University of Alberta

Tanacetum vulgare L. : Weed potential, biology, response to herbivory, and prospects for classical biological control in Alberta.

by

Donna Joan White ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

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Edmonton, Alberta

Spring, 1997

0-612-21221-1

University of Alberta

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Name of Author: Donna Joan White

Title of Thesis: *Tanacetum vulgare* L. : Weed potential, biology, response to herbivory, and prospects for classical biological control in Alberta.

Degree: Master of Science

Year this Degree Granted: Spring, 1997

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To David, Kalyca, and Aren

Abstract

Populations of *Tanacetum vulgare* L., common tansy, were studied to contribute to a pest management plan, and to assess the potential for the use of classical biological control in Alberta. *T. vulgare* populations have expanded in the past decade and colonized pasture habitats and riparian zones. Current control methods are ineffective in limiting population expansions. Annual costs of current controls approach threshold losses that are considered as justification for classical biological control.

T. vulgare employs numerous successful strategies for establishment and persistence in roadside, stream bank and pasture habitats. Maintenance of a vigorous perennial rootstock is essential to the production of large amounts of seed. However, vegetative spread does not appear to be as important to population expansion as seed dispersal and seedling establishment.

The few European descriptions of morphology and phenology of *T. vulgare* are consistent with those experimentally observed in Alberta. Of the limited number of polyphagous insects feeding on *T. vulgare* in north central Alberta, none are abundant enough nor inflict damage at a level capable of negatively affecting *T. vulgare* populations.

T. vulgare response to simulated herbivory was shown to be highly conditional depending on the type of defoliation, natural habitat, and moisture and light availability. Sexual reproductive potential was significantly reduced by defoliation but vegetative growth was relatively stable over the course of the experiments. *T. vulgare* growing in a shaded riparian zone were more adversely affected by defoliation than those in a roadside habitat. Population changes in grazed pastures, including decreases in density and changes in age classes, appear related to the type of herbivore and environmental factors.

Acknowledgements

Thank you to John Spence for providing the opportunity and encouragement to pursue this research, to Alec McClay for continued support and funding, and to Doug Craig and Anne Naeth for constructive comments and effective advice.

S. Dick, A. Meyer, N. Berg, K. Cryer, R. Hughes, I. Switzer, M. Herbert, S. Rempel, and several WISEST students provided much appreciated technical support, advice, and friendship. Thanks to M. McIntyre who built water cannons and fixed broken root blades. D. Cole and D. Maurice of Alberta Agriculture provided valuable direction and assistance in the early stages of this study. Thank you to W. McGill for laboratory space for carbohydrate analysis and to K. Osterman and C. Figueiredo for their technical advice. I extend my sincere appreciation to the Agricultural Service Board of the County of Thorhild and their employees for the provision of a field site and assistance during the course of the project. The agricultural fieldmen and district agriculturalists throughout the province all gave generously of their time and knowledge in answering questionnaires. I am also very grateful to the many individual landowners, especially the Sotnikows, Michaels, and Donalds who allowed me to work in their pastures, answered questions, and provided their perspective on common tansy. Funding for this project was supplied by the Canada Alberta Environmentally Sustainable Agriculture Association (CAESA) (through an operating grant from the Alberta Environmental Centre to J. Spence) and by an NSERC research grant to J. Spence).

R. McLean kindly identified plants associated with common tansy at George Lake. J.P. Tewari identified diseases and S. Digweed, J. Hammond, J. Amrine, M. Sharkey, and D. LaFontaine identified insects and mites. M. Williamson, K. Yee, and D. Ryan answered statistical and many other questions. Jeff Battigelli introduced me to the marvels of mites, provided technical assistance, and generous moral support. Fellow *T. vulgare* researcher, Y. Beekman and I, had many useful trans-Atlantic discussions and exchanged elusive research articles. I extend my sincere appreciation to all. I am also indebted to G. Braybrook and S. Bjornson who provided comic relief and their technical expertise in the pursuit of the perfect eriophyid and tansy micrographs.

My largest debt of gratitude I owe to my family and friends, for their limitless support, and love.

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1. Introduction

1.1 The assessment process for the classical biological control of weeds.

Classical biological control of weeds has provided some of the most economically sustainable and ecologically sensitive means of suppressing outbreaks of introduced, invasive plant species in North America (Harris, 1991). Although, the rate of control success for organisms introduced from one region to another is increasing, the past combined success of introduced invertebrate and fungal agents has been below 50% (Tisdell, 1990). Pre-selection and post introduction research has focused on the characteristics of the control agent, with little consideration given to the plant. It is generally argued that the low success rate in field application and the difficulty in adequately monitoring the progress of a control agent is predominantly a function of the lack of understanding of prey, predator systems in the area of introduction and the effects of climatic differences (Harris, 1973, Wapshere, 1985). However, the role of the target plant species in these plant-herbivore interactions has generally been ignored and this omission may also significantly limit the ability of biological control research to foster successful introductions. Recent research has been directed towards blending ecological research with the selection process for classical biological control agents (Malecki et al., 1993, Waage, 1990). Such research has potential both to increase understanding of plant - herbivore interactions, and contribute to the success of biological control programs.

Common tansy, *Tanacetum vulgare* L. (Compositae), a robust, aromatic clonal perennial has demonstrated increased weedy potential over the past decade. The plant was introduced to North America as early as 1638 (Mitich, 1992). Colonists used the plant for its repellent, preservative and medicinal qualities. some of which have been confirmed by recent research (Abad, 1995). However, the plant readily escaped from herbal gardens to waste places and roadsides where it remained as a relatively innocuous species until the past ten years. Steady increases in population levels and in the habitats colonized by the plant have resulted in its designation as a noxious weed in Quebec, Manitoba, Alberta, and British Columbia. The invasive potential of the weed has been noted in both Europe and Alberta. Prach and Wade (1992) adapted the criteria for the 'ideal weed' developed by Baker (1965) and applied it to 6 broad-leaved herbs and 4 graminoids of European origin. Of those species evaluated, *T. vulgare* ranked eighth with respect to invasive potential. Characteristics of the plant, including its origin, relative abundance in its native range, stability of habitat, and life cycle also contributed to its selection as a suitable target weed for classical biological control in Alberta (McClay, 1989).

The nature of the problems created by the increased weedy potential of *T. vulgare* and the characteristics that underlie this potential in Alberta have not been investigated. However, an understanding of the origin of this pest problem, and the factors contributing to the continued expansion of *T. vulgare* could improve weed control decisions. In addition, specific decisions about the need and potential for biological control agents of *T. vulgare* in Alberta require improved biological information on current control effectiveness, plant population structure and dynamics, and the presence of native herbivores within the system. This type of research information, which could be utilized in the early stages of selection for biological control agents, can benefit existing management strategies, improve the potential for successful agent selection, provide the ecological information necessary to monitor introduction programs, and further increase our knowledge of plant-herbivore interactions.

1.2 Objectives

The overall objectives of this research are: to assess the weedy potential of *Tanacetum vulgare* in Alberta, to determine the factors that have historically influenced the establishment of this species and to identify those which are currently related to its invasive potential. In addition, the arthropods and diseases presently causing damage to *T. vulgare* in Alberta are characterized. The influence of habitat on the biology of the plant is investigated in order to establish a biological framework for the refinement of pest management practices. Analysis of the response of *T. vulgare* to simulated herbivory of different types and intensities, as influenced by habitat, is designed to improve our general ability to successfully introduce and monitor the effects of a classical biological control agent.

In Chapter 2, the current status of *T. vulgare* populations in Alberta, their distribution, and their relationships to disturbances of the land base are examined. In Chapter 3 the general morphology, establishment, and growth characteristics of *T. vulgare* as influenced by habitat and grazing are discussed. The insects, mites, and diseases found associated with the plant in Alberta are discussed in Chapter 4 and a comparison made with insect species reported from Europe. The response of *T. vulgare* to simulated herbivory is presented in Chapter 5 with a discussion of the vegetative and sexual reproductive implications of the different types of herbivory as mediated by habitat and over time.

In the concluding chapter, additional research directions are proposed for classical biological control selection and the improvement of existing management strategies.

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2. Distribution of Common tansy (*Tanacetum vulgare* L.) in Alberta

2.1 Synopsis

The perennial herb, common tansy, (*Tanacetum vulgare* L.) was introduced to Canada from Eastern Europe and the British Isles in the 19th century. Within the past decade, populations of common tansy in Alberta have expanded rapidly. In a 1993 survey of municipal agricultural fieldmen in the province of Alberta, an estimated total of 26,384 hectares in 58 municipal districts were reported to have populations of common tansy. Of that area, 5,706 hectares had high density populations (plants or clumps of plants less than 4.5 m apart), 11,250 hectares had medium density populations (plants or clumps of plants from 4.5 m to 23 m apart), and 9,428 hectares had low density populations (plants or clumps of plants greater than 23 m apart). The geographical center of common tansy populations in terms of area and density was identified as the north central area of the province. Roadsides and railways, fence lines and field margins, permanent seeded pasture, and lake shores, river and creek banks had the highest population densities and area. The total estimated annual cost of the measures of controlling common tansy applied by municipal agencies and a small sample of sixteen private landowners in the province of Alberta was $256,612 ($9.70/hectare) in 1993 (Can$).

Duration of presence of *Tancetum vulgare* L. was not an accurate predictor of reported population increases. There was a more apparent relationship between land base development activity and the increase in common tansy populations within municipalities, particularly along the northern fringe of the non-forested area in the north central part of the province. The total area of land base with common tansy populations was the best predictor of problem severity.

Different types of habitats can be characterized by different patterns of density and distribution. Pasture/hay habitats have large areas of low and medium density populations. Ruderal type habitats have fewer hectares of low and high density populations and larger areas of medium density population. Riparian zones have larger areas in the medium to high density range and fewer areas at low densities.

Despite widespread use of herbicides and the reports of effective control, common tansy populations continue to expand and increase. The restrictions necessary to guarantee environmental safety in herbicide use and the terrain restrictions to cultivation and mowing in this plant's preferred habitats, ensure that the control of common tansy using currently available methods is ineffective. Potential exists for introduction of alternate and additional control strategies.

2.2 Introduction

A comprehensive approach to the management of pests in agroecosystems must address the social, economic, and environmental costs of current management practices (Tauber et al., 1984). Despite increasing awareness and concern about environmental contamination caused by the widespread use of chemical pesticides, and soil degradation caused by excessive cultivation, weed control in agroecosystems is largely dependent on these two control methods. Modern integrated pest management seeks to combine strategies such as cultural controls, pesticides, pathogens, and resistant varieties. Biological control can provide a fundamental part of this environmentally sensitive, cost effective integrated approach to pest control. However, successful implementation of a classical biological control strategy for an invasive plant species and long term monitoring of projects requires a knowledge of the target host plant (Malecki, 1993). Part of that knowledge is an understanding of the distribution and density of the target plant.

Common tansy (*Tanacetum vulgare* L.), an introduced perennial species of European origin, was assessed as meeting suitability criteria for biological control (McClay, 1989). Originally considered a weed of roadside and waste areas, common tansy populations have been increasing in north and central Alberta over the past ten years. Areas of increased infestation include waterways, recreation areas, and pastures. The plant is now listed as a noxious weed in Quebec, Manitoba, Alberta, and British Columbia (Anonymous, 1960, 1964, 1970, 1973, 1978, 1979, 1983a, 1983b). However, the distribution, density and habitats of common tansy in Canada, and specifically, Alberta have not previously been investigated.

While quantitative field data is viewed as the most preferable means of establishing economic losses due to "weedy" species in cultivated land (Thomas, 1985), the feasibility of obtaining that type of information in non-cultivated land and over a broad geographic area such as the province of Alberta is severely limited by financial constraints. An alternate method of establishing the provincial distribution of the plant populations within Alberta can be based on information obtained from Agriculture Service Boards employees who are responsible for weed control on the municipal land base and enforcement of provincial weed control legislation on private lands. District agriculturists serve larger scale agricultural regions, and provide a further source of information regarding the agricultural land base.

To acquire this information, a municipal survey was designed to solicit municipal estimates on the location, distribution and density, and areal extent of common tansy, as well as estimates of cost and identification of the type and intensity of current control measures. The costs of control measures included those used on lands administered by the municipalities and those applied to private lands as required in the course of enforcement of weed control legislation. The aim of the economic assessment portion of the survey was to establish an estimate of current cost of control initiatives not including losses due to reduced agricultural productivity. Although such a conservative estimate of costs may underestimate the value of further research into a biological control, the information serves as a starting point for future research.

2.3 Materials and Methods

Agricultural fieldmen and district agriculturists were surveyed in 63 rural municipalities and one urban municipality in the province of Alberta. District agriculturists were sent brief questionnaires in July 1993. Detailed questionnaires were forwarded to all agricultural fieldmen in August, 1993. Sixteen private landowners were visited and surveyed within a subset of five municipal districts in the north central area of the province in September 1993. These latter two surveys (Appendix 2.B and 2.C) were developed to determine the history, extent of infestations, types of habitat, herbicide and cultural control practices and to obtain estimates of the cost of current control practices. In addition, a district agriculturist survey was designed to solicit information on broader scale agricultural concerns (Appendix 2.A). Input for the questionnaires was solicited from Alberta Agriculture Food and Rural Development, the Alberta Environmental Centre, district agriculturists, agricultural fieldmen and provincial specialists.

The short questionnaire sent to district agriculturists sought general information on the presence or absence of the species, habitat type and approximate area infested and geographical locations (legal land locations) within the agricultural district. District agriculturists were asked to provide contact lists of producers who had common tansy on their property.

Because possible animal health concerns have been reported in bred cows grazing on common tansy, district agriculturalists were also asked to report any knowledge of stock losses attributed to the plant. A veterinarian contact was requested if the response was affirmative.

The detailed questionnaire sent to agricultural fieldmen (Appendix 2.B) was designed to establish when the plant was first noticed within the municipal district, the presence or absence of the plant, and to obtain an overall impression of the perceived problem, i.e. whether the population was spreading, and how it compared in importance to other agricultural pest species within their jurisdiction (Appendix 2.B:Questions 1 to 3). Logistic regression analysis was used to test whether pest status within a district was dependent on the duration of infestation. A test of the dependence of population stability based on the duration of reported presence within the district was made using logistic regression. Population stability was defined using the reported increases or lack thereof in populations within the districts.

Abundance and density estimates were requested for ten specific habitats known to host common tansy populations (Appendix 2.B:Question 4). Three density levels were provided (high, medium, and low) which were defined by specific distances between plants. Low density was identified as areas with plants widely spread at distances greater than 23 m (25 yards) apart. Medium density areas had plants 4.5 m to 23 m apart (5 yards to 25 yards) and high density areas were those with plants less than 4.5 m (5 yards) apart. Areas were reported as acreages, or as miles when reporting linear infestations of fence lines, field margins, roadsides, railways and waterways. Miles of infestations were converted to acreages based on an area of 2.5 acres per mile derived from an assumption of width of infestation of 7 m. This width of infestation on linear estimates was a compromise between a conservative standardization of a typical spray swath for boomless sprayers (30 ft. or 9 m) and a plausible area on either side of fencelines, roadsides, and railways (3.5m). Total acreages were then converted to hectares using a conservative estimate of 2.5 acres/mile (One mile = 1609 m by 7m swath = 11263 sq. m. (1 acre = 4047m^2) therefore 1 mile = 2.78 acres). Density category selection for the question was determined by field observation of established plant communities in a variety of habitats. The total areas at each density were then used as independent variables in a logistic regression model to determine whether habitat was related to the density level.

Habitat associations could also be related to the suitability of specific soil conditions for common tansy. Information was solicited about relationships between common tansy growth and soil drainage, texture, salinity, pH, and fertility characteristics (Appendix 2.B: Question 7). Information on possible soil associations was seen as valuable in the prediction and analysis of patterns of spread and in the efficient application of control measures in areas of high potential for colonization and/or rapid spread. Results were tabulated and descriptive statistics prepared.

A check question (Appendix 2.B: Question 4) was included to determine if the perceived problem status as established in Questions 1 to 3 could be related to an actual agricultural or habitat displacement problem. Because common tansy is a conspicuous plant, visual perception of the problem may have exceeded its actual magnitude, necessitating caution in interpreting the survey results. To examine this issue, the relationship between the perceived severity of the problem, the reported population increases or decreases and the types of problems encountered were analyzed using logistic regression analysis. Because the problems reported were multiple for each municipality, categories were defined and the problems scored as 3 = high (forage or range production losses, spread to other habitats, and stock poisoning), 2 = medium (spread to other municipalities and weed population increases), and 1 = low (unsightly). The problem scores were totaled and the resultant classification variable used to characterize the current importance to agricultural interests and future habitat disturbance. These scores were used as independent variables in logistic regression analysis to determine if agricultural interests and future habitat disturbance were related to reported severity of the problem and population increases.

Information pertaining to the type of control measure, area applied, cost, duration, and projected duration of application was also requested (Appendix 2.B: Question 8). The area treated was estimated from acreages and miles and converted to hectares as for the habitat estimates. Results were tabulated (Table 2.1). Question 9 (Appendix 2.B) specifically requested information about herbicide use.

The available information on actual field use of herbicides, specifically application rates, stages, frequency, and control achieved, is limited to research plot studies and industrial trials on cultivated crops. Typically herbicide trials do not include uncultivated areas such as roadsides and fence lines even though a large portion of municipal applications are carried out in these habitats. Thus, information was sought on the types of herbicides being used, the different application rates and stages and the relative level of control achieved. These factors were used in a logistic regression model to predict the reported levels of control. Control levels were standard descriptions used by the province and industry (Ali, 1996).

Respondents were given the opportunity to provide further comments and input regarding the questionnaire or their experience with common tansy (Appendix 2.B: Question 10).

Sixteen private landowners identified from the district agriculturist survey were interviewed in person and problems on their property viewed and documented (Appendix 2.C). Those surveyed were from agricultural districts within the north central area of the province. Questions for the producer survey were identical to the agricultural fieldmen survey with the exception of four questions. Questions 3 and 9 were omitted regarding the perception of the overall municipal problem and specific herbicide use because more detailed information regarding municipal problems was available from the agricultural fieldmen. Also, in 1993 no herbicides were registered for landowner use on common tansy, so the use of herbicide control on private land was expected to be limited. Question 5 regarding the problems caused by common tansy on their property was edited to include more site specific factors such as problems with harvesting, contamination of seed, and weed notices. Question 8 was added to assess the economic value to the producer of controlling common tansy on their property. In large part this survey was used as a basis for evaluating the accuracy of responses from the overall municipal survey and to obtain an estimated range of density dependent costs to a producer of controlling invasive populations of common tansy. Results were tabulated for all questions (Appendix 2.E: Tables 2E.6-2E.10) and the density and area, mode of spread and problem type graphically compared with the municipal survey.

2.4 Results and Discussion

2.4.1 District Agriculturist Survey

Fourteen of the 17 district agriculturists who replied to the questionnaire reported common tansy within their jurisdictions. Those able to provide producer contacts were located to the north west of Edmonton and twenty such producers were selected for direct contact. While Keindorf and Keindorf (1978) reported hyperestrogenism in cattle, possibly caused by grazing *Tanacetum vulgare* (L.), and Gress (1935) reported that common tansy was poisonous to livestock, only one district reported concerns with livestock poisoning. Animal health experts, consulted in connection with this project, maintain that a direct link has not been established between ingestion of common tansy and death or abortion of bred cattle in Alberta or the United States (Dr. J. Kendall, Alberta Agriculture Toxicology Specialist, personal communication, Dr. R. Smith, Kentucky Livestock Diseases and Diagnostic Centre, personal communication).

2.4.2 Municipal Survey

2.4.2.1 Population increase and expansion

Sixty - one municipal districts provided detailed responses to the questionnaire. Fifty - two of those reported the presence of common tansy within their municipalities. Twenty - four municipalities reported increasing populations, with 17 of those providing a range of estimated presence of the plant between 3 to 60 years. Twenty-eight municipal districts reported no increase in population levels with 17 providing an estimated range of 1 to 70 years duration of presence. Thirty - eight municipalities reported that the plant represented a minor to insignificant problem and 14 reported the weed as a significant problem within their jurisdiction.

The logistic regression model tests of duration of infestation as a predictor of reported population increase were not significant (-2 Log Likelihood=48.2, Model Chi-Square: df=1, Chi-Square=0.245, p=0.621, Overall percent correct=51.4). Similarly, the model tests of duration of infestation as a predictor of problem rating of the weed were not significant (-2 Log Likelihood=42.2, Model Chi-Square: df=1, Chi-Square=0.678, p=0.410, Overall percent correct=71.4). The relatively small sample size and the difficulty of obtaining accurate historical data over such a large area may be reasons for the lack of significance of this model. However, many introduced species remain non-invasive for long periods of time. For example, purple loosetrife (*Lythrum salicaria* L.), introduced to the eastern United States during the early 1800s, has only reached injurious densities within the past two decades. It is now responsible for severe wetland habitat displacement and also for agricultural losses due to reduced wetland pasture and hay production, and the obstruction of irrigation systems (Malecki et al., 1993). The expansion of loosetrife population coincided with the expansion of irrigation systems and the increased development and use of road systems (Thompson et al., 1987). Similarly, common tansy was introduced into Alberta during the pioneer period of the late 1800s, but it has only been during the past decade that the plant has attained high densities in Alberta (Chapter 1).

This pattern of delayed population expansion is consistent with a model of population explosions developed by Green (1990) which predicts that a lack of connectivity between sites can prevent the expansion of an invasive species. Expansion of a focal population only occurs if continuing disturbances eventually produce inter-site connections. In the present survey, municipal districts within the forested area (green zone) of Alberta have reported the presence of common tansy populations for over 60 years without expansion of populations from the original sites of horticultural introduction. The lack of connectivity and widespread disturbance within these municipal districts appear to have been associated with limited population increase and spread as is consistent with Green's model. The primary sites of increase in area and density occur within the (white) agricultural zones and most notably on the northern fringe of the north central region of this zone. Burke and Grime (1996), in a study of plant community invasibility, have shown that species with small seeds are more dependent on disturbance for establishment. Furthermore, the susceptibility of an indigenous community to invasion was strongly related to the availability of bare ground and could be improved by increased eutrophication.

Additions and deletions to the agricultural land base (white zone) adjacent to the green areas have been documented from 1976 to 1993 (Birch, 1982, Wehrhan,1985, Wright and Pearson, 1993). Fifty percent of the lands deleted from agriculture were higher capability Canada Land Inventory (CLI) class 1-3 soils that was primarily cultivated land. However, more than 66% of additions to the land base are lower capability CLI class 4-7 soils, primarily forage, range and mixed cropping lands located along the fringe of the settled land base (white area), primarily in northern Alberta (Wright and Pearson, 1993). The reductions in cultivated area and increases in perennial crop lands could be an important contributing factor in the increased "weedy" significance of a perennial plant such as common tansy. Data for additions and deletions to the municipal land bases reporting common tansy populations for the period 1986-1990 were used as a predictor for weed problem significance using logistic regression. This data set included all types of additions and deletions and covered the latter half of the decade during which common tansy populations increased. The analysis did not produce a significant model (-2 Log Likelihood=57.02, Model Chi-Square: df=1, Chi-Square=2.93, sig.=0.231, Overall percent correct=72.5). However, land base additions or deletions were significant in explaining population status (-2 Log Likelihood=63.7, Model Chi-Square: df=1, Chi-Square=6.46, sig.=0.039, Overall percent correct=66.67).

2.4.2.2 Population density and habitat distribution

Population area (ha) and the frequency of occurrence in municipal districts were categorized by eleven habitats and three density levels

(Table 2.1). There was no evidence to reject the hypothesis that density class was independent of habitat, using the data from all municipalities in Table 2.1 ($G_{obs.}$=5.29, df=20, $X^2_{,0.05,20}$=31.41, p>0.05). However, as the municipalities are not equal in area, the interpretation of this statistic is problematic. An alternative was to use the G statistic to analyze the habitat by density class contingency table where the hectares of land base are used as counts of occurrence at each density level. Analysis using this specification led to the rejection of the null hypothesis that density is independent of habitat ($G_{obs.}$=844.064 df=20, $X^2_{0.05,20}$=31.410, p<0.05).

These common habitats of *Tanacetum vulgare* L. can be grouped into three major categories: ruderal, riparian, and pasture/hay. Ruderal plants, in a broad sense, inhabit such areas as urban wasteland, railroads, roadsides, and other areas affected by human habitation (Sauer, 1988). It is in this context that ruderal is used here to describe fencelines and field margins, roadsides and railways, wasteland, farmyards, shelterbelts, and gravel pits. Riparian habitats include lakeshores, creek and river banks, slough margins, and dugouts. Pasture and hay habitats include permanent seeded pasture, native pasture and rangeland, tame hay and silage, and seeded hay and pasture. The habitat category by hectares and incidence of occurrence at the municipal level are summarized in Table 2.3. Using the G statistic to analyze the habitat by density class table, with the number of hectares representing counts of occurrence at each density level, there was sufficient evidence to reject the null hypothesis that density is independent of habitat ($G_{obs.}$=445 df=4, $X^2_{0.05,4}$=9.49, p<0.05).

The three general habitat types demonstrate different patterns in area and density distribution (Fig. 2.1). Pasture/hay habitats have high areas of low and medium density populations. These habitats are subject to smaller scale, widely dispersed, local disturbances such as those caused by ground dwelling mammals and selective grazing and treading. Competition from grass species limits vegetative spread in younger pastures and higher litter levels limit seedling establishment of common tansy (Chapter 3), resulting in widely dispersed low density populations. Population density levels in these habitats could increase in situations of overgrazing where erosion and reduced litter levels would result in increased seedling establishment (Chapter 3). However, the general pattern in pasture/hay habitats is one of low to medium density populations over a wider area.

Ruderal type habitats have fewer hectares of low and high density populations with the largest areas of medium density population. Common tansy populations exhibit a higher degree of clumping in these habitats (Chapter 3) and this reflects the more intense short duration types of disturbance associated with human activity in these areas, such as road and fence building and maintenance. Lower density areas could be smaller because of the linear nature of these habitats, which are typically bordered by cultivated or forested lands that physically limit seed dispersal and spread. High density areas could be limited by competition from seeded species that are more competitive in ungrazed conditions and also due to the absence of continuous disturbances.

Riparian zones exhibit proportionally higher areas in the medium to high density range. These habitats carry the most dense monotypic stands of common tansy (personal observation). Often these stands are associated with cycling water levels which leave open bare soil that is solidly colonized by common tansy seedlings. Activity around waterways associated with mammal and bird activity maintains a disturbance level that ensures continued seedling establishment in the absence of prolonged disturbance by water. Graminacious and legume species that appear to compete well with *Tanacetum vulgare* (L.) are not common in these habitats and reduce the competitive pressure on the plant (Chapters 3 and 4).

Strong patterns of association between tansy presence and specific soil features could not be determined from the data collected (Figs.:2.2a - 2.2e).

2.4.2.3 Spread of local populations

The modes of spread in order of the highest number of times cited were: wind, equipment, water, road maintenance, and contaminated feed/hay (Fig 2.3). Wind dispersal of common tansy seed is aided by the erect stems which persist for one to three years with viable seed remaining attached to the receptacle (Chapter 3). The seeds of common tansy weigh less than 0.05 grams (Chapter 3), and are presumed to be wind-dispersed even though they lack any distinct morphological adaptations (Fenner, 1985). Thus, common tansy combines small seed size (0.001g) with prolonged attachment of the seed to an upright woody stem to maximize its potential wind dispersal. The seeds also have a high oil content (Chapter 3) and remain on the water surface (personal observation) which probably accounts for their reported transport by water. In addition, common tansy's stable roadside habitat and presence in gravel pits are consistent with the reported spread by means of farm machinery and road maintenance equipment. However, the high value of the contaminated feed/hay response was unexpected as only a late cut would include large amounts of viable seed (Chapter 3). It is more likely that the spread associated with feed/hay is due to machinery carrying seed from field margins and/or from seed blown onto bales standing in the field and later transported.

The type of problem common tansy presented to municipalities was most frequently related to its potential for spread to other habitats, increases in the present populations, and forage or range land production losses (Appendix 2.B. and Fig. 2.4). As a check on the factors that affect whether the weed was regarded as a significant problem, the problem type score variable was included in a logistic regression analysis of the perceived importance of the plant. The analysis tested if the problem severity scores (high = forage or range production losses, spread to other habitats, and stock poisoning, medium=spread to other municipalities and weed populations increases, and low = unsightly) were significant predictors of the perceived significance of the problem. Results of the logistic regression analysis showed that there was significant evidence to support the hypothesis that the importance of the weed problem was predicted by high problem severity score (i.e. factors of economic and environmental concern) (-2 Log Likelihood = 37.0 , Model Chi-Square: 16.4 df=1, sig.= 0.0001).

2.4.2.4 Regional distribution

A map of the total area of populations as a percentage of the individual municipal district area (Appendix 2.D: Fig. 2D.1) and maps of the areas at high, medium and low density levels as percentages of municipal district area (Appendix 2.D: Figs. 2D.2-2D.4) were prepared. The geographical centre for common tansy populations in Alberta is to the north west of Edmonton, and the distribution radiates from that center with municipal districts having higher areas of infestation concentrated in a broad band moving in a south east direction towards Saskatchewan (Fig. 2D.1). Lower area municipal districts are found within the green zone along major transport corridors into British Columbia (Fig. 2D.1). The majority of municipalities with a large percentage of land base having common tansy populations are located north of the North Saskatchewan River with the exception of two counties along the Battle River. The percentage land base occupied by common tansy infestations ranges from <.001% to 3.00% (Fig.2D.1). Districts with the most land having high density common tansy populations are clustered in the north central area of the province (Fig.2D.2) with some extension of this pattern along the Calgary-Edmonton transportation corridor. The pattern of medium density infestations is similar but the percentage of the land base occupied at these densities is higher (Fig. 2D.3). Low density populations are more widely dispersed with higher percentage of the land base occupied in the north central region (Figs. 2D.4). Common tansy was reported along the Wapiti, Spirit, Athabasca, North Saskatchewan, Battle, Bow and Oldman rivers. Medium density infestations appear to be the most widespread in area and habitat distribution. Riparian zones and continuously disturbed sites are the exception where high densities can become more prevalent.

2.4.2.5 Conventional control of common tansy

The control methods reported included herbicide application, mowing, cultivation, and hand-pulling (Appendix 2E: Tables 2E.3-2E.5). Forty-two municipalities reported treating an estimated 2,705 hectares with herbicides during 1993 at an estimated total cost of $198,402 ($73.00/ha). Costs ranged from $9.30/ha to $500/ha and varied with the herbicide applied and labour and equipment costs. Common tansy was mowed on an additional estimated 562 ha. Mowing costs ranged from $32.00/ha to $98.90/ha with a total estimated cost of $46,850 ($83.00/ha). An additional $11,360.00 was expended on cultivation and hand-pulling. The estimated total annual cost of control within the counties reporting application of control measures was $256,612 (Appendix 2.E: Tables 2E.3-2E.5).

Weed control was reported using picloram, chlorosulphuron, metsulphuron methyl, dicamba or dicamba and 2,4-D (Appendix 2.E: Table 2E.6). Rates were extremely variable as were application stages and frequency. The herbicides as classified by mode of action, the frequency of application, the stage of application, and duration of application were used in a logistic regression model to predict the level of reported control (control versus suppression or limited effect). In a model including all factors, 72.41% of responses were correctly predicted with -2 Log Likelihood = 26.4, Model Chi-Square: 12.4, df=7, sig. = 0.089, indicating that all factors were not significant predictors of observed control efficacy. However, a logistic regression model using only duration of treatment as a predictor of control levels was significant (-2 Log Likelihood = 36.098, Model Chi-Square: 11.013 df=1, sig.= .0009, overall percent correct = 60%). Given the variability in herbicides, stages of application, and frequency of application, the length of time the plant has been recognized for its invasive potential and treated is the best predictor for successful control in this data set.

If herbicide control was as effective as reported, (63% of herbicide applications were reported effective in controlling common tansy) then municipalities reporting no increases in populations should be highly correlated with those that achieved control. However, a logistic regression model that used control levels as a predictor of population status was not significant (-2 Log Likelihood = 56.2, Model Chi-Square: 0.31 df=1, sig.= 0.577). There are several reasons for the apparent disparity between these responses. A herbicide is said to control a weed if it limits growth of the weed or weed stand at a level greater than 80%. Common tansy is a prolific seed producer (Chapter 3) and it is not clear that a survival rate of 20% or less of seeds which demonstrate germination potential of 75% or greater (Chapter 3) would be sufficient to prevent survival and/or expansion of the population. Secondly, the herbicide most widely used by municipal districts, picloram, is only available to registered pesticide applicators and has long term grazing restrictions and residual affects that prohibit use on cultivated land, near waterways or shelterbelts. While metsulfuron methyl, has been found to be effective in common tansy control (Millar and Callahan, 1993) it was not registered for use by private landowners in Alberta until 1996. Because of the recommended 50 meter buffer zone between the spray zone and the edge of shelterbelts, wetlands, sloughs, and dry slough borders, woodlots, vegetated ditchbanks and field margins for both chemicals (Ali, 1996) their ability to curtail population expansion is limited.

The alternate control measures of mowing and cultivation are not easily or effectively applied in many of the habitats, such as shores of waterways, shelterbelts, fencelines, and railway right of ways. The labour and equipment costs of applying these measures over large areas are also prohibitive.

2.4.3 Landowner Survey

Of the 16 landowners or landowner associations surveyed, 11 reported increasing infestations. There were not sufficient data to reliably test the relationship between population increases and the duration of infestations.

Wind, equipment and water were cited as the most important modes of spread, followed by road maintenance, contaminated feed/hay, and livestock/wildlife (Fig. 2.5). This is largely consistent with the trends noted in the municipal survey (Fig. 2.3).

Potential spread to other habitats, unsightliness, forage or rangeland production losses and the cost of control were indicated to be the most important problems associated with the weed (Fig. 2.6). The cost of control was an additional category in the landowner survey. While unsightliness of the plant was not rated as a greater problem than production losses in the municipal survey, it was of more concern to private landowners. However, it is not surprising that cost and aesthetics are very important at the scale of the individual landowner. To the individual landowner unsightliness represents a reduction in land value and, as such, should be considered as a cost.

There were insufficient data to detect trends in preferred soil conditions (Appendix 2.E: Table 2E.8).

Thirty-one percent of producers valued the control of common tansy at less than \$12.00/ha to a minimum of no value. Fifty percent valued the control of this weed at \$25.00/ha or more to a maximum of \$125.00/ha. Nineteen percent of those surveyed could not estimate the value of control to their businesses (Appendix 2.E: Table 2E.8).

Data were summarized, as in the municipal survey, according to habitat type (Table 2.4). A large outlying value for permanent seeded pasture collected from a grazing reserve was considered not representative of the private landowner survey and was omitted from the summary data. Contingency table analysis using this data set (Table 2.4) resulted in the rejection of the null hypothesis that density is independent of habitat ($G_{obs.}$=320.606 df=4, $X^2_{0.05,4}$=9.488, $p<0.05$).

The trends in density distribution by habitat type are similar to those observed in the municipal survey (Fig. 2.7).

An estimated total of \$21,160 (\$114.00/ha) was expended on treatment methods by the 16 landowners. Herbicide application costs ranged from \$12.00/ha to \$490.00/ha. High costs are associated with custom application rates and lower rates with single applications of lower cost herbicide, and do not reflect costs of fuel, labour and equipment. Mowing costs ranged from \$125.00/ha to \$320.00/ha (Appendix 2.E: Table 2E.9). Control was reportedly achieved using dicamba, metsulfuron methyl, glyphosate, and picloram, although rates, application stages, and application frequency are highly variable (Appendix 2.E: Table 2E.10).

2.5 Conclusion

Although common tansy is described primarily as a horticultural escapee inhabiting roadsides and railways, and fence lines and field margins, the results of this provincial survey indicate that the area of combined pasture type habitats exceeds the original habitats of importance (Table 2.1, Fig. 2.1). Of particular concern are the proportionally greater high density areas in riparian type habitats and the large areas of low and medium density pasture habitat.

The cost estimates of control measures applied on an annual basis in Alberta (C$256,000) are less than the losses cited by Harris (1979) as required to justify the selection cost of a biological control agent ($150,000[1976 $Can] or $320,000[1993 $Can]). However, the cost of control estimates from this survey did not reflect the costs associated with the loss of production on the largest areas of infestation in pasture/hay type habitats.

