Conservation monitoring of the Cromwell chafer beetle (*Prodontria lewisii*) between 1986 and 1997

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CONTENTS

Abstract

Cromwell chafer beetles, *Prodontria lewisii* (Coleoptera: Scarabaeidae) were studied during the spring and summer months of 1986, 1989, 1993, 1994, 1996 and 1997. Different sampling techniques proved to be a major source of variation, but within this constraint, no marked weekly differences in activity during the spring and summer months were recorded. Activity was extremely variable. Males appeared to become active slightly earlier and stay active longer than females. Activity during the spring and summer months was related to temperature and humidity, but this explained only 20% of the variation in activity. Variation in density was most marked between different study blocks, with little temporal variation evident. Within-block variation was appreciable, as densities of chafers on quadrats constituting each block were characterised by a wide range of values. Vegetation composition explained 28% of the variation in density, invertebrate community composition 25%, and substrate structure only 10%, indicating that chafers select a wide range of habitat. However, the existing chafer distribution is restricted to only a fraction of the available habitat. This may be caused by predation and parasitism of adults, female dispersal constraints, or factors limiting larval distribution. We recommend a change in the sampling regime and propose studies directed at investigating the factors influencing chafer distribution.

1. Introduction

The flightless Cromwell chafer beetle (*Prodontria lewisii* Broun, 1904) is endemic to New Zealand (Given 1952) and has a restricted and localised distribution in and near Cromwell in Central Otago (Watt 1979). It is a rare and endangered species occurring on Cromwell and Molyneux shallow loamy sand (Watt 1979; McKinlay 1997) and is one of 14 species of *Prodontria* restricted to Otago and Southland (Emerson & Barratt 1997). Cromwell chafers are therefore an important part of New Zealand's endemic invertebrate fauna. Understanding chafer biology and population dynamics may provide guidance for the conservation of invertebrates in New Zealand generally.

Adults are nocturnal and appear to be active during the spring and summer months from August to March. They spend the day buried in the soil and emerge at night to feed on the cushion plant *Raoulia australis*, speedwell *Veronica arvensis*, sheep's sorrel *Rumex acetosella* and various lichens. Very little is known about the larvae, and no pupae have been located. Larvae may be associated with the roots of silver tussock *Poa cita*; and second and third instar larvae found during November and March suggest that more than one year is required for larval development (Watt 1979). The lack of knowledge and restricted distribution of Cromwell chafer beetles provide a unique challenge to the successful conservation of this species.

The most significant step towards conservation of Cromwell chafer beetles was taken during 1979. Following a submission to the Cromwell Borough Council Joint Planning Committee (Watt 1975), a reserve was established and fenced. During 1982 the Crown bought the land and added an existing Crown property to create an 81 ha reserve administered by the Department of Lands and Survey which was gazetted as a Nature Reserve under the Reserves Act (1977) in 1983. Currently the reserve is managed by the Department of Conservation according to a management plan prepared by the Department of Lands and Survey (1985). Barratt & Patrick (1992) summarised the scientific research, monitoring, and conservation action that has been undertaken within the scope of the management plan. This involved monitoring of the chafer population, surveys of the vegetation, soils and invertebrates, and reserve management including removal of weeds and rabbits (*Oryctolagus cuniculus cuniculus*) followed by revegetation of dunes with *P. cita* (Table 1).

1.1 OBJECTIVES

Field work on the Cromwell chafer beetle started in 1985/86 (Armstrong 1987), followed by field monitoring during 1989 (Armstrong 1990), 1993 (Emerson 1993), 1994 (N.O.M. Ravenscroft, H. Moller, B. McKinlay & N. Newton, pers. comm.) and 1996 (Mudford 1996). No attempt has been made to evaluate the conservation of Cromwell chafer beetles in terms of the information available. The objective of the present study is to assess Cromwell chafer beetle conservation by:

- summarising results of population monitoring during 1997 together with previous monitoring periods,
- investigating the effectiveness of currently used sampling techniques,
- describing apparent seasonal patterns in activity,
- quantifying the influence of local biotic and abiotic variables on activity,
- determining sex-related differences in activity,
- investigating variation in density,
- determining habitat selection,
- determining distribution,
- delineating association with other invertebrates,
- refining future conservation management actions.

1.2 THE CROMWELL CHAFER BEETLE NATURE RESERVE

The Cromwell Chafer Beetle Nature Reserve is situated between Cromwell and Bannockburn (45°02'S,169°12'E, 216 m a.s.l.). It is triangular in shape and comprises a series of windblown sand dunes overlying a gravel bed. The soils have been classified as Molyneux shallow loamy sand, while dune crests consist of Cromwell sand (Leamy & Saunders 1967). The drifting sands originate from the terrace faces between Lowburn and Deadman's Point following deposition by the Clutha River (McKinlay 1997). Six major vegetation types have been identified in the reserve (Hubbard & Partridge, in Watt 1979) (Fig. 1). The

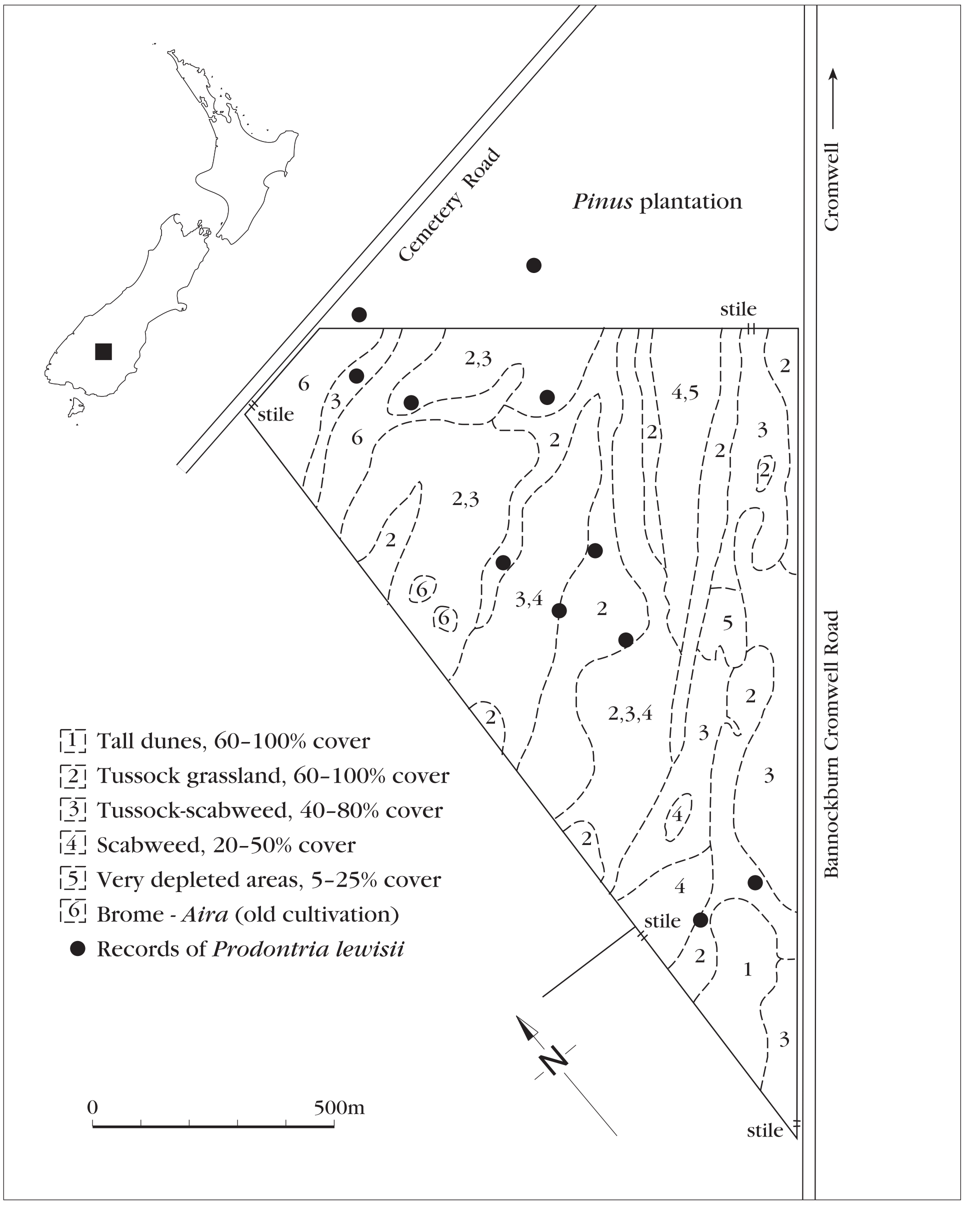
TABLE 1. SUMMARY OF THE HISTORY AND MANAGEMENT ACTIONS ON THE CROMWELL CHAFER BEETLE RESERVE.

