00	10235.730
Starting Adult Stem Density ( )	50.250	25.250	93.75	44.500
Seeds per Adult Stem (spp)	8738.246	10235.730	1178.00	1038.190
Spring Emergence Proportion (sdms)	0.004	0.006	0.02	0.024
Spring Seedling Mortality (grms)	0.780	0.160	0.84	0.160
Recruitment into Second Year Stem Population (flw)	0.360	0.475	0.14	0.249
Adult Stem Mortality (mpm)	1.145	0.544	0.55	0.278
Residual Juvenile Mortality (rm)	1.000	na	1.00	na
Proportion Seed Movement (mr)	0.900	na	0.90	na
Fall to Spring Seed Mortality	0.600	na	0.60	na
Spring to Fall Seed Mortality	0.200	na	0.20	na

na indicates a default or best guess parameter value.

Figure 25. Mean Stem Counts Over a 10 Generation Boxcar Model Run at Both Sites (n=20)



## CHAPTER 5

## DISCUSSION

Field Trial

A widely-accepted approach towards testing seed versus microsite limitation of seedling recruitment is to compare natural seedling population dynamics with situations where unnaturally high quantities of seeds are added (Crawley 1985, 1990, Louda 1990, 1995). However, seedlings do not recruit into an ecological vacuum; seed producing plants, seeds, and seedlings are all subject to plant competition as well as predation by herbivores. In light of this, it is important to understand that seed and microsite limitation are not mutually exclusive, instead they are dependent parts of the weeds biotic and abiotic environment (Eriksson 1994).

Ecological management of rangeland weeds includes the use of natural enemies as predators of weeds as well as the use of more desirable plant species as competitors. One biological approach towards the management of a weed is to reduce seed production to a point where adult mortalities cease to be replaced by new recruits. Likewise, plant communities that limit the availability of seed emergence safe sites or provide heavy competition for resources may be able to limit the recruitment of new seedlings into a weed population. Both approaches limit the recruitment of the weed albeit by influencing different aspects of the system.

In the case of Dalmatian toadflax, overseeding did not appear to significantly affect seedling recruitment into the first year adult population. The enhancement of the seed supply for the 1998 growing season was not a significant factor in seedling counts, cumulative seedling emergence, nor cumulative seedling mortality. This suggests that under the field conditions that occurred during my two-year field study the Dalmatian toadflax populations at the two sites filled most safe emergence sites. Significant interactions involving overseeding and plant competition or insecticide application at the Canyon Ferry research site suggest that there may be a subtle increase in recruitment in situations where extra seeds are placed and plant competition is removed or when Dalmatian toadflax is protected from insect herbivory.

Plant competition was the only factor in the experiment that yielded significant results in the repeated measures analyses, suggesting that seedling recruitment of Dalmatian toadflax is limited by interspecific resource competition. Interspecific competition lowered weekly total seedling counts at the Canyon Ferry site and cumulative seedling emergence at the Wyola site in the 1998 growing season. Furthermore, in most cases, plant competition-excluded quadrats had higher mean levels of seedling counts and cumulative emergence. Hence, my results suggested that plant competition was the dominant factor affecting seedling recruitment in Dalmatian toadflax.

Insecticide applications did not have a significant effect on any of the three seedling parameters at either site or year, although some interactions were detected. Furthermore, the number of seed capsules per stem measure also seemed to be unaffected by insecticide treatments, although interactions between insecticide and blocking or plant

competition were detected at the Wyola site in 1997. A probable reason for why the exclusion of *Brachyterolus* did not appear to affect Dalmatian toadflax seed capsule per stem counts is that the beetles were not abundant at either site. Neither site averaged even one beetle per sweep during 1998, and peak beetle catches were made following releases at both sites. While generalist herbivores were observed feeding on Dalmatian toadflax stems and seed capsules at the Wyola site, the continued spread of the weed under current insect predation suggests that generalists do not have a large effect on the plant's reproduction or survival at the two sites examined. Similar studies have documented relatively negligible effects of insect herbivory on the reproductive tissues of microsite limited plants (Crawley 1989a,b, Eriksson and Ehrlen 1992, Paynter et al. 1996).