Without a means to control common tansy on private land in the past and with severe limitations to the use of herbicides in habitats frequently invaded by common tansy, the effective and environmentally safe herbicide control of common tansy is limited. The apparent ineffectiveness and lack of potential for improved control levels using current methods indicates the need for the of development of alternate measures and integration of such methods with those currently employed.

Table 2.1: Summary of population area (hectares) by habitat, density and frequency of occurrence for 1993 municipal survey,

Habitat	Area and Frequency						Totals	
	Low (ha)	Freq.	Med. (ha)	Freq.	High (ha)	Freq.	Total (ha)	Total Freq.
Permanent Seeded Pasture	4276	15	4081	9	1592	6	9949	30
Fencelines/Field Margins	1497	21	1835	16	855	19	4187	56
Roadsides /Railways	774	30	1413	21	1248	18	3435	69
Native Pasture /Rangeland	796	14	747	10	263	10	1806	34
Seeded Pasture/Hay	798	9	668	4	295	3	1761	16
Lakeshores, Creeks/ Riverbanks	265	12	630	13	582	14	1477	39
Waste Land	426	14	543	8	345	10	1314	32
Farm yards/ Shelterbelts	353	27	780	15	245	13	1378	55
Tame Hay/ Silage	216	8	294	3	217	2	727	13
Slough Margins/ Dugouts	5	3	233	7	40	7	278	17
Gravel Pits	22	4	26	2	24	2	72	8
Total Area	9428	157	11250	108	5706	104	26384	369

* Miles converted to hectare values by assuming 1 mile = 1.01 ha (2.5 acres).

** Other = drainage ditches and pipeline rights of way.

High density = Plants or clumps of plants less than 4.5 m (5 yds) apart.

Medium density = Plants or clumps of plants from 4.5 m (5 yds) to 22.9 m (25 yds) apart.

Low density = Plants or clumps of plants greater than 22.9 m (25 yds) apart.

Table 2:2: Summary of population area (hectares) by habitat and density, and frequency of occurrence for the 1993 landowner survey.

Habitat	Area and Frequency						Totals	
	Low (ha)	Freq.	Med. (ha)	Freq.	High (ha)	Freq.	Total (ha)	Total Freq.
Permanent Seeded Pasture	3315	3	153	2	187	4	3655	9
Fencelines/Field Margins	8	1	48	3	66	9	122	13
Roadsides /Railways	11	4	25	2	13	2	49	8
Native Pasture /Rangeland	65	1	108	2	28	2	201	5
Seeded Pasture/Hay	0	0	8	1	0	0	8	1
Lakeshores, Creeks/ Riverbanks	1	2	1	2	14.5	3	15.5	5
Waste Land	0	0	81	1	2	1	83	2
Farm yards/ Shelterbelts	1	3	13	4	16	5	30	10
Tame Hay/ Silage	43	3	26	2	48	2	117	7
Slough Margins/ Dugouts	6	4	0	0	31	2	37	6
Other**	0	0	6	1	1	1	7	2
Total Area	3450	21	469	20	406	31	4325	72

* Miles converted to hectare values by assuming 1 mile = 1.01 ha (2.5 acres).

** Other = drainage ditches and pipeline rights of way.

High density = Plants or clumps of plants less than 4.5 m (5 yds) apart.

Medium density = Plants or clumps of plants from 4.5 m (5 yds) to 22.9 m (25 yds) apart.

Low density = Plants or clumps of plants greater than 22.9 m (25 yds) apart.

Table 2:3: Summary of population area (hectares) and incidence (nos. of times reported)grouped by habitat and density from the 1993 municipal survey.

	Area and Frequency						Totals	
Habitat	Low (ha)	Freq.	Medium (ha)	Freq.	High (ha)	Freq.	Total (ha)	Total Freq.
Ruderal	3079	96	4602	62	2723	62	10404	220
Pasture/Hay	5794	46	5495	26	2363	21	13652	93
Riparian	269	15	864	20	582	21	1715	56
Total	9142	157	10961	108	5668	104	25771	369

Table 2.4: Summary of population area (hectares) and incidence (number of times reported) grouped by habitat and density for 1993 landowner survey.

	Area and Frequency						Totals	
Habitat	Low (ha)	Freq.	Medium (ha)	Freq.	High (ha)	Freq.	Total (ha)	Total Freq.
Ruderal	20	8	173	11	98	8	291	37
Pasture/Hay	590	7	295	7	263	18	3981	22
Riparian	7	6	1	2	46	5	53	13
Total	617	21	469	20	407	31	1493	72

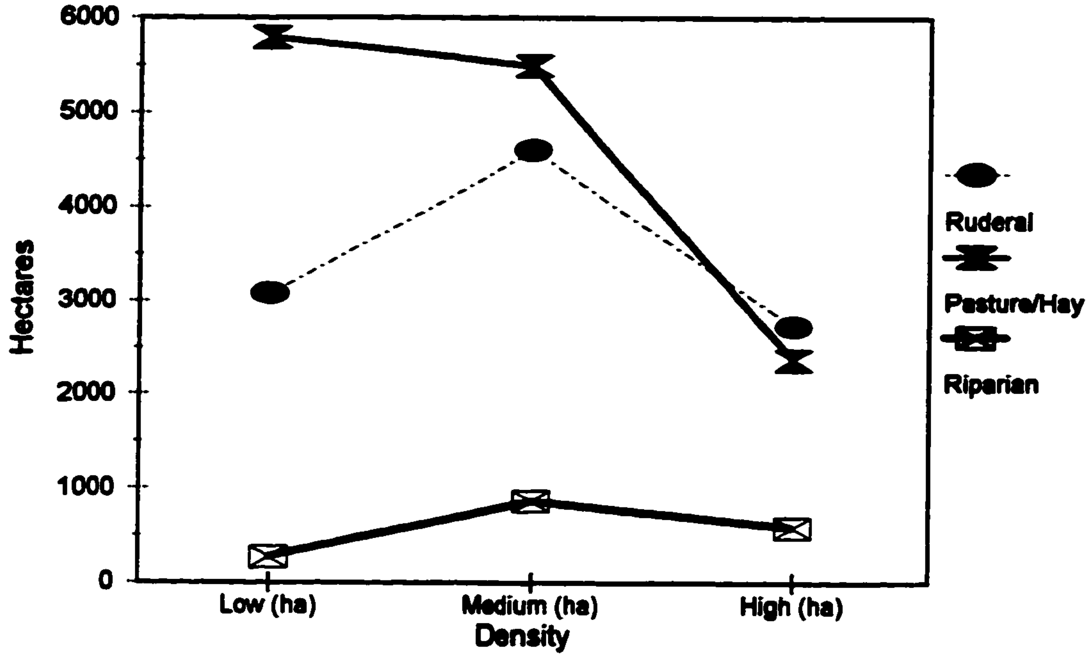

Fig. 2.1: Area of common tansy populations (ha) by density and grouped habitat from the municipal survey.

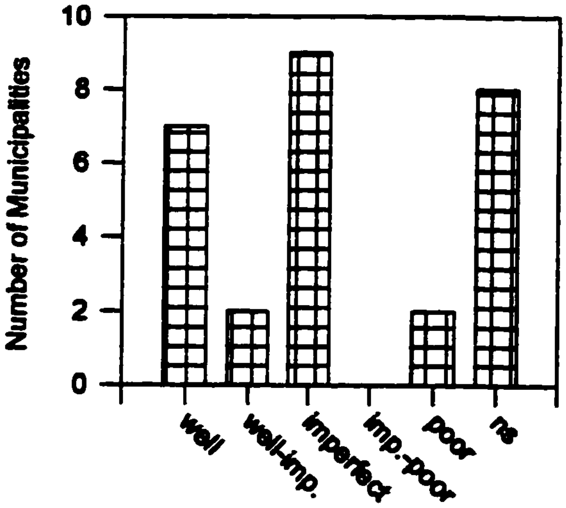

Fig. 2.2a: Soil drainage

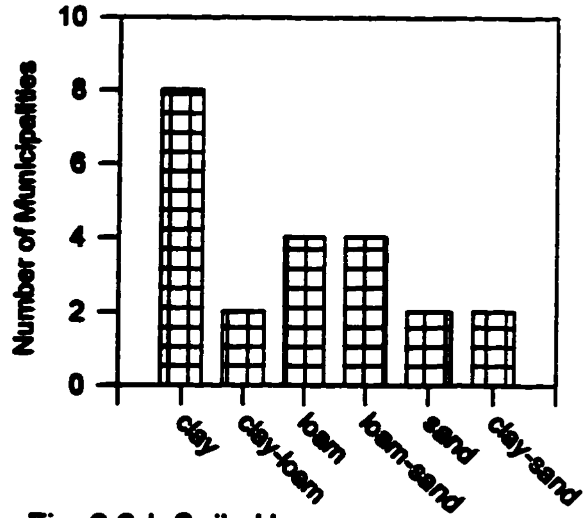

Fig. 2.2d: Soil pH

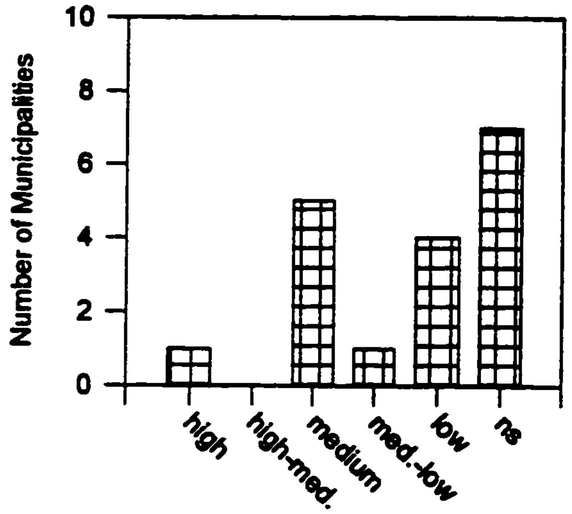

Fig. 2.2b: Soil texture

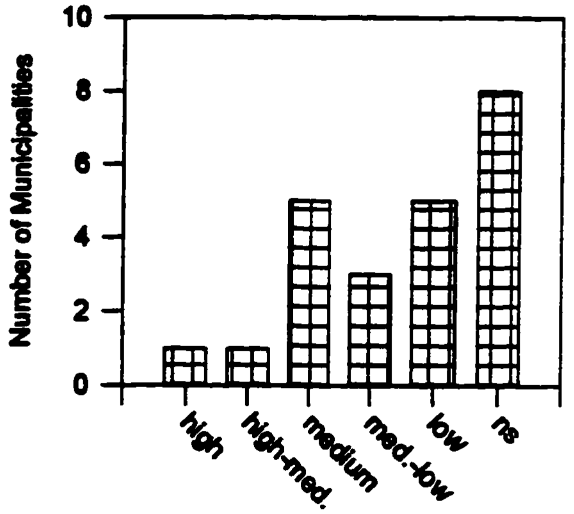

Fig. 2.2e: Soil fertility

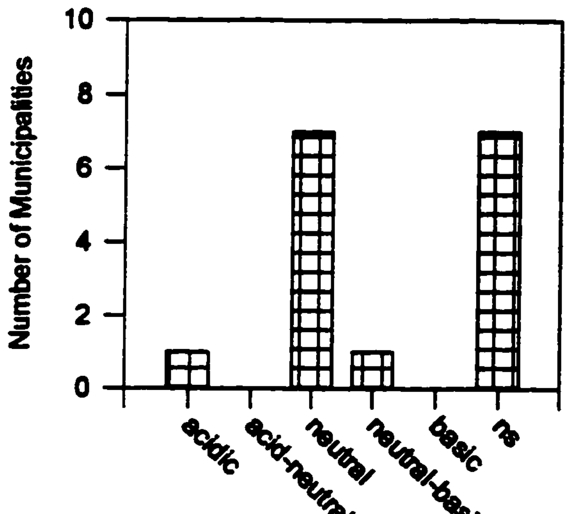

Fig. 2.2c: Soil salinity

Figs. 2.2a-2.2e:
Number of municipalities reporting soil drainage, texture, salinity, pH, and fertility characteristics associated with common tansy infestations (ns=non-specific)

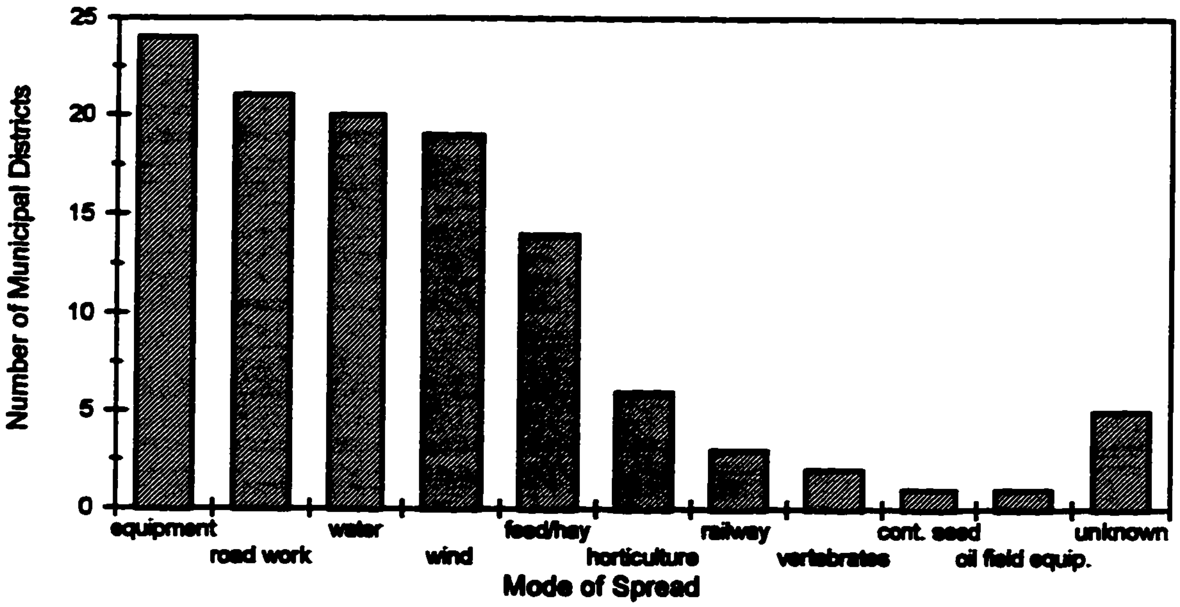

Fig. 2.3: Number of municipal districts reporting modes of spread

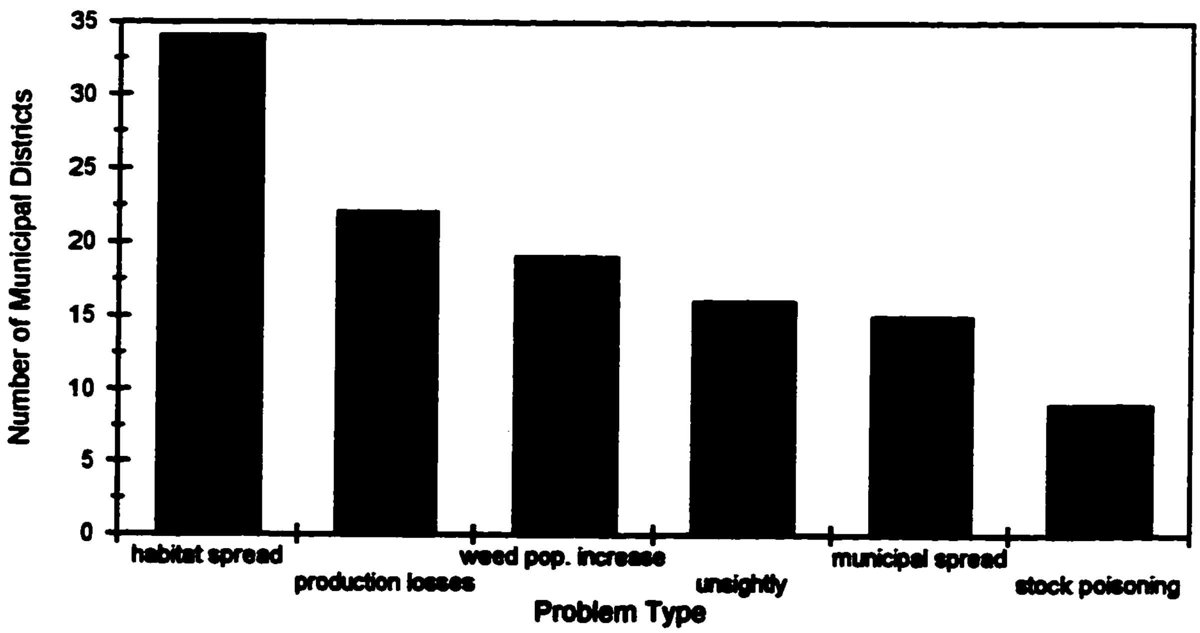

Fig 2.4: Number of municipalities reporting problem types.

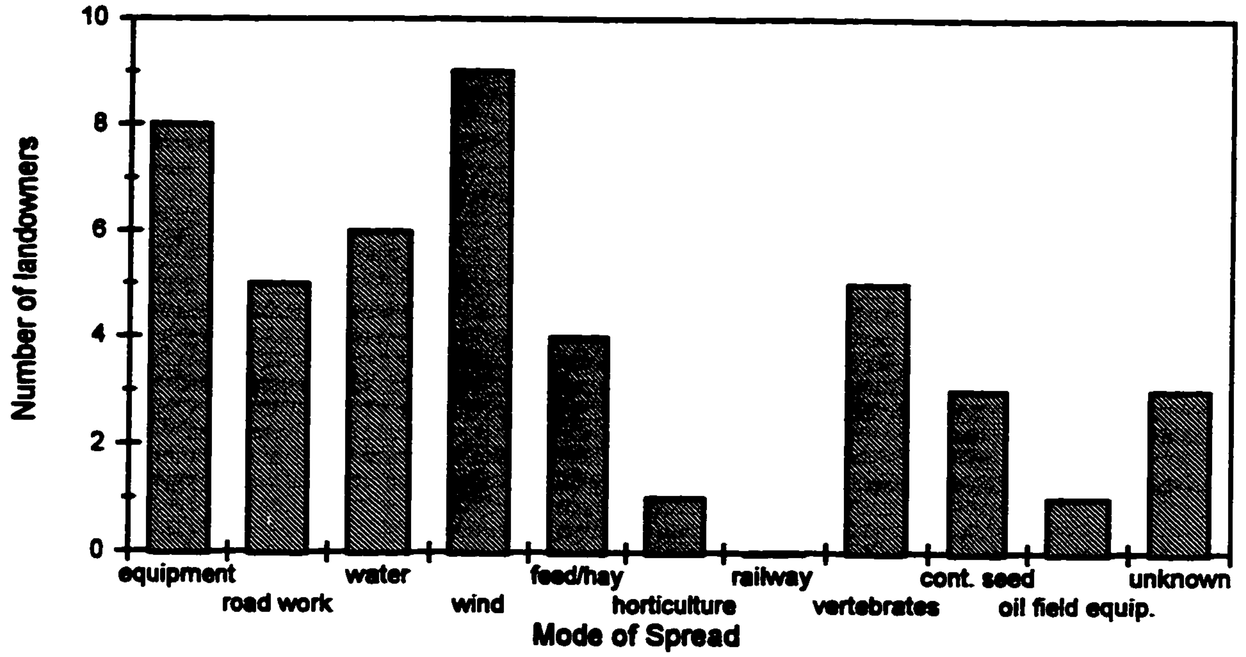

Fig 2.5: Number of individual landowners reporting modes of spread.

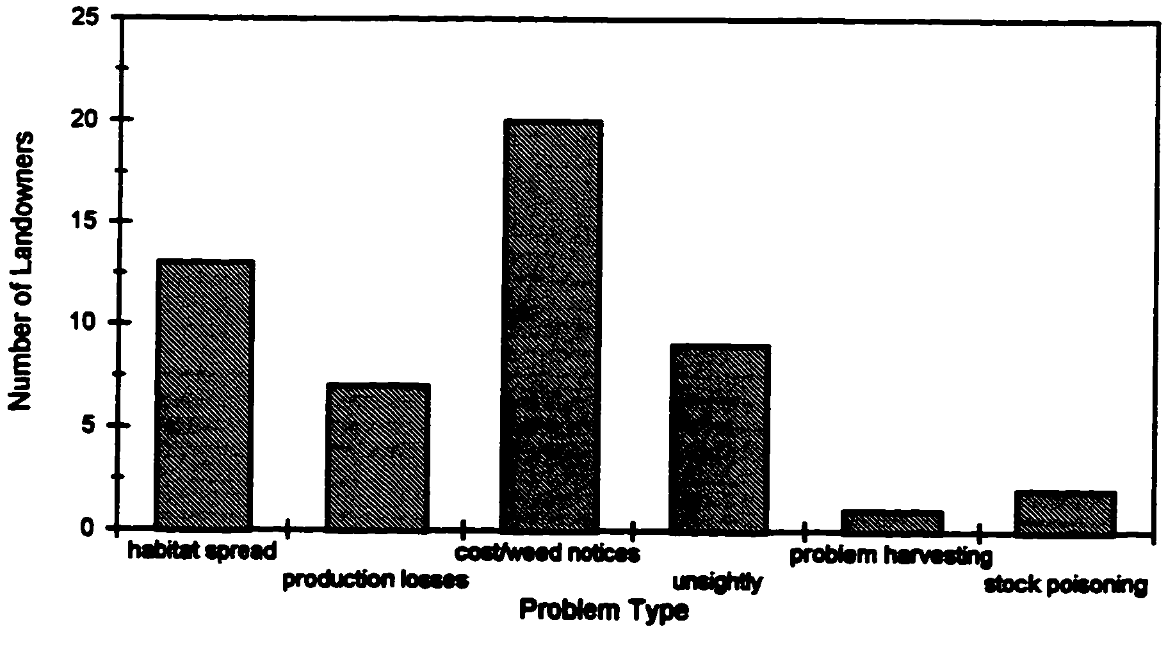

Fig. 2.6: Number of individual landowners reporting problem types.

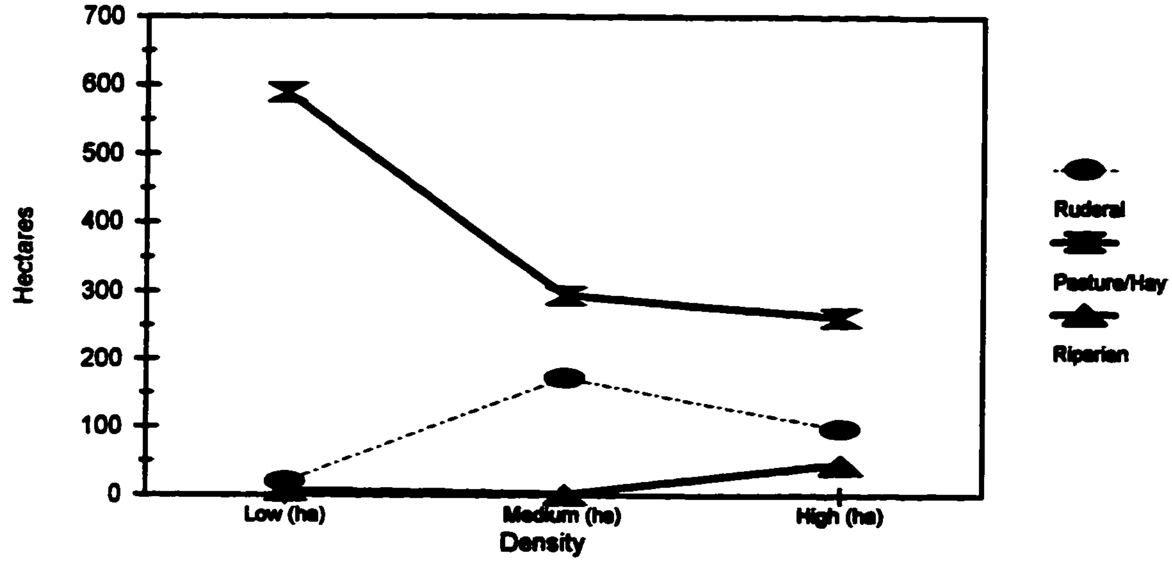

Fig. 2.7: Area of common tansy populations by density and grouped by habitat type from the landowner survey.

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Appendix 2.A: District Agriculturalist Survey

TANSY INFESTATION SURVEY

District:______________________________________
District Agriculturalist:________________________________

Weed Present in District: Yes__
No__

Infestation Area: 1) Wetland ____
- Isolated Plants ____ or
- Continuous Stand ____
- Estimate of area _______acres

2) Fence line ____
- Isolated Plants ____ or
- Continuous Stand ____
- Estimate of area _______acres

3) Pasture ____
- Isolated Plants ____ or
- Continuous Stand ____
- Estimate of area _______acres

4) Other
- ________________ _______acres
- ________________ _______acres

Legal land location of infestations.

____
____
____
____

Producers to contact:

Name	Telephone
1__________	__________
2__________	__________
3__________	__________
4__________	__________

Have stock losses attributed to tansy been reported in the district:
Yes__
No__

If yes, what types of livestock:____________________________

Veterinarian to contact: ____________________________
(to document livestock losses)

Appendix 2.B: Municipal Agricultural Fieldmen Survey

1993

Common Tansy

Municipal Questionnaire

Municipality: ____

Introduction:

The questions are multiple choice or short answer. Check the appropriate answer or provide a short written statement. Please answer all questions as completely as possible and return the questionnaire in the addressed, postage-paid envelope provided. This identifying cover sheet will be discarded and individual questionnaires will be regarded as confidential.

Questions about acres or miles of tansy infestations may be difficult to answer given the growth pattern of tansy. Please attempt to answer these questions as completely as possible and provide any comments regarding your estimates that you feel are important. If you have any questions please contact us or indicate that you would like to clarify your response if we contact you.

The completion and return of this questionnaire will assist in the development of a suitable cost effective management program for this weed.

Thank you for your assistance.

QUESTIONNAIRE

1. Is common tansy present in your municipality and if so when did this weed first appear in your municipality ?

____

2. Do you consider the area infested with comon tansy in your municipality to be increasing?

____

3. Rate common tansy as a weed problem in comparison to other noxious weed problems in your municipality. (Check one answer).

Most troublesome	______
Significant weed problem	______
Minor weed problem	______
Weed present but not a problem	______

4. How has common tansy spread in your your municipality?

1. Seeds distributed by wind	_____
2. Contaminated seed	_____
3. Plants carried on equipment	_____
4. Floating on water	_____
5. Road maintenance/grading	_____
6. Contaminated feed/hay	_____
7. Other (please specify)	_____________

____

5, How abundant is the weed in each of these habitats?
(Please estimate the actual area of tansy under the following density classifications.)

Density Classifications:	
High Density:	Plants or clumps of plants less than 5 yards apart.
Medium Density:	Plants or clumps of plants from 5 to 25 yards apart.
Low Density:	Plants or clumps of plants greater than 25 yards apart.

	Number of acres OR miles per density level					
	High Density		Med. Density		Low Density	
	Acres	Miles	Acres	Miles	Acres	Miles
1. Roadsides and railways						
2. Fencelines and field margins						
3. Native pasture and rangeland						
4. Permanent seeded pasture						
5. Seeded pasture/hay rotation						
6. Tame hay/silage						
7. Farm yards, building, shelterbelts or urban areas						
8. Waste land						
9. Slough margins and dugouts						
10. Lakeshores, creek and river banks						
11. Other						

6. What problems does tansy cause for your municipality?

1. Potential spread: To other habitats ____
   To adjacent municipalities ____
2. Population densities increasing ____
3. Forage or rangeland production loss ____
4. Stock poisoning ____
5. Unsightly ____
4. Other ______________________________
____

7. Does tansy appear to prefer any of the following types of soil or soil conditions?

1. Drainage:	Well	____	Imperfect	____	Poor	____
2. Texture:	Clay	____	Loam	____	Sand	____
3. Salinity:	High	____	Medium	____	Low	____
4. pH:	Acidic	____	Neutral	____	Basic	____
5. Fertility:	High	____	Medium	____	Low	____
6. Don't know:		____				

8. What control methods have you used in the past and what is the estimated cost of those measures? (Please provide area in acres OR miles (fenceline or roadside) whichever is applicable).

Method	Area Treated		Estimate of total average annual cost	Number of years method used	Number of additional years required
	Acres	Miles			
a) Herbicide					
b) Mowing					
c) Cultivation					
d) Hand Pulling					
e) Other					

9. If a herbicide was used please give the name of the herbicide, application rate, growth stagae and control level. (Please use the control leve categories provided).

Control Level Explanation

Control: Greater than 80% reduction in the weed stand and/or growth.

Suppression: Between 60 to 80% reduction in the weed stand and/or growth.

No Control: Less than 60% reduction in the weed stand and/or growth.

Herbicide	Application Rate		Application Stage				Control Level			Application Frequency
	L/acre or	L/mile	Young Shoot	Bud	Early Flower	Late bloom	Control	Suppression	Limited Effect	
1.										
2.										
3.										
4.										
5.										

10. Please provide any additional comments.

Appendix 2.C: Landowner Survey

1993
Common Tansy
Producer Questionnaire

Municipality: ____

Introduction:

The questions are multiple choice or short answer. Check the appropriate answer or provide a short written statement. Please answer all questions as completely as possible and return the questionnaire in the addressed, postage-paid envelope provided. This identifying cover sheet will be discarded and individual questionnaires will be regarded as confidential.

Questions about acres or miles of tansy infestations may be difficult to answer given the growth pattern of tansy. Please attempt to answer these questions as completely as possible and provide any comments regarding your estimates that you feel are important. If you have any questions please contact us or indicate that you would like to clarify your response if we contact you.

The completion and return of this questionnaire will assist in the development of a suitable cost effective management program for this weed.

Thank you for your assistance.

QUESTIONNAIRE

1. Is common tansy present on your farm and if so when did this weed first spread to your farm?

____

____

2. Do you consider the area infested with common tansy to be increasing on your farm?

____

3. How has common tansy spread onto and on your farm?

1. Seeds distributed by wind _____
2. Contaminated seed _____
3. Plants carried on equipment _____
4. Floating on water _____
5. Road maintenance/grading _____
6. Contaminated feed/hay _____
7. Other (please specify) ____________

____

8. Don't know _____

4. How abundant is the weed in each of these habitats?
(Please estimate the actual area of tansy under the following density classifications.)

Density Classifications:

High Density:	Plants or clumps of plants less than 5 yards apart.
Medium Density:	Plants or clumps of plants from 5 to 25 yards apart.
Low Density:	Plants or clumps of plants greater than 25 yards apart.

	Number of acres OR miles per density level					
	High Density		Med. Density		Low Density	
	Acres	Miles	Acres	Miles	Acres	Miles
1. Roadsides and railways						
2. Fencelines and field margins						
3. Native pasture and rangeland						
4. Permanent seeded pasture						
5. Seeded pasture/hay rotation						
6. Tame hay/silage						
7. Farm yards, building, shelterbelts or urban areas						
8. Waste land						
9. Slough margins and dugouts						
10. Lakeshores, creek and river banks						
11. Other						

5. What problems does tansy cause for your farming/ranching operation?

1. Forage or rangeland production loss ____
2. Problems harvesting ____
3. Contamination of seed produced ____
4. Potential spread to other areas ____
5. Cost of control measures ____
6. Stock losses ____
7. Weed notices ____
8. Unsightly ____
9. Other ________________________

____

6. Does tansy appear to prefer any of the following types of soil or soil conditions?

1. Drainage: Well ____ Imperfect ____ Poor ____
2. Texture: Clay ____ Loam ____ Sand ____
3. Salinity: High ____ Medium ____ Low ____
4. pH: Acidic ____ Neutral ____ Basic ____
5. Fertility: High ____ Medium ____ Low ____
6. Don't know: ____

7. What control methods have you used in the past?

Method	Area Treated		Estimate of total average annual cost	Number of years method used	Number of additional years required
	Acres	Miles			
a) Herbicide					
b) Mowing					
c) Cultivation					
d) Hand Pulling					
e) Other					

8. If a herbicide was used please give the name of the herbicide, application rate, growth stagae and control level. (Please use the control leve categories provided).

Control Level Explanation

Control: Greater than 80% reduction in the weed stand and/or growth.
Suppression: Between 60 to 80% reduction in the weed stand and/or growth.
No Control: Less than 60% reduction in the weed stand and/or growth.

Herbicide	Application Rate		Application Stage				Control Level			Application Frequency
	L/acre or	L/mile	Young Shoot	Bud	Early Flower	Late bloom	Control	Suppression	Limited Effect	
1.										
2.										
3.										
4.										
5.										

9. What is the maximum amount that you would be willing to pay to have the problem controlled?

$1.00/acre ____
$2.00/acre ____
$5.00/acre ____
$10.00/acre ____
$15.00/acre ____
$20.00/acre ____
$25.00/acre ____
$30.00/acre ____

10. Please provide any additional comments.

Appendix 2.D: Maps of Infestation Area and Density

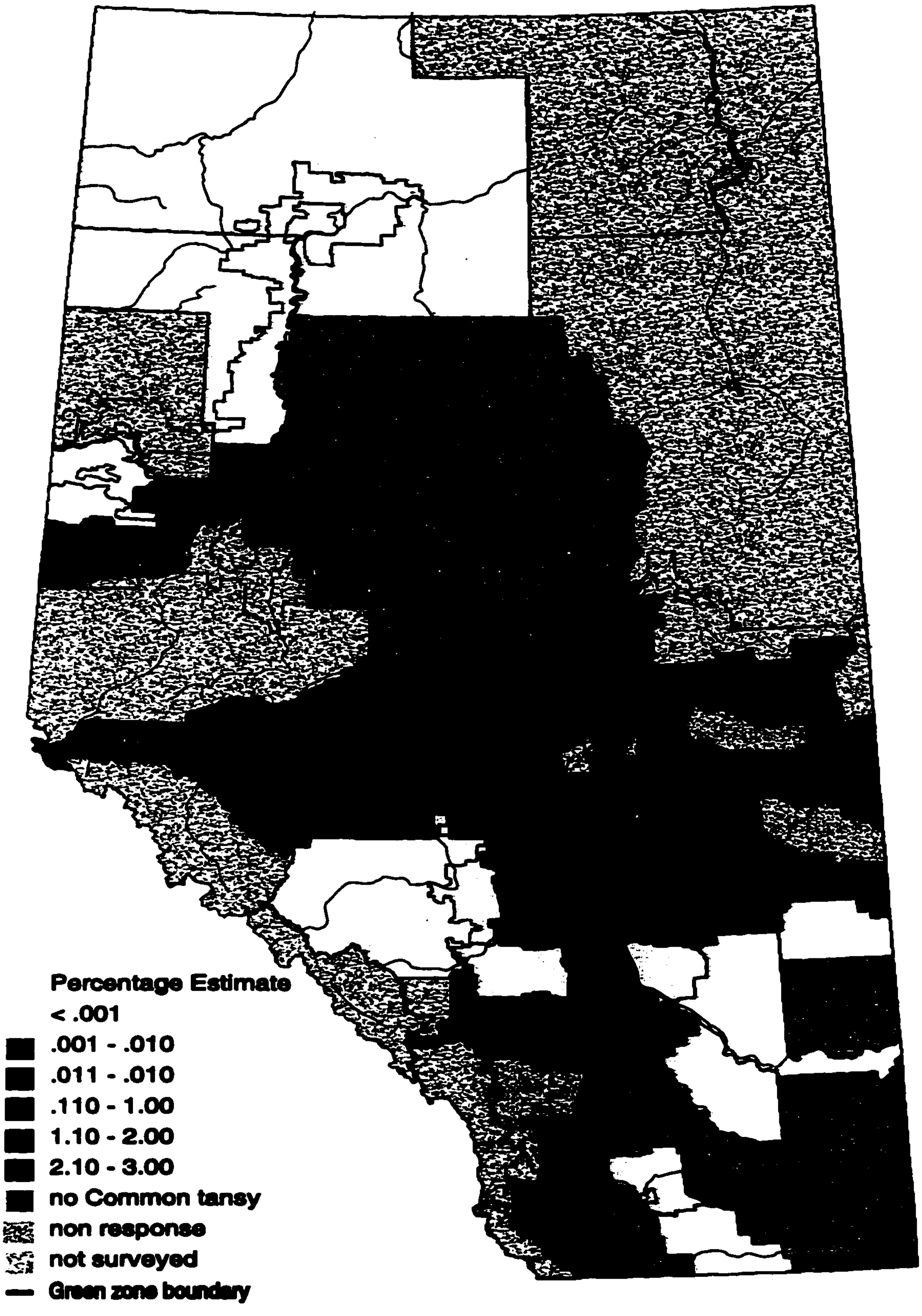

Figure 2D.1: Percentage estimate of municipal land base area with populations of common tansy (*Tanacetum vulgare* L.)