YEAR	ACTION	REFERENCE
1864	• Sand nuisance reported on the Cromwell Flats.	Parcell 1951
1868	• Reference to the vegetation of the Cromwell Flats in a description of Otago vegetation.	Buchanan 1868
1878	• Clutha River floods and deposits large amounts of sand on the Cromwell Flats.	Park 1908
1904	• *Prodontria lewisii* (Cromwell chafer beetle) described based on three specimens collected by Mr. J.H. Lewis.	Broun 1904
1911	• Diminished sand deposits by the Clutha River recorded.	Cockayne 1911
	• Stabilisation of dunes in the study area using 'little marram', 'tree-lupin' and 'common tussock'.	Cockayne 1911
1932	• Vegetation description of the Cromwell District.	McIndoe 1932
1952	• Taxonomic description of larvae.	Hoy & Given 1952
	• Evaluation of the taxonomic status of Cromwell chafers.	Given 1952
1967	• Seven soil types described and mapped on the Cromwell Flats.	Leamy & Saunders 1967
1968	• Two adults and several larvae recorded north of Cromwell (site of the old Golf Course)	Watt 1979
	• Pitfall trapping and searching fail to reveal chafers anywhere else than in and near Cromwell.	Watt 1979
1970	• Existing information made available to an interdepartmental committee considering development of the Upper Clutha Valley.	Watt 1979
1974	• Entomological survey related to the planned hydro development in the Upper Clutha Valley.	Ministry of Works and Development 1975
	• Eleven adults collected to establish an unsuccessful laboratory colony.	Ministry of Works and Development 1975
1975	• Vegetation survey in the Clutha catchment.	Hubbard 1975
	• Population of chafers discovered between Cemetery Road and the Bannockburn-Cromwell road.	Watt 1975
	• Adult chafers collected in Cromwell transferred to the locality of the new population.	Watt 1975
	• Proposal for the establishment of a reserve to the Cromwell Joint Planning Committee and the Cromwell Borough Council.	Watt 1975
	• Existing information contributed to the Clyde Power Project Environmental Impact Assessment.	Ministry of Works and Development 1977
	• Public awareness and interest created through newspaper and television reports.	Watt 1979
1977	• Several Councillors and the Town Clerk of Cromwell observe adult chafers feeding during a visit.	Watt 1979
	• Framed photograph of an adult and larvae presented to the Cromwell Borough Council and displayed in the Public Library.	Watt 1979
1979	• Cromwell Borough Council fence the proposed reserve.	Department of Lands and Survey 1985
	• Publication reviewing the existing information and status of chafers.	Watt 1979
	• Vegetation classification and mapping of the proposed reserve.	Hubbard & Partridge in Watt 1979
1982	• Department of Lands and Survey purchase the land from the Cromwell Borough Council.	Department of Lands and Survey 1985
1983	• An 81 ha area is gazetted as a Nature Reserve under the Reserves Act (1977) and the Cromwell Chafer Beetle Nature Reserve is established.	Department of Lands and Survey 1985
	• Biological survey of the reserve.	Allen 1983
	• Pilot survey to assess techniques for investigating chafer populations.	Armstrong 1987
1986	• Experimental trial to identify factors affecting the establishment of silver tussock (*Poa cita*) following suggestions of a decline in density of this species.	Eason 1986
	• Intensive study attempting to quantify chafer activity, predation rates and population sizes.	Armstrong 1987
	• Vegetation assessment on quadrats used for chafer sampling.	Armstrong 1987
1989	• Weed threats and rabbit impact on vegetation evaluated.	Allen 1989
	• Monitoring and reassessment of the chafer population.	Armstrong 1990
	• Negotiations between Department of Conservation, Forest and Bird, the Otago Conservation Board and Cromwell territorial authorities concerning a proposed rubbish tip 500 m north-east of the reserve.	

YEAR	ACTION	REFERENCE
1990	• Vegetation survey using frequency transects.	Rance 1990
	• Rabbit poisoning operation using 1080 laced carrots.	
	• Lepidoptera of the reserve described.	Patrick 1990
1991	• Agreement reached to manage the established rubbish tip to limit potential impacts on the reserve.	Bruce McKinlay, DOC, Dunedin
	• Experimental trial to use pindone as a rabbit control agent.	Bruce McKinlay, DOC, Dunedin
1992	• Extended trials to use pindone as a rabbit control agent.	Bruce McKinlay, DOC, Dunedin
	• Rabbit cull using spotlights.	Bruce McKinlay, DOC, Dunedin
	• Vegetation survey using frequency transects.	Brain Patrick, DOC, Dunedin
	• Summary of the conservation of chafers presented at the NZ Entomological Society's 41st Annual Conference.	Barratt and Patrick 1992
1993	• Population monitoring and adaptation of monitoring techniques.	Emerson 1993
	• Predator monitoring.	Bruce McKinlay, DOC, Dunedin
	• Formal rabbit management programme initiated: Shooting using spotlights.	Bruce McKinlay, DOC, Dunedin
1994	• Planting of 760 silver tussock on experimental sites.	Bruce McKinlay, DOC, Dunedin
	• Upgrading of the rabbit fence around the reserve.	Bruce McKinlay, DOC, Dunedin
	• Vegetation survey using two of the original frequency transects while three new transects were established.	Bruce McKinlay, DOC, Dunedin
	• Vegetation reassessment of the 20 quadrats used for chafer sampling.	Bruce McKinlay, DOC, Dunedin
	• Establishment of fixed point photographs at the 20 quadrats used for chafer sampling.	Bruce McKinlay, DOC, Dunedin
	• Development of a tussock browse index.	Bruce McKinlay, DOC, Dunedin
	• Poisoning of rabbits using 1080.	Bruce McKinlay, DOC, Dunedin
	• Monitoring of the chafer population including climatic influences.	Bruce McKinlay, DOC, Dunedin
	• Survey to assess the distribution of chafers on the reserve.	Bruce McKinlay, DOC, Dunedin
1995	• Study initiated on the predation of chafers.	M. Brignall-Theyer, Otago University
	• Reassessment of the taxonomy of the genus *Prodontria*.	Emerson 1995
1996	• Continuation of the predation study.	M. Brignall-Theyer, Otago University
	• Monitoring of the chafer population including climatic influences.	Mudford 1996
	• Vegetation survey using frequency transects.	Bruce McKinlay, DOC, Dunedin
	• Planting of 3000 silver tussocks on experimental sites.	Bruce McKinlay, DOC, Dunedin
	• Description of the phylogenetic relationship of Cromwell chafers within the genus *Prodontria*.	Emerson and Barratt 1997
1997	• Completion of the predation study.	M. Brignall-Theyer, Otago University
	• Fixed point photographs retaken at the 20 quadrats.	Bruce McKinlay, DOC, Dunedin
	• Monitoring of the chafer population.	Present study.
	• Vegetation reassessment of the 20 quadrats used for chafer sampling.	Sam Ferreira, DOC, Dunedin
	• Survey to assess the distribution of chafers on the reserve.	Present study.
	• Extensive vegetation survey of the reserve using 200 point samples.	Present study.
	• Description of vegetation characteristics surrounding each pitfall on quadrats.	Present study.
	• Assessment of chafer habitat requirements.	Present study.
	• Evaluation of chafer distribution in terms of vegetation availability on the reserve.	Present study.
	• Historic account of soil and vegetation changes of Cromwell Terraces.	McKinlay 1997
	• Action plan prepared by Wildlife Management students.	Nelson, Scott and Uren 1997

