

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**Interaction of population processes in ragwort (*Senecio
jacobaea* L.) and ragwort flea beetle (*Longitarsus jacobaeae*
Waterhouse)**

**A Thesis presented in partial fulfillment of the requirements for the
Degree of Doctor of Philosophy in Ecology at Massey University.**

Aung Kyi

April 2000

Declaration of Originality

This thesis represents the original work of the author, except where otherwise acknowledged. It has not been submitted previously for a degree at any University.



Aung Kyi

Acknowledgements

I am sincerely grateful to my supervisors, **Professor Brian Springett**, **Dr Ian Stringer** (Ecology, the Institute of Natural Resources, Massey University), and **Dr Peter McGregor** (Landcare Research) for their encouragement, supervision and patience over this study and their help in drafting this thesis.

I am also indebted to Mr Keith Betteridge (AgResearch) for his valuable advice on the laboratory study on the movement of first instar larvae of ragwort flea beetle in different soils; Dr. Ed Minot (Ecology, Massey University) for explaining how to use the STELLA model; Dr. Jill Rapson (Ecology, Massey University) for comments on my PhD thesis proposal; Dr. Siva Ganesh, Dr. Jenny Brown and Mr. Duncan Hedderley (Statistics, Massey University) for help with univariate and multivariate analyses; and Dr. Kerry Harrington (Plant Science, Institute of Natural Resources, Massey University) for his comments and suggestion on the toxicity of ragwort and its chemical control.

Thanks also to Paul Peterson (Landcare Research) and Brent Page (Food and Crop Research) for their help in collecting ragwort flea beetle and Liz Grant for Figs 2.1 & 3.1. I also thank Barbara Just, Jens Jorgensen, Hamish Mack, Paul Barrett, Tracy Harris, Cathy Lake, Erica Reid, Jodi Matenga and all other staff from the Ecology Group, Institute of Natural Resources, Massey University for their help during my studies.

David J. Bull (Grounds supervisor, Massey University) kindly obtained an area for my field experiments, Dr David Barker, (AgResearch) generously made weather records for Ballantrae available to me, Dr Travis Glare (AgResearch) identified the fungal disease of ragwort flea beetle larvae, and Dr Mike Baxter (Microbiology, Massey University) identified the fungal disease of ragwort flea beetle. Thanks are due to Landcare Research for permission to use the three upper photographs on the title page.

My sincere gratitude is due to the **New Zealand Ministry of Foreign Affairs and Trade** under its Official Development Assistance Post Graduate Scholarship (NZODA-PGS) Scheme for financial support. In addition, I am grateful to Bruce Graham, Charles Chua, Dianne Rieley, Margaret Smillie, Dianne Fountaine Cody, and Jo Donovan, (all of Massey University) for their help and support during my studies.

I am grateful for the friendship and interest shown by the senior students of the Ecology Group, Institute of Natural Resources, Massey University.

Finally, special thanks to my parents, my wife Daw Yi Yi Thein, my son Aung Myat Thar, and my two daughters Chun Myat Thar and Soe Pyay Thar for their encouragement during this study.

Abstract

The primary goal of this study was to improve understanding of biological control of weeds by investigating how population processes in ragwort and herbivorous insect interact.

Specific aims were to measure the consumption rates of the three larval instars of ragwort flea beetle (*Longitarsus jacobaeae*), to investigate how the process of herbivory by ragwort flea beetle affects the population density of ragwort, and to investigate how soil moisture influences the population densities of ragwort flea beetle and ragwort.

An extraction apparatus was constructed to obtain *L. jacobaeae* larvae from ragwort roots and root crowns. This apparatus was 84% efficient.

A preliminary survey of ragwort flea beetle numbers included ragwort plants from Ballantrae, Turakina, and Pahiatua (Southern North Island, New Zealand). The larval population was highest at Ballantrae but the adult population was highest at Turakina.