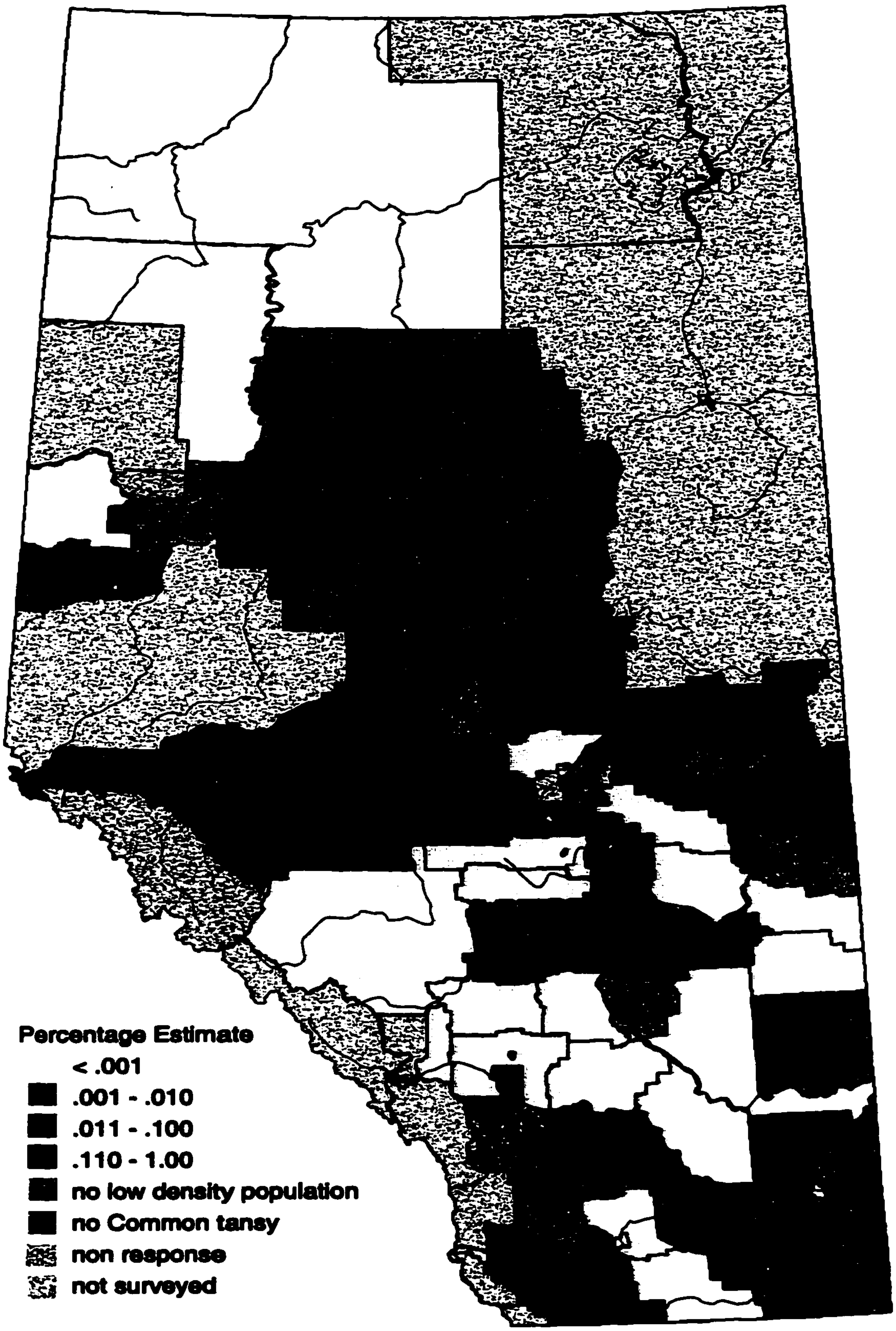

Fig. 2D.2: Percentage of municipal land base with low density populations of common tansy.

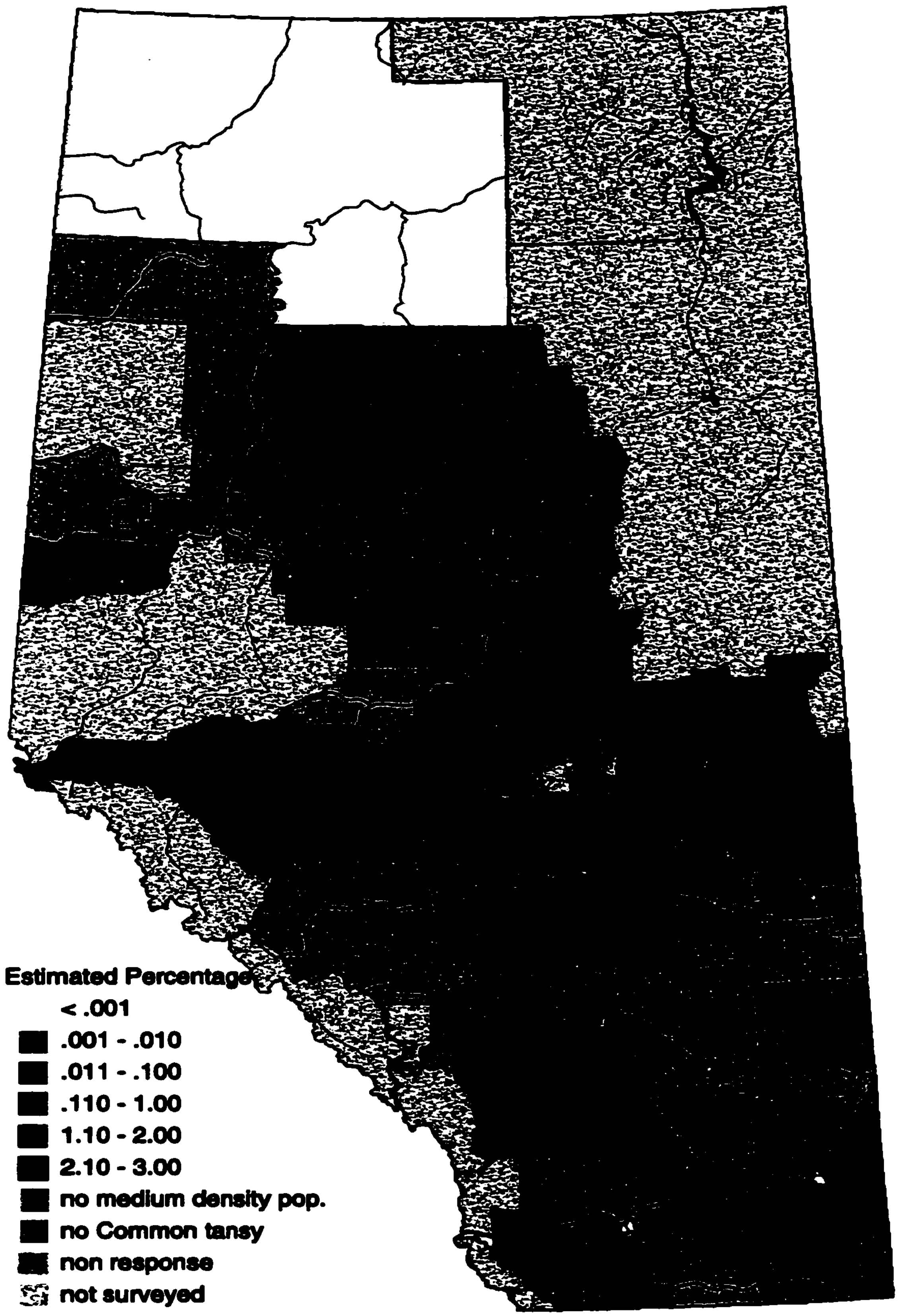

Fig. 2D.3: Percentage of municipal land base with medium density populations of common tansy.

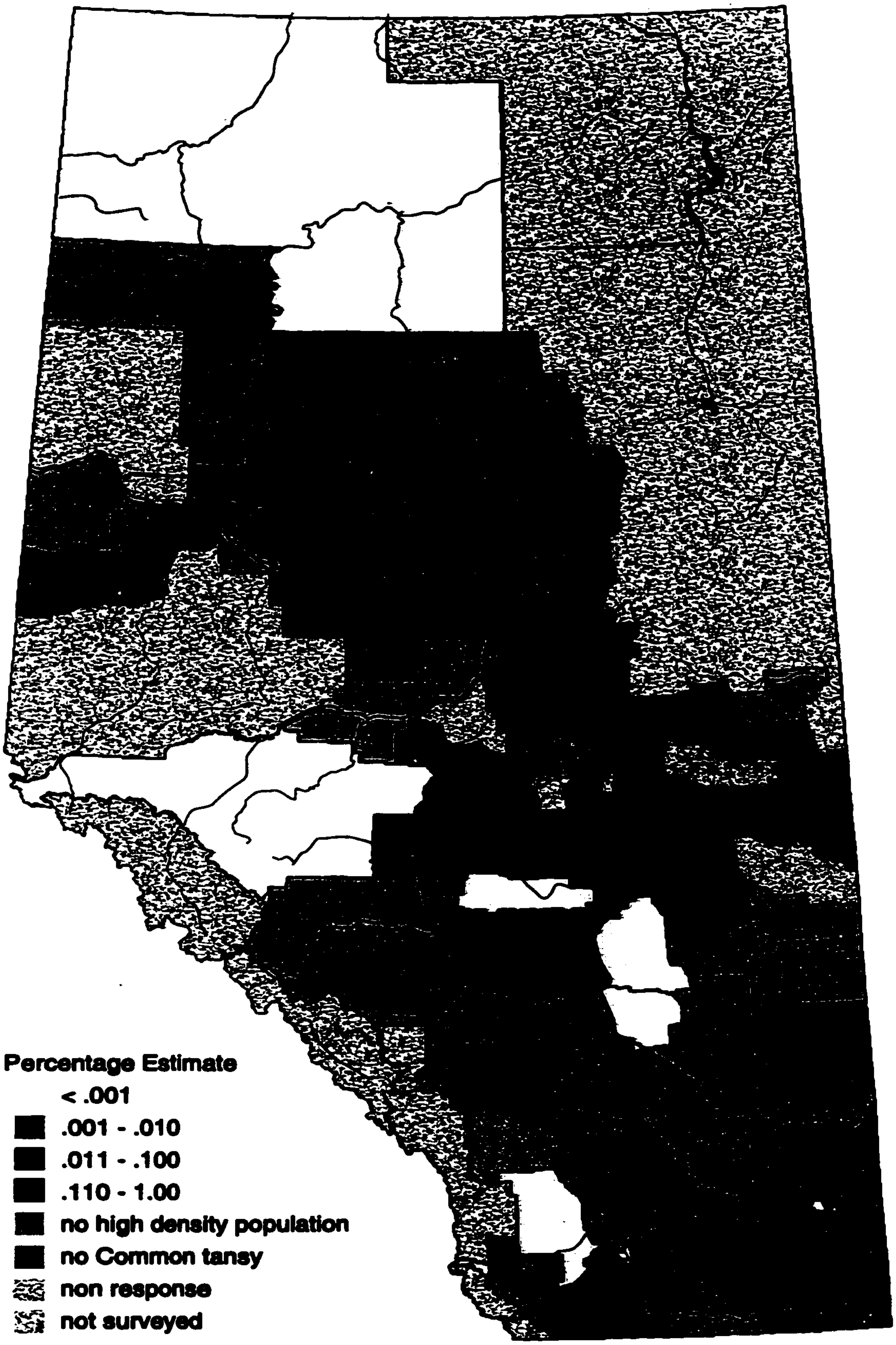

Fig. 2D.4: Percentage of municipal land base with high density populations of common tansy.

Appendix 2.E: Tabulated Survey Results

Table 2.E.1: Presence, Duration of Infestation, and Population Status of Common tansy (Questions 1, 2, and 3).

Survey Nos.	Number of Years Present	Weed Pop. Increase	Weed Rating
1	>10	NO	M
2	?	YES	S
3	>10	YES	S
4	?	YES	S
5	>15	YES	S
6	>40	YES	M
7	>40	NO	M
8	>70	NO	NP
9	?	NO	M
10	>25	NO	NP
11	>30	YES	S
12	?	YES	M
13	>20	NO	S
14	?	NO	NP
15	>15	NO	NP
16	>20	YES	S
17	>10	YES	M
18	>75	YES	S
19	?	YES	M
20	>15	YES	S
21	>40	YES	S
22	>30	NO	M
23	?	NO	M
24	?	YES	S
25	>25	YES	S
26	>60	YES	M
27*	>60	YES	S
28**	?	NO	M
29**	?	NO	M
30	?	NO	S
31	>20	NO	M
32	>60	NO	NP
33	5	NO	NP
34	UK	NO	NP
35	5	NO	NP

Table 2.E.1: Presence, Duration of Infestation, and Population Status (cont'd) of Common tansy (Questions 1, 2, and 3).

Survey Number	Number of Years Present	Weed Population Increase	Weed Rating
36	1	NO	NP
37	5	NO	NP
38	>60	NO	NP
39	UK	YES	M
40	3	YES	M
41	15	YES	M
42	UK	NO	NP
43	10	YES	NP
44	UK	NO	NP
45	25	YES	M
46	12	YES	NP
47	>40	YES	M
48	>40	NO	NP
49	10	NO	NP
50	UK	NO	NP
51	UK	NO	NP
52	3	NO	NP

UK = Unknown

Weed ratings:
MT = Most troublesome
S = Significant problem
M = Minor problem
NP = Present but not a problem

Table 2E.2: Mode of Spread, Perceived Problem, and Preferred Conditions of Common Tansy (Question 4,6, and 7).

Survey Number	Mode of Spread	Perceived Problem	Preferred Conditions
1	1,3,5	1a,5	NS
2	1,4,5	1a,2,3	Di,Tl,Fml
3	1,3,4,5,6,	1a,3,5	Dw,Tc,Sl,Fhm
4	1,3,5	1a,1b,2,3	DK
5	3,4,5,6,7	1a,1b,2,3,5	Dwi,Tls,Sml,Pnb,Fl
6	3,5	1a,3	Tc
7	1,3,4,5	2,4,5	Dw,Tls,Fml
8	3	NP	DK
9	1,3	1a,4	Di,Tl,Sm,Pn,Fm
10	3,5	1a,1b,3,5	NS
11	3,5	1a,1b,2,3,4,5	NS
12	1,6	1a,2	DK
13	3	1a,1b,2,3,5	Dw,Tc,Sh
14	9	NS	DK
15	1,3,5,6	1a,3	NS
16	1,3,4,5,6	1a,1b,2,3,5	Dwi,Tcl,Fhml
17	UK	2	DK
18	1,3,4,6	1a,1b,2,3,4	NS
19	1,2,3,5,6	1a,1b,2,3,4	Di,Tls,Sm,Pn,Fm
20	3,4,6	1a,2,3,5	Dp,Tc,Sm
21	3,4,6	1a,2,3,5	DK
22	1,3,	5	DK
23	1,3,4,9	1a,2,3,5	Dw,Tls,Fl
24	1,3,4,5,	1a,1b,3	DK
25	1,4	1a	Dwp,Tcs,Sm,Fm
26	3,4,5,6,10	1a,1b,2,5	DK
27	4	1a,1b,2,3,4	Tcl

Mode of spread:

1=wind
2=contaminated seed
3=equipment
4=water
5=road maintenance
6=contaminated seed
7=oil field equipment
8=horticultural introduction
9=railway right-of-ways
10=livestock
UK=unknown

Perceived Problem:

1a=Spread to other habitats
1b=Spread to other municipal districts
2=Weed population increases
3=Forage or range production losses
4=Stock Poisoning
5=Unsightly

Preferred Soil Conditions:

D=Drainage	w=well	i=imperfect	p=poor
T=Texture	c=clay	l=loam	s=sand
S=Salinity	h=high	m=medium	l=low
P=pH	a=acidic	n=neutral	b=basics
F=Fertility	h=high	m=medium	l=low

NS=Non-specific
DK=Don't know

Table 2E.2: Mode of Spread, Perceived Problems, and Preferred Conditions of Common Tansy (Questions 4, 6,and 7). (cont'd)

Survey Number	Mode of Spread	Perceived Problem	Preferred Conditions
28	5,6	1b,3,4	NS
31	4	1a,4	DK
32	5,8	1a	Di,Tc,Pn,Fm
33	4,5	1a	Dp,Tc,Fm
34	3	1a	DK
35	4	1a,1b,3,5	DK
36	8	1a	Dw,Tl,Sl,Pn,Fl
37	4,6	?	Di,Tl,Sl,Pn,Fh
38	3	5	Dw,Ts,Pn
39	3,5	1a,2	Di,Tcs,Fl
40	UK	1a,1b,2,3	NS
41	1,3,6	3,5	DK
42	1,4,8	5	DK
43	6	1a,2	Di,Tc,Sl,Pa,Fl
44	?	?	DK
45	1,3,4,5,8,10	1a,3	Di,Tcls,Sm,Pn,Fml
46	5,9	?	DK
47	1,4,8	1a,1b,2,5	DK
48	8	?	DK
49	2	1a,3	Di,Tc
50	?	?	DK
51	5,6	?	Dw,Ts
52	?	4	DK

:

Mode of spread
1 = wind
2 = contaminated seed
3 = equipment
4 = water
5 = road maintenance
6 = contaminated feed/hay
7 = oil field equipment
8 = horticultural introduction
9 = railway right of ways
10 = livestock/wildlife
UK = Unknown

Perceived problem:
1a = Spread to other habitats
1b = Spread to other municipal districts
2 = Weed population increases
3 = Forage or rangeland production losses
4 = Stock poisoning
5 = Unsightly

Preferred Soil Conditions

D = Drainage	w = well	i = imperfect	p = poor
T = Texture	c = clay	l = loam	s = sand
S = Salinity	h = high	m = medium	l = low
P = pH	a = acidic	n = neutral	b = basic
F = Fertility	h = high	m = medium	l = low
NS = Non - Specific	Dk = Don't know		

Table 2E.3: Herbicide Treatment Area, Cost of Application, Duration of Current Treatment Program and Projected Treatment Duration (Question 8).

Survey Number	Area Treated ha	Area Treated miles	Total Average Annual Cost Estimate	Duration of Current Treatment Program (Years)	Projected Treatment Duration (Years)
1		10	$1,000.00	14	UK
3	49	80	$1,200.00	10	IND
4		1	$150.00	2	IND
5	41		$10,000.00	2	2
6		4	$200.00	3	UK
7		65	$5,000.00	4	UK
9		5	$300.00	?	UK
10	8	4	$1,050.00	25	IND
11		625	$30,000.00	8	10
13		40	$7,500.00	4	UK
14		?	$100.00	5	UK
15	1		$500.00	15	UK
16		100	$4,978.00	4	10
17		44	$750.00	8	UK
18		1100	$100,000.00	UK	UK
19		80	$3,264.00	1	?
20	80	60	$5,000.00	3	?
21		150	$11,000.00	2	2
22		25	$1,020.00		
26		50	$4,000.00	3	2
27			$3,500.00	20	UK
28		25	$1,540.00	?	?
31		0.25	$75.00	2	IND
32	0.4		NT	3	5
33	?	?	$500.00	1	UK
34	1.2		$20.00	3	UK
35	0.2	1	$100.00	5	5
36	0.4		$100.00	2	UK
38	0.8		$200.00	1	UK
39		2	?	8	UK
40	4	2	$850.00	2	1
41	0.4		?	1	?
42	0..04		$5.00	1	?
43	?		$500.00	8	?
44	0.6	0.5	?	?	?
45		40	$4,000.00	5	IND
TOTAL	187	2489	$198,402.00		

UK = Unknown NT = No Treatment IND = Indefinite ? = Not answered

Note: Where cost was not included but area/miles and herbicide applied were supplied, cost estimates were made on the basis of "Estimated Retail Prices of Pesticides, 1993". S. Ali, Soil and Crop Management Branch, Alberta Agriculture.

Table 2E.4: Mowing Treatment Area, Cost of Treatment, Duration of Current Treatment Program, and Projected Treatment Duration (Question 8).

Survey Number	Area Treated ha	Area Treated miles	Annual Cost Estimate	Duration of Current Treatment Program (Years)	Projected Treatment Duration (Years)
3	51		$1,800.00	5	UK
5		20	$2,000.00	2	4
10		1	$100.00	4	IND
11		200	$30,000.00	15	IND
12	8	10	$2,000.00	10	UK
13	10		$300.00	2	UK
18		250	$10,000.00	?	?
19	2		?	1	?
31		0.5	$150.00	2	IND
33	?		$100.00	1	?
45	4		$400.00	10	IND
TOTAL	75	481.5	$46,850.00		

UK = unknown ND = Indefinite ? = Not answered

Table 2E.5: Other Treatment Methods, Treatment Area, Cost of Treatment, Duration of CurrentTreatment and Projected Treatment Duration (Question 8).

Survey Number	Treatment Method	Area Treated ha	Area Treated miles	Total Average Annual Cost Estimate	Duration of Current Treatment Program (Years)	Projected Treatment Duration (Years)
1	Hand Pulling	1		?	14	?
5	Cultivation	51		$750.00	3	2-4
	Hand Pulling	4		$1,500.00	2	2-4
	Burning	8		$2,000.00	1	UK
7	Cultivation	8094		UK	?	?
20	Cultivation	65		$5,000.00	1	UK
	Hand Pulling		40	1500	10	UK
27	Hand Pulling	1		$190.00	?	?
32	Hand Pulling	0.4		?	3	5
36	Hand Pulling	0.1		$100.00	1	?
42	Hand Pulling	0.004		$10.00	1	?
46	Hand Pulling	?		$500.00	?	IND
TOTAL		8225	40	$11,360.00		

UK = Unknown IND = Indefinite ? = Not answered

Table 2E.6: Herbicide Applied, Application Rate, Application Stage, Control Level, and Application Frequency (Question 9).

Survey Number	Herbicide Applied	ApplicationRate				Application Stage	Control Level	Application Frequency (per year)
		L/acre	L/mile	g/acre	oz./gal.			
1	Dycleer				3	YS	C	1
3	Tordon 101	4				All	C	1
	Tordon 22K	3				All	C	1
4	Tordon 22K	3				EF	C	As Required
5	Roundup	2.5				YS,B	S	2
	Ally			3		YS,B,EF	C,S	1
	Glean			25		YS,B	C	2
	Tordon			1.8		YS,B,EF	C	3
6	Tordon 22K	1				EF	S	3
	Tordon 101	2				LB	S	3
7	Tordon 22K	2				All	C	1
	Glean			49		All	S	1
8	Tordon 22K	2				LB	C	1-2
9	Tordon 22K	2				EF	C	1
10	Glean	Label				B	S	3
	Tordon 22K	Label				B,EF,LB	C	3-4
11	Ally			5		All	C	3-5
	Glean			28		All	C	4-5
	Tordon 101	2.8				All	C	5-10
	Tordon 22K	0.455ml				All	C	5-10
13	Tordon 22K	1.5				B,EF,LB	?	3
14	Tordon 22K	2				EB	C	
15	Tordon 22K	3				All	C	
16	Tordon 101	2				All	C	4
	Dycleer/2,4-D	1.8/1				YS,B,EF	?	1
17	2,4-D	1.14				B,EF	C	1
18	Banvel	2				YS,B,EF	C	
	Tordon 101	1.7				YS,B,EF	C	
19	Tordon 22K	Label				EF,LB	S	1

Table 2E.6: Herbicide Applied, Application Rate, Application Stage,Control Level, and
(cont'd) Application Frequency (Question 9).

Survey Number	Herbicide Applied	ApplicationRate				Application Stage	Control Level	Application Frequency (per year)
		L/acre	L/mile	g/acre	oz./gal.			
20	Tordon 22K	1.8				All	C	1
	Glean			3		EF,LB	C	1
21	Tordon 101	3.67				All	C	3
	Ally			10		YS	C	
	Glean			30		?	S	
	Banvel	1.8					L	
	Banvel/2,4-D	1.8/1.8					L	
22	Tordon 22K	1.5				EF,LB	S	
23	Tordon 22K	2				EF,LB	C	
24	Ally			2		B,EF	C	
	Tordon	2-4				B,EF,LB	C	
25	Tordon	1				B,EF,LB	C	4-5
26	Tordon 22K	2.5				All	C,S,L	As required
	Tordon 101	10				All	C,S,L	As required
	2,4-D	5				All	C,S,L	1
	Ally			9		YS,B,EF	S,L	1
27	Tordon 22K	1.5				EF	C	3

Districts reporting: 27 or 90%

Districts Reporting Herbicides Used: 25 or 83%

? = Not Answered

Application Stages:
YS = Young shoot
B = Bud
EF = Early Flower
LB = Late Bloom

Control Levels:
C = Control - >80% reduction in weed growth or stand
S = Suppression - 60% to 80% reduction
L = Limited effect - <60% reduction

Table 2E.7: Landowner Survey - Duration of Infestation, Population Status, and Mode of Spread of Common Tansy.

Survey Number	Number of Years Present	Weed Population Increase	Mode of Spread
1	>30	YES	1,4
2	>70	YES	3
3	>75	YES	2,4,10
4	>15	NO	1,2,4,6
5	>60	YES	1,3,6
6	>25	YES	1,3,5,6,7
7	>5	NO	3,8,10
8	>30	YES	1,3,5
9	UK	YES	UK
10	>30	NO	1,3,5,10
11	>75	NO	1,2,3,5,6
12	>30	YES	UK
13	>20	NO	1,4,10
14	>3	YES	4
15	>20	YES	UK
16	>10	YES	1,3,4,5,10

Mode of spread:
1 = wind
2 = contaminated seed
3 = equipment
4 = water
5 = road maintenance
6 = contaminated feed/hay
7 = oil field equipment
8 = horticultural introduction
9 = railway right of ways
10 = livestock/wildlife
UK = unknown

Table 2E.8: Landowner Survey - Perceived Problem, Preferred Soil Conditions, and Value of Control to Producer.

Survey Number	Perceived Problem	Preferred Condition	Value of Control ($/ha)
1	4	Dwi,Tl,Fhm	$37.00
2	4	NS	UK
3	8	Dwi,Tcl	0
4	4,5,8	Dip,Tl,Fh	$24.00
5	1,2,4,8	UK	$50.00
6	1,4,5,8	UK	$37.00
7	4,5	NS	$74.00
8	1,3,4,5,8	Dwi,Tcls,Fhml	$74.00
9	1,3,8	NS	$2.50
10	5	Dw,Ts	$2.50
11	4,6,7,8	NS	$12.00
12	4,5	NS	$5.00
13	1,4,8	UK	$50.00
14	4,8	NS	UK
15	1,4	UK	$24.00
16	1,4,5,6,8	NS	UK

Perceived Problem:
1 = Forage or rangeland production losses
2 = Problems harvesting
3 = Contamination of seed produced
4 = Potential spread to other areas
5 = Cost of control
6 = Stock poisoning
7 = Weed notices
8 = Unsightly

Preferred Soil Conditions:

D = Drainage	w = well	i = imperfect	p = poor
T = Texture	c = clay	l = loam	s = sand
S = Salinity	h = high	m = medium	l = low
P = pH	a = acidic	n = neutral	b = basic
F = Fertility	h = high	m = medium	l = low
NS = Non-specific		UK = Unknown	

Table 2E.9: Landowner Survey - Treatment Methods, Treatment Area, Cost of Treatment, Duration of Current Treatment Program, and Projected Treatment Duration (Question 8).

Survey Number	Treatment Method	Area Treated		Total Average Annual Cost Estimate	Duration of Current Treatment Program (Years)	Projected Treatment Duration (Years)	
		ha	miles				
1	Cultivation			?	?	?	*
2	Herbicide	4		$165.00	1	?	
3	NA	NA	NA	NA	NA	NA	
4	Herbicide	44.5		$575.00	1	1-2	
	Cultivation			?	?	?	*
5	Cultivation			?	?	?	*
6	Herbicide		4	$300.00	1	IND	
	Mowing		4	$200.00	2	IND	
	Cultivation	40		?	?	?	**
	Hand pulling			?	?	?	
7	Herbicide	1.5		$40.00	3	1	
8	Herbicide		5.5	$1,000.00	3	5	
	Cultivation	20		$2,500.00	5	5	
	Hand pulling			?	?	?	
9	Herbicide	6		$250.00	2	IND	
10	Herbicide	0.8		$120.00	6	IND	
11	Herbicide	28		$3,400.00	6	IND	
12	Mowing	?		$320.00	1	1	
13	Cultivation	?		?	?	?	
14	Herbicide	0.6		$90.00	?	?	
	Mowing	0.6		$200.00	?	?	
15	NA	NA	NA	NA	NA	NA	
16	Herbicide	24		$12,000.00	3	IND	***
TOTAL		171	14	$21,160.00			

IND = Indefinite
NA = No control applied
? = Not answered

* = Normal rotation
** = Rotated early, no cost estimate available
*** = Custom application including extensive spot treatment on non-estimable area.

Table 2E.10: Landowner Survey Herbicide Applied, Application Rate, Application Stage, Control Level, and Application Frequency (Question 8).

Survey Number	Herbicide Applied	Application Rate				Application Stage	Control Level	Application Frequency (per year)
		L/acre	L/mile	g/acre	oz./gal.			
1	NA							
2	Tordon 22K	Label				LB	?	1
3	NA							
4	Ally			?		YS,B	C	1
5	NA							
6	Tordon 22K	?				B,EF	S	1 *
7	Roundup	2				YS,B	C	2
8	Glean	?				B,EF	C	1
	Tordon	?				B,EF	C	1
9	Roundup	Label				B	C	1
	Ally			2g/20L		YS	C	1
10	Glean	?				?		1
	Ally			2g/20L		B	S	1
	Roundup	?				?		1
11	Roundup	2				EF,LB	S	1
	Ally			4		EF,LB	S	1
12	NA							
13	NA							
14	Glean	?				B,EF,LB	L	2
	Roundup	?				B,EF,LB	L	1
15	NA							
16	Glean	?				EF,LB	C	1
	Tordon 22K	1.8				LB	L	1
	Estaprop	?				B,EF,LB	L	1 *

*=Application rate noted as heavy

Application Stages:
YS = Young Shoot
B = Bud
EF = Early Flower
LB = Late Bloom

Control Levels:
C = Control - > 80% reduction in weed stand or growth
S = Suppression - Between 60% to 80% reduction
L = Limited Effect - Less than 60% reduction

3. Plant Performance Characteristics

3.1 Synopsis

The clonal perennial herb, *Tanacetum vulgare* L. exhibits considerable pest potential as a weed in western Canada. Although its importance in European folk medicine has prompted extensive research on its phytochemistry, and pharmacological actions, only limited research has been directed towards an understanding of those factors relevant to regulation of its weedy potential. Studies were conducted in roadside and stream bank habitats and in grazed pastures to establish the variation in morphology and growth characteristics of the plant.

The external morphology of common tansy in Alberta was consistent with descriptions from European populations, apart from some differences in plant height. Seed weight varied markedly between stream bank and roadside habitats but height varied more over time within each site than between sites. The mid season levels of non-structural carbohydrates in the roots and rhizomes of common tansy were higher in ungrazed than in grazed habitats. Overgrazing decreased common tansy populations but also promoted continued seedling establishment on bare ground microsites. Establishment of common tansy was greatest when seeded with pasture species that did not quickly produce high levels of ground cover.

3.2 Introduction

Over the past two decades, numerous studies have reported on the phytochemistry and pharmacological actions of the essential oil of common tansy, *Tanacetum vulgare* L. (Abad et al., 1995). Coincidentally, common tansy has been declared a noxious weed in three western Canadian provinces and has recently invaded pasture and riparian habitats. *T. vulgare* has also proven to be difficult to control using conventional herbicides and cultural means (Chapter 2). Few herbicides are registered for control of common tansy, and no research has been completed to improve the efficacy of cultural controls (Chapter 2). Classical biological control could be a valuable adjunct to an integrated management strategy for the plant. However, to provide the ecological background necessary to integrate and improve existing management strategies, assess biological control potential, and monitor control agents after introduction, an evaluation of this plant's growth characteristics and a review of the chemical characteristics of the plant related to its weedy potential were required.

The overall goal of this study was to establish a more complete understanding of the characteristics of common tansy as they relate to effective application of existing control measures, the introduction of classical biological controls , and the subsequent monitoring of those agents. Specific objectives were: 1) to investigate the morphological characteristics of *Tanacetum vulgare* L. in north central Alberta, 2) to review the aspects of existing phytochemical research relevant to weed control 3) to compare growth patterns of common tansy between stable and recently invaded habitats, 4) to establish the seasonal pattern of non-structural carbohydrate concentration, 5) to study the effects of vertebrate grazing on plant morphology, population growth and spread, and 6) to study the establishment of common tansy from seed in competition with pasture species seeded concurrently.

3.3 Materials and Methods

3.3.1 General Morphology

To ensure accurate taxonomic identification and determine plant surface characteristics that could relate to insect feeding behaviour, scanning electron microscopy was used to study the structure of pollen, seeds, flowers, mature leaf surfaces, and fall re-growth leaf surfaces. A dichloromethane extract of resinous beads on the surface of the mature seed was prepared and analyzed using high resolution mass spectrometry as a preliminary investigation of the chemical constituents of these glandular structures.

Seed weight is frequently used as an indicator of change in plant performance (Fenner, 1985). As such, this characteristic could be valuable in the post-introduction monitoring of a classical biological control. However, to confirm the absence of variation in this characteristic between habitats, seed weight was determined from a sub-sample of 50 seeds from the total seed production of 12 randomly selected plants in each of two habitats, roadside and stream bank. Receptacle weight was estimated from a random sample of 5 receptacles per seed sample and seed production per shoot was estimated.

Root morphology of common tansy is poorly described and changes in root biomass or structure caused by a classical biological control agent would be difficult to assess. Therefore, a description of gross root morphology was prepared by excavating root systems in two habitats. A 75 cm diameter clump of tansy growing in the roadside habitat was excavated to a depth of 1 meter. Roots were washed with a water cannon and length and diameter were measured. Along the stream bank, a plant was excavated *in situ* using steel rods to maintain the root architecture and a water cannon to remove the soil.

3.3.2 Growth Characteristics

Five seed samples collected at different times during the 1993 growing season from the roadside habitat at George Lake, AB, were tested for germination at a diurnal flux of 30°C/10°C and 12 hour alternating light cycle in a Dual Program Illuminated Incubator (Precision Scientific™ Model 1818). Samples of seed from each collection date were held at room temperature until January, 1994 when subsamples were shifted to cold storage for eight weeks (-4°C). Five replicates of 20 randomly selected seeds for cold and dry stored samples were placed on 90 mm qualitative filters in 100 by 15 mm sterile plastic petri dishes. Filter papers were wet with distilled water and kept moist as required. The number of germinated seeds was recorded every two days until germination of seeds within the replicate had not progressed for three days.

Maximum plant height was measured in both roadside and stream bank habitats at George Lake (Chapter 5). Two groups of twelve plants in each habitat were assessed over three years (Group 1: 1993 to 1994 and Group 2: 1994 to 1995). The stem diameters of three stems on each of 12 plants in two habitats from group 2 were measured in 1995.

3.3.3 Response to grazing

Five $9m^2$ quadrats were established in each of two one-quarter section adjacent pasture habitats located near George Lake. The 1994 grazing rotation and herd sizes were provided by the landowners for each pasture. The sheep pasture was grazed by 200 head of ewes and grazing lambs and the cattle pasture supported 30 head of cows with calves. The numbers of common tansy shoots were counted from 1993 to 1995, in each of the five $9m^2$ quadrats per habitat. Ground cover and litter depth were measured in four $0.25m^2$ quadrats within the $9m^2$ permanent quadrats in 1995.

Total non-structural root carbohydrate (TNC) content was measured by harvesting a standard core (15 cm by 10 cm) of roots from clumps of common tansy. Five root cores from three sites (roadside, cattle pasture, sheep pasture) were harvested in May, June, July, and September of 1994 and five cores from four sites (roadside, stream bank, cattle pasture, and sheep pasture) were harvested in May, June, July, September, and October of 1995. In 1995, overgrazing in the sheep pasture resulted in limited availability of mature plants for analysis. All roots were harvested between 1000 and 1200 hours, placed directly on ice and transported to a freezer within 30 minutes.