native vegetation comprises *R. australis* and *R. parkii* where sand is absent and *P. cita* on patches of deeper sand. Mosses and bare soil are common. Vegetation cover on the reserve is dynamic due to heavy grazing by rabbits. The reserve has been invaded by exotic plant species: *R. acetosella*, *Trifolium arvense* and *Hypericum perforatum* are abundant herbs, while *Anthoxanthum odoratum* is the dominant grass.

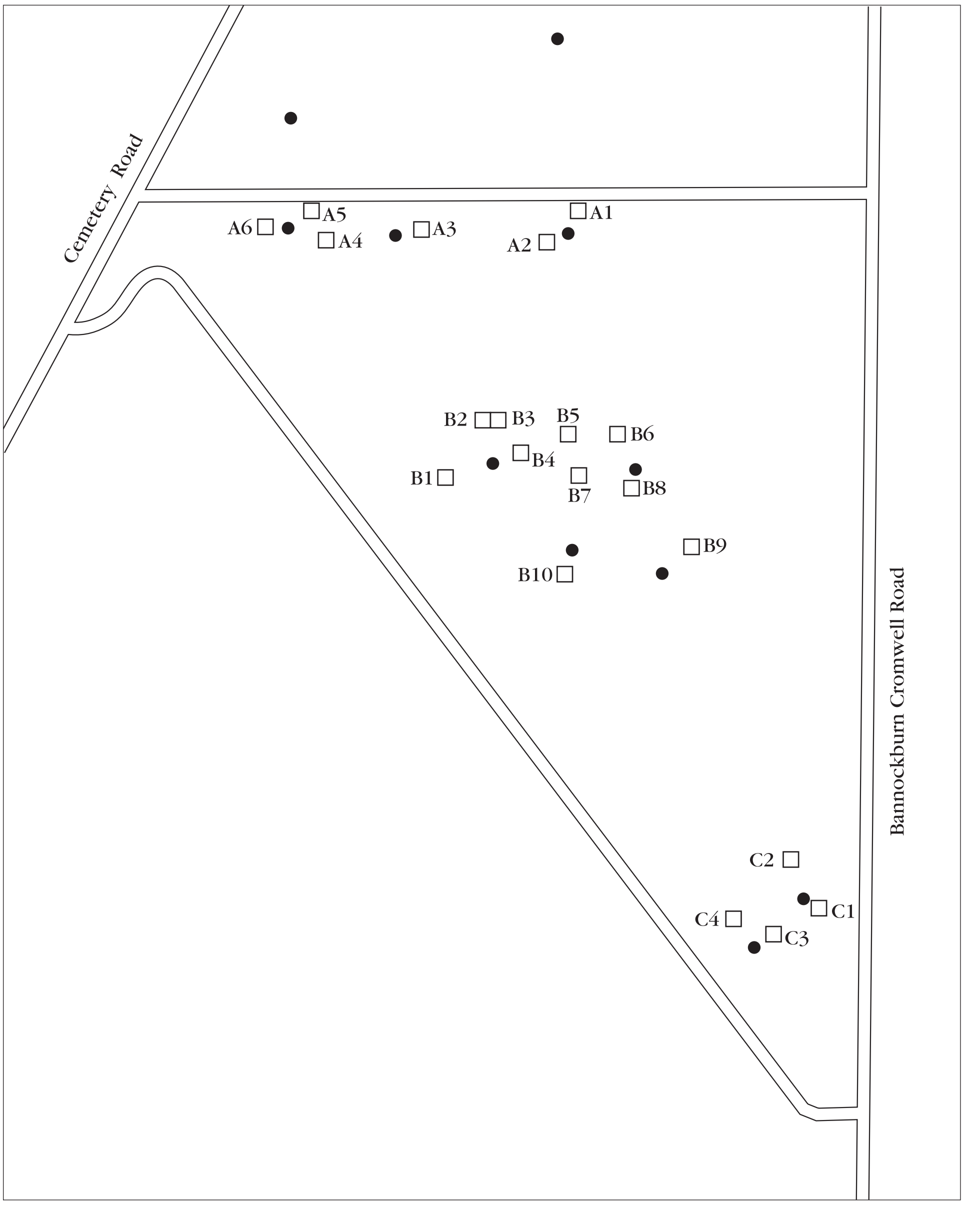
Figure 1. Vegetation map of the Cromwell Chafer Beetle Reserve (from Watt 1979).



2. Material and methods

Chafer populations were sampled from 5 September to 30 November 1997 on twenty quadrats used in previous studies (Armstrong 1987, 1990; Emerson 1993; Mudford 1996; N.O.M. Ravenscroft, H. Moller, B. McKinlay & N. Newton, pers. comm.). These quadrats represented three study blocks (Block A: 6 quadrats; Block B: 10 quadrats; and Block C: 4 quadrats) as defined by Armstrong (1987) (Fig. 2). Ten pitfall traps were established on each quadrat using Lily Polarcup 210 × 600 mm plastic containers (Mudford 1996) pierced for drainage. An outer container was placed in the ground followed by an inner container flush with the soil surface. Each trap had approximately 5 cm of sand placed inside the inner container. Traps were checked in the morning and immediately reset following clearance of beetles and other invertebrates.

Figure 2. The Cromwell Chafer Beetle Reserve showing the location of quadrats (squares) arranged to match the distribution of specimens (closed circles) collected by Watt (1979).



All invertebrates captured were recorded and identified to a morpho-species. Captured Cromwell chafer beetles were sexed, marked according to the method of Emerson (1993), and released approximately 1 m north of the pitfall. At release, each individual was buried approximately 5 cm deep and lightly covered with soil. Chafer capture data were combined with data obtained during previous study periods and collated from Armstrong (1987, 1990), Emerson (1993), N.O.M. Ravenscroft, H. Moller, B. McKinlay & N. Newton (unpubl. data) and Mudford (1996).