Based on the results obtained in my study I conclude that seedling recruitment in Dalmatian toadflax is more commonly microsite limited, which in view of the plant's life history would seem plausible. Dalmatian toadflax's potential to produce large numbers of small seeds, coupled with its vegetative mode of reproduction would seem to limit the importance of individual seedling recruitment. Dalmatian toadflax appears to deal with the problem of seedling recruitment in the face of resource limitations by maximizing the probability of seeds ending up in microsite circumstances through mass production and release of seeds and through vegetative reproduction via its lateral root buds. The large quantities of seed it produces may also serve as a means of compensating for pre- and post- dispersal seed predation.

Accepting this conclusion means that limiting seed in existing patches of Dalmatian toadflax through the attack of reproductive structures is unlikely to result in a reduction of

stand density. Similar conclusions have been reached for tansy ragwort by Crawley (1985, 1989a). Successful management of Dalmatian toadflax will most likely depend on limiting adult stem and lateral root-bud densities. This could be accomplished through the establishment of natural enemies that feed on stem or root structures of Dalmatian toadflax, selective herbicide application timed to affect only Dalmatian toadflax stems or over-wintering rosettes, and the encouragement of healthy, desirable plant populations that provide strong competition for resources.

#### Discussion of the Partial Addition Series

While field trials examined recruitment of Dalmatian toadflax seedlings into preexisting weed stands, the partial addition series studies examined seedling recruitment at two sites where no adult stems were present. Much can be gained through weed population dynamic experiments that seed weeds into controlled areas without existing stands of the weed. Crawley (1990) used such an approach to study tansy ragwort, while Erriksson (1992) admitted surprise that such studies were not performed on a more frequent basis.

Results from the partial addition series were radically different between the Canyon Ferry and the MSU Post Farm sites. The Canyon Ferry site produced microsite limitation results more or less consistent with the field trials, whereas, the Post Farm results suggest that Dalmatian toadflax seedling recruitment into a new, disturbed environment is limited by seed quantity.

The lack of significant Dalmatian toadflax stem counts, percent cover, or above-ground dry biomass results among seeding levels at the Canyon Ferry site suggests that Dalmatian toadflax is not seed limited when recruiting into a new environment. Cheatgrass may or may not have a competitive effect upon Dalmatian toadflax in this situation, since the cheatgrass factor returned a marginally non-significant result ( $P = 0.08$ ). While it is logical to expect cheatgrass to have a negative competitive effect on Dalmatian toadflax seedling recruitment given its fast developmental rate and relatively early emergence time (Lajeunesse 1999), the effect of interspecific competition due to cheatgrass may in fact be negligible in all but high cheatgrass densities. The fact that cheatgrass coexists with toadflax at both field study sites, suggests that negative interspecific interactions between the two plants may be minimal.

The results of the partial addition series at the Post Farm suggests that an increase in the number of Dalmatian toadflax stem counts, cover, and biomass would likely result from increases in seeding density. While these results appear contradictory to those at the Canyon Ferry site, they are not comparable since no cheatgrass was found in any of the 32 quadrats analyzed at the Post Farm site, despite cheatgrass seeding efforts. Instead, a variety of cropweeds were present across all blocks and treatments, the most numerous being redroot pigweed and field pennycress. Post Farm blocks may have received supplementary water and perhaps additional nutrients from adjacent irrigated plots. Furthermore, a t-test comparing total plant dry biomass between the two sites was highly significant suggesting that the Post Farm site was a richer environment. In short, increased moisture availability as well as residual nutrient levels from previous fertilizer applications

may have created an abundance of seed emergence safe sites and resources. This leads to the conclusion that Dalmatian toadflax recruitment in an irrigated cropland may very well be seed limited rather than microsite limited.