When daily site sampling was complete, individual samples were removed from the freezer, washed, and returned to the freezer. Frozen roots were then transported to the laboratory on ice and dried for one hour at 100°C, followed by 48 hours of drying at 60°C. Dry roots were weighed, and chopped by hand to facilitate grinding in a Wiley mill. A phenol-sulphuric acid assay was used to determine the total amount of non-structural carbohydrate per gram of root sample (Chapman, 1994). Absorbency of two replicate samples was measured at 490 nm (PYE UNICAM SP1800^{Tm} Ultraviolet Spectrophotometer). An average absorbency was calculated for each sample and TNC concentrations were calculated and reported as percentages of oven-dry sample weight.

3.3.4 Establishment with seeded pasture species.

An experiment was conducted in the County of Thorhild, Alberta during 1994 and 1995 to assess the establishment and growth of common tansy when dispersed on freshly seeded pasture. Six treatments were broadcast on 2 x 4 m plots in a completely randomized block design with 6 replicates (Table 3.1). The estimated seed yield from one tansy stem (3.75g) was broadcast onto 5 of the plots in each treatment at the time of seeding. All non-seed species were removed by hand on a bi-weekly basis throughout the first summer and on a monthly basis during the second season. Three 0.25 m^2 quadrats per plot were harvested in September, 1994 and two 0.25 m^2 quadrats were harvested per plot in July, 1995. Samples were sorted, dried at 100°C for 48hrs and weighed for analysis. An assessment of common tansy establishment potential was made based on the relative measures of vegetative biomass, and relative percentages of ground cover and species composition.

3.4 Results and Discussion

3.4.1 Morphology and Chemistry

T. vulgare pollen is oval to spherical shape, divided into three lobes by deep furrows, and evenly covered with broadly conical spines (Pl.3a). These grains are similar to the generic spherical shape attributed to *T. vulgare* by Wodehouse (1965). The internal exine elements of *T. vulgare* were not investigated but a detailed description can be found in Vezey et al. (1994).

Numerous bi-lobed glands and five celled glandular trichomes are found on the leaf surface (P3. 1c). Glandular hairs are prolific on the terminal bud of the plant, serving to maintain a tightly adherent leaf covering for the terminal meristem and developing flower heads. These hairs are persistent along the rachis of the young leaf. The leaf surface appears waxy with numerous oval stomata (P3. 1d).

The floret with the developing seed attached (P3. 1.b) and the mature seed (P3. 1e) confirm the tubular floret and five-sided achene structures. The mature achene has a rudimentary five-pointed corona. Numerous resinous beads are evident on the surface of the developing floret and the mature seed. The beads are bi-lobed and glandular in pits of the cypsela cuticle and on the surface of the floret (P3. 1f). The exudates are persistent on the surface of the seed for up to three years. However, the dechloromethane extract of the beads, could not be identified using mass spectrometry. The glandular morphological features described are characteristic of the aromatic nature of this plant and its high essential oils content.

There are numerous studies of the essential oil content and metabolism of the essential oils of *T. vulgare* L. (Appendino et al., 1984; Banthorpe et al., 1983; Chandra, et al., 1987; Collin et al., 1993; Gallino, 1988; Gershenzon, 1993; Hendriks et al. 1990; Hethelyi, 1987,1991; Holopainen, 1989; Ognyanov and Todorova, 1983; , Nemeth et al. 1994; De Pooter et al., 1989; Von Rudloff and Underhill, 1965; Sanz and Marco, 1991; Shalamova and Sysoeva, 1985; Tetenyi, 1974, 1964; Yakovlev and Sysoeva, 1983). A renewed interest in the chemical composition of the plant relates to its chemo- therapeutic potential. The phytochemistry and pharmacological actions of the genus *Tanacetum* L. (Compositae) are reviewed by Abad et al. (1995). Collectively, these studies show that *T. vulgare* demonstrates a wide range of infraspecific concentrations in the main terpenoid components of its essential oil. Collin et al. (1993) investigated chemotype variation in the essential oil of *T. vulgare* of Canadian origin, specifically Quebec, and found a high degree of mixing of four well defined chemotypes not commonly reported in European literature. Identification of the chemotypes of western Canadian populations is limited to a few populations in Saskatchewan (Von Rudloff and Underhill, 1965), in which two different groups based on variations in thujone content were identified.

An extensive study of the chemotypes of western Canadian *T. vulgare* populations was beyond the scope of this thesis. However, the phytochemistry of North American populations is not well understood and could present significant complications to the successful introduction and monitoring of an insect control agent. Research on the insecticidal and acaracidal properties of *T. vulgare* are in their infancy, but early indications are that the essential oils have considerable biological activity (Chapter 4). In addition, the allocation of essential oils to different plant parts, and the seasonal patterns in that allocation, represent additional factors to be considered in the potential success of an introduced biological control agent. As Nemeth et al.(1994) found in a study of Hungarian populations of *T. vulgare*, the patterns of essential oil accumulation in the terminal portion of the shoots (10 to 15 cm) were highest at sprouting with the limited exception of one chemotype. The rate of decrease in essential oil content, to its lowest level at seed ripening, differed widely between chemotypes and the proportion and level of dominant components in the essential oil changed for each chemotype during vegetative development. In addition, the proportion of the dominant component allocated to different organs within a single development phase differed by chemotype.

3.4.2 Growth Characteristics

Recognition of different external characteristics associated with high essential oil content, the implications of chemotype variance, and the dynamics of essential oil allocation are important both to the selection of classical control agents and also in understanding the variability of plant morphology. Nemeth et al. (1994) found that growth characteristics (height), varied significantly with chemotype. Variability in height between individuals from the two habitats in this study was similar (roadside coefficient of variation V=10%; stream bank V=12%). Height of individuals ranged from 105 to 160 cm. In contrast, plants from Nemeth's (1994) Hungarian populations were considerably shorter, ranging from 40 to 103 cm, with the tallest two types being β-thujone and thujenyl types.

There were no significant differences in height between roadside and streambank populations in 1993 and1994 at George Lake. However, the interaction between year and site was significant, with height decreasing along the stream bank and increasing in the roadside habitat over time (Repeated Measures ANOVA: year by site, $F_{1,.05}$=8.14, p=0.01; Fig. 3.1). Maximum clump height was significantly lower on the streambank site in both 1994 and 1995 and significantly lower in 1995 for both sites (Repeated Measures ANOVA: year, F=47.28, df=1, p=0.00; year by site, F=6. 82, df=1, p=0.02; Fig.3.1). Stem diameters were significantly less on the stream bank than on the roadside in 1995 (stream bank mean = 0.21 cm, SE=0.01, roadside mean = 0.31 cm, SE=0.03) (ANOVA: site, $F_{1,0.05}$=13.374, p=0.00) (Fig. 3.2).

Lotz and Olff (1988) found marked differentiation in plant height of *Plantago major* (L.) sbsp. *pleiosperma*, related to spatial variation in nutrient supply and water availability . Different microhabitats of *P. major* produced plants with different levels of phenotypic plasticity. Plant height in common tansy does not differ between stream bank and roadside habitats. However, plant height did decrease over time and was the lowest in both habitats in 1995, most probably related to low precipitation levels in spring and early summer of that year (Chapter 5). Under high light conditions along the roadside, height was reduced by moisture limitations but stem diameters were maintained. The combined reduction in height and stem diameters in stream bank plant plants in 1995 resulted in a significant reduction in plant biomass (Chapter 5). Thus, plant height in common tansy appears to be influenced by environmental conditions as mediated by habitat.

In contrast to height and seed size, which have been shown to vary markedly with parental growth conditions, seed weight is one of the least flexible phenotypic characteristics (Fenner, 1985). In 1993, the weight of 50 seeds on the roadside (mean = 6.66 mg, SE=0.47) was significantly lower than the stream bank (mean = 8.47 mg, SE=0.41; ANOVA: F=4.55, df=1, p=0.046; Fig. 3.3). The weight of a single common tansy seed ranged from 0.133 mg to 0.170 mg. Thompson (1984) showed that when seeds of the perennial herb *Lomatium grayi* (Umbilliferae) are weighed individually there is more variability in individual seed masses grown under similar conditions than is indicated by the common ecological impression that seed masses tend to be fairly constant. The generally assumed constancy in weight may be a result of the large number of seeds (1000 seed weight) employed in standard measures (Fenner, 1985). The 50 seed weight employed here identifies differences in seed weight due to parental habitat. However, monitoring the effects of classical biological control agents using seed weight as a non-plastic indicator will require further investigation.

Germination of common tansy seeds from the roadside habitat appears to be influenced by allotted development time and cold stratification (Fig. 3.4). A small percentage of common tansy stems were observed to flower at the beginning of July and produce viable seed with a 10% to 20% germination rate when collected in late July to mid-August. Plants flowering in August to September produce seed that, when collected in October, germinates at a rate of 10% without cold stratification and 40% with cold stratification. Seed collected from erect stems following over-wintering germinate at a rate of 70%, with further increases to 90% following additional cold treatment. Increases in germination due to cold treatment were significantly greater for seed collected in the spring and late fall (ANOVA on arcsine transformed percentages: June, $F=10.82$, $df=1$, $p=0.011$: October, $F=20.92$, $df=1$, $p=0.002$). The time to reach 50% germination for cold and dry stored seeds, collected in spring and fall, was 5 to 7 days.

Grime et al. (1981) found that freshly collected seed (Sept. 20, 1973), from the Sheffield area of Britain, grown under a lower diurnal flux of 20°C/15°C, 15/9 hours light. germinated at the 60% level. Pre-chilling of seed to 5°C increased germination to 94%. Dry storage also increased germination percentages to the same level. The time to reach 50% germination in freshly collected seeds was 13 days and 3 to 5 days for cold and dry stored seeds. The time to reach 50% germination in light and shade was three days for stored seed. The number of seeds germinating in the dark (6%) was significantly lower than in the light. In Alberta, Hogenbirk and Wein (1992) found a ten fold increase in emergence of *T. vulgare* seedlings from boreal wetland soils at high temperature (30°C/15°C, 18/6 hr light as opposed to 20°C/10°C, 18/6 hr light). As is consistent with many small seeded species, *T. vulgare* requires high light and temperature for optimum germination and these requirements appear consistent across continents. The production of small amounts of viable seed dispersed in August allows for seedling establishment in the fall and spring, maximizing potential for survival. Cold stratification improves germination potential and ensures increased viability of spring dispersed seed.

The longevity of seed on the woody stalks in Alberta is not consistent with that reported in Europe (Prach and Wade, 1992). The persistence of the seed on stalks throughout the winter and increases in germination percentages following cold stratification suggest methods for the control of population spread. Mowing in early to mid - season (June) and late season could limit seed production and eliminate long distance wind spread of seed on the snow surface.

Rhizome diameters ranged from 1.0 to 2.7 cm. Rhizomes were tightly coiled and extremely woody. The expansion of common tansy through rhizomatous extensions does not appear to occur over long distances. The length of connecting rhizomes was relatively short and ranged from 10 cm to 35 cm. Many short fibrous roots extend from the body of the woody rhizome (5 cm) but the longer deep secondary roots are less dense. Root diameter at 10 cm from the rhizome clump ranged from 0.1cm to 0.7 cm and the length of roots exceeded 130 cm. The higher density distribution of short rhizomatous roots may have implications for the ability of the plant to respond to moisture stress. Under reduced surface moisture conditions plant performance would be expected to be limited, with an ability to persist but not expand. This is consistent with the observations regarding the geographical distribution of the plant (Chapter 3).

3.4.3 Response to grazing

The carbon assimilates allocated to the roots and rhizomes of common tansy fuel its perennial habit. An understanding of these allotment patterns is important in predicting the plant's response to herbivory and in the timing of application of control measures. The pattern of total non-structural carbohydrate (TNC) in the underground organs of *T. vulgare* differed between the roadside and stream bank habitats and the two pasture habitats. The roadside and stream bank pattern is characterized by a sharp drop during early shoot production in April and May, followed by a steady increase until the complete expansion of all leaves at the beginning of June. In contrast, TNC concentrations in plants from the grazed pasture habitats near George Lake showed a steady increase from May to September. There were no apparent differences in TNC caused by differences in grazing pressure as would have been expected given the differences attributable to 200 ewes with lambs and 30 cattle and calves. However, the concentration of TNC in roots of common tansy under grazed conditions are lower (Fig. 3.5 and 3.6)

The annual distribution pattern and percentage levels of carbohydrate found in *T. vulgare* roots and rhizomes from the roadside and stream bank are similar to those measured for the perennial herb *Solidago canadensis* taken from abandoned pastures in Ontario (Bradbury and Hofstra, 1977). The arrest in assimilate partitioning to roots and rhizomes from July to September is associated with flower development. The pattern of TNC concentration in the taproots of the herbaceous perennial weed species *Solanum carolinense* in grazed pastures (Nichols et al., 1991) was similar to that of common tansy under grazed conditions. Steady TNC concentration increases from June to September are attributable to the constant vegetative state of the plant. Grazing of common tansy prevents the formation of flower heads and the arrest of assimilate partitioning to underground organs. TNC concentrations provide a general indication of the pattern of assimilation of carbohydrates in roots and rhizomes and demonstrate differences between ungrazed and vertebrate grazed populations.

Vertebrate grazing did have significant effects on the number of shoots of common tansy in the two pasture habitats over time (2-Way ANOVA: year, F=14.55, df=2, p=0.00; year by site, F=3.56, df=2, p=0.04). There were significant differences in the number of common tansy shoots (per five $9m^2$ quadrats) between the two pasture sites in 1993 (Fig. 3.7). However, by 1995 the population in the sheep pasture was largely limited to seedlings which were similar in number to older shoots in the cattle pasture. There was a steady and significant reduction in shoot numbers in the sheep pasture that could be largely attributed to overgrazing and in particular late fall grazing in 1994 (Figs. 3.7 and 3.8). The numbers of shoots per quadrat in the cattle pasture were constant for 1993 and 1994 and decreased slightly in 1995. Limited precipitation in the spring and early summer of 1995 undoubtedly contributed to population decreases in both pastures (Chapter 5). Grazed height in the sheep pasture ranged from 3 to 6 cm and from 10 cm to 20 cm in the cattle pasture. While, common tansy does appear to be sensitive to overgrazing, these observations suggest that the increase in bare ground and decrease in litter depth associated with heavy grazing provide more opportunities for establishment of new seedlings.

3.4.4 Establishment with seeded pasture species

In the seeded pasture establishment trials, *T. vulgare* biomass was highest in the bare ground, meadow foxtail, and streambank wheatgrass plots. Alsike clover produced the largest biomass amounts in the first and second year, with the next largest amounts being produced by the two alfalfa mixes. However, biomass decreased over the two years in the alsike clover plots and increased in the alfalfa mix plots (Table 3.1). Total grass and alfalfa biomass from the alfalfa mixes exceeded that of the grass clover mix in the second year.

Litter depth was highest on the creeping red fescue, alfalfa and intermediate wheatgrass plots in 1995 (Fig.3.9). Live vegetation and litter percent ground cover were highest on the reed canary grass and alsike clover plots and on the creeping red fescue, alfalfa and intermediate wheatgrass plots (Fig. 3.10 - 3.11). Bare ground percentages were highest on the meadow foxtail, streambank wheatgrass, and smooth brome and alfalfa plots (3.12). Common tansy establishment and competitive ability appears positively related to low percentages of ground cover and litter and to reduced litter depth.

3.5 Conclusion

The external morphology of common tansy is largely consistent with European descriptions of the plant. The presence of glandular structures are characteristic of the aromatic nature and essential oil content of the plant. The complexity of the variation in common tansy chemotypes as reported in Europe and Canada will necessitate the careful screening of insect control agents on a wide variety of plants from Canadian common tansy populations. This plant's pharmacological and insecticidal potential could conflict with and restrict efforts to implement control measures.

Monitoring an introduced insect control agent will require the use of a variety of plant performance measures. Differences in seed weight between habitats indicates the need for a more detailed study if seed weight and size are to be used to measure efficacy of control. Plant height varies markedly with environmental conditions but could be used in combination with stem diameter in the non-destructive estimation of plant biomass for the purposes of monitoring control agent success. The pattern of total non-structural carbohydrates provides a useful profile of the partitioning of assimilate to roots and rhizomes during the growing season that is useful in monitoring the effects of vertebrate grazing and in application timing of herbicide and cultural controls. However, monitoring of the effectiveness of insect control agents may require a more sensitive measure.

Common tansy employs numerous and apparently successful strategies for establishment and persistence in a variety of habitats. While heavy grazing resulted in decreased populations, the presence of plants in surrounding ungrazed vegetation resulted in the observed persistent establishment of new seedlings on readily available bare ground microsites. This was mirrored by the establishment success of common tansy with seeded pasture species that failed to establish heavy ground cover and litter cover. Maintenance of a vigorous perennial rootstock appears essential to the production of large amounts of seed in undisturbed habitats. However, vegetative spread does not appear to be as important to population expansion as seed dispersal and seedling establishment.

Plate 3.1: *Tanacetum vulgare* L. pollen, leaf and seed morphology. a) pollen grain b) floret and developing ovary c) upper leaf surface with bi-lobed glands and glandular trichomes d) upper leaf surface and stomata e) mature achene f) glands on achene surface

Table 3.1: Mean biomass yield by vegetation type for pasture and forage species seeded with common tansy and assessed over two years (n=3 x per 6 replicate 4 by 9 m plots in 1994 and 2 x 0.25m^2 quadrats per plot in 1995)

		Mean Weight (g) by Vegetation Type							
		Common tansy		Forbs		Grasses		Weeds	
Seeded Species	Date	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Bare Ground	Aug. 1994	32.94	7.32	1.93	1.44	0.16	3.84	1.12	0.20
Control		0.00	0.00	0.00	0.00	0.00	0.00	22.72	3.89
Bare Ground	July 1995	62.24	11.72	5.37	5.37	0.00	0.00	4.81	1.26
Control		0.00	0.00	8.54	8.54	0.00	0.00	9.61	9.61
Meadow Foxtail	Aug. 1994	20.74	4.68	0.85	0.60	13.64	2.92	4.41	1.01
Control		0.00	0.00	0.00	0.00	2.35	0.48	3.47	0.25
Meadow Foxtail	July 1995	30.94	6.18	0.00	0.00	12.69	2.86	0.33	0.12
Control		0.19	0.19	0.00	0.00	32.31	0.76	3.61	0.72
R. Canary Grass & Alsike Clover	Aug. 1994	1.81	0.69	62.46	7.17	1.59	0.26	1.84	0.52
Control		0.00	0.00	74.25	13.35	13.82	4.13	0.00	0.00
R. Canary Grass & Alsike Clover	July 1995	5.76	2.38	46.36	5.27	4.19	0.87	0.19	0.11
Control		0.00	0.00	38.13	10.17	12.88	5.69	0.00	0.00

Table 3.1: Mean biomass yield by vegetation type for pasture and forage species seeded with common tansy and assessed over two years (n=3 x per 6 replicate 4 by 9 m plots in 1994 and 2 x 0.25m^2 quadrats per plot in 1995). (continued)

		Mean Weight (g) by Vegetation Type							
		Common tansy		Forbs		Grasses		Weeds	
Seeded Species	Date	Mean	SE	Mean	SE	Mean	SE	Mean	SE
C. R. Fescue, Alfalfa & Int.ermediate Wheatgrass	Aug. 1994	3.35	1.29	28.38	2.71	9.56	1.19	3.98	1.58
Control		0.00	0.00	7.25	1.79	10.01	3.13	2.40	0.18
C. R. Fescue, Alfalfa & Int.ermediate Wheatgrass	July 1995	5.78	2.03	43.42	6.53	16.72	2.28	0.55	0.25
Control		0.00	0.00	37.08	10.22	24.02	6.17	0.00	0.00
Streambank Wheatgrass	Aug. 1994	27.90	5.89	1.70	1.21	0.80	0.38	1.01	0.40
Control		0.00	0.00	0.00	0.00	0.00	0.00	8.50	8.50
Streambank Wheatgrass	July 1995	42.45	6.98	0.00	0.00	1.55	0.81	4.19	1.88
Control		0.00	0.00	0.00	0.00	12.92	12.20	7.41	7.41
Smooth Brome & Alfalfa	Aug. 1994	6.21	1.70	22.56	2.26	13.00	2.92	2.48	0.50
Control		0.00	0.00	48.89	11.59	3.72	0.64	2.62	0.95
Smooth Brome & Alfalfa	July 1995	5.96	1.13	41.82	6.42	18.91	3.60	0.28	0.15
Control		0.00	0.00	40.26	26.61	20.06	1.09	0.81	0.81

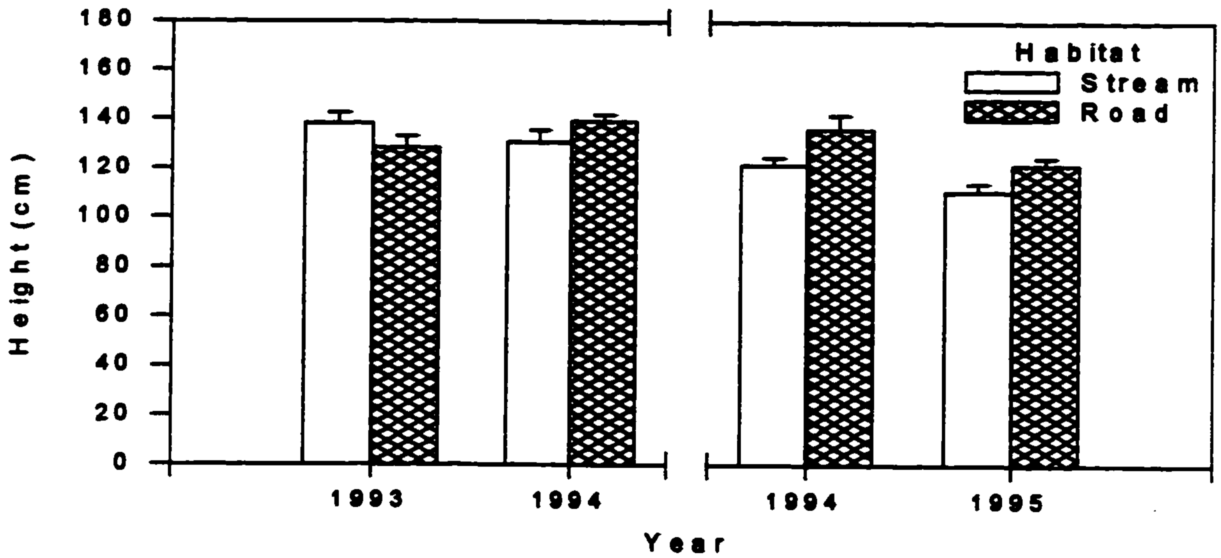

Fig. 3.1: Maximum plant height (cm) in two habitats over two, 2 year periods(1993-1995). (n=12, Error bars are + 1 SE of mean).

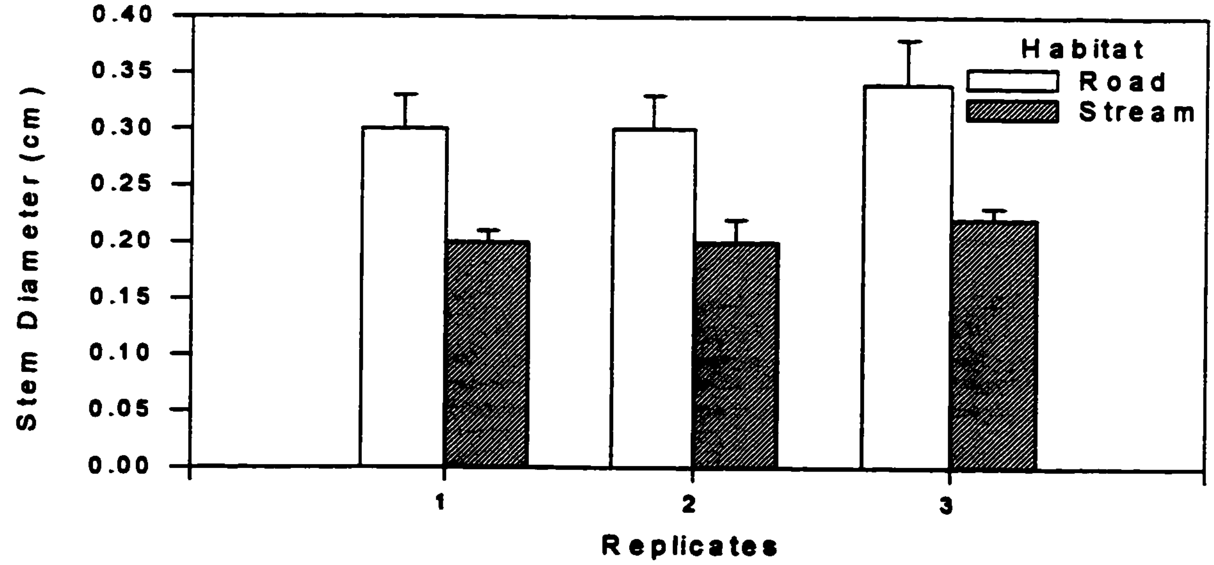

Fig.3.2: Stem diameter for three replicates on twelve *T. vulgare* plants in at two habitats1995. (n=12, Error bars are + 1 SE of mean)

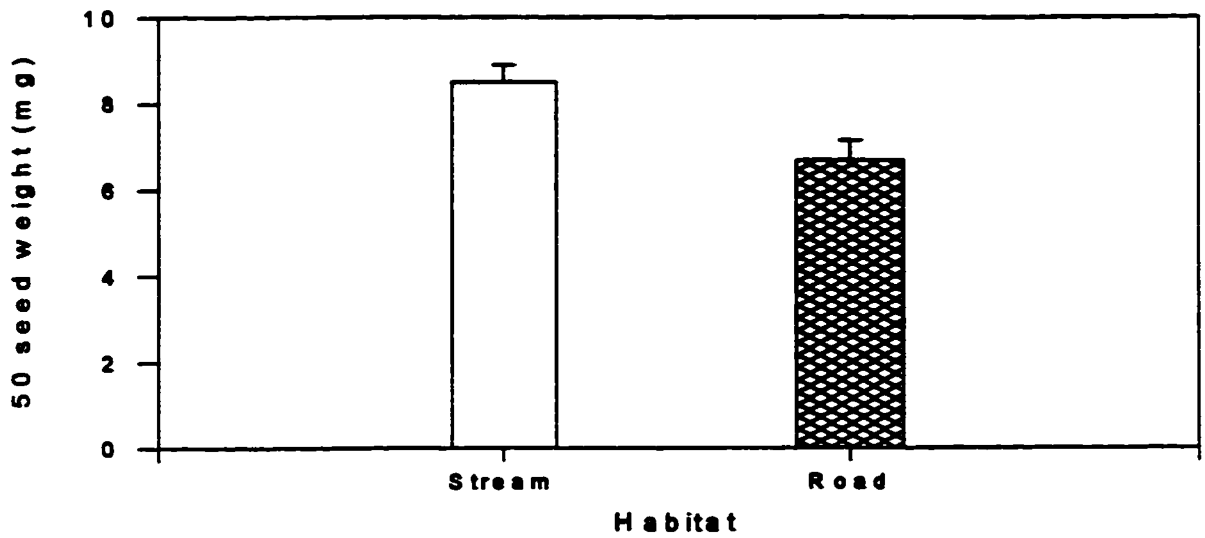

Fig. 3.3: Weight of 50 seeds (mg) from two habitats (1993). (n=12, Error bars are + 1 SE of mean)

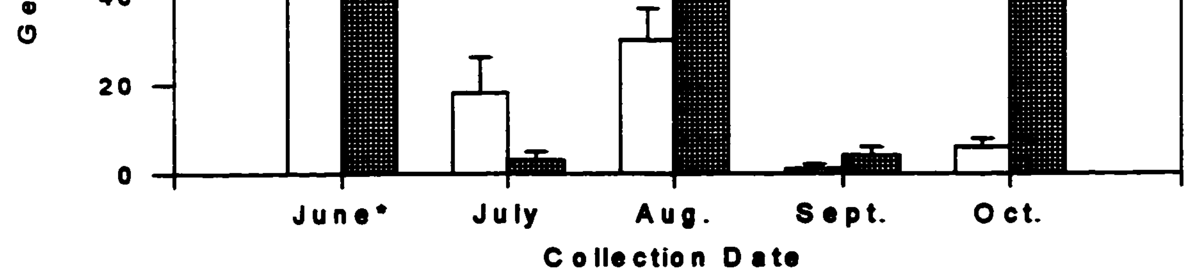

Fig. 3.4: Germination percentage of dry stored and cold treated seed, collected during 1993. (n=20, 5 replicates, Error bars +1 SE of mean).

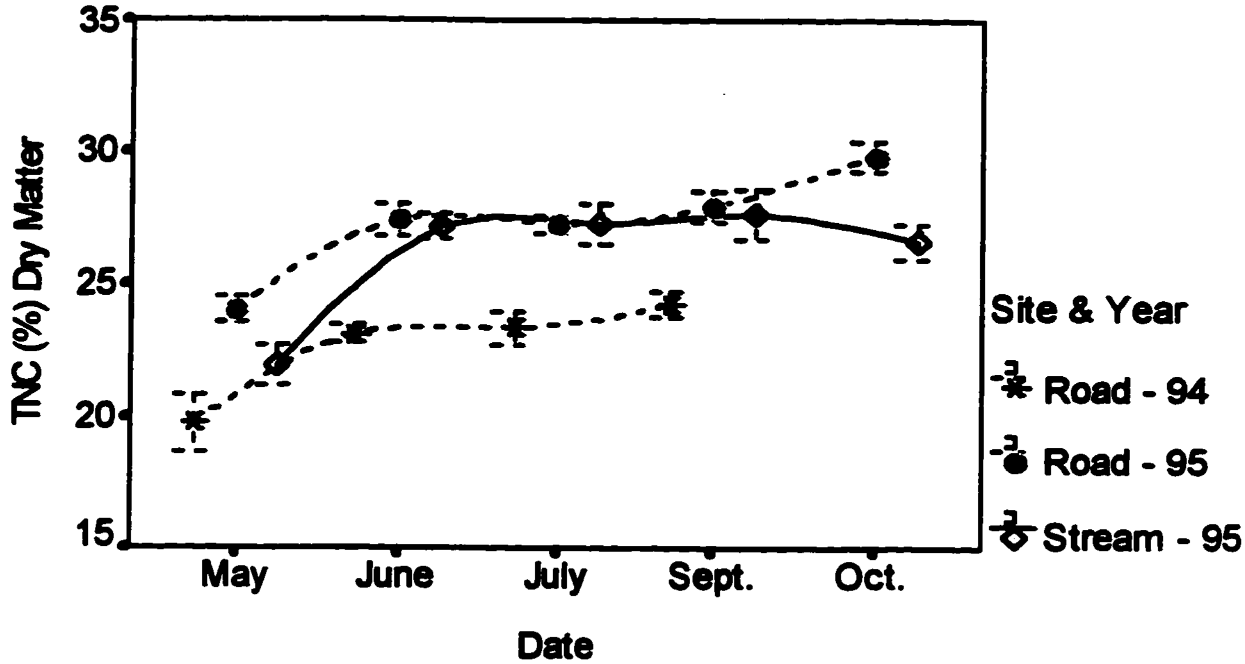

Fig. 3.5: Total non-structural root carbohydate (TNC) as a percentage of sample dry weigh from roadside and stream bank habitats - 1994-95 (n=6 to 14, Error bars are + 1SE of mean)

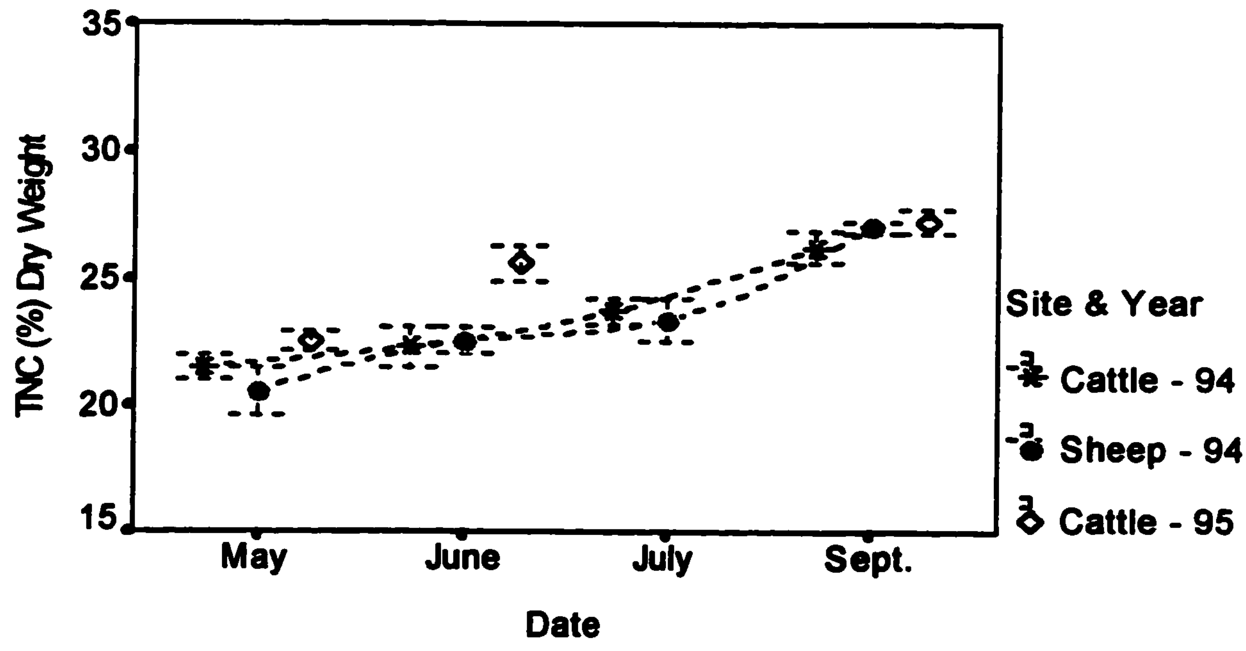

Fig. 3.6: Total non-structural carbohydrate (TNC) as a percentage of sample dry weight in cattle and sheep pasture habitats - 1994-1995 (n=6 to 12, Error bars are + 1 SE of mean).

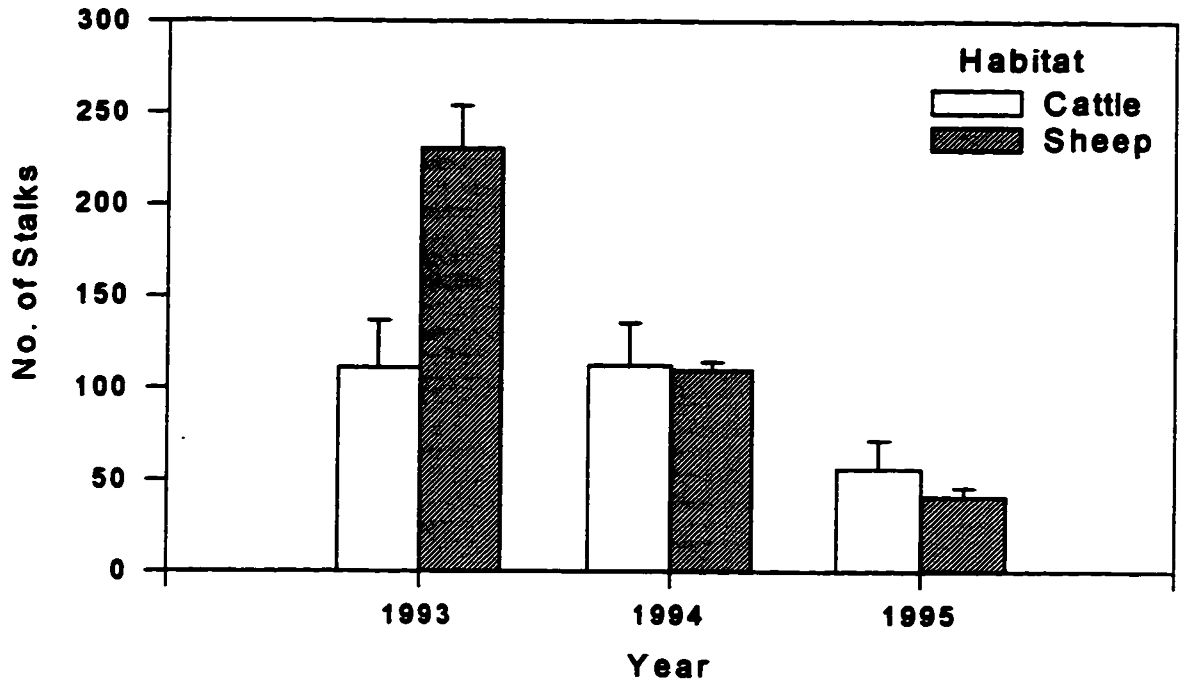

Fig. 3.7: Number of *T. vulgare* shoots per $9m^2$ quadrat in two habitats, over three years, and under different grazing rotations - 1995. (n=5, Error bars are + 1 SE of mean).