The vegetation within a 1 m radius from each pitfall trap was quantified between 10 and 28 November 1997 using the method described by Allen (1992). Percentage cover was estimated for all species present at 3 height classes (<5 cm, 5–10 cm and >10 cm) and assigned to one of 6 cover classes (<1%, 1–5%, 6–25%, 26–50%, 51–75%, 76–100%). Substrate structure was also assessed by estimating percentage of area containing bare ground, and the grain and pebble densities were estimated using the same 6 cover classes. Four sizes of grain and pebbles were distinguished: <1 mm, 1–5 mm, 6–10 mm, >10 mm.

Beetle habitat selection was investigated using ground surveys between 2200 and 0200 hours at night by walking transects across the reserve. The vegetation within a 1 m radius from each locality at which beetles were found was quantified as described. To assess habitat availability, vegetation was surveyed in a similar way to before, but along 18 transects spaced at approximately 75 m with sample points distributed 50 m apart along each transect.

2.1 DATA ANALYSES

Sampling effort: Each day's total of quadrats surveyed (see Table 2 for a summary of sampling during the different study periods) and numbers of new individuals found were added to all the previous daily totals to provide daily and yearly cumulative values of sampling effort and number of new individuals found.

Seasonal activity: Chafer capture data were arranged chronologically for each year and the number of beetles emerging every week starting 1 September estimated for each quadrat or transect sampled. Unequal sampling efforts were corrected for potential bias. Beetle activity was standardised for each quadrat due to potential differences in density between years (Armstrong 1990; Emerson 1993; Mudford 1996). The measure of activity used here is density-dependent. Each weekly activity estimate was expressed as a ratio of the highest weekly activity measured on that particular quadrat during a specific year. Standardised weekly activity could therefore range between 0 and 1 for a particular quadrat. Quadrats on which no beetles were recorded during a particular year were excluded for that specific part of the analysis. Seasonal activity measured as weekly differences in activities was investigated for each block during each year using Kruskal-Wallis Analysis of Variance (Sokal & Rohlf

TABLE 2. SUMMARY OF SAMPLING EFFORT OF CROMWELL CHAFER BEETLES ON THE CROMWELL CHAFER BEETLE RESERVE. ALSO PRESENTED IS A TOTAL DENSITY INDEX EXPRESSED AS THE NUMBER OF CHAFER BEETLES PER FITFALL.

YEAR	DATES	QUADRATS	REFERENCE	REMARKS	DENSITY INDEX
1986	30 Sep 1986–25 Jan 1987	All	Armstrong 1987	Paint marking	0.93
1989	17 Sep 1989–27 Oct 1989	All	Armstrong 1990	Paint marking	2.30
1993	5 Sep 1993–31 Oct 1993	All	Emerson 1993	Numbers for marking 40 pitfalls on A4, B7 and C1	1.61
1994	14 Sep 1994–19 Sep 1994 12 Oct 1994–19 Oct 1994 3 Nov 1994–13 Nov 1994 21 Nov 1994–28 Nov 1994 14 Dec 1994–17 Dec 1994	All B-quadrats All B-quadrats B3–8, B10 B4–8 B4–8	Ravenscroft, Moller, McKinlay and Newton (Pers. comm.)	Numbers for marking 40 pitfalls on B7	7.09
1996	3 Sep 1996–24 Sep 1996 11 Oct 1996–31 Oct 1996	All All	Mudford 1996	Numbers for marking	0.84
1997	5 Sep 1997–30 Nov 1997	All	Present study	Numbers for marking	1.44

1983). The data for 1986 and 1989 were not treated in this way as no distinction was made between quadrats for each week (see Armstrong 1987, 1990). Between-year variation on each block for each week was also investigated using Analysis of Variance as above.

To investigate the overall patterns of seasonal activity, a standardised weekly beetle activity was calculated for each year using all quadrats and transects sampled during a particular year (referred to as total activity pattern). Weekly differences in total activity indices were investigated using Analysis of Variance as above.

Differences in activity of males and females were investigated by calculating standardised weekly activity for males and females separately using all quadrats and transects sampled during a particular year. Each sampling year was used as a repetition, and the standardised activity of males and females compared for each week using Kruskal-Wallis ANOVA (Sokal & Rohlf 1983). Mean activity dates for males and females were calculated and compared using a modified version of Caughley's (1977) method to determine mean date of births for vertebrates.

The minimum number of days an individual was active was also calculated and compared between the sexes (Student's *t*-tests for samples with equal variances, and approximate *t*-tests for samples with unequal variances: Sokal & Rohlf 1983). Only recaptured individuals were used for this part of the analysis, and the data were analysed for years separately and also for all sampling years combined.

The influence of local environmental variables on beetle activity: Data were collated from Armstrong (1990), Emerson (1993) and Mudford (1996) to investigate variation within a season. Variation in activity within season (September, October and November included in the analysis) was related to temperature, humifity and wind speed. The data were classified into two sets defined by nights during which beetles were recorded and nights of no activity; for each set the frequency distribution of nights across the three environmental variable gradients was obtained.

Temperature classes were defined at 2°C intervals from 2°C to 16°C, with a separate class below 2°C or above 16°C, and a frequency distribution of nights obtained. Mean night temperature for night of beetle activity was also calculated. Beetle activity was expressed as number of beetles per 100 traps. To investigate its relationship with temperature, all nights below 5°C were excluded (mean – 2 × standard deviation) and a polynomial regression analysis conducted (Sokal & Rohlf 1983).

Humidity and wind-speed were treated in a similar way, excluding nights with humidity over 38% or wind-speed under 21 m/s.

The combined effect of these three variables on beetle activity was investigated using forward stepwise multiple regression analysis (Sokal & Rohlf 1983). We also incorporated polynomials (x^2 and x^3) of each variable, as we expected non-linear relationships between beetle activity and environmental variables. The *F*-ratio to enter the model was set at 0.01 to force all three variables and the respective polynomials into the model after the initial variable selection was done at *F*-to-enter = 4.00. The difference obtained in R^2 values indicated the significance of the forced variable in explaining additional variation in beetle activity.

Catchability of beetles: The catchability of individual beetles was investigated using Leslie's catchability test (Caughley 1977).

Influence of pitfall trap-density on density estimates: This part of the analysis used only data collected on quadrats A4 , B7 and C1 during 1993, and B7 during 1994. Sampling on these quadrats was more intensive than elsewhere (Emerson 1993; N.O.M. Ravenscroft, H. Moller, B. McKinlay & N. Newton, pers. comm.). Each quadrat was treated separately as follows. The number of beetles recorded during the total sampling period for all 40 pitfall traps was counted, and the cumulative number of beetles as pitfall trap-density increased from 0 to 40 was estimated by modelling an assemblage of 20 sequences each of 40 traps. For each independent sequence, a new individual was only added if it had not been recorded by a previous pitfall trap in that specific sequence. A mean was calculated for each pitfall trap-density from the cumulative sequences and subsequently plotted against pitfall trap-density. The prediction was that if pitfall trap-density was sufficient, an asymptote of new individuals should be reached with an increase in pitfall trap-density.

Sex ratio: The number of individual males and females recorded during each study period were noted. Deviation from a sex ratio of 1:1 was tested using Caughley's (1977) method.

Density: The minimum number of beetles recorded (recaptures were excluded) on each quadrat during September, October and November (across all sampling years) was used to calculate a density index for each study period. These three months were selected as no differences in activity between individual weeks within these months was recorded (see results). Because of unequal sampling efforts between study periods during these months, the minimum number of individual beetles recorded was corrected for the number of pitfall traps that were used each day. Density is therefore expressed as number of individuals per 100 pitfall traps. Kruskal-Wallis ANOVA (Sokal & Rohlf 1983) was used to test for differences between study periods for each study block.