Data were collected from Ballantrae from 1996 to 1998 to develop the interaction model between *L. jacobaeae* and ragwort. The interaction depended on the effect that soil water content had on the populations of both *L. jacobaeae* and ragwort, the effect that larval density has on larval mortality, and the effect of ragwort density on the population of *L. jacobaeae* larvae. Soil water content was positively correlated with the increase in numbers of *L. jacobaeae*. *L. jacobaeae* larval mortality was dependent on larval density. High numbers of larvae per plant resulted in a reduction in the number of larvae over time (13.6 larvae/plant on November 1997 to 1.8 larvae/plant in December 1997). The average number of larvae extracted at Ballantrae was lower in October and November 1996 (4.4 and 4.6 larvae/plant) than in October and November 1997 (13.4 and 13.6 larvae/plant). However, the average numbers of rosettes was higher in October and November 1996 (7.6 and 5.78 m⁻²) than in October and November 1997 (2.8 and 2.7 m⁻²). There was a significant inverse correlation between the numbers of *L. jacobaeae* larvae and ragwort rosettes (-0.4608). When

0.8983 in 15 day old larvae, 0.9261 in 30 day old larvae, and 0.9454 in 45 day old larvae. The lowest percentage survival (0.9067 in 15 day old larvae) was found at the highest larval density (40 larvae per plant). Finally, the same experiment was tested in a field and the data from this was used to construct an interaction model for *L. jacobaeae* and its food, ragwort. This model was based on the correlation between soil water and populations of *L. jacobaeae* and ragwort; the effect of larval density on the mortality of larvae and on the weight loss of ragwort; and on the effect that ragwort density has on the mortality of *L. jacobaeae* larvae. Mean soil water was 12 ± 0.29 to 76 ± 1.81 % over the first 15 days, then 36 ± 1.10 to 82 ± 0.99 % up to 30 days, and 35 ± 0.76 to 65 ± 1.78 % up to 45 days of larval life. These were the soil water contents that occurred during the field experiment. The model showed that the highest larval survival again occurred when few larvae were introduced to ragwort plants (17.5% survival from 0-15 days, 14.33% from 16-30 days, and 18.5% from 31-45 days). High larval densities also produced the lowest survival (8.4% survival over 0-15 days, 5.87% over 16-30 days, and 6.7% over 31-45 days).

The effect of plant density on larval survival was also tested in the field. The highest larval survival (10.76%) occurred when there were on 16 plants m^{-2} , and the larvae were 0 to 15 -days old. The lowest larval survival (6.61%) occurred with 16-30 day old larvae on plants at a density of 4 plants m^{-2} . A cohort life-table was constructed for predicting population fluctuations of *L. jacobaeae*. Values from this life table were used to model populations of *L. jacobaeae*, ragwort and the interactions between these species using "STELLA" software. Data for the ragwort model was obtained from published papers. Additional data from the experimental determination of feeding rates of *L. jacobaeae* larvae were used when both the *L. jacobaeae* and ragwort models were combined to examine the interactions between these species. This latter model was used to estimate population fluctuations of *L. jacobaeae* and its food over two years. It indicated that *L. jacobaeae* is a very effective control agent for ragwort, and that it can cause ragwort populations to decline to extinction within two years.

Table of Contents

Title i

Declaration of Originality ii

Acknowledgements iii

Abstract v

Table of Contents viii

List of Figures xii

List of Tables xv

SECTION I: INTRODUCTION AND METHODS

Chapter One: Introduction

1.1 Introduction 1

1.2 *Senecio jacobaea* L., Ragwort (Asteraceae) 1

Biology and Ecology of Ragwort 1

Vegetative and Reproductive Stages 1

Seeds 2

Dispersal 3

Germination and Dormancy 3

Establishment 4

Weed Status 5

Distribution 5

Abundance 5

Toxicity of ragwort 6

1.3 Methods of Management 7

Mechanical Removal 7

Management by Herbicides 8

Management by Grazing 9

Management by Microbial agents 9

Management by Tetranychid mite 9

Management by Insects 10

Cinnabar moth *Tyria jacobaeae* (Lepidoptera: Arctiidae) 11

Ragwort Seedfly *Hylemyia spp* (Diptera: Anthomyiidae) 12

Ragwort Flea Beetle *Longitarsus jacobaeae* Waterhouse 13

 (Coleoptera: Chrysomelidae)