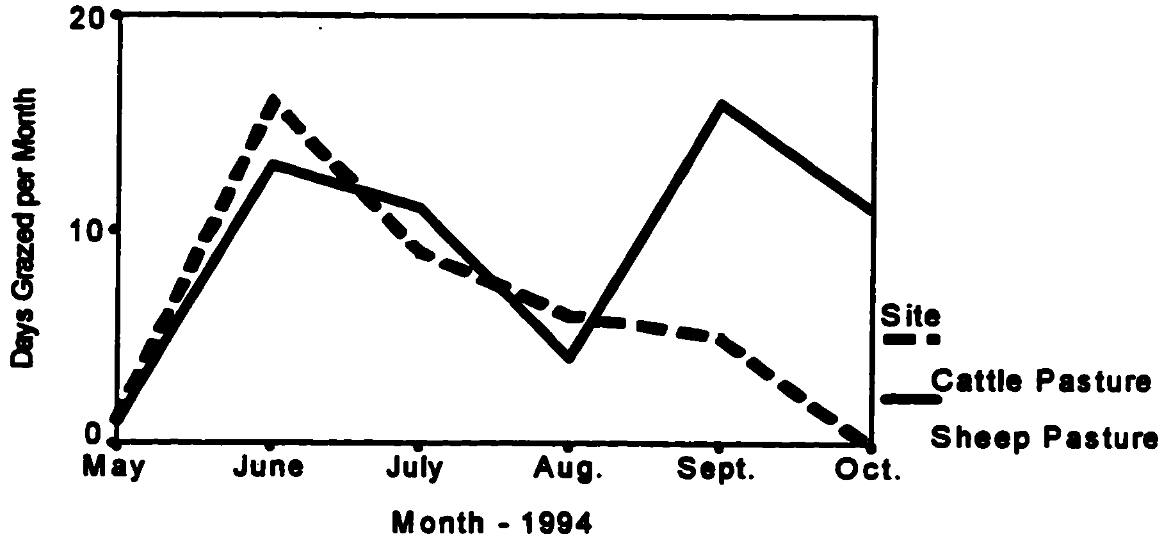

Fig. 3.8: Days grazed per month in cattle and sheep pasture habitats-1994.

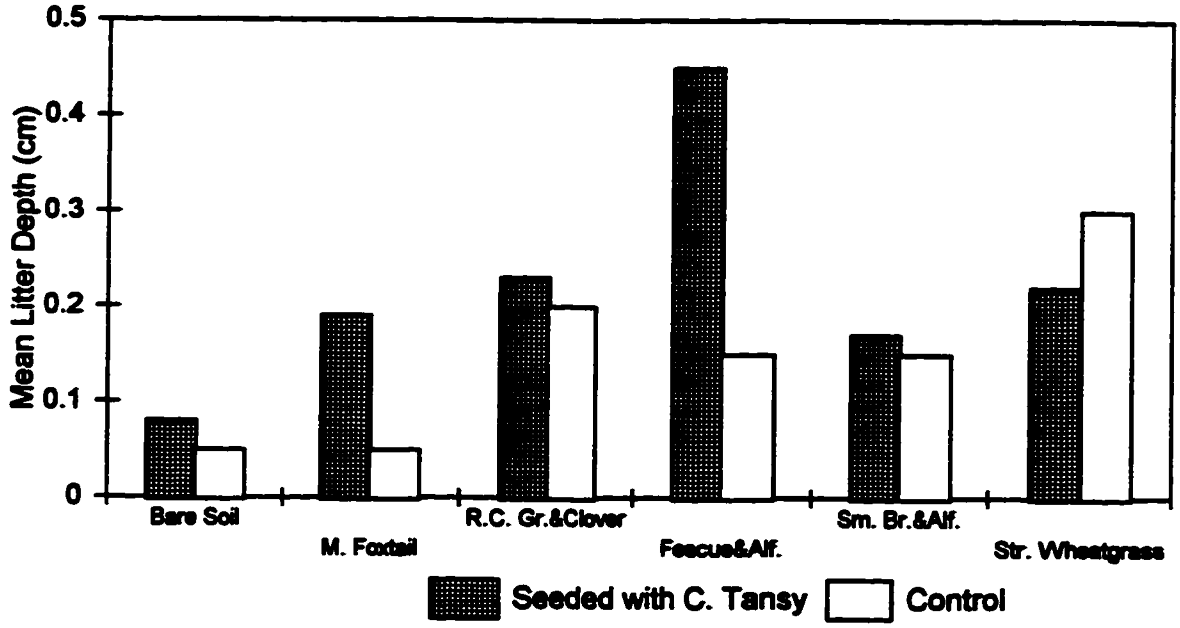

Fig. 3.9: Mean litter depth - Thorhild AB. - 1995. (n=2 x 0.25m2 quadrats per $8m^2$ lot) (treatments=5 plots, control=1 plot)

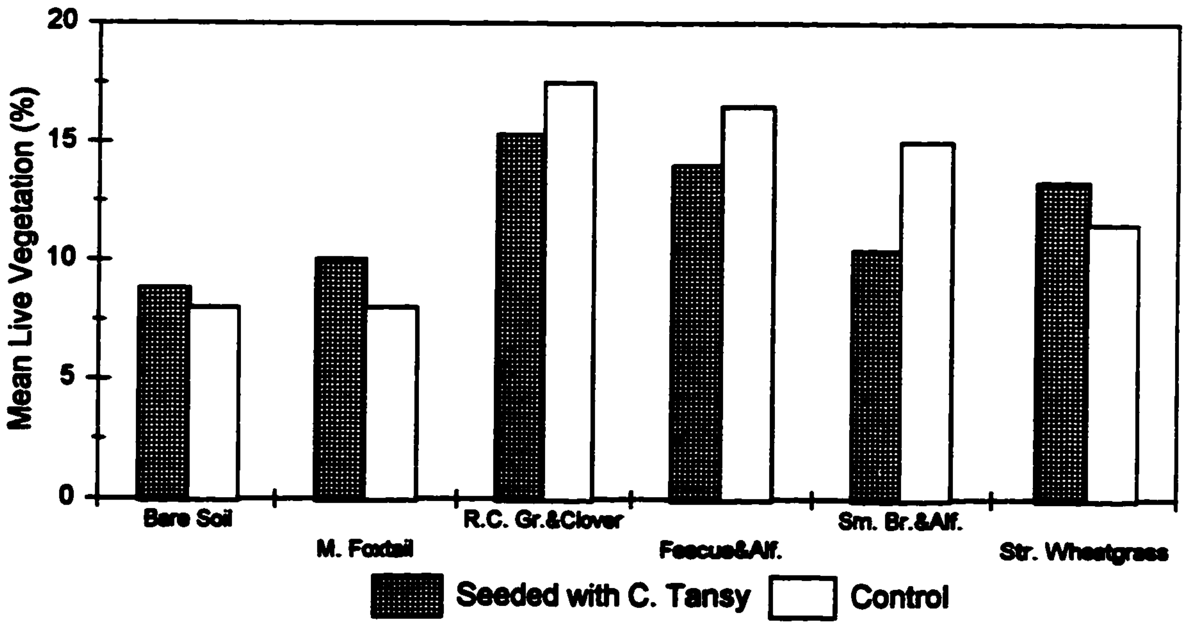

Fig. 3.10: Mean percentage of live vegetation ground cover- Thorhild AB. - 1995 (n=2 x 0.25m2 quadrats per $8m^2$ plot)(treatments=5, control=1)

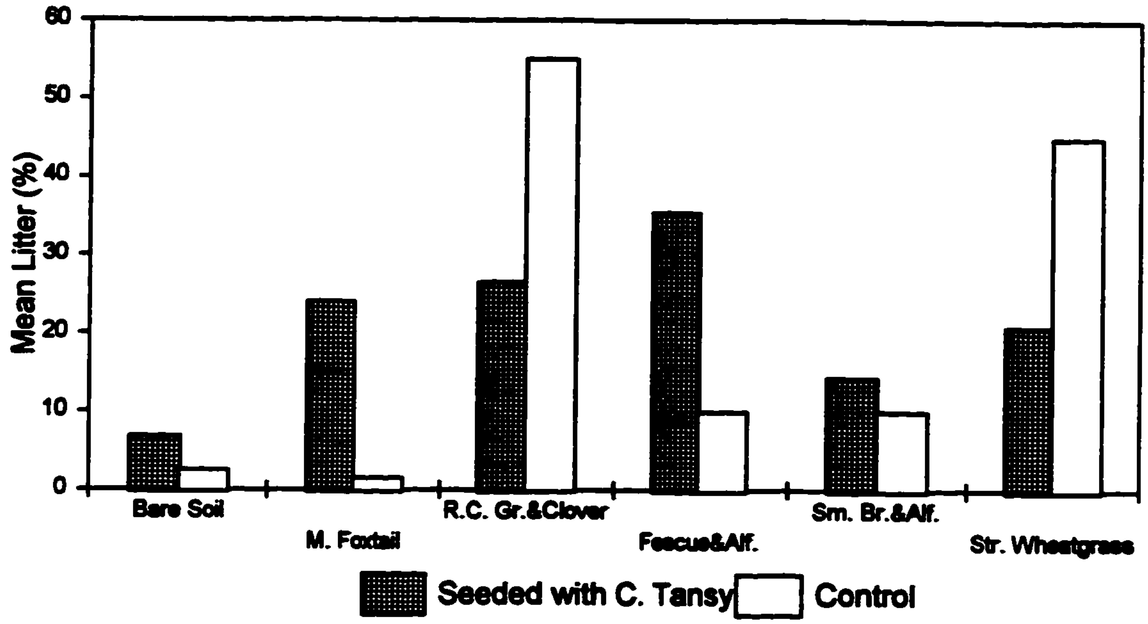

Fig. 3.11: Mean percentage of litter - Thorhild AB. - 1995. (n=2 x 0.25m^2 quadrats per 8m^2 plot) (treatments=5, controls=1)

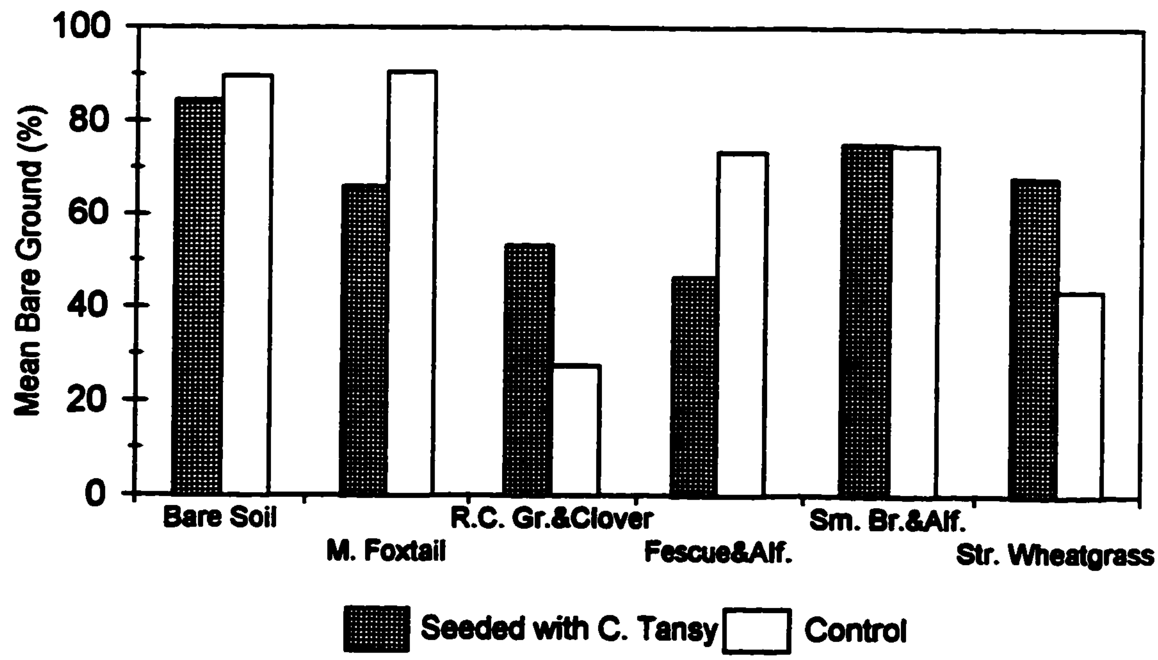

Fig. 3.12: Mean percentage of bare ground cover - Thorhild AB. - 1995. (n=2 x 0.25m^2 quadrats per 8m^2 plot) (treatments=5, controls=1)

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4. Associated Insects, Mites and Diseases

4.1 Synopsis

Classical biological control has considerable potential for the population regulation of perennial herbaceous weed species such as *Tanacetum vulgare*. As a pre-requisite for successful selection, introduction and monitoring of possible control agents, knowledge of the insects, mites and diseases associated with the plant in the area of introduction is required. This paper reports such a survey, conducted in north central Alberta, of the phytophagous insects, mites and disease associated with *T. vulgare*.

Size and diversity of insect populations associated with common tansy were depauparate when compared with those reported in the European literature. A single monophagous mite species, *Aceria calathinus* (Nalepa) was found on *T. vulgare*. This is a new record for North America of this species, which was known formerly only from eastern Europe. Arthropod species found feeding on *T. vulgare* were native to North America and not restricted to this plant. A stem rust species affecting *T. vulgare* is also reported. The damage caused to *T. vulgare* in central Alberta by insects, mites and diseases was minimal.

4.2 Introduction

Attempts to suppress the expanding populations of the invasive perennial herb *Tanacetum vulgare* in north central Alberta have met with only limited success (Chapter 2). These attempts have relied heavily on herbicide application. Alternatives to this conventional approach to weed control, such as classical biological control, have proved to be successful with other perennial weed species (Burdon and Marshall, 1981) and could provide a sustainable, cost effective method of population regulation for common tansy. However, in addition to knowledge of the population and individual characteristics of the target weed (Chapter 3), introduction of a classical biological control agents for a weed species could be enhanced by an understanding of those species of phytophagous insects, mites, and plant diseases already associated with the weed in the habitat of introduction. Such knowledge improves the efficiency of screening and selection of exotic control agents by eliminating from the process those species found in both habitats of origin and introduction. It also establishes the ecological framework for monitoring and assessment of introduced agents. Despite the growing literature accumulated in Europe, and to a certain extent in North America, on the phytochemistry of the plant, knowledge of the fuanal and disease associations of *T. vulgare* is extremely limited.

The objectives of this research were to sample and describe the insect, mite, and disease populations associated with *T. vulgare* in north central Alberta and relate those findings to suitability of this plant for classical biological control.

4.3 Materials and Methods

4.3.1 Study Sites

A survey of arthropod populations was conducted in two habitats, stream bank and roadside, at the University of Alberta Field Station at George Lake, Alberta between 1993 and 1995. Stems and roots were collected for dissection from five counties in north central Alberta: Parkland, Athabasca, Barrhead, Thorhild, and Beaver. The terminal shoots of populations in George Lake and Edmonton, AB and Rivers, and Beulah, Manitoba were sampled for Acari.

Populations in seeded plots at Thorhild, AB and in natural habitats at George Lake and Edmonton, AB were regularly observed for signs of disease.

4.3.2 Associated Insects, Mites and Diseases

At George Lake, in 1993, 10 standard sweeps, replicated six times, were taken from stands of tansy on a weekly basis. Insects were killed and washed out of the nets with 95% ethanol. Three sweeps were taken from adjacent vegetation, without *T. vulgare* in the canopy, at biweekly intervals for comparison. During inclement weather (high precipitation and low temperature) collections were made from tansy by hand. All specimens were placed in 70% alcohol and labelled for later sorting and identification. Specimens were sorted according to order and family.

Four root core samples (15cm diameter x 10cm depth) were taken from tansy clumps and four samples from adjacent areas in July 1993, at each site. These cores were extracted in low gradient Berlese funnels under 60w incandescent bulbs for 48 hrs and specimens were collected in ethyl glycol and alcohol. Samples were stored in 70% alcohol and later sorted to the family level. During the first two weeks of August, 1993 five complete clump samples were collected from each of the five counties of Parkland, Athabasca, Barrhead, Thorhild, and Beaver in north central, Alberta. Roots were washed and the samples were returned to the laboratory for dissection. Stems were examined for gross signs of damage. Damaged stems were dissected and 5 additional stems/clump were selected at random and dissected. All roots were split and examined for insect damage.

Arthropods that were common and or appeared to effect damage to the plant were identified to genus or species with the assistance of competent specialists. Following this preliminary investigation research attention was focused on the identification and general biology of two geometrid species and one eriophyid mite.

Field populations at George Lake, Edmonton, and Thorhild AB were regularly monitored in the course of this arthropod survey and other research (Chapters 3 and 5) for evidence of disease. Specimens exhibiting disease symptoms were collected and taken to a plant pathologist for identification.

4.4 Results and Discussion

4.4.1 Insecta

There was no evidence, from dissections of root or stems, of arthropod caused damage to *T. vulgare*. Results of the funnel extractions showed no striking difference in the number of arthropods associated with common tansy roots in stream bank and roadside habitats at George Lake (Table 4.1).

Insects with piercing and sucking mouth parts were relatively common in the sweep samples from common tansy. Representatives of Miridae, Lygaeidae, Aphidoidae, and Cercopidae were the most abundant groups of phytophagous insects collected from common tansy at the George Lake site in 1993 (Table 4.2). Mirid and lygaeid nymphs were not observed on the tansy plants, however, and adults were not observed to feed on the plant. In constrast, cercopids, thrips, aphids, and geometrids were observed feeding on the *T. vulgare*. Cercopid nymphs were collected from stems and leaf axils. Aphids were occasionally found on the pre-emergent flower buds and below the flower head along the pedicels of the corymb (1 to 2 cercopyd nymphs per plant were found only occasionally on plants and the occasional aphid colony was found on terminal shoots of maturing plants).

The impact of sucking insects in terms of actual plant damage is difficult to assess. However, it is doubtful that the limited populations observed could cause damage that is important at the population level. Wilting was not observed in response to this feeding, and floral development was not apparently interrupted.

The sporadic occurrence of cercopid and aphid nymphs on *T. vulgare* may relate to the ability of these species to tolerate only certain chemotypes of *T. vulgare* that are scattered throughout the population. It is also of interest to note that cercopids feed at the leaf axil and along the stems where essential oil content is low (Chapter 3). Aphids, as phloem feeders, are exposed to lower a quantities of secondary plant compounds and may be selecting terminal shoots of mature plants because of reduced chemical content.

Thrips and geometrids were collected from the flower heads. Thrips were observed to score the wax surface of immature flower heads but damage was not sustained on the mature flower. Two geometrids, the Holarctic species, *Eupethecia satyrata dodata* Taylor and the Nearctic species, *Synchlora albolineata* Packard were identified from individuals collected from and reared on *T. vulgare*. *Eupethecia satyrata dodata* larvae began feeding as the outer florets of *T. vulgare* expanded, producing a shot hole pattern in the centre of the emerging flower. These larvae inflicted the highest levels of overt physical damage to the plants observed during 1993 to 1995, but the damage was limited to an extremely small percentage of flowerheads (Fig. 4.1).

Bolte (1990) reports feeding of *E. satyrata dodata* on the flowers, fruits and occasionally leaves of numerous plant species including those of Compositae. However, *T. vulgare* is not specifically listed among the hosts in Canada or Europe. Success in rearing *E. satyrata dodata* for identification was limited due to heavy parasitism by a *Microgaster* species (Brachonidae) and an ichneumonid species in the first two years of collection. However, in 1995, first and second instar larvae collected at the beginning of August were successfully reared and identified.

McGuffin (1988) reported one species of *Synchlora* in Canada, *Synchlora aerata* which is a nominate species with two subspecies: *S. aerata albolineata* (Packard) and *S. aerata liquoraria* Guenée. Early instar larvae resembling those of *Synchlora aerata* (Comstock and Dammers, 1937, McGuffin, 1988) were collected from flowerheads of *T. vulgare*. Larvae attached pieces of the tubular florets and pollen to spiculiferous processes on the dorsal flattened surface of each segment using silken threads. Larval colour varied and appeared adaptive to the fading of the flower head. Larvae collected in late August and September, stored in *Sphagnum* moss at 4^0C, failed to survive. However, larvae collected on the foliage of *T. vulgare* in early June of 1995 were successfully reared to the adult stage on *T. vulgare*. Larvae pupated during the third week of July and moths emerged two weeks later. Larvae pupated in litter at the base of the plant or on the floor and sides of the rearing cage. Ferguson (1985) suggests that two generations of *S. aerata abolineata* occur in Oregon, Washington, and Southern B.C. (approximately April to June and late July to September) with one generation in the northern great plains. *Synchlora aerata albolineata* is a polyphagous species that has been reported feeding on *Artemesia californica* Lessing, *Chilopsis linearis* De Candolle, *Coreopsis* species, *Eriogonum fasciculatis* Benthram, *Solidago* species and *Mentha spitica* L. While the species is reported to mainly prefer buds and flowers of Compositae, *T. vulgare* is not listed as a host for this plant (Ferguson, 1985, McGuffin, 1988, Treiber, 1979).

A list of phytophagous insects on *T. vulgare* prepared from European literature (Friese and Schroeder, 1996) shows a large number of poly- and oligophagous lepidopteran species feeding on common tansy, mainly Tortricidae, Pyralidae, and Geometrideae (Table 4.3). Of the geometrid species reported in Europe, *S. aerata albolineata* appears most closely related to *Euchloris smaragdaria*. However, Skou (1986) describes *Thetidia smaragdaria* (Fabricuis, 1787) and indicates *Euchloris* to be synonymous, and Raineri (1994) refers to *Euchloris* as a previous genus now included in *Thetidia* and describes a new genus and species from Italy, *Antonechloris smaragdaria*. Waring (1994) gives an update on the endangered status of *Thetidia smaragdaria maritima* (Prout) in Britain and reports *T. smaragdaria maritima* to be polyphagous with host plants, including *T. vulgare*. Ferguson (1985) notes the changes in frenulum structure that has occurred in the separation of members of *Thetidia* and *Synchlora*. Taxonomic confusion aside, there does appear to be a host plant association for *T. vulgare* in these geometrid genera.

Among European Lepidotera , *Dichrorampha* is the most frequently reported genus, feeding almost exclusively on roots and rhizomes of *T. vulgare*. It includes the only monophagous lepidopteran species reported, *Dichrorampha flavidorsana* Knaggs. The absence of root and rhizome damage in *T. vulgare* from Alberta indicates that this apparently common European guild could be important in population regulation of the plant. However, the predominant feeding site for both European and Canadian lepidopteran known to feed on *T. vulgare* are flower and seed heads. Furthermore, the feeding habits of these species are predominantly oligophagous and poligophagous.

Ten species are listed as known monophagous species on *T. vulgare* in Europe or with questionable host specificity (Table 4.3, highlights). Three species from different orders feed on the shoot, leaves and flowers of the plant (1 heteropteran, 1 homotoperan and 1 gall midge). Three species of aphids feed on the leaves. Two species of gall midges feed exclusively on the flowers and one species of weevil feeds only on the shoot. There is a single tortricid moth that feeds on the root. Several of these monophagous species appear adapted to feeding on the plant at different stages and at a combination of sites despite the plant's high essential oil content.

Feeding deterrent effects of the essential oil of common tansy have been reported for lepidopterous larvae and the Colorado potato beetle (*Leptinotarsa decemlineata*) (Brewer and Ball, 1981; Schearer, 1984). The strongest deterrent components isolated by Schearer (1984) were 1, 8-cineole, bornyl acetate, ρ-cymene, γ-terpene, and camphor. Nemeth (1994) reported that borneol and cineole chemotypes of *T. vulgare* showed a 50% decrease in essential oil content from sprouting to flowering with a 10% decrease in camphor phenotypes. Other chemotypes, thujone and davanon, show increases to time of flowering, followed by 10% and 30% decreases respectively. These overall changes in content are moderated by fluctuations in the percentages of main components. Thus the influence on insect feeding behaviour in the field can be expected to be complex, and monitoring the success of herbivores will require knowledge of the chemotypes present in the population.

The mosquito-repellent activity of *T. vulgare* has been confirmed but the active component has yet to be identified (De Pooter et al., 1989). The odours from extracts of *T. vulgare* have been shown to repel the black bean aphid, *Aphis fabae* and mask an attractant response to its host plant (Nottingham and Hardie, 1993). Tansy flowers and odour have been shown to inhibit oviposition behaviour and mating behaviour and reduce adult longevity of *Lobesia botrana* Den. Et Schiff. (Lepidoptera, Tortricidae) (Gabel and Thiéry, 1993). Their study suggests that only certain genera appear able to successfully use *T. vulgare* as a food plant despite indications from the European literature survey that a number of tortricids are adapted to feeding on it.

4.4.2 Acari

Eriophyid mites were collected from the terminal buds of *T. vulgare* from George Lake and Edmonton AB (October, 1995 and May, June, and July of 1996) and from Rivers, Man. (October, 1990 only). The mites were identified as *Aceria calathinus* (Nalepa) by J. Amrine (personal communication). *A. calathinus* has been reported on *T. vulgare* in Europe along with one other eriophyd species *Aceria tuberculatus* (Nalepa) (Amrine and Stasny, 1994). *Epitremerus tanaceti*, another eriophyd species, was reported on *T. vulgare* in Florida (Boczek and Davis, 1984).

Scanning electron micrographs of *A. calathinus* were prepared and used to confirm the species description (Pl. 4.1a to 4.1f). There are resinous beads on the surface of the feather claws not readily attributable to specimen preparation and suggestive of the contents of the glandular trichomes present in abundance on the terminal buds of *T. vulgare* (Pl.4.1e).

The habit of *A. calathinus* has not been previously described. In Alberta, *A. calathinus* are found on the terminal spring shoots and fall regrowth shoots of *T. vulgare*. Eggs are laid on the terminal fall regrowth buds. The number of mites per shoot is greater in the spring and fall than those occasionally found on axillary leaf shoots as the plants mature. *A. calathinus* were not sampled from *T. vulgare* between mid-July and late September. While thicker leaf margins and ruffling of pinnae were observed in conjunction with presence of the mites, further study is required to confirm plant injury and determine the type of damage.

4.4.3 Diseases

Teliospores of an unknown fungus were found on leaves of *T. vulgare* at an urban site (Edmonton, AB) in September, 1995 and the fungus was identified as *Puccinia tanaceti* (Basidiomycotina). *Puccinia tanaceti* has been reported on *Tanacetum capitalum* (Nutt.), *Artemesia tridentata* Nutt., and two host plants of Indian origin (Anonymous, 1960, Farr. et al., 1989). However, there are no reports of *Puccinia tanaceti* infecting *T. vulgare*.

Leaves and stems infected with a powdery mildew were collected from a field site at Thorhild, AB in August 1994 and the mildew identified as *Erysiphe cichoracearum*. *E. cichoracearum* has been reported on *T. vulgare* in Pennsylvania, South Dakota and Washington (Anonymous, 1960, Farr. et al., 1989).

Other fungi reported on *T. vulgare* include; *Oidium* sp. in Mississippi, *Ramularia tanaceti* Lind. in Wisconsin and Manitoba, *Camarosporium tanaceti* Oud. and *Leptosphaeria dolioloides* Awersw in Nova Scotia, *Micosphaerella tassiana* (de Not.) Johans. and *Pleospora herbarium* (Fr.) Rabh. in British Columbia. However, consistent with my observations, there are no indications from the literature of high levels of plant injury due to disease agents in North America.

General observation of leaf surfaces under scanning electron microscopy indicated that fungal growth did not proliferate until late fall when hyphae were observed on the leaf surface. In antimicrobial studies on the essential oils of *T. vulgare*, multiplication of several thread fungi genera, *Candida, Fusarium, Ophiobolus*, and *Saccharomyces*, were completly inhibited by the mainly ketonic essential oils of six chemovariants (Héthelyi et al,.1991). The inhibitory activity of essential oils of *T. vulgare* on other types of fungi, such as the Ascomycotina described, are lacking, but the absence of fungal growth on actively growing plant tissue indicates the need for further investigation.

4.5 Conclusion

There are few polyphagous insects feeding on common tansy in north central Alberta. Of those identified, none are abundant enough nor inflict damage at a level capable of adversely affecting *T. vulgare* populations. Two geometrid moths (*Eupethicia satyrata dodata* and *Synchlora aerata albolineata*) larvae not previously reported on *T. vulgare* were identified feeding on the plant. A single mite species (*Aceria calathinus*), of European origin, not previously reported in North America is found on the plant but does not cause conspicuous damage. Two plant fungi, *Puccinia tanaceti* and *Erysiphe cichoracearum* were found on mature and senescent vegetation. While *E. cichoracearum* has been previously reported on *T. vulgare* in Canada, *P. tanaceti* is a newly reported fungus on *T. vulgare*.

The number and diversity of insects reported feeding on *T. vulgare* in Europe are greater than those found to inflict damage on the plant in Alberta. While most of the diverse species reported on *T. vulgare* in Europe are oligophagous and polyphagous, there appear to be a number of potential monophagous species not present in Alberta that could be suitable agents for biological control. Of particular interest is the absence of root damage to common tansy in Alberta and the presence of a root feeding guild in Europe.

Plate 4.1: Female *Aceria calathinus* (Nalepa). a) dorsal body b) ventral body c) rostrum, dorsal shield and legs d) female genital aperture e) feather claw (empodia) f) posterior abdomen with caudal setae.

Table 4.1: Relative abundance of species by order obtained from Burlese funnel extractions, 1993.

Order	Number of individuals		Number of individuals	
	Roadside - T. vulgare	Roadside - Control	Streambank - T. vulgare	Streambank - Control
Coleoptera				
Adults	7	11	24	31
Larvae	8	17	12	92
Diptera				
Adults	3	0	14	18
Larvae	6	0	2	6
Hemiptera	0	0	1	1
Homoptera	2	4	18	6
Hymenoptera	8	2	10	8
Lepidoptera				
Adults	0	0	6	0
Larvae	0	3	0	0
Protura	0	3	4	2
Plecoptera	0	0	5	0
Acari	189	220	139	127
Araneae	3	7	11	27
Collembola	458	704	547	607
Annelida	96	37	2	3
Millipeda	0	2	0	0
Various pupae	2	0	10	5

Table 4.2: Number of insect species obtained from sweep net samples and hand collections, 1993. The "Other" Order category refers to the arachnid order Araneae.

		Sweeps				Hand Collections	
			Number of individuals			Number of individuals	
Order	Subordinal Taxon	Roadside	Roadside Control	Streambank	Streambank Control	Roadside	Streambank
Coleoptera	Chrysomelidae	1	1			-	-
	Coccinelidae	1				-	-
	Curculionidae	3		9		-	-
	Carabidae			1		-	-
	Mordellidae	1				-	-
Diptera	Various	180	38	247	30	7	6
Hemiptera	Lygaeidae	22		5	1	31	5
	Miridae	32	2	18		9	6
	Pentatomidae	1				2	1
	Reduviidae	1		1	1	2	-
	Thyreocoridae			1		-	-
	Various nymphs	4				1	24
Homoptera	Aphididae*	11		48	16	46	31
	Chrysopids	1		1			
	Cicadellidae	10	6	39	2		
	Circopidae	9		12	3	3	
	Fulgoridae	1					
	Various nymphs**	9		9		5	13
Hymenoptera	Various	23		9		2	1
Lepidoptera	Geometrid larvae	2		1		5	1
	Various adults	5		2		-	-
Thysanoptera	Thripidae	9	3	2		12	4
Other		41		18		6	11

• Aphididae nymphs and adults

** Various nymphs predominantly Cercopidae

Table 4.3 Phytophagus insects on Tanacetum vulgare L. in European literature (Modified from Friese, and Schroeder, 1996)

Order	Family	Genus	Species	Site of Injury	Feeding Habit
Heteroptera	Miridae	*Megalocoleus*	*pilosus* (Schrank)	shoot, flower, unripe ovary	monophagous
		Lygocoris	*lucorum* (Meyer-Dür)	shoot, flower, unripe ovary, overwintering in the shoot	oligophagous
		Orthocephalus	*coriaceus* (Fabricius)	overwintering in shoot(probably at the base of the shoot)	polyphagous
		Neides	*tipularius* (Linnaeus)	not known	polyphagous
Homoptera	Aphidae	*Macrosiphoniella*	*tanacetaria* (Kltb.)	leaf	monophagous
		Uroleucon	*tanacetum* (L.)	leaf	monophagous
		Dactynotus	*tanaceti* (L.)	shoot, leaf, and flower	monophagous
		Metopeurum	*fuscoviride* Stroyan	leaf	monophagous
	Cercopidae	*Philaenus*	*spumarius* (L.)	shoot and flower	oligophagus
		Coloradoa	*tanacetuina* (Walk)	shoot tip and flower	not known
Coleoptera	Chrysomelidae	*Cassida*	*denticollis* (Saffrian)	not known	oligophagous
			sanguionosa (Saffrian)	not known	oligophagous
			stigmatica (Saffrian)	not known	oligophagous
		Galeruca	*tanaceti* L.	not known	polyphagous*
		Longitarsus	*succineus* (Foudras)	not known	oligophagous
	Curculionidae	*Cycloderes*	*pilosus* (Fabricius)	flower	polyphagous
		Tropiphorus	*tomentosus* (Marsham)	flower	polyphagous
		Cyclocleonus	*tigrinus* (Panzer)	flower	polyphagous
		Phyllobius	*brevis* (Gyllenkal)	flower	oligophagous
		Lixus	*fasciculatus* Boheman	shoot	oligophagous
		Ceutorhynchus	*millefolii* Schultze	shoot	monophagous
		Ceutorhynchus	*barnevillei* (Grenier)	not known	oligophagous
			tristis (Scopoli)	not known	oligophagous

Table 4.3 Phytophagus insects on Tanacetum vulgare L. in European literature (Modified from Friese, and Schroeder, 1996) (continued)

Order	Family	Genus	Species	Site of Injury	Feeding Habit
Diptera	Cecidomyiidae	*Clinorhyncha*	*tanaceti* KFFR	flower	not known (monophag?)
		Contarinia	*tanaceti* Rübs.	flower	not known (monophag?)
		Rhopalomyia	*tanaceticola* (Karsch)	shoot, leaf, and flower	monophagous
Lepidoptera	Tortricidae	*Dichrorampha*	*petiverella* (L.)	root	oligophagous
			obscuratana (Wolff)	root	oligophagous
			sequana (Hübner)	root	oligophagous
			montanana (Dupondel)	root	oligophagous
			gueneeana (Obratzov)	root	oligophagous
			alpiniana (Treitschke)	root	oligophagous
			senectana Guenée	not known	oligophagous
			agilana Tengström	upper shoot	oligophagous
			flavidorsana (Knaggs)	root	monophagous
		Thiodia	*citrana* Hübner	flower	oligophagous
		Cnephasia	*virgaureana* Treitschke	shoot tip and flowerbud	polyphagous
			longana Haworth	not known	polyphagous
			genitalana	flower and seed head	oligophagous
		Aethes	*marginata* Haworth	flower and seed head	oligophagous
		Celypha	*rufana* Scopoli	roots	oligophagous
		Eana	*incanana* Stephens	leaves or root collars	polyphagous
	Pyralidae	*Homeosoma*	*cretacellum* (RÖSSL)	shoot	oligophagous
			nebulellum	flower and seed head	oligophagous
			cretacellum	flowerbud	oligophagous
			binaevellum	flowerhead	oligophagous
			nimbellum	flowerhead	polyphagous
	Geometridae	*Tephroclystia*	*succenturiata*	flower	oligophagous
			absinthiata	not known	polyphagous
		Euchloris	*smaragdaria*	not known	polyphagous
	Noctuidae	*Cucullia*	*tanacetoi*	not known	oligophagous
	Cochlidiidae?	*Cochlidia*	*implicitana* Wocke	shoot, flower and seed	polyphagous
		Rodostrophia	*vibirica*	not known	polyphagous
		Coleophora	*caelebipennella* Zeller	not known	not known

see Prevett, 1953 for description of feeding habit.