Vegetation, substrate structure and invertebrate communities on quadrats: Data matrices describing the substrate structure, vegetation and invertebrate community respectively at each pitfall were established. Each of these matrices was used to test for significant differences between quadrats utilising Analysis of Similarities (Clarke & Greene 1988). On each quadrat, using the same method, vegetation and invertebrate communities recorded at pitfall traps where beetles were caught were compared with those that trapped none. For all tests, significance was taken at the 95% level. Associations between these three matrices were investigated using ANOSIM-RELATE (Clarke & Greene 1988). Using only pitfall traps which recorded beetles, a multiple regression linear model (Sokal & Rohlf 1983) was constructed to determine habitat and invertebrate characteristics favoured by chafer beetles. *F*-to-enter was set at 4.00. Once again we incorporated polynomials for each variable.

Habitat selection and available habitat: Percentage cover for individual plant species was recorded at sites where beetles were trapped. This was used to calculate a mean index of density for each species of plant and to indicate vegetation composition preferred by beetles. The euclidean distance (Sokal & Rohlf 1983) between the preferred vegetation composition and the composition at each locality where beetles were encountered was calculated.

This resulted in each locality of beetle activity having a description (euclidean distance) of the similarity (smaller distances between samples indicate closer similarity) to the preferred vegetation composition. The 95% confidence limit was determined using locality-specific euclidean distances.

Available habitat was assessed by calculating the euclidean distance for each vegetation sample point from the vegetation composition preferred by beetles. A sample point was considered suitable if the recorded euclidean distance fell within the 95% confidence limit. Using the classification for each point as either suitable or not, the percentage suitability of the reserve was estimated.

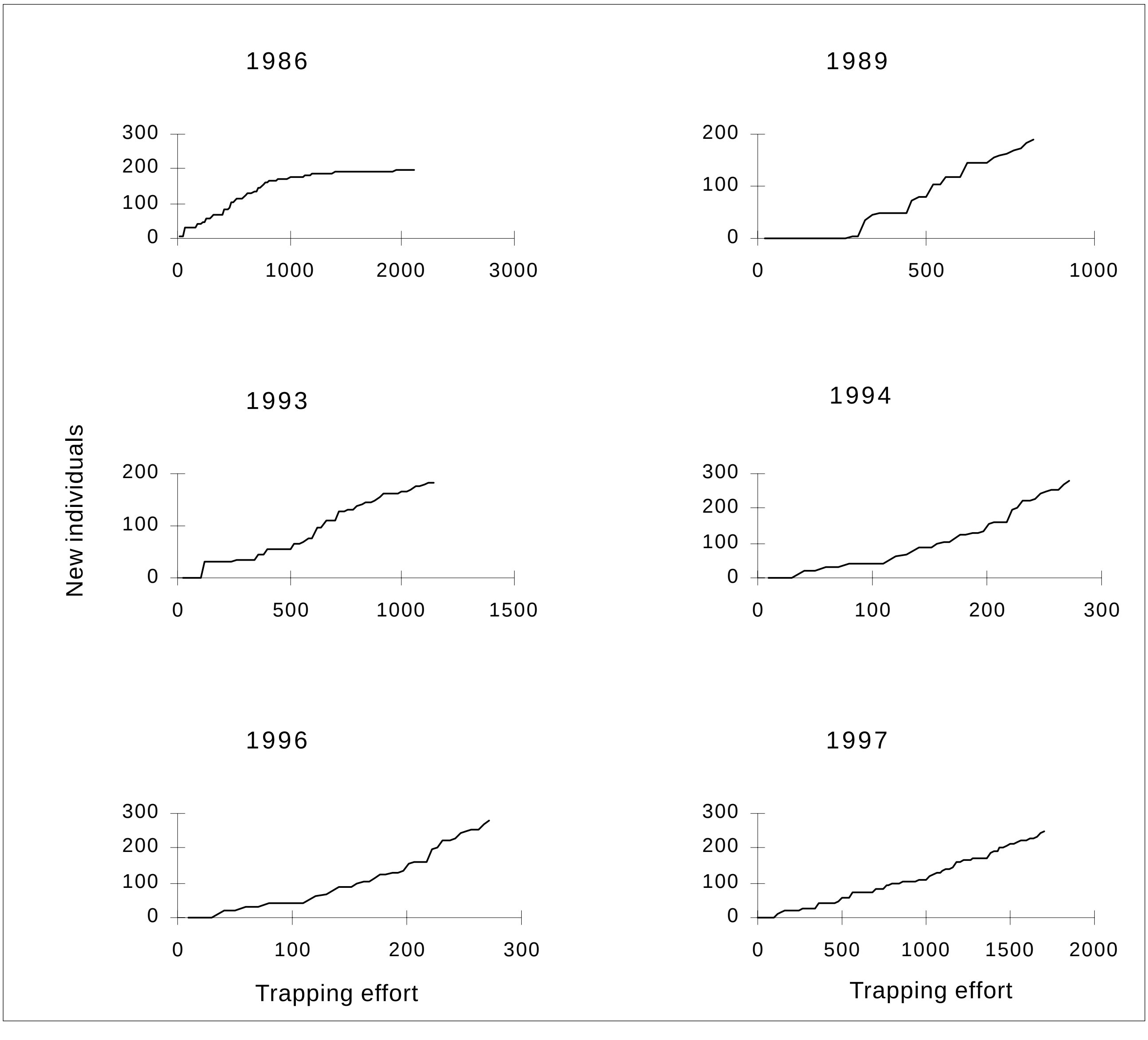


Figure 3. The accumulation of new individuals with an increase in trapping effort during 1986, 1989, 1993, 1994, 1996 and 1997. Note the x and *y*-axes are of unequal length.

TABLE 3. BLOCK-SPECIFIC WEEKLY CHAFER BEETLE ACTIVITY (MEAN ± STANDARD ERROR) DURING FOUR YEARS OF SAMPLING AT THE CROMWELL CHAFER BEETLE RESERVE, OTAGO. READING VERTICALLY GIVES WEEKLY DIFFERENCES FOR A BLOCK DURING A SPECIFIC YEAR; READING HORIZONTALLY SHOWS ACTIVITY ON A BLOCK DURING THE SAME WEEK, BUT IN DIFFERENT YEARS.

BLOCK A

WEEK	1993 (*n*=5)	1996 (*n*=4)	1997 (*n*=5)	*H*-value	N	*p*-value
1-7 Sep	0.00	0.00	0.00		14	–
8-14 Sep	0.27 ± 0.19	0.00	0.33 ± 0.19	3.00	14	0.22
15-21 Sep	0.00	0.75 ± 0.25	0.23 ± 0.11	6.47	14	0.04
22-28 Sep	0.27 ± 0.19	0.00	0.20 ± 0.20	1.80	14	0.41
29 Sep-5 Oct	0.53 ± 0.22	–	0.39 ± 0.19	0.30	10	0.59
6-12 Oct	1.00 ± 0.00	0.00	0.13 ± 0.10	11.30	14	<0.01
13-19 Oct	0.20 ± 0.20	0.00	0.16 ± 0.10	1.67	14	0.43
20-26 Oct	0.07 ± 0.07	0.08 ± 0.08	0.43 ± 0.17	4.95	14	0.08
27 Oct-2 Nov	0.05 ± 0.05	0.37 ± 0.24	0.43 ± 0.23	2.04	14	0.36
3-9 Nov	–	–	0.00	–	5	–
10-16 Nov	–	–	0.17 ± 0.17	–	5	–
17-23 Nov	–	–	0.39 ± 0.19	–	5	–
24-30 Nov	–	–	0.08 ± 0.08	–	5	–
H-value	21.06	18.51	15.53			
N	45	36	65			
p-value	0.01	0.02	0.21			