While the contradictory results of the two experimental sites indicate that recruitment of Dalmatian toadflax into new environments is not entirely seed limited, they provide a good example of how seed and microsite limitation are interrelated via environmental conditions (Errikson 1991). In situations where emergence safe sites and resources are environmentally limited, such as in arid mountain or rangeland environments, Dalmatian toadflax can probably saturate all possible safe sites, resulting in microsite limited recruitment. However, in situations where a greater abundance of resources are available, the weed becomes seed limited, since there may be more microsites available for seedling emergence and recruitment than viable seeds. Hypothetically, the differences in results between the two sites are due to microsite availability and the probability of viable seeds making it to these microsites.

In the context of integrated weed management of rangeland threatened by Dalmatian toadflax, the partial addition series results support the field trial. Managing sources of weed seed by limiting seed production solely through attack on reproductive tissues will probably not reduce the probability of new site colonization by Dalmatian toadflax, since a relatively small amount of weed seed can infest disturbed areas. Curbing the spread of Dalmatian toadflax into new areas will rely on reducing stem density at weed seed source points and the maintenance of a competitive plant community in adjacent rangeland. The relative importance of stem density reduction and plant competition for

Dalmatian toadflax management are further reinforced by output from boxcar simulations run for either site.

### Discussion of Model Output

Construction of mechanistic models to predict the outcome of weed population trends and the effects of management strategies on rangeland plant succession has a great potential to increase both our understanding of plant community function as well as the efficiency of weed management strategies (Call and Roundy 1991, Sheley and Larson 1994a,b). Boxcar models provide a particularly good approach for modeling weed interactions within plant communities (Lindquist 1995, Maxwell and Sheley 1997). The boxcar model for Dalmatian toadflax initiated in this study, while incomplete, provides a starting point for the eventual construction of a complete model, and allows for the prediction of toadflax population trends at the two field study sites.

Model output demonstrated extreme variability between the two sites. Dalmatian toadflax populations at the Canyon Ferry site increased rapidly, while populations at the Wyola site decreased equally rapidly. This difference between sites likely was due to Wyola's comparatively high rate of mortality between first and second year stems (flw), as well as the high level of adult stem mortality between years (mpm).

However, results of the two simulations should be evaluated with caution, since only one full year of data was used in the construction of parameters. Standard deviations of the parameters were generally as large or larger than the parameters themselves, indicating the need for a much larger sample size. Large standard deviations are partly due

to parameters created by averaging observations from all quadrats at a respective site, regardless of block or treatment. However, the general trend of both simulations are supported by five year cover and stem transects maintained at both sites (Figures 26 and 27) (Nowierski and FitzGerald unpublished data). Furthermore, the model illustrates the need for stem/root management as opposed to seedhead management in established Dalmatian toadflax patches.

Weed management decisions are most effective when we understand a weed's biology and how it reacts to a specific form of disturbance (Sheley 1996). Boxcar models of weed population dynamics present us with an unique viewpoint of how weed populations function, and have great potential for improving management efficiency. From the standpoint of biological control of weeds, releases of natural enemies will be most effective when the biological control agents impact the vulnerable stages of the target plant's life history. In the specific case of Dalmatian toadflax, the low rate of seedling emergence and recruitment indicates that seed quantity is not of primary importance to stand density. Rather, recruitment of new mature stems from first year plants and the survival of already existing stems appear to be the crucial points in the plant's life history. In the context of site specific management strategies the simulation results suggest that the most effective management strategies, at either site should attempt to reduce existing stands of Dalmatian toadflax, and place less emphasis on strategies that only affect seed production (e.g., inflorescence and seed capsule feeding herbivores).

Figure 26. Mean Dalmatian Toadflax Stems per Daubenmire Frame (Wyola).