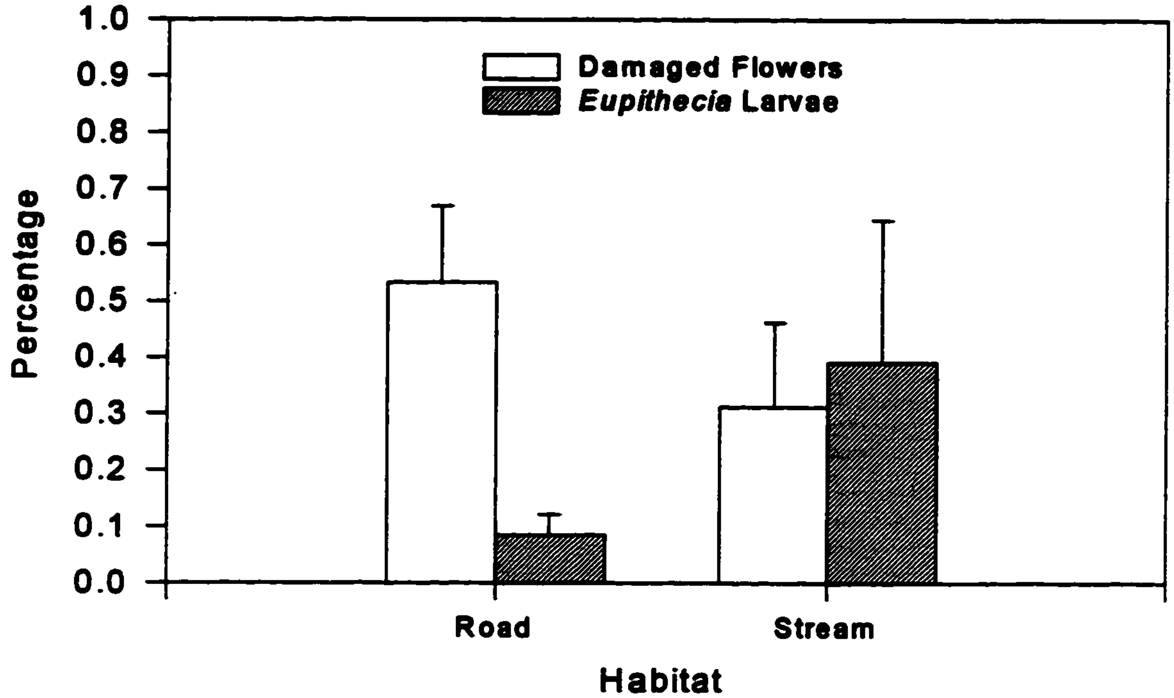

Fig. 4.1: Mean percentage of *T. vulgare* flowerheads per clump with *Eupithecia satyrata dodata* damage and *Eupithecia* larvae present in two habitats - 1995. (Error bars are + 1 SE of mean).

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5. Effects of Simulated Herbivory on *Tanacetum vulgare* L.

5.1 Synopsis

Common tansy is a non-native, clonal, perennial herb that has invaded large areas of north central Alberta over the past decade. Development of an effective integrated management strategy for this invasive weed is dependent, in part, upon understanding both individual and plant population responses to herbivory. The effect of simulated herbivory on the growth and reproduction of individual common tansy (*Tanacetum vulgare* L.) plants was studied in populations from two typical habitats using a pair of experiments that varied intensity, frequency and type of herbivory.

One application of high intensity, simulated defoliation significantly reduced flower head weight, flower head number, and total vegetative biomass within a given year, and over a two-year period. Higher frequency, and lower intensity simulated defoliation also significantly reduced flower head weight within a given year and over a two year period. Plants growing in a shaded riparian environment were more affected by both types of defoliation than those growing on an open roadside. These site differences were significant for all measured variables under high frequency, low intensity defoliation, reflecting the increased effect of early tissue loss under low light conditions and differences in population structure between habitats. Under low frequency, high intensity defoliation, site and treatment differences were significant for effects on flower head weight and numbers of flowers per clump. Low intensity root severance did not significantly affect plant performance. Response to the different types of herbivory was mediated by environmental factors over the three years of the experiment.

5.2 Introduction

The perennial herb, common tansy (*Tanacetum vulgare* L.) was introduced to Canada from Eastern Europe and the British Isles in the 19th century and populations have expanded to occupy large areas within north central Alberta (Chapter 2). Traditional efforts to manage this invasive weedy species have met with only limited success (Chapter 2). Although knowledge of this plant's response to herbivory within natural habitats could be valuable for developing more effective management, there have been no studies of this nature in North America.

The effects of herbivores on their host plants are quite controversial (Crawley, 1989) and most of the debate centres on the ability of plants to compensate for herbivore damage (Whitham et al., 1991). Studies of plant - animal interactions cover a wide spectrum of animal and plant species, and the range of plants studied to date exhibits a continuum of responses mediated by biotic and abiotic factors (Hunter et al., 1992; Price et al., 1991). The processes and timing of responses to herbivory vary significantly among species, locations, and seasons (Paige and Whitham; 1987, Maschinski and Whitham, 1989; as referenced in Reichman and Smith, 1991).

There have been limited studies of effects of herbivory, patterns of regrowth, or effects over time of continued herbivory on the reproductive potential of natural populations of perennial herbaceous species (Doak, 1991, 1992). The size and fecundity of dwarf fireweed, (*Epilobium latifolium* L. (Onagraceae)), differed with plant structure type (single shoot or entire clump) and temporal (days, months, or years following injury) scale under direct and simulated herbivory (Doak, 1991, 1992). The biomass of the introduced weed Canada thistle (*Cirsium arvense* L. (Compositae)) was reduced by artificial defoliation and competition, but the response varied with environmental conditions and plant competition (Ang et al., 1994). The high production of easily dispersed diaspores (in space and/or time) and effective vegetative reproduction within herbaceous species, such as *Cirsium arvense* L., have been closely linked with expansive potential (Prach and Wade, 1992). However, there is only a limited understanding of the influence of herbivory on these aspects of weedy potential.

Much of the relevant information on insect - plant interactions is taken from the literature on biological control of weeds. However, these experiments are generally not well replicated or randomized within natural habitats of the plants. Furthermore there have been few investigations of target weed response to herbivory, prior to the establishment of a management strategy (Crawley, 1989, Harris, 1973, Waage, 1990). While insect herbivores have been used with variable success as classical biological control agents of invasive weed species, the focus of research, prior to introduction of a control agent, has been on insect population dynamics, feeding behaviour, and biotic factors affecting insect populations. Screening trials for potential biocontrol agents are generally not conducted in typical habitats of the weed species, a factor which may contribute significantly to the varied field results from successfully screened agents. Plants have considerable influence on the dynamics of insect populations and this inability to consistently select successful insect control agents, and thus limitations and variability of control effectiveness may simply reflect limited research on plant population structure and individual plant response to herbivory.

The objectives of the experiments described here were to investigate the response of common tansy to different frequencies, intensities and types of simulated herbivory within two natural habitats of the plant and to relate the findings to an assessment of the potential for biological control.

5.3 Materials and Methods:

5.3.1 Site Selection and Characterization

Evaluation of the susceptibility of common tansy to defoliation and root severance was conducted in two habitats at the University of Alberta Field Station at George Lake, Alberta between 1993 and 1995.

As has been recognized in the management of other perennial weed species, such as purple loosestrife (*Lythrum salicaria*) and Canada thistle (*Cirsium arvense*), non - cultivated lands and areas where herbicide use is restricted are primary sites for application of biological control (Ang., et al., 1994, Malecki, et al., 1993, Thompson, et al., 1987). Because these types of habitats are the primary stable habitats for common tansy (Chapter 2), and since the relative fitness of an individual plant changes according to the environment in which fitness is measured, experiments were conducted along a roadside and a stream, two common habitats of *T. vulgare* (Abrahamson, 1989).

Sites were selected to maximize differences in aspect, soil moisture and light availability between habitats. Soils were characterized by a mixture of poorly to moderately well drained, orthic gray wooded, orthic humic gleysol, and organic soils. The roadside site was dry and open with a southern exposure and was located between mixed boreal forest and the fence line adjacent to secondary highway 651. The stream bank location was moist and shaded with a northern exposure between mixed boreal forest and Newton Creek.

Experiments were conducted in 10 m by 150 m transects running east - west along these habitats. Common plant species lists were compiled for each experimental transect using Moss (1983) and Johnson et al. (1995) (Appendix 5.A, Table 5A.1). Adjacent to each experimental transect, five 9m^2 plots were established. The number of shoots of common tansy within these plots and percent canopy cover were assessed in September and October of each year. In September of 1993 and late May of 1994, canopy cover was assessed at both sites by estimating the percentage of vegetation type covering each 9 m^2 quadrant from the height of a 2 m step ladder. In June of 1995, ground cover, litter depth, and vegetation composition were measured in four 0.25m^2 quadrants within the 9m^2 quadrants. In 1995, the August mid-day photosynthetically active radiation (PAR) for each clump of common tansy was measured at 50 cm and maximum canopy heights using a LI-COR™ radiation sensor.

Meteorological data were collected from instrumentation at George Lake to establish general patterns in growing degree days and precipitation. A growing degree day was defined as one degree of deviation, on a single day, of the daily mean temperature from 5°C. Technical failure of this meteorological equipment caused some gaps in the data which were filled using data from alternative weather stations close to George Lake, located respectively at Scion and Busby, AB (Environment Canada, 1996).

5.3.2 Experimental Design

Two experiments were conducted: (1) a single frequency defoliation experiment to assess the effects of different levels of defoliation and, (2) an experiment that combined multiple frequency defoliation and root severance to determine the effects of lower levels of persistent foliar and root herbivory. The single frequency defoliation experiment consisted of three treatments, (0, 50%, 100% defoliation), applied to clumps of common tansy prior to the exposure of flower buds. The multiple frequency defoliation and root severance experiment consisted of four treatments (0%, 50% leaf defoliation, 15% root severance, and combined 15% root severance and 50% leaf defoliation) applied at three intervals to clumps of common tansy. Plants were selected haphazardly along the transect with individuals defined as being discrete clumps greater than 30 cm apart. All size stages larger than three shoots per clump were included. Individuals were demarcated at the base by a circle of silicon tubing joined with wooden dowel. Each treatment was randomly assigned to twelve plants. The application of treatments corresponded with the phenological development of the plant; prior to the full exposure of flower buds in the single frequency experiment and initiated at the 3- to 4-leaf stage for the multiple frequency and root severance experiment.

5.3.3 Defoliation Method

Simulated herbivory can be representative of insect herbivory and has been used effectively to increase understanding of plant performance under stress (Michaud, 1991; Ryle and Powell, 1975). Paper punch and bisections along the midrib leaflet are considered to be the most adequate methods of simulating insect defoliation (Poston et al., 1976). Because the pinnately compound structure of common tansy did not lend itself to paper punch methods, the along the midrib leaflet bisection method was chosen for these studies. This defoliation pattern appeared to effectively mimic that of a naive native Lepidopteran (Arctiidae) caged on the plant (D. J. White, personal observation) and has been used to mimic defoliation by a chrysomelid species (Cartwright and Kok, 1990).

In the single frequency defoliation experiment, the clumps of common tansy were defoliated prior to the exposures of flower buds on July 1 - 4th, 1993 and July 14-15, 1994. The multiple frequency defoliations were applied at three intervals to clumps of common tansy on June 17-18, June 29-30, July 21-22 in 1994 and June 3-4, June 17-18, and July 3-4 in 1995. Pinnae were removed using bandage scissors, on one or both sides of the rachis, to effect the 50% and 100% single defoliation treatments. In the multiple frequency defoliation the same removal technique was used on all new growth leaves at each clipping.

Clipping was initiated at the 3- to 4-leaf stage and repeated on 3 successive occasions at two week intervals. Plants typically produced 3 to 4 new leaves between each clip. Clipped material was dried for 48 hrs at 61C, weighed and included in the total vegetative biomass weight.

5.3.4 Root Severance Method

Common tansy has a large rhizome with numerous short fibrous extensions and longer roots spreading downward from the base of the rhizome. The latter average 0.4 cm in diameter and extend beyond depths of 180 cm (Chapter 2). In addition, shallow lateral roots produce vegetative shoots. All individual clumps of common tansy in the multiple frequency experiment were marked centrally with a permanent 1 cm by 20 cm steel rod. This eliminated any bias caused by possible damage to the rhizome of non-root severed plants and served as the central marker for measurement of spread and shoot density and application of root severance treatments. To effect root severance, a 1 x 21 x 60 cm steel blade was driven into the ground at a distance of 23 cm from the central rod, at an angle of 45 degrees (Appendix 5A, Fig 5A.1) with a six pound sledge hammer. Treatments were applied in a counter clockwise direction and resulted in a seven-sided conical severance pattern with each application severing approximately 15% of the described root structure. Root severance treatments were performed on the same schedule as the low level defoliations in 1994. In 1995, an additional two severance treatments were applied at the same time as the first two defoliation treatments, resulting in an approximate total severance of 75% of the lateral root growth over the course of the experiment.

5.3.5 Plant Performance Indicators:

Vegetative and generative stages were monitored on a monthly basis during the growing season in 1994 and 1995. A standardized phenological coding system (Province of British Columbia, 1990) was used to describe life cycle stages. Local vegetative spread, in the multiple frequency experiment, was determined with reference to a 1.0 m diameter hoop centered on the marker rod of each clump. Vegetative shoots were counted between the outer circumference of each clump, as demarcated by silicon tubing, and the inner margin of the larger hoop. Maximum height of each clump, shoots per clump, and the number of flower heads per clump were measured.

Because common tansy is a woody perennial, with leaves that do not detach until late autumn (October) and stems that were observed to remain erect for up to two years after death, direct measurement of the harvested aboveground biomass was used. After the first frost (September 14, 1993; September 2, 1994; September 10, 1995), the top growth was harvested, separated, dried for >48hrs and weighed for analysis. This corresponded to 67 days (1993) and 50 days (1994) after clipping for the single frequency defoliation and 77 days (1994) and 99 days (1995) after clipping for the multiple frequency defoliation. Care was taken during harvesting not to disturb any basal regrowth and to preserve any fragile senescent leaves.

5.3.6 Analysis

The number of shoots per 9 m^2 quadrant in the two habitats over three years were compared using Kruskal - Wallis One - Way ANOVA. The total vegetative biomass per clump (g) (including the clippings), the flower head weight per clump (g), the number of flower heads per clump, the number of flower heads per shoot, the number of shoots per clump, the number of shoots within a one meter radius of the clump, and maximum plant height were compared. Both experiments were analyzed using Repeated Measures ANOVA (SPSS Advanced Statistics, 6.1, 1994) and Cochran's test for homogeneity of variance (Day and Quinn, 1989) with treatments and site as between subject factors and year as the within or repeated measure. Weight measurements were transformed using log(x + 1) to correct for heteroskedastic variance (Zar, 1984). Unequal variance in the count data was corrected using the square root transformation of x+0.375 (Zar, 1984). A value of $\alpha = 0.025$ for repeated measures tests was employed for epsilon corrected F values (Stevens, 1992 as referenced by von Ende, 1993). Multiple comparisons based on Scheffe's 95% confidence intervals following MANOVA were used to determine significant differences between treatments within years and sites. Photosynthetically active radiation was compared between treatments and sites using general factorial ANOVA (SPSS Advanced Statistics, 6.1, 1994).

5.4 Results

5.4.1 Single Frequency Defoliation Experiment

The number of flower heads per clump was significantly less for the 100% defoliation treatment at both sites and in both years (Tables 5.1,5.2 and Fig. 5.1). The stream bank site had significantly fewer flower heads per clump than the roadside site. Differences were not significant between years. The mean weight of flower heads per clump at the 100% defoliation levels was significantly lower at both sites and in both years (Fig. 5.2). There were no significant site differences. Along the stream bank, flower head weight per clump was significantly less for the 50% defoliation in the second year. Total vegetative biomass per clump was significantly lower at the 100% defoliation levels at both sites, each year and over time (Fig. 5.3). However, there was no significant difference in total vegetative biomass between sites. The number of shoots per clump was significantly lower for the 100% defoliation treatment eac year and over time in the streambank habitat. (Fig. 5.4)

The maximum height of clumps was not significantly different between treatments, sites, or years (Tables 5.1, 5.2). However, height of the roadside plants was lower than those on the stream bank in the first year of the experiment (Fig. 5.5) Small differences in flower head development were noted for the 100% defoliation in the first year but were not apparent between other treatments or in the second year (Figs. 5.6, 5.7).

5.4.2 Multiple Frequency Defoliation and Root Severance Experiment

Significant differences in flower head weight and height were observed between treatments (Tables 5.3, 5.4). Habitat differences were significant for all variables with the exception of vegetative biomass and shoots per clump. All variables were significantly different between years. The major source of this variation originated from the stream bank site. The stream bank site had significantly lower numbers of flower heads (Fig. 5.8) and flower head weight (Fig. 5.9) per clump than the roadside. Treatment differences at this site in both years were significant for all variables at the 50% defoliation level, except for the number of shoots per clump (Figs. 5.8-5-11).

The number of shoots within a .5 m radius of main clumps was significantly different between fall and spring dates (Repeated measures ANOVA, fall 94, $F=12.15$, $df=1,87$, $p=0.001$, fall 95, $F=42.49$, $df=1,87$, $p=0.00$; Fig. 5.12). The maximum height of clumps was significantly different between treatments, sites and years (Repeated measures ANOVA, treatment, $F=7.98$, $df=3$, $p=0.00$; site, $F=12.43$, $df=1$, $p=0.00$; year, $F=117.86$, $df=1$, $p=0.00$; Fig. 5.13). A trend towards delayed flower head development was apparent between the controls and the 50% defoliation and combined 50% defoliation and root severance treatments in the stream bank habitat (Figs. 5.14 and 5.15). Differences in generative phenotypic stages were notable between sites and between treatments on the stream bank site (Figs. 5.16 and 5.17). Plants from the 50% defoliation and combined 50% defoliation and root severance treatments in both habitats exhibited a trend towards delayed generative development.

5.5 Discussion

T. vulgare population structure differed between sites. Roadside plants were more highly clumped than the streambank population (Appendix 5.A, Fig. 5A.2). Clumping along the roadside could be the result of a more competitive environment. The roadside vegetation was predominantly composed of naturalized pasture grass species along with a large number and variety of weed species. Increased ground cover and litter depths, and competition from these relatively larger populations of established grass and weedy species could limit colonization and spread in this habitat to sporadically available micro-sites. Stream bank vegetation included fewer individuals of tall growing native grass species and more native type forbs. The low litter depths and higher percentage of bare ground along the stream bank may result in greater opportunities for seedling colonization and in a more regular distribution of common tansy (Appendix 5.A, Table 5A.1;Figs. 5A.3 to 5A.5). Recurrent and wider scale disturbances associated with stream bank erosion, changes in water levels, and wildlife activity maintain the opportunities for colonization by common tansy seedlings.

Changes in the number of shoots per tightly formed clump and the number of lateral shoots of *T. vulgare* represent alterations in the vegetative reproductive potential of the plant. Significant reductions in the number of shoots per clump occurred under high intensity defoliation (100%) along the stream bank and over two years, but overall site differences were not significant. In the higher frequency defoliation and root severance experiment, shoots per clump differed significantly between years but there were no significant treatment or site effects. Yadav and Tripathi (1981), in a study of dynamics and regulation of the ruderal weed *Eupatorium odoratum*, found that the presence of associated vegetation within a single habitat greatly influenced the production of fertile shoots and seeds. While the number of new recruits was found to fluctuate within a growing season in their study, the shoot number remained relatively stable over the years. Habitat variation in the vegetation associated with common tansy was evident between the two study sites and seasonal variation in the number of vegetative recruits was significant. However, recruitment within and outside of the plant clump over the two years was relatively stable. There are significant habitat differences and short term variation in vegetative reproductive potential for *T. vulgare*. Defoliation also has a limited effect on that potential, particularly in roadside habitats.

The results for total vegetative biomass were consistent with the patterns in shoot development. Single frequency, high intensity (100%) defoliation produced a significant reduction in the total vegetative biomass production per clump. Plants in the stream bank site were more adversely affected by this treatment in the second year. There were no significant reductions in vegetative biomass attributable to lower intensity, multiple frequency defoliation treatments or to habitat. Significant reductions in vegetative biomass did occur over the two years and again these reductions were more evident to the stream bank site. Reductions in the total vegetative biomass occurred despite stable shoot numbers due to significantly decreased height.

Differences in the number of flower heads produced per clump and shoot, and in the flower head weight per clump following treatment indicate alterations in the sexual reproductive potential of *T. vulgare*. The 100% defoliation treatment in the single frequency experiment produced significant differences in the number of flower heads and flower head weight per clump. Differences in the number of flower heads per clump between sites were significant, with larger reductions in the second year along the stream bank. Differences between years were not significant. However, changes in flower head weight between years and treatments were significant. Measurements of individual flower head size were not obtained for all clumps in the experiment, but the absence of a reduction in the number of flower heads between years despite the accompanying reduction in weight suggests that plants could have produced similar numbers of smaller flower heads during the second year. The absence of significant reductions in the number of flower heads under 50% defoliation also indicated that the plant was able to withstand relatively high levels of single incidence defoliation without compromising short term reproductive potential.

In the multiple frequency defoliation (50% defoliation), no significant differences in the number of flower heads per clump were observed between treatments. Significant differences did occur between sites and over time. However, defoliation at the 50% level produced significant reduction in flower head weight when applied at low levels over several weeks in contrast to the single frequency experiment where no such effect was observed. Thus, multiple frequency defoliation at the 50% level produced significant reductions in the short term reproductive potential.

Differences in flowering period, not strongly evident in the single defoliation experiment, could be related to the time of clipping. In the single event defoliation experiment, removal of foliage at the beginning of July when flower buds were fully formed did not disrupt formation of flower heads. Indeed, in this experiment, the only case where the flowering period was delayed occurred with one hundred percent defoliation in the shaded riparian zone. Thus with 50% of leaf material *T. vulgare* was able to produce flowers at the same rate and in the same quantity in a shaded environment and at the same rate with no leaves in a high light environment. However, the differences in flowering period and generative stages seen in the multiple defoliation were apparent at the 50%

defoliation level in the shaded habitat in both years of the experiment. Both time to flowering and flower head weight were affected by earlier clipping.

Habitat differences in *T. vulgare* performance in response to defoliation were significant for variables related to sexual reproduction. The ability of a perennial clonal species to compensate for defoliation has been shown to be affected by irradiance (Dirzo, 1984 as referenced in Whitham et al., 1991). Photosynthetically active radiation on the roadside habitat was significantly higher than along the stream bank and may be a determinant in the significantly reduced effect of this type of defoliation on vegetative characteristics at this site (Appendix 5.A, Fig. 5A.6). In addition to the effect of low light levels on plant performance in the stream bank habitat, these individuals were significantly smaller than roadside clumps for the multiple frequency defoliation experiment. The two types of defoliation experiments were conducted within the same transects but with a one year lag between them, and second year selection appeared biased by lack of availability of the larger clumps that were available in the first experiment. However, a significant reduction in flower head numbers occurred at both sites over the two years with an increased reduction at the stream bank site. The smaller plants may have increased these site and between years effects. Doak (1992) found in a model of the lifetime impacts of herbivory for *Epilobium latifolium,* that size influenced the effect of defoliation on seed production and interacted with both year and defoliation treatment.

Another factor in site differences evident in this experiment may be related to the history of colonization of these types of sites. Roadside and waste areas were the most common habitats for common tansy until the increase in spread that has occurred over the past two decades (Chapter 2). Riparian zones are more recent sites of colonization and selective pressure may have yet to produce a population with maximum adaptive potential (Doust, 1981). However, the significant differences in sexual reproductive potential of *T. vulgare* in response to defoliation between habitats in this experiment were dominantly influenced by two factors; plant size and light availability.

The reduction in the value of variables for untreated clumps over time in both experiments with the exception of shoot number suggests that there may have been carry over effects associated with the experimental design. Identifying the possible causes of significant differences in these variables requires the consideration of several confounding factors; variation in available moisture and growing degree days, clipping dates, and time of harvest. In the multiple frequency experiment, May and June moisture levels and growing degree days between 1994 and 1995 decreased dramatically (Appendix.5.A, Figs. 5A.7 and 5A.8). Part of the marked differences in performance between these two years is undoubtedly due to the absence of moisture. However, early application of defoliation is theoretically more likely to cause reductions in size and fecundity (Whitham et al. 1991, Harper, 1989). In the multiple event experiment, the later onset of clipping (June 14) in the first year and the earlier clipping onset (June 3) in the second year, would have been expected to moderate the effects of defoliation between years. That this did not occur suggests that most of the differences in flower head weight per clump between these years were attributable to moisture availability.

The geographical center of distribution of common tansy in north central Alberta and its absence in the drier southeast also lends supports to the argument that moisture sensitivity is an important restricting factor in this plant's development (Chapter 2). The harvest times at the end of the first year and their effect on *T. vulgare* performance in the subsequent years could be an important factor in annual differences. In the single event experiment, plants were harvested in the third week of September at the end of the first year. However, plants in the multiple event defoliation experiment were harvested in the first week of September. The early senescence of basal *T. vulgare* leaves and the presence of fall regrowth in this species indicated that allocation of carbohydrates to roots and rhizomes by current year's foliage could be minimal. Total non-structural root carbohydrate storage patterns (Chapter 3) indicate that the current year's growth in early September contributes far less to root and rhizome carbohydrate replenishment than does the June pre-flowerbud growth allocations. This is consistent with the assimilate partitioning patterns seen in Canada thistle (*Cirsium arvense*) under field conditions (Tworkoski, 1992). Under field conditions, more photoassimilate moved to the roots of Canada thistle at the bolt stage than at the bud, flower, or postflower stages.

In summary, these results suggest that the earlier clipping associated with the multiple defoliation experiment would appear to be more important than early fall harvesting in reductions in annual performance. Early clipping and/or fall harvesting could have a more profound effect on younger plants with less developed root systems. Roots and rhizomes of perennial herbaceous species without fall regrowth have been shown to retain storage functions for two to three years (Bradbury and Hofstra, 1977). If *T. vulgare* roots and rhizomes retain similar storage functions, then younger root systems would be less able to buffer the effects of defoliation. This factor could account for the more dramatic effects seen in the multiple defoliation experiment on the smaller streambank site plants.

While sexual reproduction of *T. vulgare* is negatively affected by defoliation the plant retains vegetative reproduction potential. Shoot numbers are maintained at the expense of height, vegetative biomass, flowers and flower head weight . This type of ordered response to herbivory, in which maintenance of vegetative potential of established individuals is favoured over seed production, has been demonstrated under field conditions for the perennial herb *Solidago altissima* (Compositae) (Root, 1996). This ordering has certain implications for the use of defoliators as a biological controls of *T. vulgare,* given the levels of defoliation required to produce reductions in vegetative shoots per plant in this experiment. High intensities of sustained defoliation would be required to influence sexual reproduction, with no associated effect on vegetative reproductive potential. The limited effect on vegetative potential would ensure the persistence of established populations and could only be expected to somewhat reduce spread to new habitats.

5.6 Conclusion

The response of common tansy to herbivory is shown to be highly conditional on the type of defoliation, natural habitat, and moisture and light availability. Sexual reproductive potential was significantly reduced by single frequency, high intensity defoliation and by multiple frequency, lower intensity defoliation. Multiple measures of plant performance were required to adequately characterize this response. Despite the widespread use of vegetative characteristics, such as height and the number of shoots, to characterize and measure response to herbivory in terrestrial plants, these vegetative differences in common tansy were not reliable measures of the effects of simulated herbivory on sexual reproductive response.

The potential for biological control of common tansy using a defoliating insect agent appears most promising for an agent that produces 50% or more damage to individual clumps over a six week period or which damages the plant at high levels (100%) in a single incidence defoliation, both prior to flower exposure. This type of defoliation would limit seed production and population expansion. Given the concerns regarding common tansy invasion of riparian habitats and the difficulty of controlling the plant in shaded environments (Chapter 2), the increased effect of simulated herbivory in a shaded riparian habitat suggests that control could be more effectively achieved in these areas. However, vegetative growth and spread appear to be only affected by catastrophic (100%) intensities of single incidence defoliation and an additional type of agent such as a rhizome or seed feeder would appear essential to the effective regulation of established populations. Monitoring insect- plant dynamics following introduction of an agent will require the measurement of multiple response variables in varied habitats.

This study re-emphasizes the need to examine a variety of individual plant characteristics, within natural plant populations, to adequately characterize plant response to herbivory. Furthermore, it demonstrates the plant growth and response characteristics of *T. vulgare* within natural habitats in Alberta. These characteristics highlight the factors responsible for the weedy potential of this plant and provide direction for research in the selection of a potentially successful biological control agent.

Table 5.1: Summary of Plant Performance Variables - Single Frequency Defoliation - 1993-1994. Mean and standard error values with n = 12 for three treatments in two habitats.

	Defoliation Treatment					
	0%		50%		100%	
Site and Year	Mean	SE	Mean	SE	Mean	SE
Stream bank - 1993						
Flower head Weight (g)	43.4a	6.7	34.5 a	6.3	13.5b	4.1
Total Vegetative Biomass (g)	184.8 a	30.0	149.3 a	23.2	109.5 b	15.1
Flower heads/clump	754 a	112	695 a	103	249 b	63
Shoots/clump	17 a	1	13a	2	12 b	1
Height (cm)	138.3	4.2	138.8	2.9	131.2	3.4
Stream bank - 1994						
Flower head Weight (g)	33.8 a	5.3	19.5 b	5.8	8.2 b	1.7
Total Vegetative Biomass (g)	166.5 a	23.2	113.4 a	24.7	65.6 b	13.3
Flower heads/clump	672a	105	453 a	137	178 b	38
Shoots/clump	21 a	2	20 a	7	11 b	2
Height (cm)	130.7	5.0	130.3	5.1	129.5	2.6
Roadside - 1993						
Flower head Weight (g)	43.5 a	8.1	32.9 a	4.6	14.4 b	2.0
Total Vegetative Biomass (g)	187.0 a	34.8	146.1 a	19.7	96.4 b	13.7
Flower heads/clump	1018 a	188	770 a	96	406 b	50
Shoots/clump	19 a	2	20 a	3	17 a	2
Height (cm)	128.3	4.6	123.08	2.7	112.3	5.2
Roadside - 1994						
Flower head Weight (g)	28.8 a	4.5	35.4 a	9.5	14.1 b	2.1
Total Vegetative Biomass (g)	149.4 a	26.2	174.3 a	52.7	87.0 b	11.1
Flower heads/clump	822 a	126	902 a	221	466 b	64
Shoots/clump	17 a	2	22 a	7	14 a	2
Height (cm)	139.3	135.1	135.1	4.1	141.1	3.1

Shaded values with different letters were significantly different using 95% Scheffe confidence intervals following One-way ANOVA.

Table 5.2: Repeated Measures Analysis of Variance - Single Frequency Defoliation - 1993-1994.

	Source of Variation											
	Treatment (df=2)			Site (df=1)			Year (df=1)			Site by Year (df=1)		
Variable	MS	F	p	MS	F	p	MS	F	p	MS	F	p
Flower head weight *	16.31	21.92	0.000	2.97	3.99	0.050	3.34	9.80	0.003	0.59	1.72	0.195
Vegetative biomass *	0.10	7.49	0.001	0.01	0.40	0.530	0.09	17.44	0.000	0.02	4.48	0.038
Flower heads per clump**	1466.6	17.01	0.000	1097.1	12.72	0.001	111.10	3.11	0.082	92.74	2.60	0.112
Shoots**	4.24	2.65	0.078	2.79	1.75	0.190	3.34	9.80	0.003	0.59	1.72	0.195
Height	146.31	0.66	0.520	957.80	1.75	0.042	453.13	2.85	0.096	4345.44	27.30	0.000

* Transformed data using log(x + 1)

** Transformed data using sqrt(x+0.375)

Note: treatment by site, treatment by years, and treatment by site by years interactions were non significant at α=0.05

Table 5.3: Summary of Plant Performance Variables - Multiple Frequency Defoliation and Root Severance - 1994-1995. Mean and standard error values with n = 12 for three treatments in two habitats.

	Defoliation and Severance Treatment							
	0%		Roots		50%		50% + Roots	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Stream bank - 1994								
Flower head Weight (g)	12.5 a	1.5	13.9 a	3.0	6.2 b	1.4	5.2 b	1.8
Total Veg. Biomass (g)	50.4 a	4.2	69.9 a	12.1	37.7 b	6.1	35.9 b	8.1
Flower heads/clump	273 a	36	377 a	86	170 b	42	175 b	59
Shoots/clump	9 a	1	10 a	1	8 a	1	7 a	1
Height (cm)	121.5a	3.2	120.8a	3.9a	106.6b	5.1	98.1b	7.5
Stream bank - 1995								
Flower head Weight (g)	3.7 a	0.7	5.0 a	1.8	1.6 b	0.7	1.1 b	0.5
Total Veg. Biomass (g)	27.6 a	4.1	32.6 a	10.5	18.2 b	4.6	11.5 b	3.3
Flower heads/clump	128 a	23	153 a	51	56 b	25	51 b	21
Shoots/clump	8 a	1	9 a	2	6 a	1	5 a	1
Height (cm)	110.8a	3.5	99.6a	9.4	89.1b	7.4	70.5b	7.4
Roadside - 1994								
Flower head Weight (g)	37.3 a	15.0	37.6 a	17.2	16.5 a	2.8	19.3 a	5.6
Total Veg. Biomass (g)	233.6 a	107.2	154.0 a	69.2	79.4 a	14.2	90.1 a	24.4
Flower heads/clump	997 a	347	868 a	420	511 a	108	588 a	143
Shoots/clump	18 a	5	10 a	3	10 a	1	10 a	2
Height (cm)	136.1a	5.7	137.2a	4.8	124.3a	5.0	121.1b	3.9
Roadside - 1995								
Flower head Weight (g)	19.4 a	7.4	14.3 a	8.0	6.0 a	1.8	6.3 a	2.6
Total Veg. Biomass (g)	77.2 a	35.6	31.7 a	8.9	41.2 a	12.5	40.5 a	16.5
Flower heads/clump	730 a	328	581 a	405	199 a	56	264 a	106
Shoots/clump	17 a	6	11 a	5	8 a	1	10 a	2
Height (cm)	121.5a	3.2	120.8a	3.9	106.6a	5.2	98.1a	7.5

Shaded values with different letters were significantly different using 95% Scheffe confidence intervals following One -way ANOVA.

Table 5.4: Repeated Measures Analysis of Variance - Multiple Frequency Defoliation and Root Severance- 1994-1995.

	Source of Variation											
	Treatment (df=3)			Site (df=1)			Year (df=1)			Site by Year (df=1)		
Variable	MS	F	p	MS	F	p	MS	F	p	MS	F	p
Flower head weight*	7.70	5.07	0.003	39.54	26.06	0.000	51.00	230.72	0.000	0.07	0.32	0.574
Vegetative biomass*	3.87	2.28	0.085	484.84	2.32	0.081	52.97	168.29	0.000	0.02	0.05	0.815
Flower heads per clump**	484.81	2.32	0.081	2437.01	211.26	0.000	2437.01	211.26	0.000	47.63	4.13	0.045
Shoots**	3.87	1.64	0.186	10.67	4.51	0.036	4.40	15.53	0.000	0.11	0.40	0.531
Height	5924.09	7.98	0.000	9228.82	12.43	0.001	24697.06	117.86	0.000	634.91	3.03	0.085

* Transformed data using log(x + 1)

** Transformed data using sqrt(x+0.375)

Note: treatment by site, treatment by years, and treatment by site by years interactions were non significant at α=0.05

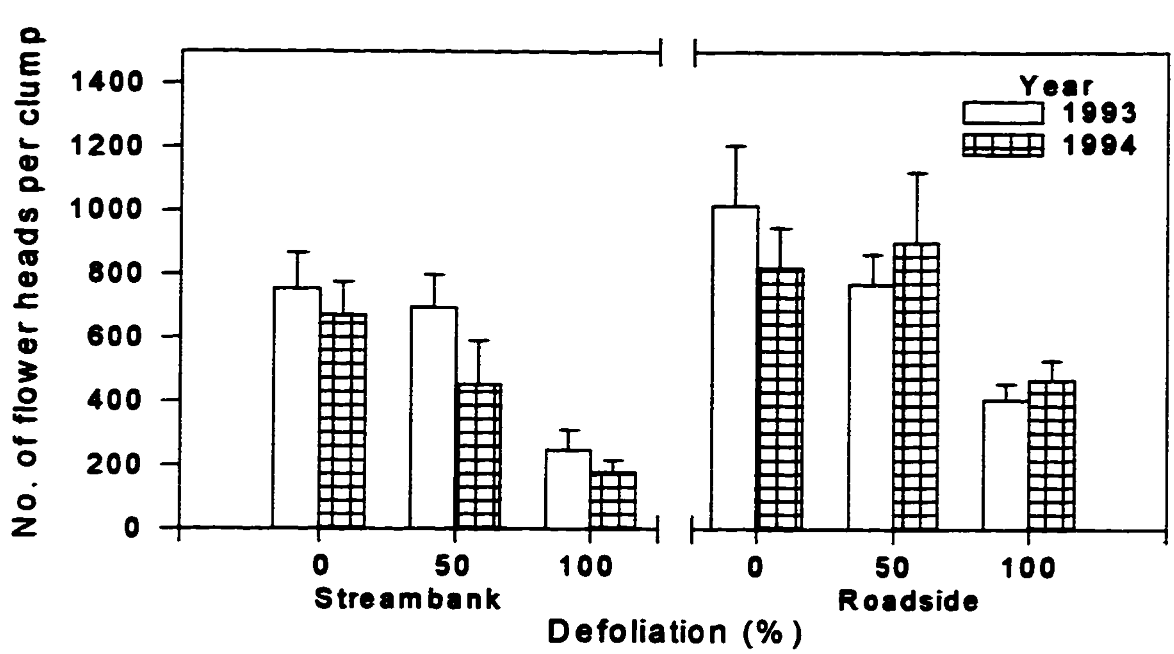

Fig. 5.1: Mean flower heads per clump for single frequency, defoliation in two habitats during 1993-94 (n=12, Error bars are + 1 SE of the mean).