BLOCK B

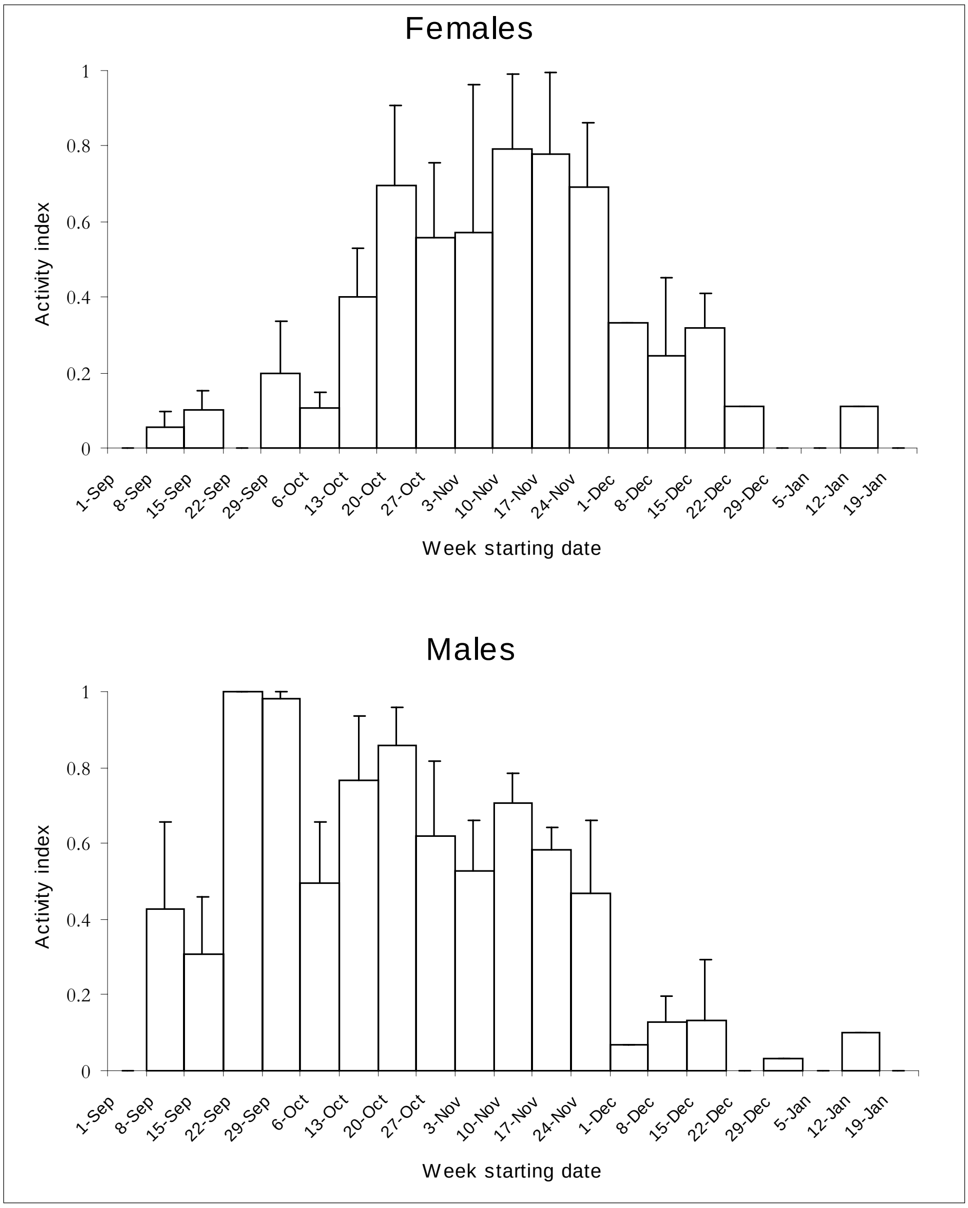
WEEK	1993 (*N*=10)	1994 (*n*=5)	1996 (*n*=8)	1997 (*n*=9)	*H*-value	N	*p*-value
1-7 Sep	0.00	–	0.00	0.00	–	27	–
8-14 Sep	0.00	0.00	0.28 ± 0.11	0.27 ± 0.10	9.63	32	0.02
15-21 Sep	0.04 ± 0.04	0.16 ± 0.09	0.17 ± 0.07	0.03 ± 0.02	3.28	32	0.35
22-28 Sep	0.44 ± 0.10	–	0.00	0.31 ± 0.15	9.04	27	0.01
29 Sep-5 Oct	0.65 ± 0.13	–	–	0.38 ± 0.12	2.14	19	0.14
6-12 Oct	0.56 ± 0.13	0.37 ± 0.23	0.14 ± 0.09	0.33 ± 0.11	6.14	32	0.11
13-19 Oct	0.30 ± 0.11	0.19 ± 0.14	0.36 ± 0.12	0.16 ± 0.09	0.55	32	0.91
20-26 Oct	0.32 ± 0.11	–	0.63 ± 0.10	0.37 ± 0.10	4.00	27	0.14
27 Oct-2 Nov	0.14 ± 0.10	0.00	0.58 ± 0.14	0.58 ± 0.14	9.82	32	0.02
3-9 Nov	–	0.14 ± 0.09	–	0.49 ± 0.14	3.10	14	0.08
10-16 Nov	–	0.72 ± 0.13	–	0.43 ± 0.14	1.84	14	0.18
17-23 Nov	–	0.51 ± 0.16	–	0.43 ± 0.12	0.07	14	0.79
24-30 Nov	–	0.48 ± 0.15	–	0.43 ± 0.14	0.22	14	0.64
1-7 Dec	–	–	–	–	–	–	–
8-14 Dec	–	0.40 ± 0.17	–	–	–	5	–
15-21 Dec	–	0.53 ± 0.19	–	–	–	5	–
H-value	37.26	26.45	43.26	25.85			
N	90	55	99	117			
p-value	<0.01	<0.01	<0.01	0.01			

BLOCK C

WEEK	1993 (*n*=4)	1996 (*n*=1)	1997 (*n*=2)	*H*-value	N	*p*-value
1-7 Sep	0.00	0.00	0.00	–	6	–
8-14 Sep	0.00	0.00	0.00	–	6	–
15-21 Sep	0.00	0.00	0.00	–	6	–
22-28 Sep	0.00	0.00	0.00	–	6	–
29 Sep-5 Oct	0.50 ± 0.29	–	0.50 ± 0.50	0.75	6	0.69
6-12 Oct	0.25 ± 0.25	0.00	0.00	0.75	7	0.69
13-19 Oct	0.75 ± 0.25	0.00	0.00	3.38	7	0.19
20-26 Oct	0.00	0.00	0.00	–	6	–
27 Oct-2 Nov	0.00	1.00	0.00	–[1]	6	–
3-9 Nov	–	–	0.00	–	2	–
10-16 Nov	–	–	0.50 ± 0.50	–	2	–
17-23 Nov	–	–	0.00	–	2	–
24-30 Nov	–	–	0.00	–	2	–
H-value	17.50	–	11.46			
N	36	–	26			
p-value	0.03	–	0.49			

[1] Too many ties to do test.

Figure 4. Comparison between male and female weekly activity during the reproductive season. See Table 4 for sample sizes and statistical results.