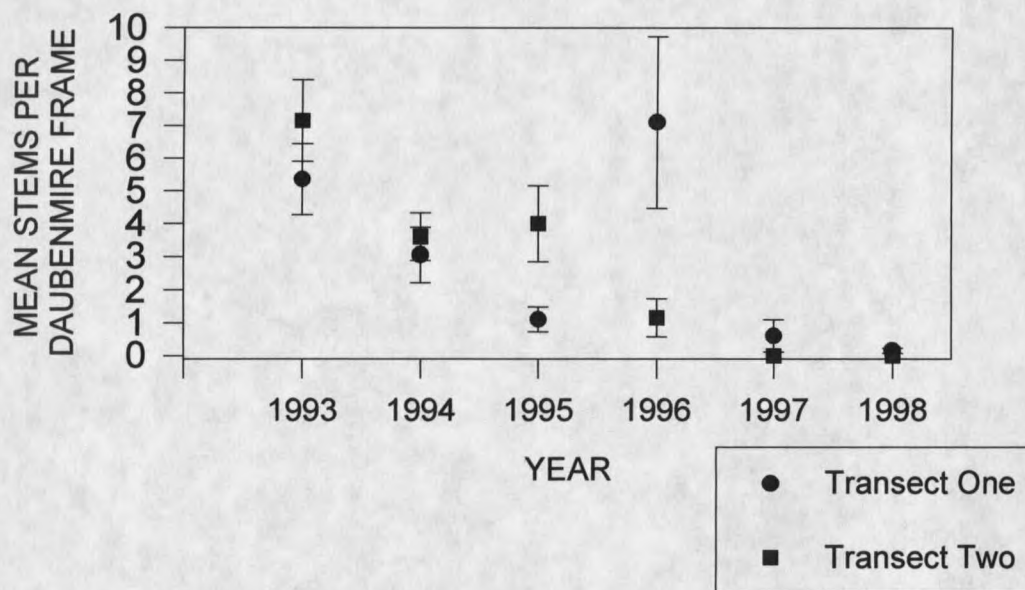
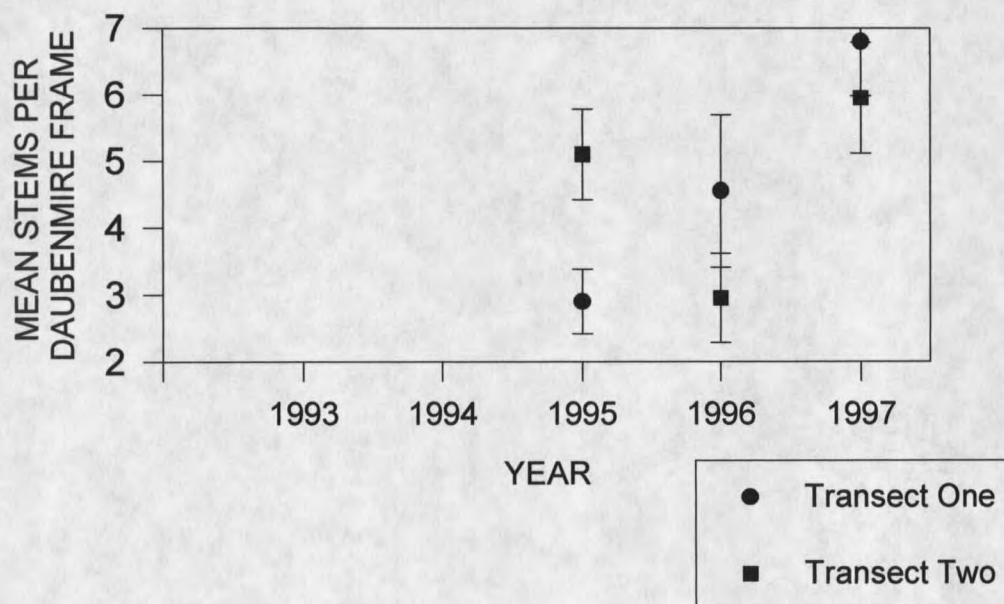


Figure 27. Mean Dalmatian Toadflax Stems per Daubenmire Frame (Canyon Ferry).