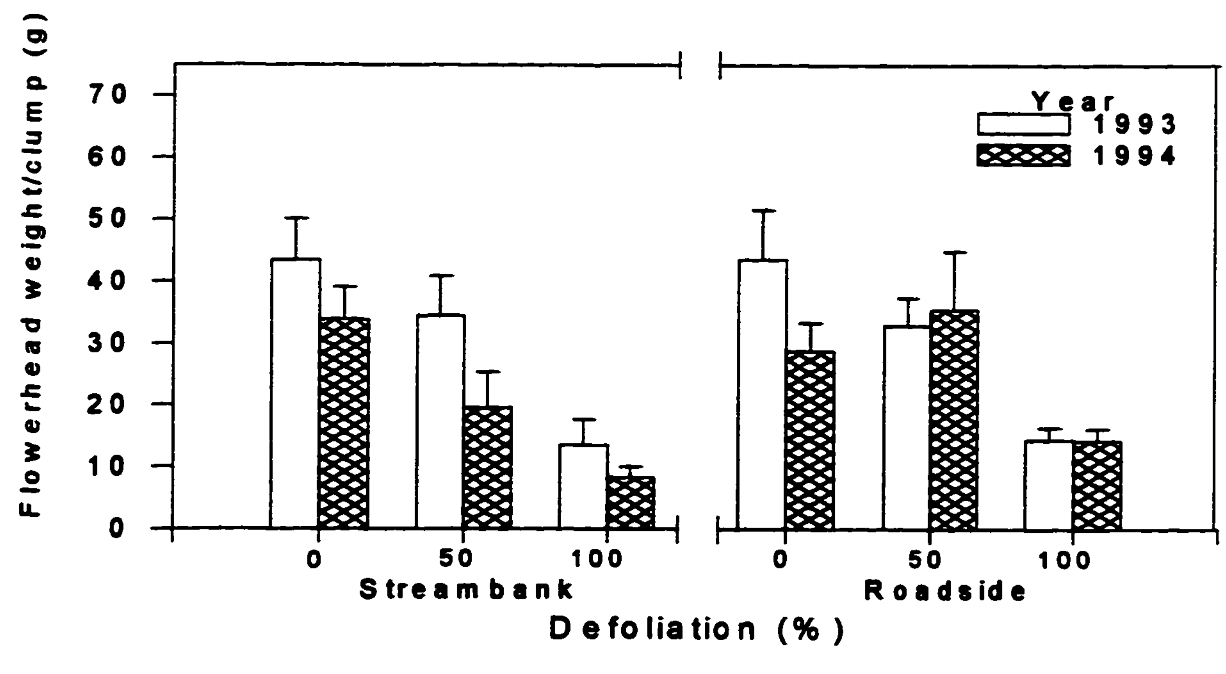

Fig. 5.2: Mean flower head weight per clump for single frequency, defoliation in two habitats during 1993-94 (n=12,Error bars are + 1 SE of the mean).

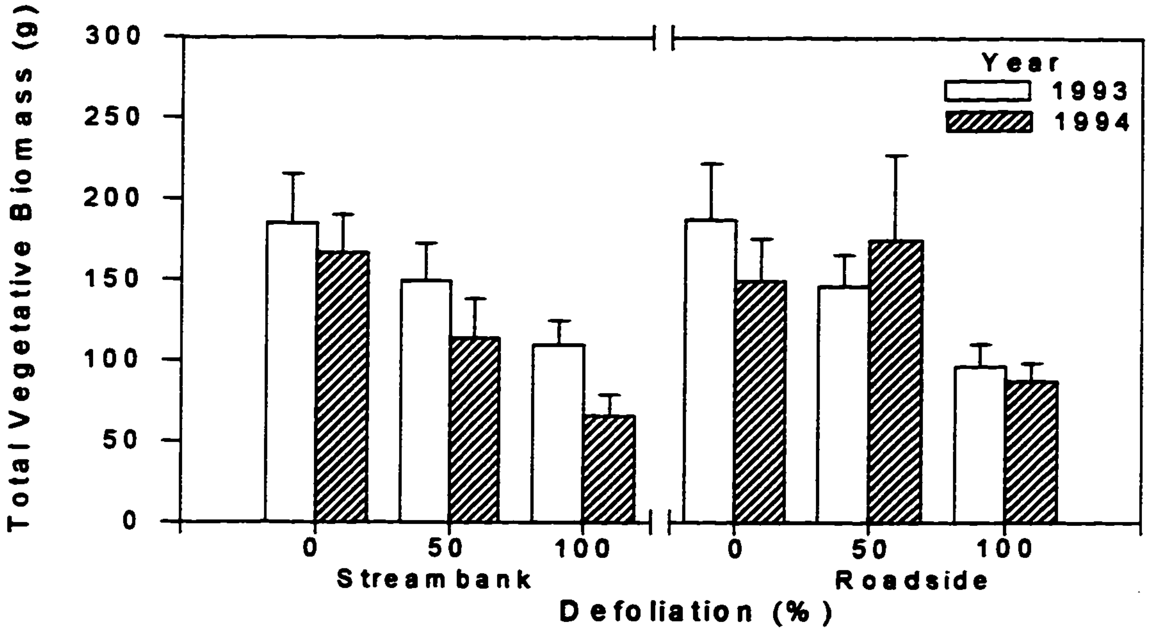

Fig. 5.3: Mean total vegetative biomass per clump for single frequency defoliation in two habitats during 1993-94 (n=12, Error bars are + 1 SE of the mean).

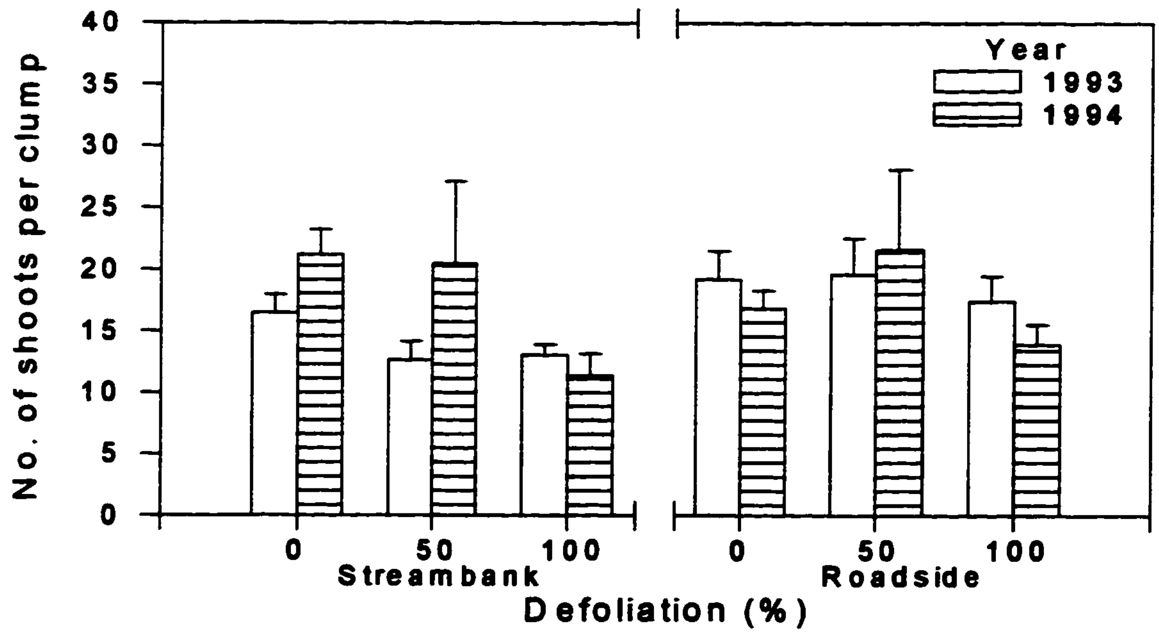

Fig.5.4: Number of shoots per clump for single frequency, defoliation in two habitats during 1993-94 (n=12, Error bars are + 1 SE of the mean).

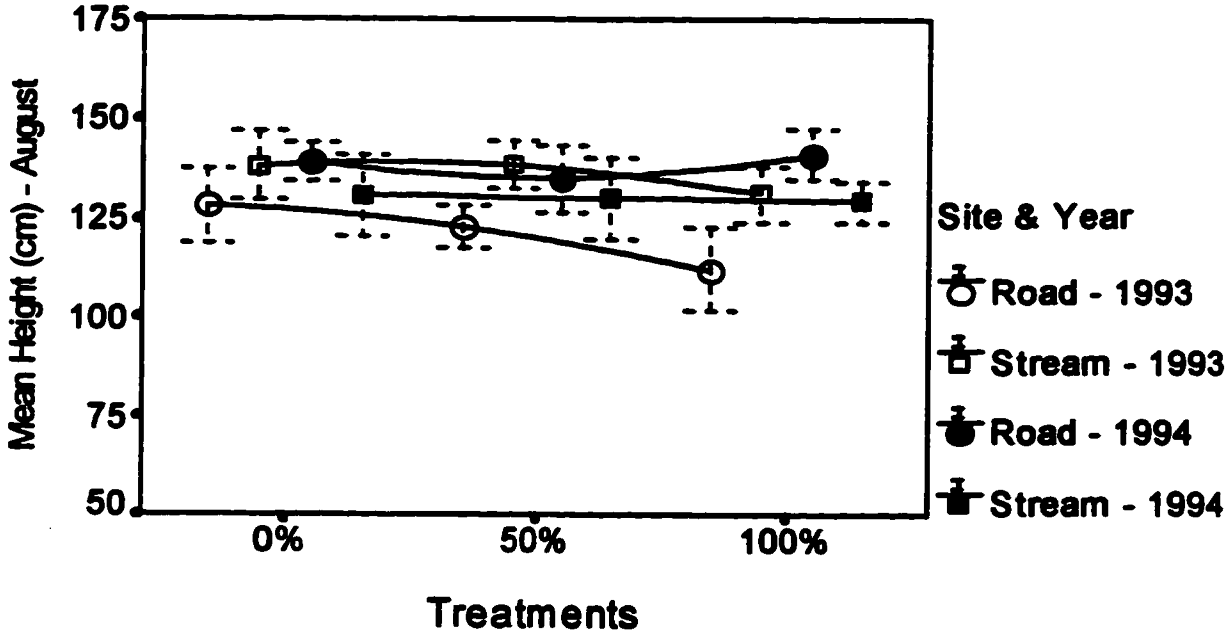

Fig. 5.5: Mean maximum height per clump for single frequency, varied intensity defoliation in two habitats during 1993-94 (n=12, Error bars are ± 1 SE of the mean).

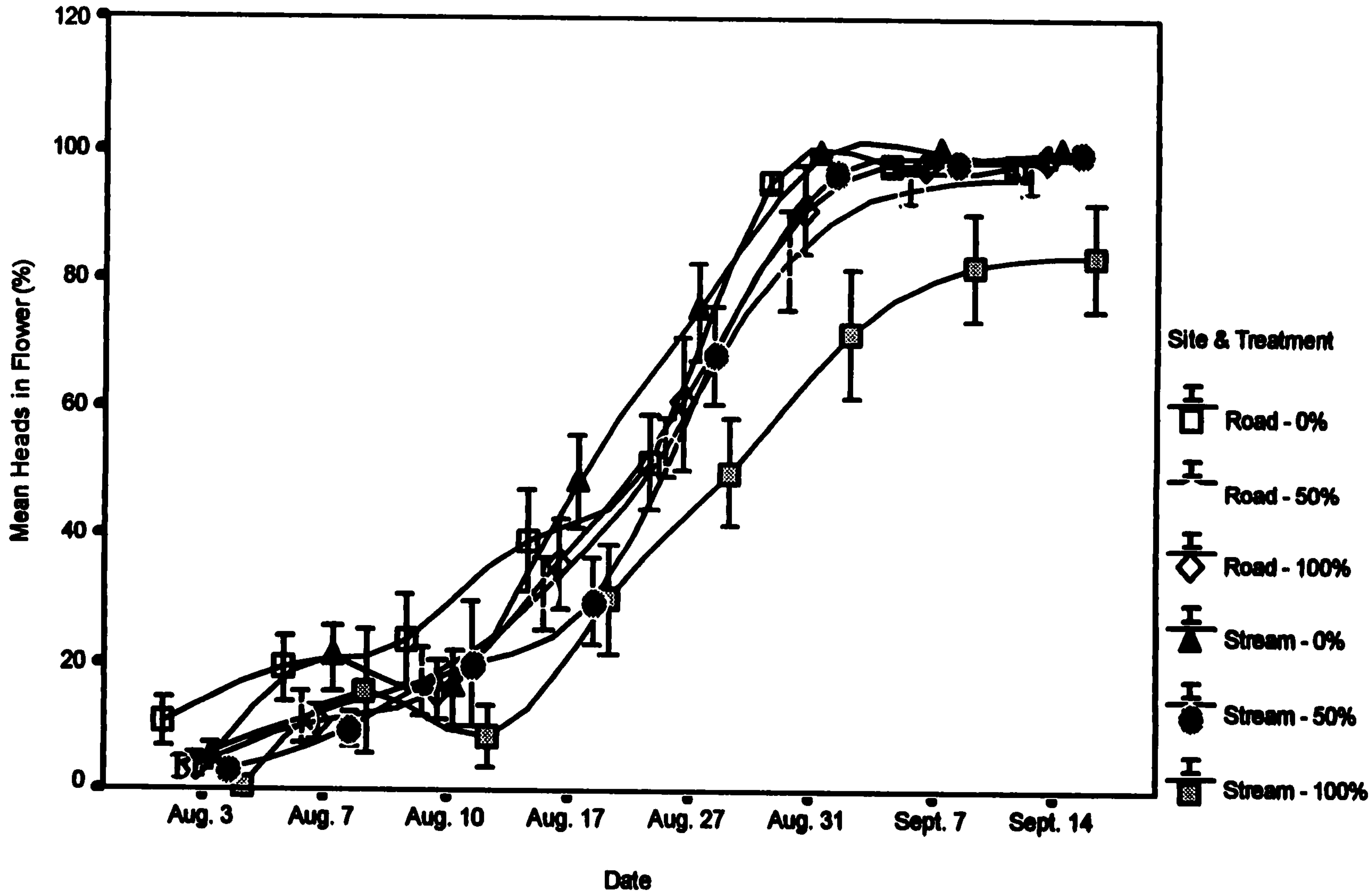

Fig. 5.6: Mean percentage of flower heads in flower for single frequency, varied intensity defoliation in two habitats during 1993 (n=12, Error bars are ± 1 SE of the mean).

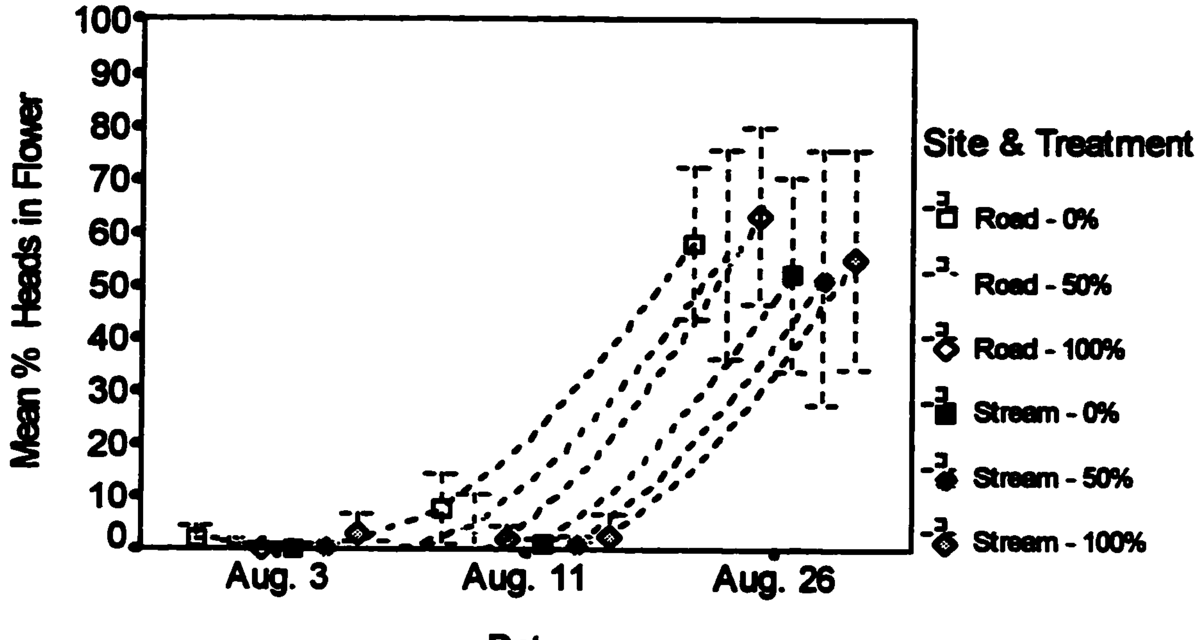

Fig. 5.7: Percentage of flower heads in flower for single frequency, varied intensity defoliation in two habitats during 1994 (n=12, Error bars are ±

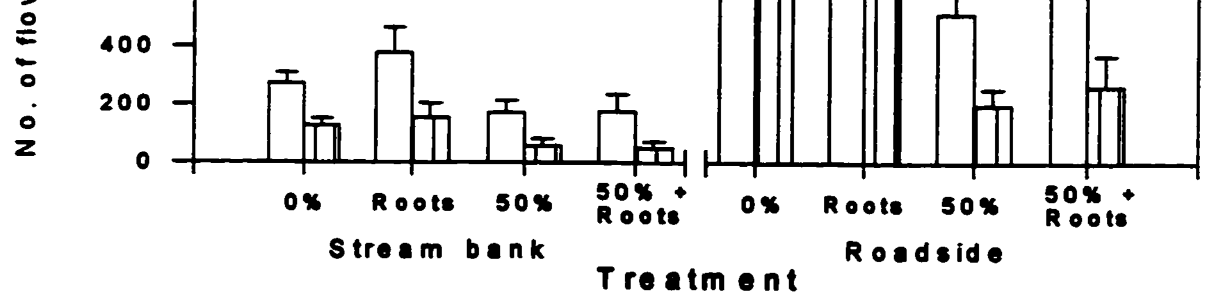

Fig. 5.8: Number of flower heads per clump for multiple frequency defoliation and root severance in two habitats during 1994-95 (n=12, Error bars are + 1 SE of the mean).

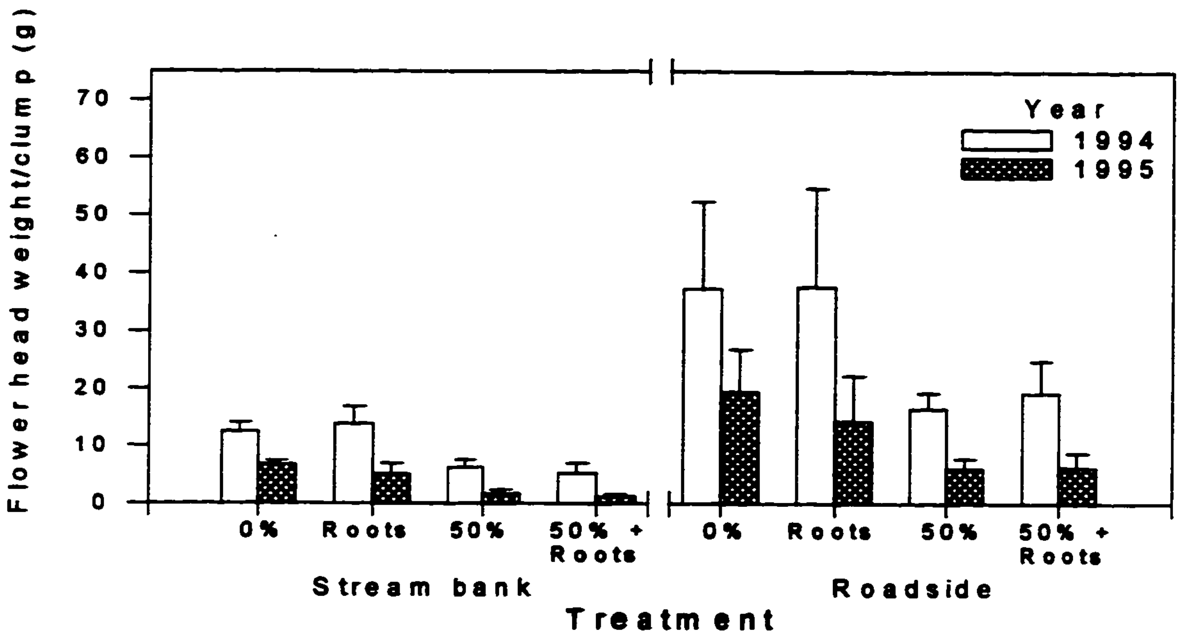

Fig. 5.9: Mean flower weight per clump for multiple frequency defoliation and root severance in two habitats during 1994-95 (n=12, Error bars are + 1 SE of the mean).

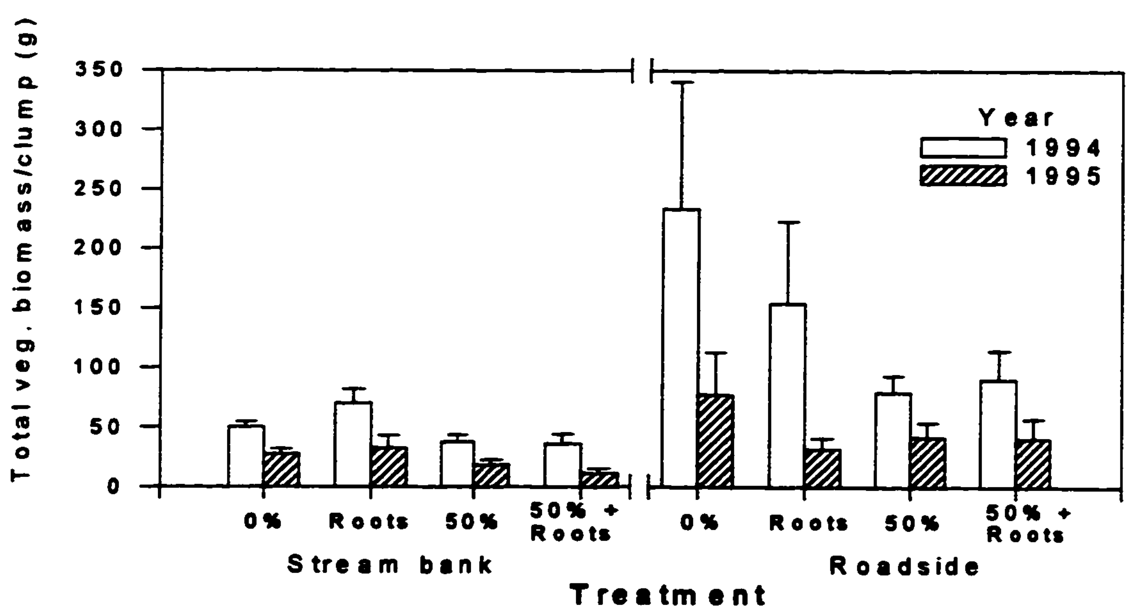

Fig. 5.10: Mean vegetative biomass per clump for multiple frequency defoliation and root severance in two habitats during 1994-95 (n=12, Error bars are + 1 SE of the mean).

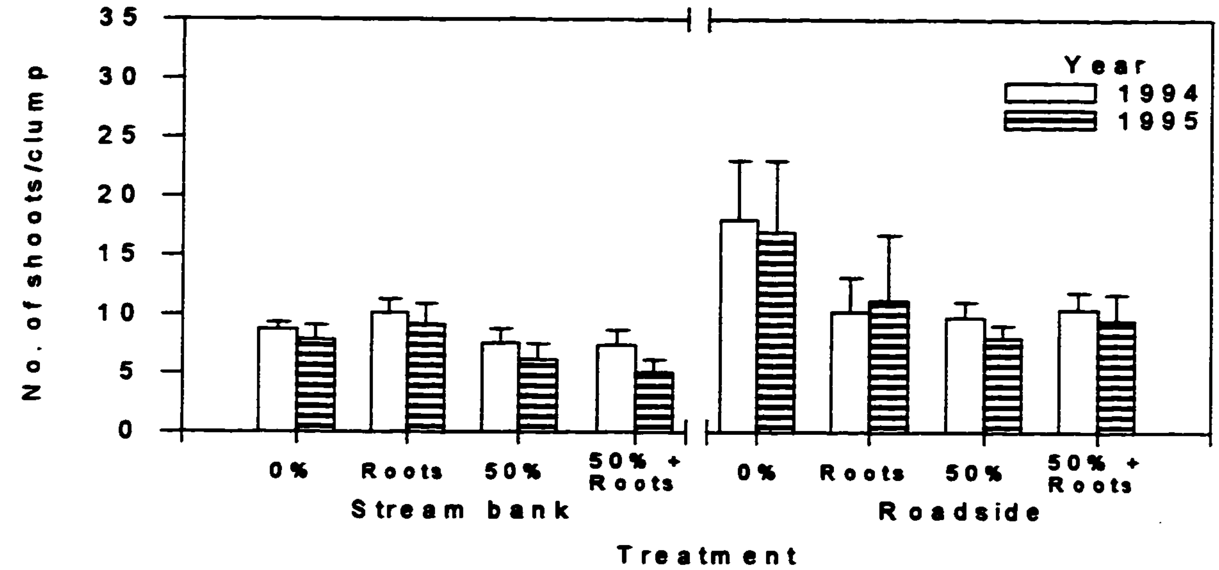

Fig. 5.11: Number of shoots per clump for multiple frequency defoliation and root severance in two habitats during 1994-95 (n=12, Error bars are + 1 SE of the mean).

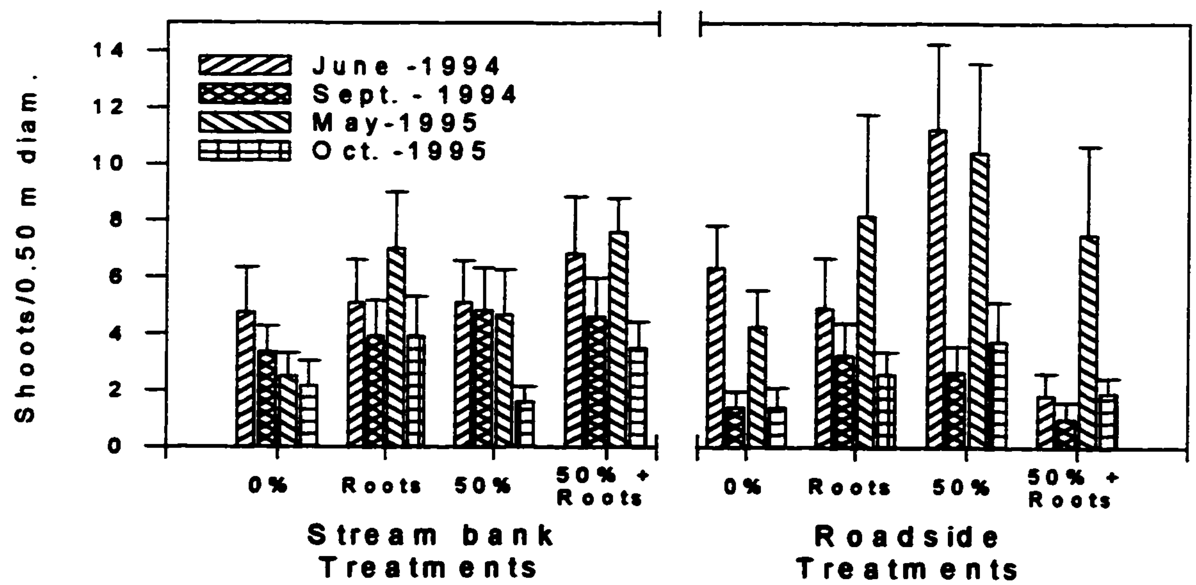

Fig. 5.12: Mean number of shoots (per 0.50 m diam. around clumps) for multiple frequency defoliation and root severance in two habitats - early and late sea, 1994-95 (n=12, Error bars are + 1 SE of the mean).

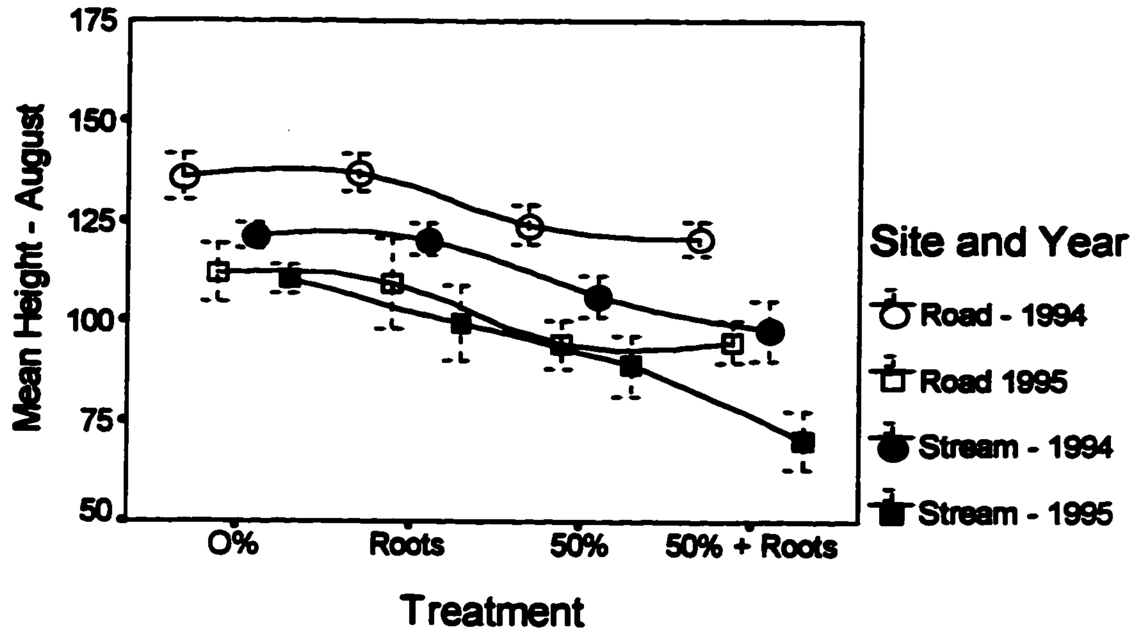

Fig. 5.13: Mean maximum height per clump for multiple frequency defoliation and root severance in two habitats during 1994-95 (n=12, Error bars are ± 1 SE of the mean).

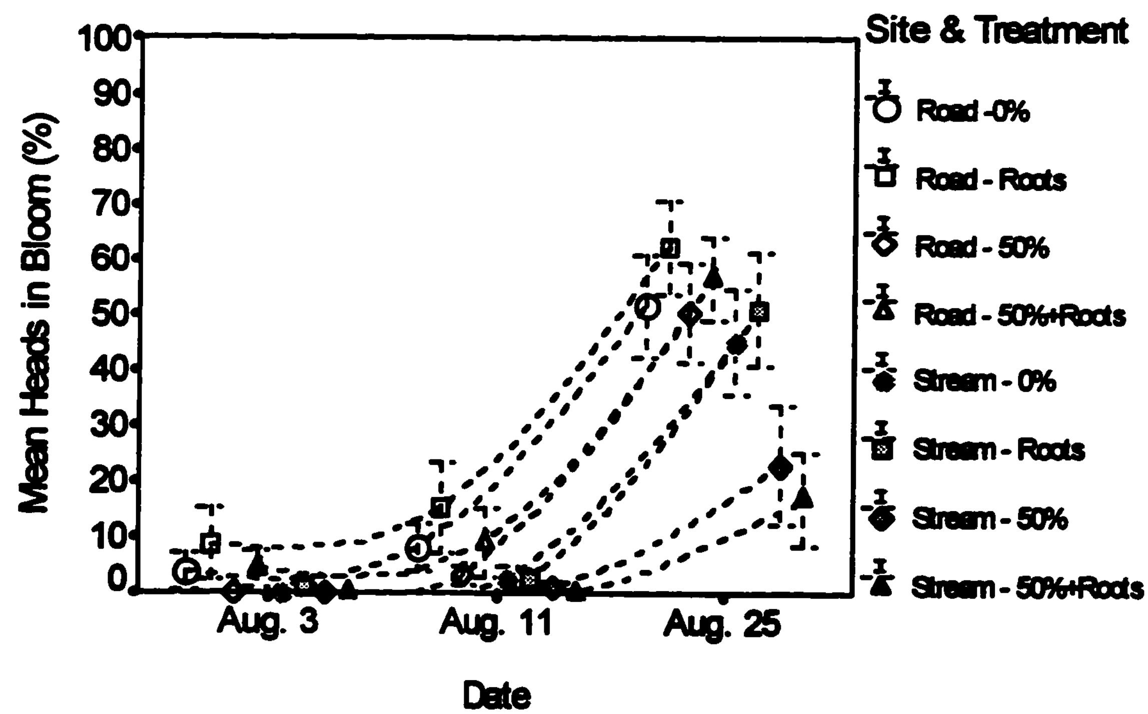

Fig. 5.14: Mean percentage of fully developed flower heads for multiple frequency, low intensity defoliation and root severance in two habitats during 1994 (n=12, Error bars are ± 1 SE of the mean).

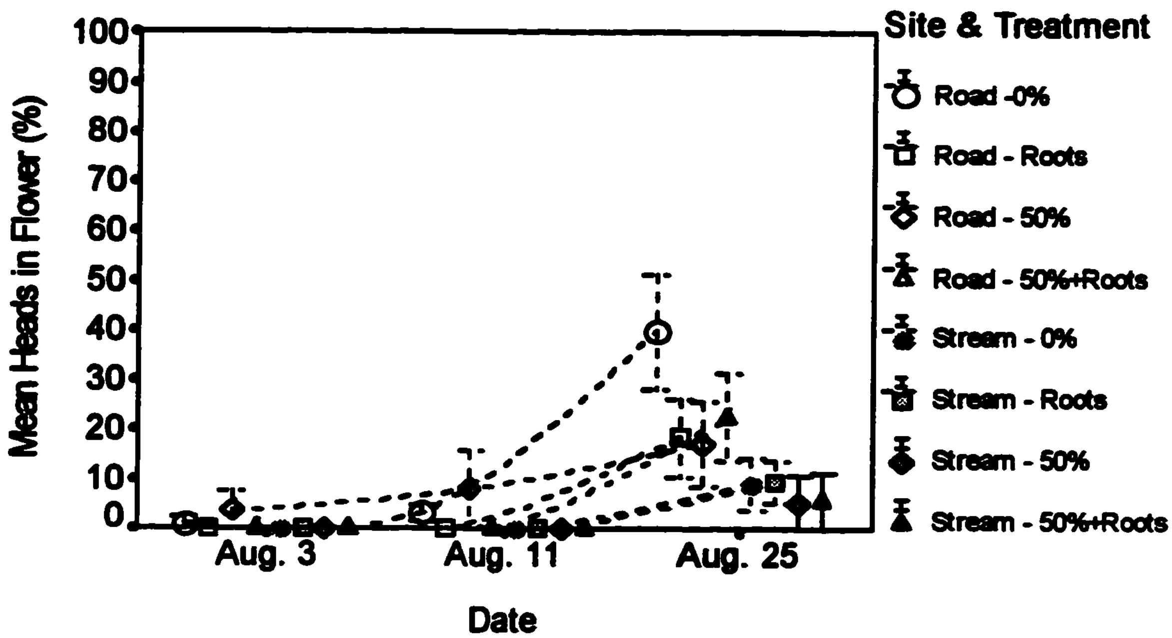

Fig. 5.15: Mean percentage of fully developed flower heads for multiple frequency defoliation and root severance in two habitats during 1995 (n=12, Error bars are ± 1 SE of the mean).