3. Results

Sampling effort: The number of new individuals was still on the increase for the duration of sampling during all sampling periods (see Table 2 for dates) with the exception of 1986 (Fig. 3). Sampling was terminated either at the end of October (1989, 1993, 1996), November (1997) or December (1994) except for 1986 when it continued until 25 January 1987. The total number of individuals recorded at the end of each sampling period varied substantially. Corrected density estimates disregarding potential seasonal effects ranged from 0.84 to 7.09 individuals per pitfall trap (Table 2).

Seasonal activity: Seasonal chafer beetle activity was unpredictable and characterised by large within-block variation, as well as within- and between-year variation (Table 3). Furthermore, variation between quadrats in a particular block resulted in low confidence in the activity estimates for blocks during a particular year.

Armstrong (1987) recorded a drop off in activity from 30 September 1986 to 25 January 1987. For the six sampling periods reviewed here, the combined activity patterns were characterised by chafer beetle activity being initiated in early September. Significant differences were found in activity between weeks over the combined sampling period (H_{62} = 35.72, p = 0.02), but this was due to no 'activity' during the week of 1–7 September, which was significantly lower than the highest activity during the weeks of 29 September–5 October and 10–16 November.

Males were active slightly earlier than females but not significantly so (Fig. 4), with the mean date of activity for males (23 October ± 26.67 days) 20 days earlier than that of females (12 November ± 23.30 days). Males and females were active for the same number of days during all years except in 1997 (Table 4), when males

TABLE 4. MINIMUM DAYS OF ACTIVITY (a), DISTANCE MOVED BETWEEN CAPTURES (b) AND MOBILITY (c) OF CHAFER POPULATIONS SAMPLED DURING SIX STUDY PERIODS. DATA ARE PRESENTED AS MEAN FOLLOWED BY ONE STANDARD ERROR OF THE MEAN. SAMPLE SIZES ARE GIVEN IN PARENTHESES.

a. MINIMUM DAYS ACTIVE

STUDY PERIOD	MALES	FEMALES	*t*-statistic	*p*-value
1986	9.83 ± 4.62 (6)	–	–	–
1989	–	–	–	–
1993	11.70 ± 0.89 (94)		–	–
1994	22.61 ± 3.48 (41)	18.67 ± 5.07 (12)	t_{51}= -0.56	0.58
1996	14.71 ± 3.20 (24)	32.00 (1)	–	–
1997	18.09 ± 3.60 (23)	6.00 ± 2.37 (5)	$t_{22.3}$= -2.81	0.02
Total	18.56 ± 2.00 (93)	15.89 ± 3.77 (18)	t_{109}= -0.55	0.58

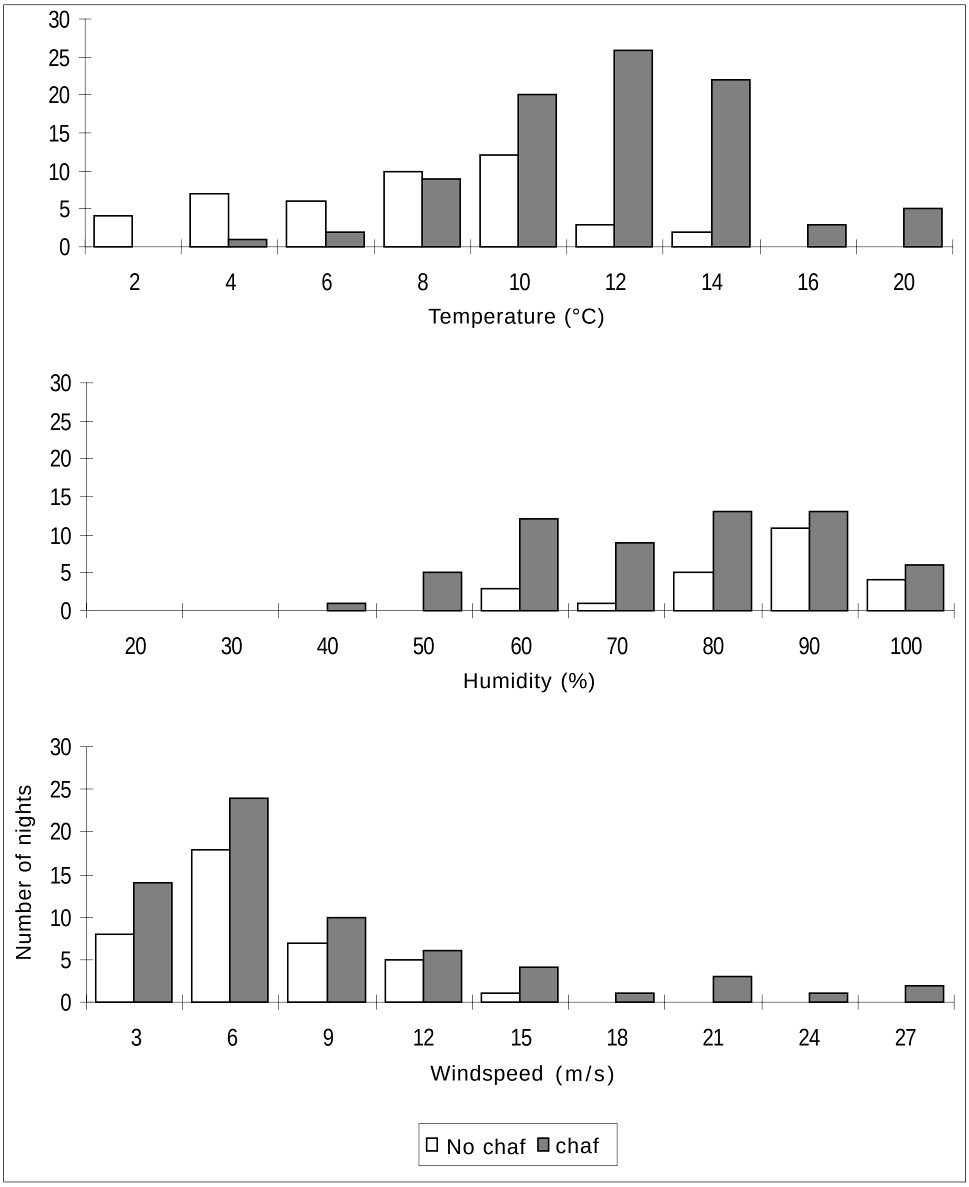
b. DISTANCE MOVED BETWEEN CAPTURES

STUDY PERIOD	MALES	FEMALES	*t*-statistic	*p*-value
1986	–	–	–	–
1989	–	–	–	–
1993	12.82 ± 1.37 (128)		–	–
1994	13.94 ± 2.59 (51)	9.69 ± 3.19 (14)	$t_{32.1}$= -1.03	0.31
1996	16.35 ± 4.75 (26)	0.00 (1)	–	–
1997	18.29 ± 6.26 (28)	3.60 ± 2.29 (5)	$t_{31.1}$= -2.20	0.04
Total	15.60 ± 2.40 (104)	8.08 ± 2.48 (19)	$t_{58.6}$= -2.18	0.04

c. MOBILITY (m/day)

STUDY PERIOD	MALES	FEMALES	*t*-statistic	*p*-value
1986	–	–	–	-
1989	–	–	–	–
1993	2.63 ± 0.43 (128)		–	–
1994	1.64 ± 0.27 (51)	1.53 ± 0.73 (14)	$t_{16.6}$= -0.15	0.87
1996	3.92 ± 2.32 (26)	0.00 (1)	–	–
1997	1.00 ± 0.30 (28)	0.56 ± 0.43 (5)	t_{31}= -0.61	0.55
Total	2.05 ± 0.60 (104)	1.27 ± 0.55 (19)	$t_{68.9}$= -0.95	0.34

Figure 5. Comparison for temperature, humidity and wind-speed between the frequency of nights with beetle activity and those without.



were active significantly longer than females. However, overall sex-specific number of days active did not differ significantly. Males moved further than females between captures during 1997 (Table 4), but the overall results illustrated no marked differences in mobility between the sexes.