Background 13

Description and Life History 14

Host Plant Specificity 16

Effectiveness as a Biological Control Agent 17

Factors affecting the survival of L. jacobaeae 18

1.4 Aims of the Project 19

1.5 References 20

Chapter Two: MATERIALS AND GENERAL METHODS

2. A An apparatus for extracting ragwort flea beetle larvae and other organisms from soil.	34
2.1 Abstract	34
2.2 Introduction	34
2.3 Materials and Methods	35
<i>Heating box</i>	35
<i>Collecting Funnels</i>	35
<i>Cooling</i>	37
<i>Extraction</i>	37
<i>Raring first instar larvae of L. jacobaeae</i>	38
<i>Efficiency test</i>	38
2.4 Results	39
2.5 Discussion	41
2.6 References	42
 2.B Description of Statistical Analysis	 45

SECTION II: FIELD STUDIES

Chapter Three: Preliminary Studies

3 Preliminary studies of <i>Longitarsus jacobaeae</i> and the different stages of ragwort plant in three sites.	50
3.1 Abstract	50
3.2 Introduction	50
3.3 Study areas	51
3.4 Materials and Methods	51
<i>Sampling Technique</i>	51
<i>Statistical method</i>	53
3.5 Results	53
3.6 Discussion	55
3.7 References	56

Chapter Four: Interaction between *L. jacobaeae* and ragwort.

4 Analysis of a simple interaction model of <i>L. jacobaeae</i> and its food plant, ragwort.	58
4.1 Abstract	58
4.2 Introduction	58
4.3 Methods	59
<i>Study area: Ballantrae</i>	59
<i>Sampling Technique</i>	59
<i>Soil water content</i>	60
<i>Method of Extraction</i>	60
<i>Statistical Analysis</i>	61

4.4 Results	61
4.5 Discussion	72
4.6 References	75

SECTION III: EXPERIMENTAL STUDIES

Chapter Five: Larval Consumption rates

5 Measuring the consumption rates of ragwort by ragwort flea beetle <i>Longitarsus jacobaeae</i> (Coleoptera: Chrysomelidae)	79
5.1 Abstract	79
5.2 Introduction	80
5.3 Methods	80
<i>Laboratory experiment</i>	80
<i>Glasshouse experiment</i>	81
5.4 Results	81
5.5 Discussion	85
5.6 Acknowledgements	86
5.7 References	87

Chapter Six: Larval movement

5 An experimental study of movement by first instar larvae of ragwort flea beetle <i>Longitarsus jacobaeae</i> Waterhouse through soil of different textures.	89
6.1 Abstract	89
6.2 Introduction	89
6.3 Materials and Methods	89
<i>Statistical analysis</i>	92
6.4 Results	92
6.5 Discussion	97
6.6 References	100

Chapter Seven: Larval Interplant Movement

7 Experimental determination of effect of interplant distance on the ability of <i>L. jacobaeae</i> larvae (Coleoptera: Chrysomelidae) to transfer between ragwort plants.	103
7.1 Abstract	103
7.2 Introduction	103
7.3 Materials and Methods	104
7.4 Results	105
7.5 Discussion	107
7.6 References	108

Chapter Eight: Larval Survival

8 The relationship between larval survival and larval and plant densities in the field.	110
8.1 Abstract	110
8.2 Introduction	110
8.3 Materials and Methods	111
8.3.1 <i>Effects of soil water on L. jacobaeae and ragwort populations.</i>	112
8.3.2 <i>Effects of L. jacobaeae larval density and ragwort density on survival of larvae and growth of ragwort.</i>	112
8.3.3 <i>Fertility rate and Age-specific life table.</i>	113
8.3.3.1 <i>Fertility rate</i>	113
8.3.3.2 <i>Age-specific life table for L. jacobaeae</i>	114
8.4 Results	115
8.4.1 <i>Environmental conditions during the study</i>	115
8.4.2 <i>Effect of soil water on L. jacobaeae and ragwort populations</i>	115
8.4.3 <i>Effect of larval density and ragwort density on survival of larval L. jacobaeae.</i>	117
8.4.4 <i>Effect of L. jacobaeae larval density and ragwort density on growth of ragwort rosette</i>	117
8.4.5 <i>Fertility and age-specific life table</i>	123
8.5 Discussion	124
8.6 References	127

SECTION IV: MODELLING *L. JACOBAEAE* AND RAGWORT

Chapter Nine: Analysis of an insect-plant interaction model.