At the Canyon Ferry site weed management needs to increase first year and existing plant/stem mortality. Seedling recruitment is providing more than adequate replacement of stems at this site leading to a building toadflax population. Reduction of seed density alone will probably be an ineffective means of managing toadflax density since most likely available microsites are saturated many times over. Furthermore, real reduction of seeds per unit area would probably be most easily achieved through the reduction of stem density.

If we accept the Wyola simulation results, Dalmatian toadflax appears to be on the way out of the plant community. While percent seed emergence was higher at the Wyola site than at the Canyon Ferry site, first year stems were not able to replace preexisting stems at the current rate of mortality. In this scenario, maintaining a healthy plant community may be the only factor needed to maintain a steady decline in Dalmatian toadflax stem density, although it is important to note that it is unlikely that the weed will ever completely drop out of the plant community.

Density dependent factors, biological control impacts, and plant competition were not included in these simulations. Hence, in a more realistic context, rather than maintaining a perpetual rate of increase or decline, both populations of the weed would be expected to reach some new equilibrium level in the future when density dependent factors such as self thinning or resource availability come into play. Furthermore, vegetative stem recruitment was not adequately addressed in this experiment and needs to be fully explored in order to determine its importance in Dalmatian toadflax population dynamics.

### Synergy of Experiments

Model output, results of the field and partial addition series, as well as data previously collected on Dalmatian toadflax all suggest that management should focus on stem and root-bud densities for a maximum level of control. Currently, the natural enemies involved in the biological control of Dalmatian toadflax affect stems in a non-lethal fashion. Although, *B. pulicarius* may compromise the reproductive output of Dalmatian toadflax, and defoliation by *C. lunula* may reduce plant resources available for seed production, to date, these two insects have not shown the capacity to significantly affect plant density.

The conclusion that Dalmatian toadflax is not likely to be managed through the attack of reproductive structures has wide ranging consequences on biological and integrated strategies of weed management. Enhancement of the seed bank in both existing stands of the weed, as well as in areas without the weed did show concomitant increases in seedling emergence or recruitment. Hence the most critical management targets in Dalmatian toadflax's life history appear to be the recruitment and maintenance of adult stems and root-buds. A management approach successfully reducing these targets would result in reduced seed production as the number of flowering stems are reduced.

The Dalmatian and yellow toadflax biological control agents *M. janthinus*, *G. linariae*, and *E. serratella* and *E. intermediella* all affect stems or roots of Dalmatian toadflax through direct attack on the structures. *M. janthinus* larvae mine the pith of toadflax stems causing terminal tissues to wither and as a consequence may provide

avenues for attack by plant pathogens. *G. linariae* induce larval root hair galls, limiting the plants ability to absorb nutrients and produce new stems or lateral root-buds. *E.*

*intermediella* and *E. serratella* attack the root system of toadflax causing direct damage to the taproot via larval feeding. Assuming these four natural enemies will have a negative effect on Dalmatian toadflax stem recruitment and survival, they offer the greatest potential in reducing weed stand densities.

However, as is the case with all other management strategies, biological control is not a silver bullet; successful management of Dalmatian toadflax also will depend on other control strategies in combination with pressure from natural enemies. Selective herbicides applied at a responsible rate and during appropriate times in the plant and natural enemies' life cycles could potentially augment the effectiveness of biological control. Grazing management of Dalmatian toadflax might lead to a reduction of stand density. Grazing in concert with other management strategies has been shown to have significant effects on stand densities of leafy spurge and spotted knapweed (Lacey, et al. 1996, Lym, et al. 1997 Maxwell, et al. 1992). Likewise, cultural management of Dalmatian toadflax through tillage, mowing, and pulling could have significant impacts on the weed's density. However, the single most important factor in the management and prevention of Dalmatian toadflax infestations appears to be the maintenance of a healthy plant community.