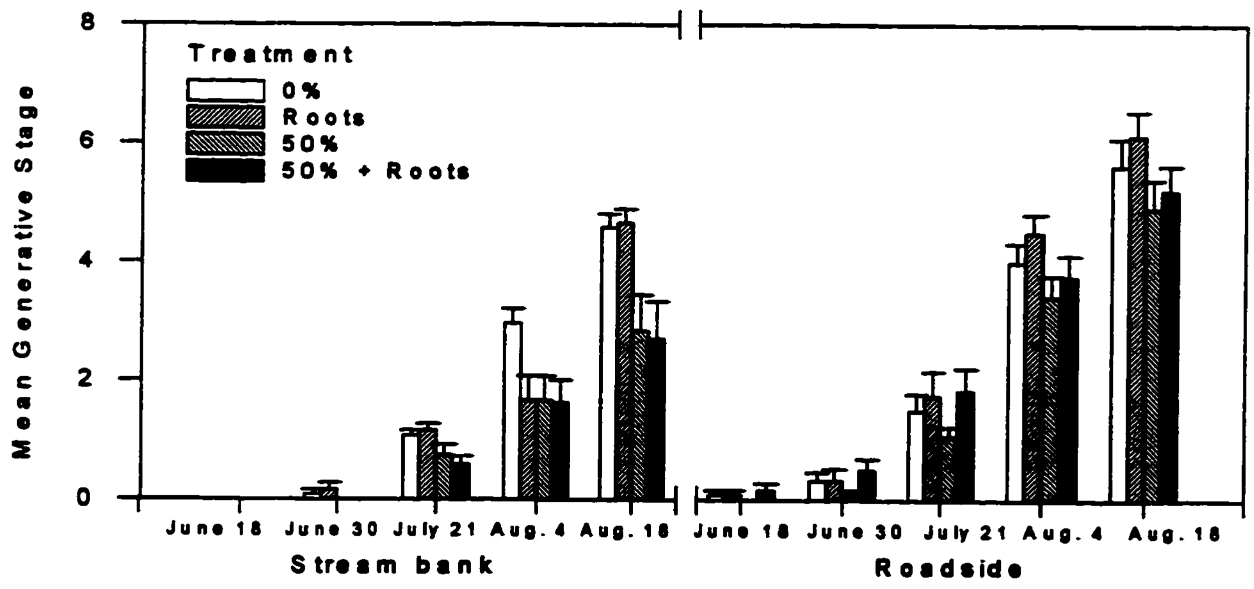

Fig. 5.16: Mean generative phenotypic stages for multiple frequency defoliation and root severance in two habitats during 1994. Stage 2=Buds strongly swollen, 4=Beginning bloom, 6=Greater than 50% bloom (n=12, Error bars are + 1SE of mean).

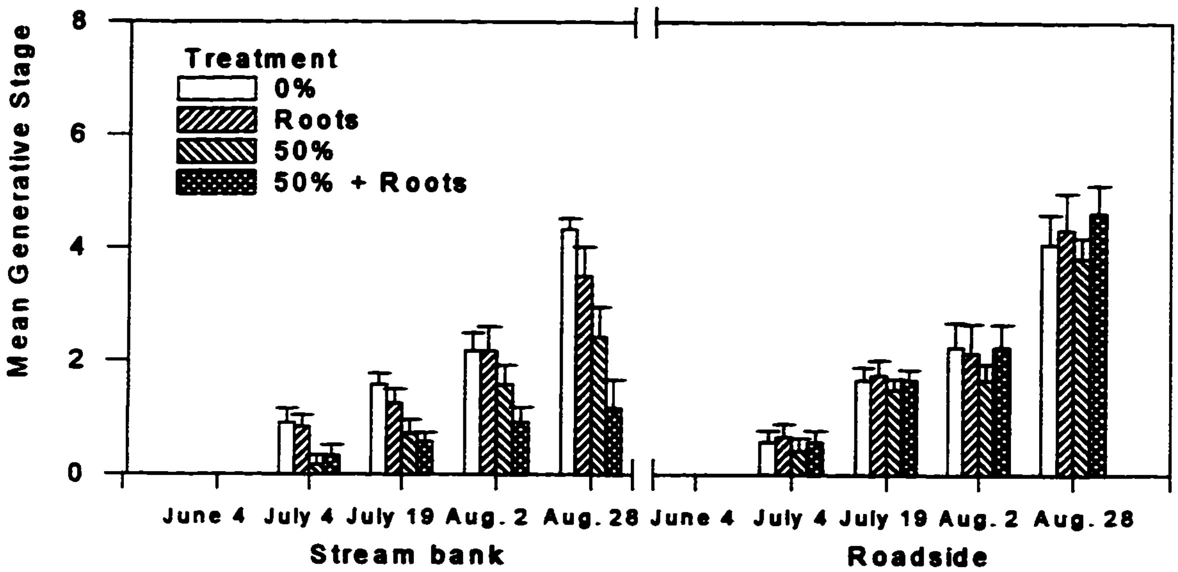

Fig. 5.17: Mean generative phenotypic stages for multiple frequency defoliation and root severance in two habitats during 1995. Stage 2=Buds strongly swollen, 4=Beginning bloom, 6=Greater than 50% bloom (n=12, Error bars are + 1SE of mean).

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Appendix 5.A: Site characterization data

Table 5A.1: List of Identified Plant Species by Habitat:

Roadside Habitat		Streambank Habitat	
Family and Species	Common name	Family and Species	Common name
Betulaceae		**Betulaceae**	
Corylus comuta	Beaked hazelnut	*Corylus comuta*	Beaked hazelnut
Caprifoliaceae		**Caprifoliaceae**	
Lonicera dioica	Twining honeysuckle	*Lonicera dioica*	Twining honeysuckle
		Symphoricarpos sp.	Buck brush
Caryophyllaceae			
Stellaria sp.	Chickweed sp.		
Chenopodiaceae			
Chenopodium album	Lamb's quarters		
Compositae		**Compositae**	
Taraxacum officinale	Common dandelion	*Senecio pauperculus*	Balsam groundsel
Sonchus arvensis	Perennial sow thistle	*Aster sp.*	Aster
Sonchus oleraceus	Common sow thistle	*Sonchus arvensis*	Perennial sow thistle
Hieracium umbellatum	Narrow-leaved hawksbeard	*Sonchus oleraceus*	Common sow thistle
Cirsium arvense	Canada thistle	*Taraxacum officinale*	Common dandelion
Senecio vulgaris	Common groundsel		

Table 5A.1: List of Identified Plant Species by Habitat (continued)

Roadside Habitat		Streambank Habitat	
Family and Species	Common name	Family and Species	Common name
Senecio eremophilus	Cut-leaved ragwort		
Solidago canadensis	Canada goldenrod		
Aster ciliolatus	Fringed aster		
Cruciferae		**Cruciferae**	
Capsella bursa-pastoris	Shepherd's purse	*Erysimum cherianthoides*	Wormseed mustard
Cyperaceae		**Cyperaceae**	
Carex crawfordii	Crawford's sedge	*Carex viridula*	Green sedge
Carex sp.	Sedge sp.	*Carex media*	Norway sedge
		Carex bebbii	Bebb's sedge
		Juncus nodosus	Knotted rush
		Juncus alpinus	Alpine rush
		Scirpus microcarpus	Small-fruited bullrush
		Carex crawfordii	Crawford's sedge
		Carex deweyana	Dewey's sedge
Equisetaceae			
Equisetum arvense	Common horsetail	*Equisetum arvense*	Common horsetail
Gentianaceae		*Equisetum sylvaticum*	Woodland horsetail
Gentianella amarella	Northern gentian		

Table 5A.1: List of Identified Plant Species by Habitat (continued)

Roadside Habitat		Streambank Habitat	
Family and Species	Common name	Family and Species	Common name
Grossulariaceae		**Grossulariaceae**	
Ribes oxycanthoides	Northern gooseberry	*Ribes oxycanthoides*	Northern gooseberry
Gramineae			
Agropyron repens	Quack grass	*Agropyron trachycaulum*	Slender wheatgrass
Agropyron trachycaulum	Slender wheatgrass	*Poa palustrus*	Fowl bluegrass
Bromus inermis	Northern brome	*Calamagrostis canadensis*	Marsh reed grass
Festuca sp.	Fescue sp.	*Glyceria grandis*	Tall manna grass
Koeleria sp.	June grass sp.	*Phalarus arundinacea*	Reed canary grass
Phalaris arundinacea	Reed canary grass	*Bromus ciliolatus*	Hairy brome
Phleum pratense	Timothy	*Beckmania syzigachne*	Slough grass
Poa pratensis	Kentucky bluegrass		
Labiatae		**Labiatae**	
Agastache foeniculum	Giant hyssop	*Mentha arvensis*	Wild mint
Mentha arvensis	Wild mint	*Scutellaria galericulata*	Marsh skullcap
Dracocephalum sp.	Dragonhead sp.	*Urtica dioca*	Stinging nettle
		Galeopsis tetrahit	Hemp nettle

Table 5A.1: List of Identified Plant Species by Habitat (continued)

Roadside Habitat		Streambank Habitat	
Family and Species	Common name	Family and Species	Common name
Leguminoseae		**Leguminoseae**	
Vicia americana	Wild vetch	*Vicia americana*	Wild vetch
Lathyrus ochroleucus	Creamy peavine		
Medicago sativa	Alfalfa		
Trifolium repens	White clover		
Onagraceae		**Onagraceae**	
Epilobium augustifolium	Fireweed	*Epilobium augustifolium*	Fireweed
		Orchidaceae	
		Listera cordata	Heart-leaved twayblade
Plantaginaceae			
Plantago major	Common plaintain		
		Polemoniaceae	
		Collomia linearis	Narrow-leaved collomia
		Polygonaceae	
		Polygonum lapathifolium	Pale persicaria

Table 5A.1: List of Identified Plant Species by Habitat (continued)

Roadside Habitat		Streambank Habitat	
Family and Species	Common name	Family and Species	Common name
Rosaceae		**Rosaceae**	
Fragaria sp.	Wild strawberry	*Fragariia sp.*	Wild strawberry
Rosa acicularis	Prickly rose	*Rosa acicularis*	Prickly rose
Rubus idaeus	Wild red raspberry	*Rubus idaeus*	Wild red raspberry
		Potentilla norvegica	Rough cinquefoil
		Geum aleppicum	Yellow avens
Rubiaceae		**Rubiaceae**	
Galium boreale	Northern bedstraw	*Galium boreale*	Northern bedstraw
Umbelliferae		**Umbelliferae**	
Heracleum inanatum	Cow-parsnip	*Sium sauve*	Water parsnip
Moss sp.		*Moss sp.*	
		Moss sp.	
Trees and shrubs		**Trees and Shrubs**	
Populus balsamifera	Balsam popular (saplings)	*Salix sp.*	Willow

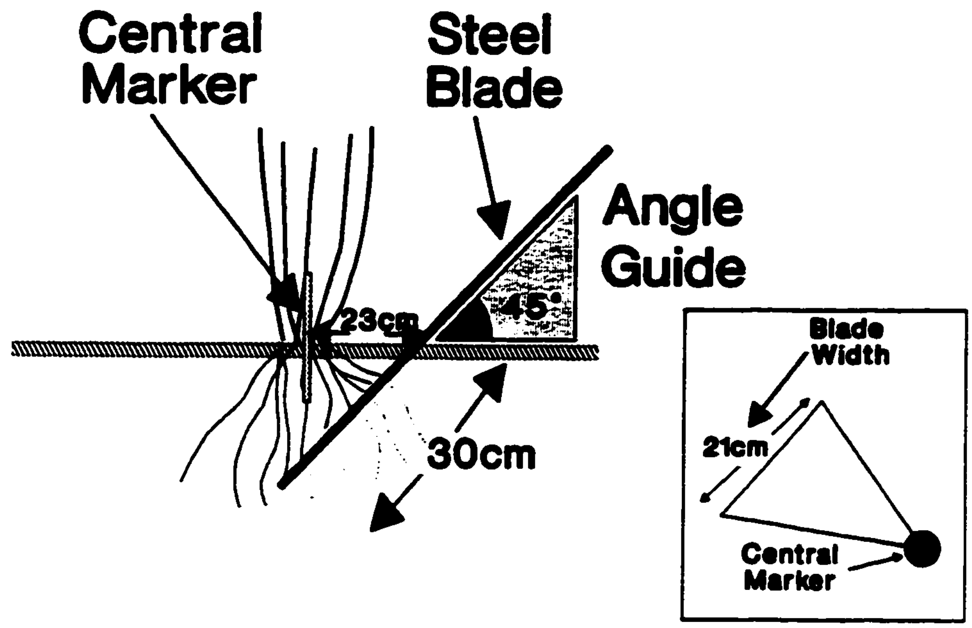

Fig. 5A.1 : Illustrated root severance technique.

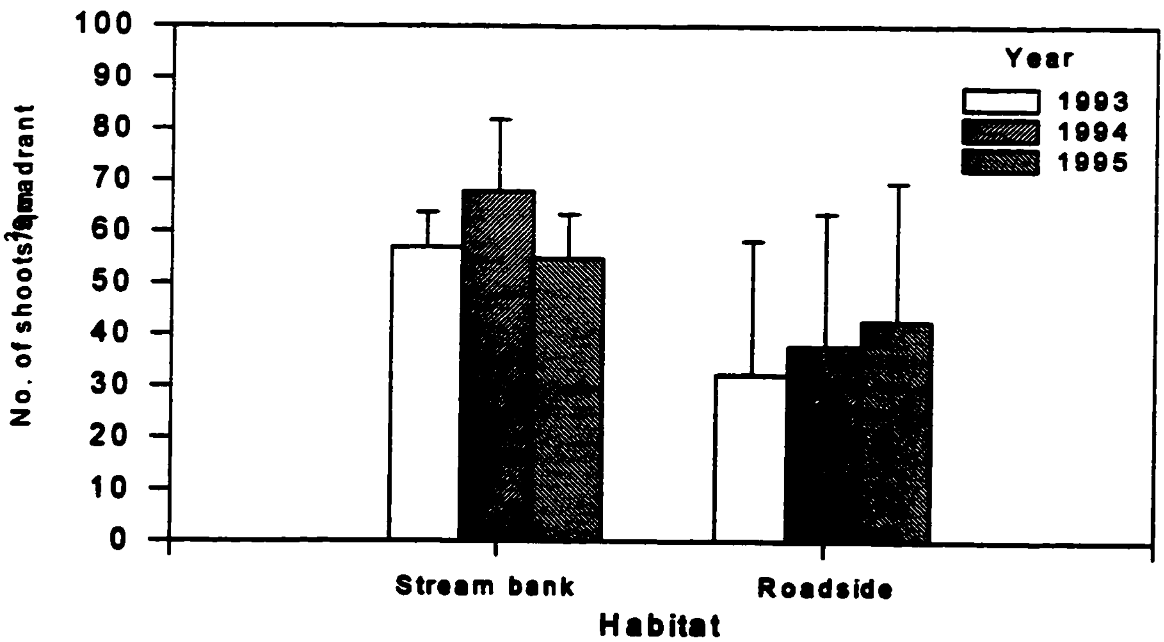

Fig. 5A.2: Mean Number of *Tanacetum vulgare* shoots per $9m^2$ quadrant in two habitats during 1993 -1995. (Error bars are + 1SE of the mean)

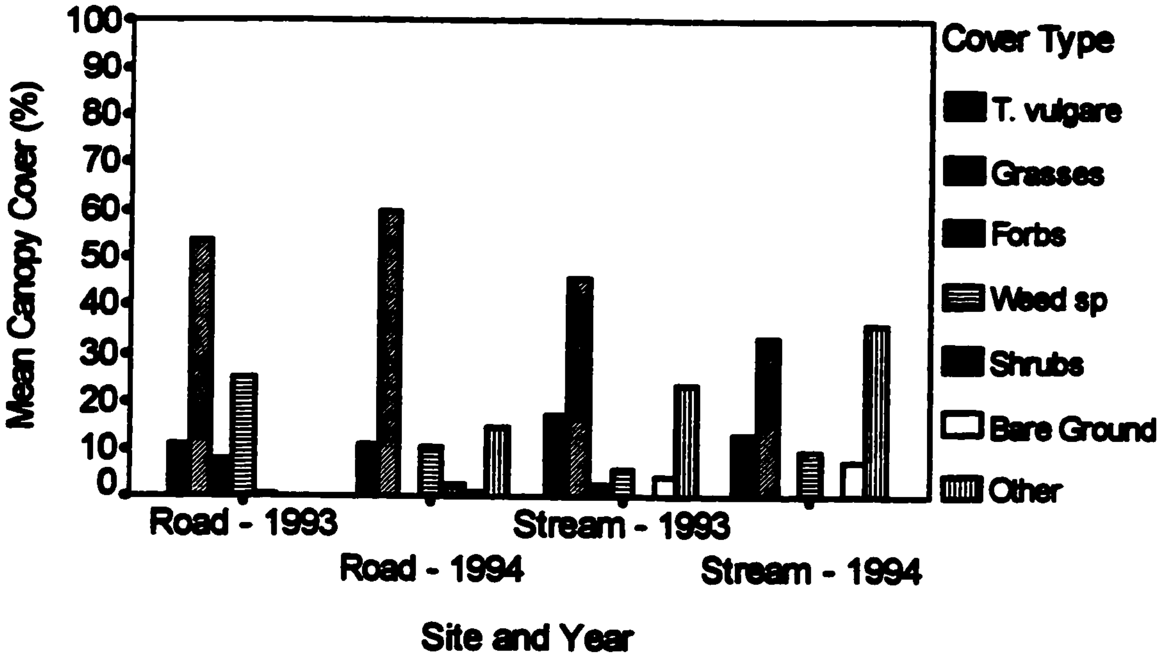

Fig. 5A.3: Mean canopy cover (%) in five $9m^2$ quadrants in two habitats during 1993-94

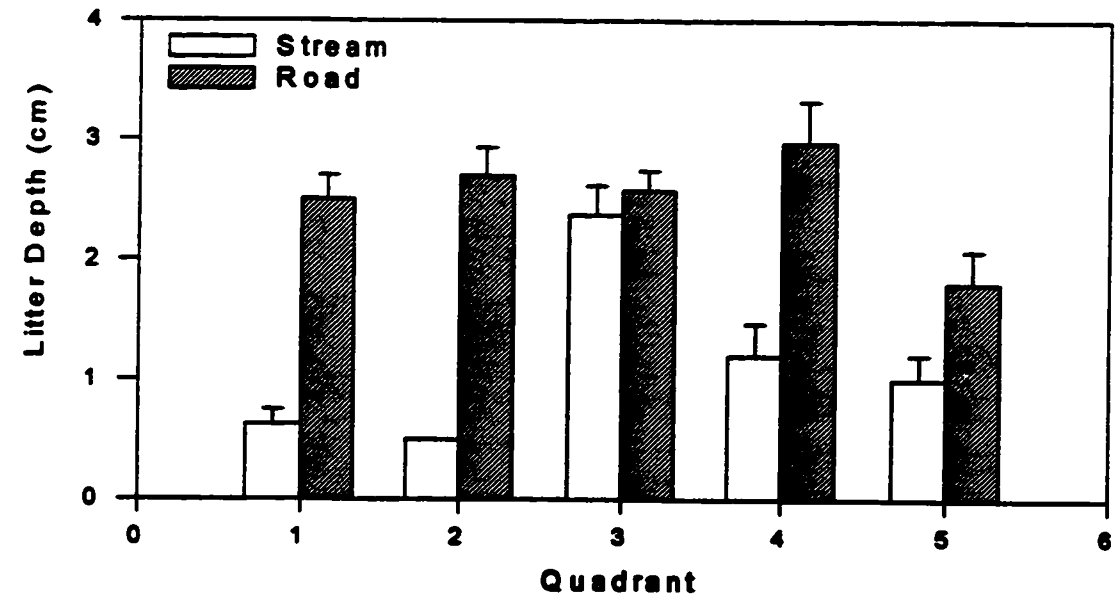

Fig. 5A.4: Mean litter depth (cm) in four $0.25m^2$ quadrants sub-sampled from five 9 m^2 quadrants in two habitats during 1995 (Error bars are + 1SE of the mean).

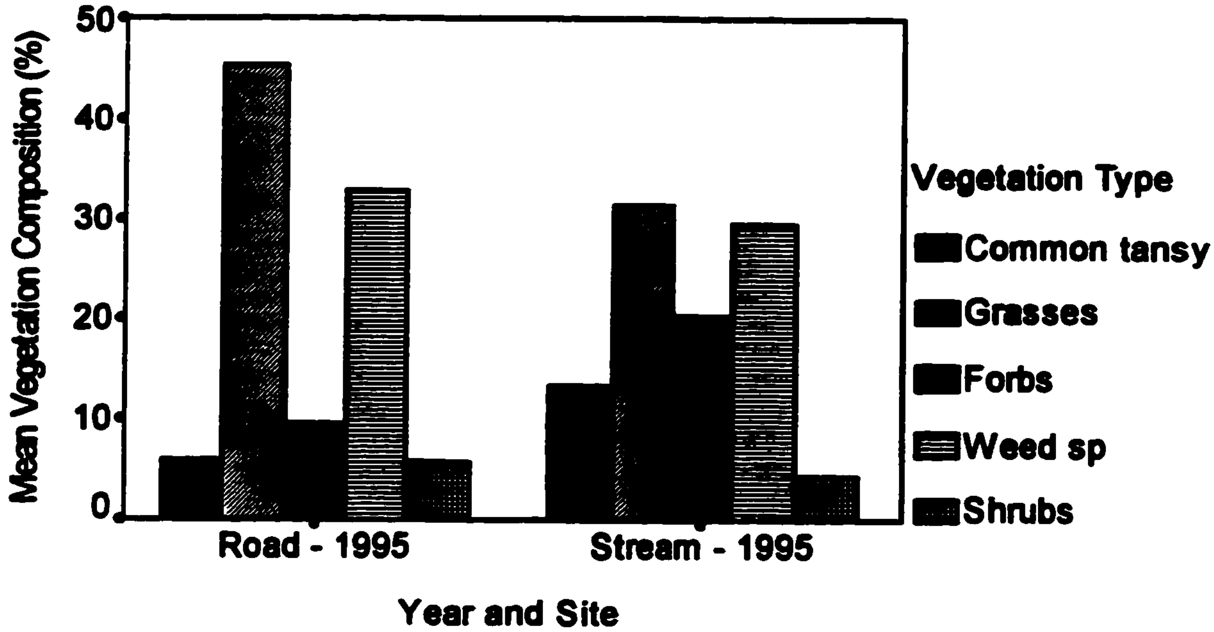

Fig. 5A.5: Mean vegetation composition (%) in two habitats - 1995 (n=10 0.25m^2 quadrants).

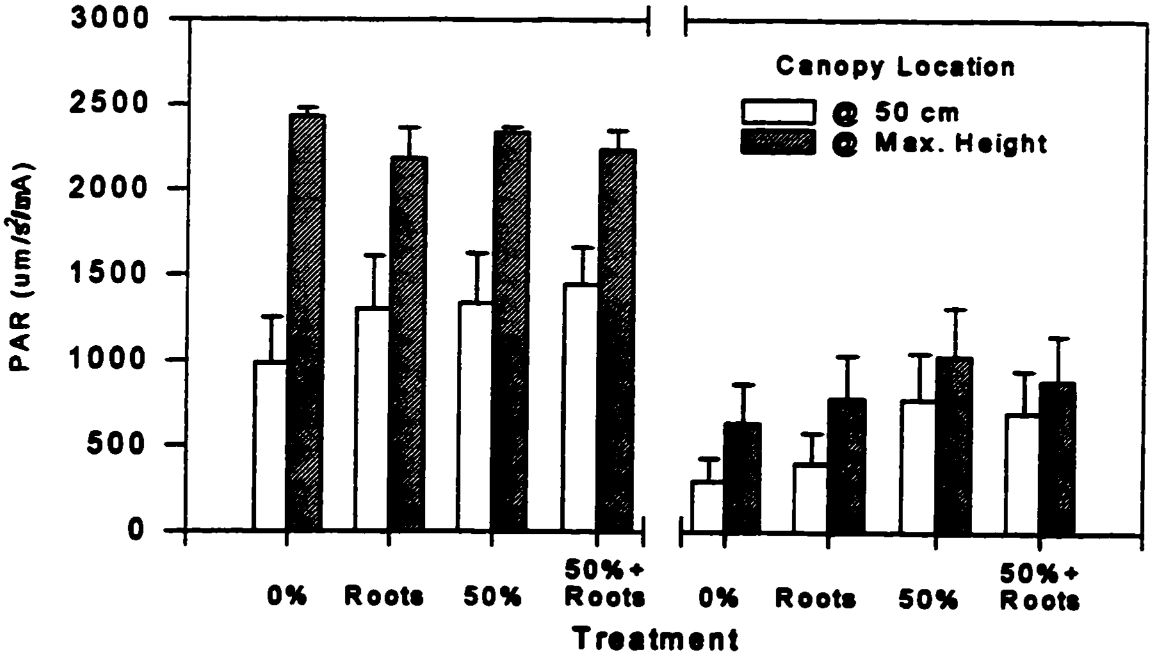

Fig. 5A.6: Photosynthetically Active Radiation (PAR) at maximum canopy height for all treatment groups in two habitats during 1995 (n=12, Error bars are + 1 SE of the mean).

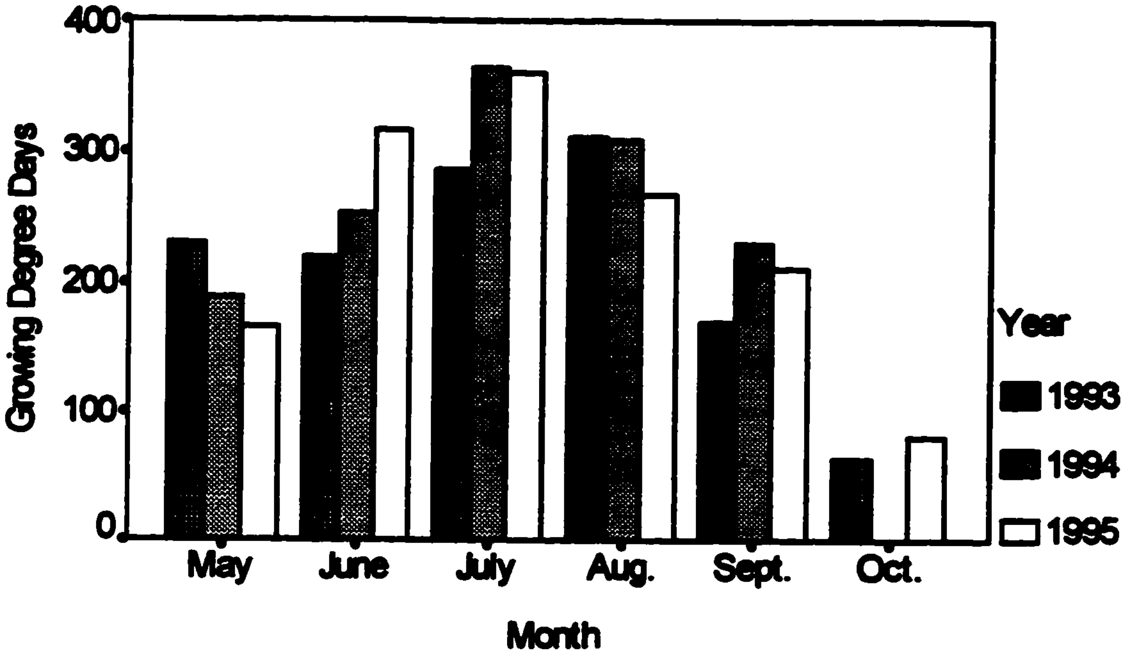

Fig. 5A.7: Growing Degree days for George Lake Site during 1993 - 1995. (Growing degree day = one degree of deviation, on a single day, from 5°C)

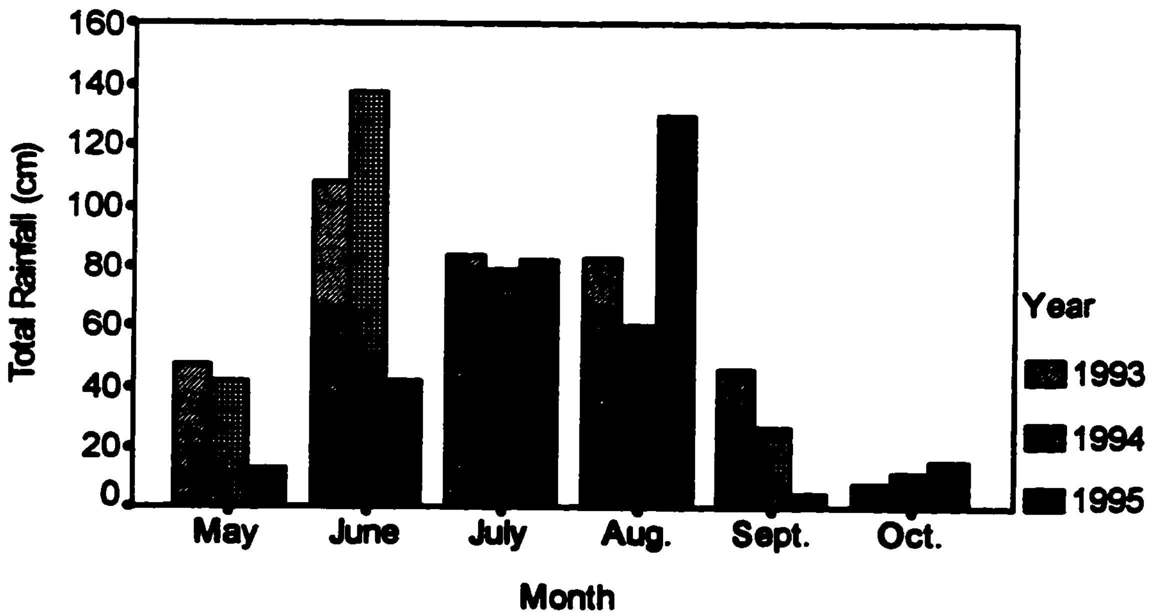

Fig. 5A.8: Total monthly rainfall 1993 - 1995 at George Lake, AB.

6. Conclusion

6.1 The problem, patterns and prospects.

Pest control management in agriculture is affected by decisions made by government agencies, chemical firms, marketing organizations, and farmers. The foundation of improved decision making in this system is accurate assessment of the nature of problems (Norton and Mumford, 1983). If classical biological control is to be a successful part of the solution to pest problems then, as Waage (1990) recognized, existing approaches to biological agent selection, both reductionist and holistic, require reorientation away from static niche-based perspectives towards more dynamic and integrated approaches. This thesis research has examined both the problem and the underlying characteristics of *T. vulgare*, in a variety of habitats, to provide groundwork for selection of agents and monitoring of population interactions between control agents and weed populations.

The problem for agricultural producers of Alberta, as identified in this study, is the persistent and increasing colonization of pasture and hay habitats by *T. vulgare*. In addition, the proportionally greater high-density areas of *T. vulgare* reported in riparian habitats serve as continued sources of re-infestation and result in serious native habitat displacement (Chapter 3). The limited effectiveness of conventional herbicide and cultural control methods and the environmental risks associated with these methods, (toxicity and erosion in areas of high infestation), prompt recommendations for alternative control measures.

Although European morphological descriptions of the plant and the information available about growth characteristic are consistent with those observed experimentally in Alberta, *T. vulgare* exhibits traits common in most successful weed species. It is a plastic perennial which grows quickly, flowers early in its life span, produces many seeds which are easily dispersed, reproduces vegetatively, and is a good competitor (Baker, 1965). As such, the high plasticity of the plant makes the measurement of a combination of plant performance characteristics essential to adequately monitor the response of the plant to control efforts. Stem diameter, plant height, total vegetative biomass, and the number of vegetative shoots per clump would be required to adequately monitor changes in plant vegetative performance. Large scale changes in reproductive potential in response to moderate to high defoliation can be assessed by measuring flower head number and weight (Chapter 3 and 5). More subtle changes in individual fecundity will require more detailed study of habitat influence on seed size and weight.

Patterns in carbohydrate allocation to roots and rhizomes established in Chapter 3 indicate that herbicide control would be most effectively applied prior to the full exposure of flower heads, which coincides with the periods of maximum transport to the root system. In grazed pastures the carbohydrate allocation to the roots and rhizomes increased at a slower rate throughout the growing season and the optimum timing of herbicide application in these systems requires individual assessment of grazing pressures and rotations. Mowing to achieve control would be best applied prior to flower bud exposure to limit carbohydrate storage in the root system and prevent early flower head formation. A second mowing at the 50% to 100% bloom stage would further limit carbohydrate storage and prevent late flower maturation. Variations in climatic conditions, most notably decreased growing degree days or precipitation in May and June can result in one or two week variations in plant development.

Common tansy employs numerous successful strategies for establishment and persistence in a variety of habitats. In both grazed and newly established pasture stands and continually disturbed riparian habitats, the amount of bare ground and litter are most closely related to population density and successful establishment and colonization. Thus, overgrazing and under seeding are conditions to be avoided in areas where *T. vulgare* is abundant in the surrounding vegetation. While the vigorous perennial rootstock appears essential to the production of large amounts of seed, vegetative spread does not appear to be as important in population expansion as seed dispersal and seedling establishment.

T. vulgare provides shelter for many arthropods, but there are only a few polyphagous insects that feed on common tansy in north central Alberta. The holarctic species found in Alberta and Europe are generalist feeders that inflict minimal damage on the plant. There are no monophagous insects feeding on *T. vulgare* in Alberta, in contrast to the species reported from Europe, which is highly suggestive of the potential for successful introduction of a control agent in North America. However, this potential has to be tempered with the knowledge of the complex infraspecific chemotype variation of *T. vulgare* and its persistence under heavy vertebrate and simulated insect herbivory.

The response of common tansy to defoliation appeared to be conditional on natural habitat and moisture and light availability. High levels of defoliation were required to limit sexual reproductive potential, and vegetative potential remained relatively stable over the two year period of the experiments. Given these defoliation responses, it appears unlikely that a single defoliator could effectively limit population expansion of common tansy. However, reductions in height caused by defoliation could limit the wind dispersal of seed on the snow surface.

6.2 Perspective

Further research is required to establish if the costs estimated in this study, when combined with the losses of productivity in pasture/hay habitats, approach the estimated justification for the biological control cost requirements of Harris (1979). Additional factors not included in such cost requirements include the environmental cost and risks of continued reliance on herbicides, and the cost of reduced biodiversity associated with the invasion of natural habitats by nonindigenous species.

While initial comparison of insect populations found on *T. vulgare* in Alberta with those reported on the plant in Europe appears to indicate the potential for biological control, species level comparisons between insect collections from this study and the European species listed are required.

The potential pharmacological benefits of the essential oils of *T. vulgare* and the losses it inflicts as a weedy pest are in direct conflict. As the bulk of essential oil is harvested from cuttings prior to flower head production (Nemeth et al., 1994), there may be an opportunity for compromise in the selection of a control agent that limits seed production on the one hand, and hence colonization of new habitats, but on the other doesn't limit vegetative shoot growth and oil production. If population regulation was the only factor to be considered, the large root feeding guild that is present in Europe would be a potentially good candidate for biological control. However, given that root feeding would more effectively limit shoot production than would defoliation or flower bud feeding, the potential losses to commercial production of essential oil could be unpalatable in the long term.

Further research can now be directed towards the refinement of an integrated approach to the regulation of *T.vulgare* populations in agricultural ecosystems and the expansion of our understanding of plant - herbivore dynamics.

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