9 Using STELLA to model Ragwort Flea Beetle and Ragwort.	131
9.1 Abstract	131
9.2 Introduction	131
9.3 Ragwort flea beetle model	133
9.4 Ragwort model	134
9.5 Combining ragwort flea beetle and ragwort model	135
9.6 Results	136
9.7 Discussion	138
9.8 Acknowledgements	139
9.9 References	140

SECTION V: GENERAL DISCUSSION

Chapter Ten: General Discussion	142
--	------------

Appendices	157
-------------------	------------

List of Figures

Chapter Two:

- | | | |
|-----|--|----|
| 2.1 | Extracting apparatus for <i>Longitarsus jacobaeae</i> . | 36 |
| 2.2 | Relationship between extraction time (hours), temperature, and the number of <i>L. jacobaeae</i> larvae recovered. | 40 |

Chapter Three:

- | | | |
|-----|--|----|
| 3.1 | Locations of the three study sites at Ballantrae, Pahiatua and Turakina. | 52 |
| 3.2 | Mean numbers of <i>L. jacobaeae</i> and stages of ragwort plants found at the three study sites. Bars indicate ± 1 standard error. | 54 |

Chapter Four:

- | | | |
|-----|---|----|
| 4.1 | The relationship between percent soil water and the mean population density of <i>L. jacobaeae</i> larvae and adults at Ballantrae between May 1996 to August 1998. | 62 |
| 4.2 | The relationship between percent soil water and the mean population densities of ragwort seedlings, rosettes and flowering plants. | 63 |
| 4.3 | Average monthly weather records (air temperature, soil temperature, and rainfall) and percent soil water for Ballantrae between May 1996 and August 1998. | 64 |
| 4.4 | Changes in the numbers of <i>L. jacobaeae</i> larvae and adults from May 1996 to August 1998 at Ballantrae. Bars indicate ± 1 standard error. | 67 |
| 4.5 | Changes in the numbers of ragwort seedlings, rosettes, and flowering plants from May 1996 to August 1998 at Ballantrae. Bars indicate ± 1 standard error. | 67 |
| 4.6 | Correlations between the numbers of <i>L. jacobaeae</i> larvae and adults, and ragwort seedlings, rosettes, and flowering plants found at Ballantrae between 1996 and 1998 (Bars indicate | 68 |

	\pm standard error).	
4.7	Plot of the first canonical scores for the mean values for <i>L. jacobaeae</i> larvae and for ragwort rosette plants of each sample.	70
4.8	Plot of the second canonical scores for the mean values for <i>L. jacobaeae</i> adults and for ragwort seedlings and flowering plants of each sample.	70
Chapter Five:		
5.1	Feeding rate of <i>L. jacobaeae</i> larvae in the laboratory and glasshouse. Bars indicate ± 1 standard error.	83
5.2	Average weight of single rosette ragwort plants in the laboratory and in the glasshouse. Bars indicate ± 1 standard error.	84
Chapter Six:		
6.1	Exploded view of the test chamber used to investigate movement of first instar <i>L. jacobaeae</i> larvae through soil. The three glass-sided trays shown fit one above the other in the test chamber.	91
6.2	(a) Movement of <i>L. jacobaeae</i> 1 st instar larvae in nine compartments (sectors) in sand. In figure 6.2 (a-c) "Middle, Lower, and Upper" sectors refer to the three trays shown in Fig6.1. "Centre, Cotton wool, and Roots are three compartments in each tray. Bars indicate ± 1 standard error.	94
	(b) Movement of <i>L. jacobaeae</i> 1 st instar larvae in nine compartments (sectors) in silt. Bars indicate ± 1 standard error.	94
	(c) Movement of <i>L. jacobaeae</i> 1 st instar larvae in nine compartments (sectors) in 50% sand +50% silt. Bars indicate ± 1 standard error.	95
6.3	Means for movement experiment of <i>L. jacobaeae</i> 1st instar larvae in sand, silt, and sand silt mixture.	96