Land that is subject to intense physical disturbance will most likely always be threatened by weed invasion due to increased resource availability (Tilman 1997). Overgrazing by ungulates can seriously limit the competitive abilities of desirable grass

and forbs species both through intensive feeding-related damage as well as through soil disturbance (Dyksterhuis 1949, Tyser, et al. 1988, Svejcar et al. 1991, Sheley et al. 1996). Since Dalmatian toadflax seedling recruitment into arid rangeland situations appears to be limited by microsite availability, consistent plant competition is probably the most important factor in limiting weed population maintenance and expansion. Assuming interspecific plant competition will have an effect on Dalmatian toadflax, seeding desirable species may decrease stand density. Seeding programs targeting spotted knapweed have been shown to reduce stand density and lower the probability of re-invasion through interspecific plant competition (Velagala et al. 1997, Sheley et al. 1999). Kennet et al. (1992) demonstrated the positive interactions of biological control agents and grasses competitive with spotted knapweed.

An excellent example of a weed that has been successfully managed through the use of natural enemies and careful grazing management is musk thistle (*Carduus nutans*). The flower feeding weevil *Rhinocyllus conicus* (Froeh.) is a widespread and very effective biological control agent of several exotic thistles. Weevil larvae were found to significantly reduce seed production in musk thistle by feeding on seeds and developing plant reproductive tissue (Rees 1977). In the absence of biological control, musk thistle is capable of producing enough seeds to saturate seed emergence microsites in most rangeland, especially rangeland that has seen heavy use and disturbance by ungulates. Furthermore, the weed manages to recruit sufficient seedlings to maintain its population even when under heavy pressure by *R. conicus*, so long as grazing pressure on desirable plants precludes them from competing with musk thistle seedlings for resources. However,

when seed predation and plant competition are combined, musk thistle often ceases to be a problem weed. The keys to this system are not only the limitation of future plant generations through seed predation, but also the hindrance of seedling development by a healthy plant community (Nowierski et al 1999).

Dalmatian toadflax presents the weed manager with problems much more difficult than musk thistle through its capability to produce hundreds of thousands of seeds per adult plant, its vegetative reproduction, and its ability to infest rocky, gravelly, xeric sites. Such sites provide poor opportunities for chemical management and interspecific plant competition. Field and simulation results of the Wyola toadflax study site seem to indicate that plant competition and/or resource limitations coupled with low adult stem recruitment and high adult stem mortality may be important factors that contribute to a reduction of Dalmatian toadflax stem densities. This supports the hypothesis that the number of stems per unit area rather than seedheads per stem limit toadflax populations.

Further research needs to be conducted in order to better understand the recruitment of adult stems into Dalmatian toadflax populations as well as to complete and validate the proposed boxcar model. Impact of *B. pulicarius* on seedhead production was not obtained in the field trials due to the low densities of beetles at both sites. The influence of interspecific plant competition on Dalmatian toadflax population dynamics also needs further exploration. Experiments that re-seed native or desirable exotic grasses and forbs into sites infested with Dalmatian toadflax would further quantify the importance of interspecific plant competition to the Dalmatian toadflax system. Finally, Dalmatian toadflax stem recruitment from first year plants and vegetative recruitment of new stems

also need to be quantified in order to better understand the relative importance of seedling recruitment in the context of Dalmatian toadflax persistence within infested plant communities.

Vegetative reproduction presents an interesting challenge to the researcher, as non-destructive sampling is precluded by Dalmatian toadflax's sub-soil surface linkages between parent and daughter stems. The most reasonable experimental approach to second year stem recruitment and vegetative reproduction in Dalmatian toadflax would probably be in a series of five to ten year partial addition series experiments with varying levels of initial seeding, interspecific plant competition, and herbivory. Such an experiment would allow individual toadflax plants to be tracked through each stage of the weed's life history. Data from experiments carried out within this proposed framework would answer many of the remaining questions concerning the life history and management of this noxious weed.

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APPENDIX

EXTENSION BROCHURE

## The Blackfoot Challenge: Progress in The Biological Control of Yellow Toadflax 1997-98.



Yellow Toadflax Infestation (USDA)

Montana State  
University  
Department of  
Entomology

## Project Objectives and Biological Control of Yellow Toadflax

### Overall Project Objectives Are:

- To establish insectaries of *Mecinus janthinus* and *Brachyterolus pulicarius* on cooperator managed land.
- To develop an internal system of distribution, once natural enemies become established on insectary sites.
- To establish plant transects at each release site in order to observe the impacts of natural enemies on yellow toadflax and desirable plants.

### Objectives for the 1997-98 Seasons Were:

- Initiation of cage releases of *Mecinus janthinus* and free release sites for *Brachyterolus pulicarius* and *Calophasia lunula*.
- Establishment of plant transects at each release site.
- To find and mark new patches of yellow toadflax, suitable for cage releases in future years.

Successful biological control of yellow toadflax will depend on the establishment of a complex of natural enemies that attack multiple stages of the plant's life cycle, due to the plant's ability to reproduce through both sexually and asexually. The biological control agents that are currently available to the Blackfoot Challenge for the management of toadflax consists of three insects; a flower-feeding beetle, a stem-boring weevil, and a foliage-feeding caterpillar.

## Yellow Toadflax (*Linaria vulgaris*): Biology and History

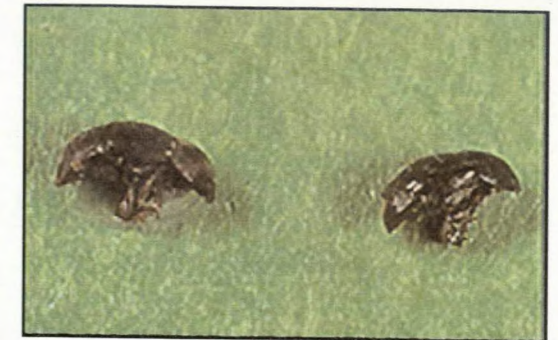


Yellow Toadflax (MSU)

Yellow toadflax (*Linaria vulgaris* Fam. Scrophulariaceae) is a perennial herb that reaches between one and two feet in height. Foliage is pale green and consists of tubular stems and numerous elongate, pointed leaves 1-3 inches in length. Flowers are yellow to pale orange, one inch long with snapdragon-like flowers. Fruits are roughly spherical with a diameter of about a quarter inch, and consist of two green to brown lobes. Seeds are flattened, circular about one twelfth inch in diameter with dark brown to black coloration. Yellow toadflax reproduces both sexually, through seed production as well as vegetatively, through root buds on lateral roots.

Yellow toadflax originates from Medeteranian Eurasia and was introduced to the United States sometime in the 1840's. It became a problem weed once it escaped gardens.

## Toadflax Flower Feeding Beetle: *Brachyterolus pulicarius*



Two Adult *Brachyterolus pulicarius* (MSU)

*Brachyterolus pulicarius* (Fam: Nitidulidae) is a small ovoid-shaped beetle that feeds on the shoot tips and developing flowers of both yellow and Dalmatian toadflax. Adult beetles feed on the shoot stems causing increased branchiness and shorter plants. Larva feed on the reproductive tissues of the plant causing seed capsules to abort. Beetles go through up to two generations per year. *Brachyterolus* was accidentally introduced in the North Eastern United States in 1918 and has since become a widespread and common to both species of toadflax. Beetles can be redistributed by collection with a sweep net and release on new toadflax infestations. Adult beetles should be released on early season or newly flowering plants. *Brachyterolus* is presently present in most older infestation of yellow toadflax in the Blackfoot Valley.