6.4	Means for movement experiment of <i>L. jacobaeae</i> 1 st instar larvae at nine compartments in sand, silt, and sand silt mixture.	96
-----	---	----

Chapter Seven:

7.1	Number and percentage of <i>L. jacobaeae</i> larval movement from centre plant to the plants around the center plant which were 50mm and 100 mm far from center plant between three larval durations.	105
-----	---	-----

Chapter Eight:

8.1	The relationship between soil water content (%), the survival of <i>L. jacobaeae</i> larvae (%), and mean plant weight (g/day).	116
8.2	Variation in soil water content during the experiment.	116
8.3	The effects of <i>L. jacobaeae</i> larvae on single rosettes of ragwort (fresh weight) in relation to larval density and plant density. Bars indicate \pm standard error.	120
8.4	The effects of <i>L. jacobaeae</i> larvae on single rosettes of ragwort (dry weight) in relation to larval density and plant density. Bars indicate \pm standard error.	121

Chapter Nine:

9.1	The elements of a STELLA module.	132
9.2	STELLA-RFB Model.	133
9.3	The RAGWORT Model.	134
9.4	Interrelationship between RFB and ragwort, STELLA-RFB-RAGWORT Model.	135
9.5	Population fluctuations of different stages of <i>L. jacobaeae</i> from 1 to 13 years from the output of the STELLA-RFB Model. The numbers of each stage are shown for each year.	137
9.6	Output of STELLA-RAGWORT Model for population changes of different stages of ragwort during 13 years. The numbers of each stage are shown for each year.	138

List of Tables

Chapter Two:

2.1	Changes in the soil temperature and the number of <i>L. jacobaeae</i> leaving the soil over time during the extraction process.	39
2.2	Extraction efficiency using 1 st instar <i>L. jacobaeae</i> larvae.	40

Chapter Three:

3.1	Mean (\pm standard error) numbers of <i>Longitarsus jacobaeae</i> and ragwort found at three study sites (n=100).	53
-----	--	----

Chapter Four:

4.1	Correlation coefficients between percent soil water, <i>L. jacobaeae</i> (RBF) larvae, <i>L. jacobaeae</i> adults, ragwort seedlings, rosettes, and flowering plants.	61
4.2	Correlations between the numbers of <i>Longitarsus jacobaeae</i> and <i>Senecio jacobaea</i> , and soil water and weather records from Ballantrae.	63
4.3	ANOVA of the relationship between the percentage of soil water and the numbers of <i>L. jacobaeae</i> larvae and adults (Model) at Ballantrae.	64
4.4	Results of multiple canonical correlations analysis between the percentage of soil water and the numbers of <i>L. jacobaeae</i> larvae and adults: parameter estimates.	65
4.5	ANOVA of the relationship between the percentage of soil water and the numbers of ragwort seedlings, rosettes, and flowering plants at Ballantrae.	65

4.6	Mean and standard error of population densities of <i>L. jacobaeae</i> larvae and adults, and ragwort seedlings, rosettes and flowering plants, and the percentage of soil water content at Ballantrae.	66
4.7	Mean numbers of <i>L. jacobaeae</i> larvae, adult, ragwort seedlings, rosettes and flowering plants per sample and the water content of the soil at Ballantrae between 1996 and 1998.	68
4.8	Canonical correlation matrix for <i>L. jacobaeae</i> and ragwort variables.	69
4.9	Canonical correlations between weather records, and numbers of <i>L. jacobaeae</i> and Ragwort at Ballantrae.	71

Chapter Five:

5.1	Consumption rate of different stages of <i>L. jacobaeae</i> larvae in the laboratory and glasshouse.	82
5.2	Relationship between survival of <i>L. jacobaeae</i> larvae in the laboratory and glasshouse and numbers of larvae per plant and lengths of time with ragwort. Survival is given as the probability of a larva surviving for one day.	84

Chapter Six:

6.1	ANOVA of movement by <i>L. jacobaeae</i> 1 st instar larvae in three different soils. The Type I MS was used for BLOCK*SOIL as an error term. The block term is the experimental replication.	93
6.2	Mean number and Standard Error of <i>L. jacobaeae</i> 1 st instar larvae in different sectors (nine compartments) in three different soils during 12 hours. (Data from 4 replicates.)	93
6.3	Tukey's studentized range multiple comparison test for movement of <i>L. jacobaeae</i> 1 st instar larvae in the test chamber. Means are for all three soil types combined; those with the same letter are not significantly different.	95

Chapter Seven:

- | | | |
|-----|---|-----|
| 7.1 | TW-ANOVA (Two ways analysis of variance) for the effects of interplant distance on ability of larvae to transfer between plants, the effects of larval durations and larval densities on larval movement. | 105 |
| 7.2 | Movement of larval <i>L. jacobaeae</i> between ragwort plants 50 mm and 100 mm apart. | 106 |

Chapter Eight:

- | | | |
|-----|---|-----|
| 8.1 | Relationship between duration of <i>L. jacobaeae</i> larvae in ragwort rosettes and soil water (%), larval survival (%), and plant growth (g/day) (raw data is given in Appendix 8.3 & 8.4). | 115 |
| 8.2 | Survival of <i>L. jacobaeae</i> larvae in relation to density of ragwort rosettes and time. | 117 |
| 8.3 | Survival of <i>L. jacobaeae</i> larvae in relation to density of ragwort rosettes and time. | 117 |
| 8.4 | ANOVA for the effect of <i>L. jacobaeae</i> larval density (0, 10, 20, 40/plant), plant density (1, 2, 4, 8 plant 0.5m ²), and larval feeding duration (15 days, 30 days, and 45 days) on ragwort rosette weight gain (dependent variable). | 118 |
| 8.5 | (a) Mean fresh ragwort weight (g) with standard error in relation to plant density and larval of <i>L. jacobaeae</i> density 15 days after larval introduction. | 119 |
| | (b) Mean dry ragwort weights (g) with standard errors in relation to plant density and larval of <i>L. jacobaeae</i> density 15 days after larval introduction. | 119 |
| 8.6 | (a) Mean fresh ragwort weight (g) with standard error in relation to plant density and larval of <i>L. jacobaeae</i> density 30 days after larval introduction. | 119 |
| | (b) Mean dry ragwort weights (g) with standard errors in relation to plant density and larval of <i>L. jacobaeae</i> density introduction. | 119 |
| 8.7 | (a) Mean fresh ragwort weights (g) with standard errors in | 120 |

	relation to plant density and larval of <i>L. jacobaeae</i> density 45 days after larval introduction.	
	(b) Mean dry ragwort weights (g) with standard errors in relation to plant density and larval of <i>L. jacobaeae</i> density days after larval introduction.	120
8.8	Tukey's studentized range test for comparisons of larval densities effect on plant fresh weight (df = 167, MSE = 3329.2781, critical value of studentized range = 3.67, All comparisons are significant at the 0.05 level).	122
8.9	Tukey's studentized range test for comparisons of ragwort densities effect on plant fresh weight (alpha = 0.05, confidence = 0.95, df = 167, MSE = 3329.2781, critical value of studentized range = 3.67).	122
8.10	Tukey's studentized range test for comparisons of feeding duration effect on fresh weight of ragwort (alpha = 0.05, confidence = 0.95, df = 167, MSE = 3329.2781, critical value of studentized range = 3.67). All comparisons were significant at the 0.05 level.	123
8.11	Age specific life table for <i>L. jacobaeae</i> at 20°C (see 8.3.3.2 for definitions). (l_x and d_x are calculated from Appendix 8.4 - lva columns, and observed from Appendix 8.7 and 8.8).	123