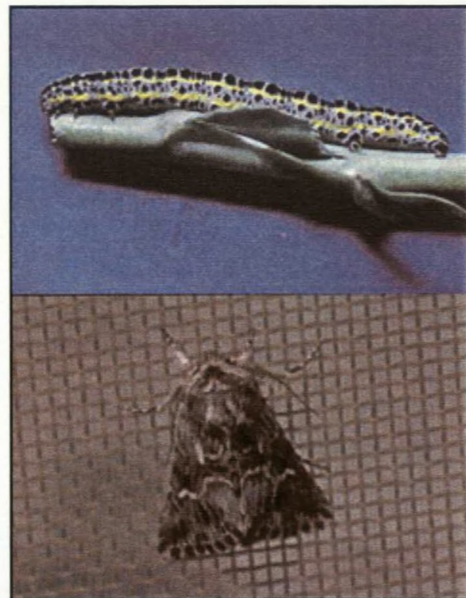
## Toadflax Stem-Boring Weevil: *Mecinus janthinus*



Larval and Adult *Mecinus janthinus* (MSU)

*Mecinus janthinus* (Fam. Curculionidae) is a small ovoid weevil that mines the stems of both species of toadflax. Adult weevils feed on the foliage of toadflax and lay eggs in holes chewed into stems. Larvae hatch and bore into stems mining the interior pith and eventually causing stems to fall over. Adults are iridescent black and about an eighth inch in length. Larvae are pasty white-colored, ranging from less than a sixteenth to an eighth of an inch long, and live in bored out chambers of toadflax stems. *Mecinus* was first released in the United States in 1996, and is undergoing initial establishment in Montana. Weevils can be redistributed by collection with a sweep net and release on new toadflax infestations, beetles should be released early in the season when toadflax stems are just emerging.

## Toadflax Foliage Feeding Moth: *Calophasia lunula*



Larval and Adult *Calophasia lunula* (MSU)

*Calophasia lunula* (Fam. Noctuidae) or the toadflax foliage-feeding moth is a small gray moth, about half an inch long. The larvae feed on plant foliage, stripping leaves from stems. Caterpillars are black and green with yellow spots, and range from an eighth to one and a half inches long. Moths may have up to three generations per year when warm weather prevails. *Calophasia* was first introduced into the United States in 1968 and is now found in a few western states. Caterpillars can be redistributed after they are collected off of stems. Caterpillars should be released on tender foliage no later than the beginning of August.

## Progress in the 1997-98 Season and Future Directions

### Insect Releases

- Released 900 *Calophasia lunula* at three sites in 1997 and 400 in 1998.
- Released 1100 *Brachyterolus pulicarius* at four sites in 1997 and 400 in 1998.
- Released 180 *Mecinus janthinus* at two sites in 1997 and 150 in 1998.

*Mecinus janthinus* successfully overwintered at one of two Rolling Stone release cages.

### Transects and Release Cages

- Initiated four permanent plant transects at release sites.
- Positioned two release cages in 1997.
- Acquired six new cages for use in 1999.
- Scouted three new sites for cages in 1998.

Future directions will include the establishment of two or three new *Mecinus janthinus* insectary sites, further redistribution of existing *Brachyterolus pulicarius* to newer toadflax patches, and continued release of *Calophasia lunula*. In addition, permanent plant transects will be maintained to monitor toadflax population trends. Long term efforts will include the introduction of new natural enemies of toadflax to the Blackfoot Valley.

## Contact Information and Resources Regarding Integrated Weed Management.

### References:

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### Contact Information:

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Blackfoot Challenge Cooperator, Jim Stone; Evaluates a *Mecinus janthinus* Release

Pamphlet Composed by Matthew Grieshop and R.M. Nowierski.

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