The influence of local environmental variables on beetle activity: The average temperature, humidity, and wind speed were 10.65 ± 2.80°C (n = 88), 70.24 ± 2.06% (n = 59) and 6.91 ± 0.75 m/s (n = 65), respectively. Beetles were caught when the temperature ranged from 4 to 14°C (Fig. 5). Activity was positively related to temperature, but only 27% of the variation could be explained by temperature ($y = -4.96+0.78x$, $R^2 = 0.27$, $n = 119$). There was no such relationship with either humidity or wind speed (Fig. 5). Humidity explained 18% of the variation in activity ($y = 11.48-0.12x$, $R^2 = 0.18$, $n = 82$), while wind speed explained only 2% of the variation in beetle activity ($y = 1.29+0.13x$, $R^2 = 0.02$, $n = 101$). Wind speed was excluded from a model constructed using all three variables and third degree polynomials of each to explain beetle activity within a season ($activity = 3.18+0.36temperature-0.06humidity$, $R^2 = 0.20$, $n = 74$). Including wind speed in the model resulted in only an additional 3% of the variation being explained.

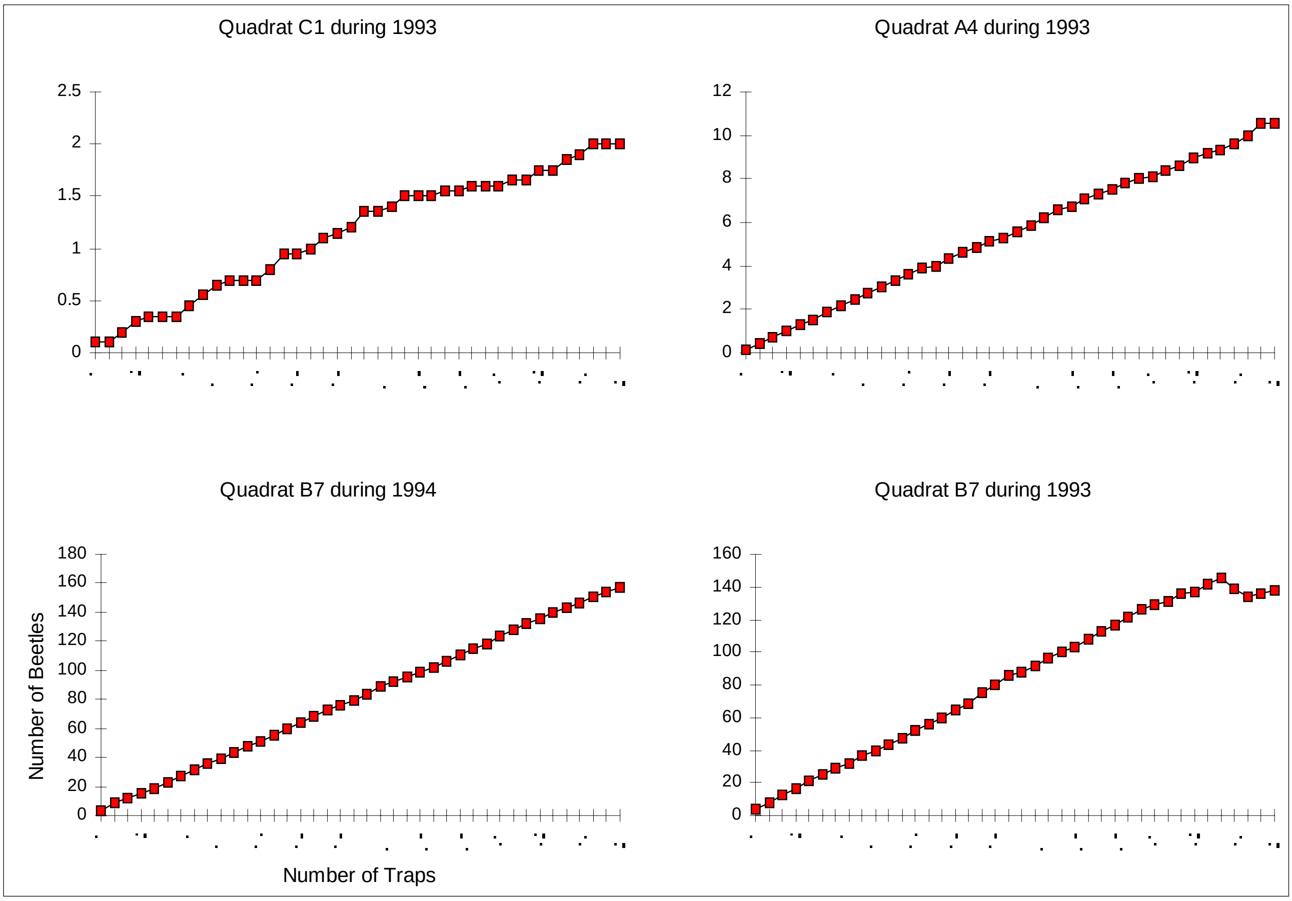


Figure 6. Simulation of the effect of trap-density and the number of beetles recorded for four quadrats sampled during 1993 and 1994.

Catchability of beetles: Some individuals were trapped more frequently than others in all study periods (1986: $\chi_{206} = 486.63$, $p < 0.05$; 1989: $\chi_{214} = 605.13$, $p < 0.05$; 1993: $\chi_{387} = 851.91$, $p < 0.05$; 1994: $\chi_{233} = 490.31$, $p < 0.05$; 1996: $\chi_{268} = 2054.49$, $p < 0.05$; 1997: $\chi_{245} = 410.27$, $p < 0.05$). The capture data was also characterised by low capture probabilities (1986: $p = 0.057$; 1989: $p = 0.083$; 1993: $p = 0.017$; 1994: $p = 0.053$; 1996: $p = 0.079$; 1997: $p = 0.036$).

Influence of pitfall trap-density on density estimates: The number of beetles recorded on a quadrat increased as the pitfall trap-density increased (Fig. 6). The simulation for quadrat B7 during 1993 was the only one that revealed an asymptote, which occurred at approximately 34 pitfall traps per 400 m^{2}. There was some indication that an asymptote might be reached at 38 pitfalls on quadrat C1 and 39 pitfalls on quadrat A4.

Sex ratio: Sex ratios recorded by pitfall trapping were significantly different from 1:1 (Table 5). Consistently more males than females were recorded during all study periods.

Density: Beetle densities did not differ significantly between study periods on Blocks A and B (Block A: $H_{(N=30)} = 5.97$, $p = 0.20$; Block B: $H_{(N=60)} = 7.42$, $p = 0.19$), while significant differences were recorded between study periods for Block C ($H_{(N=20)} = 9.69$, $p = 0.05$) (Fig. 7). Densities recorded during 1996 and 1997 on this block were significantly lower than those recorded during 1986.

Figure 7. Block-specific between year variation in beetle density. Standard error bars are included. Block A n = 6, Block B n = 10, Block C n = 4.

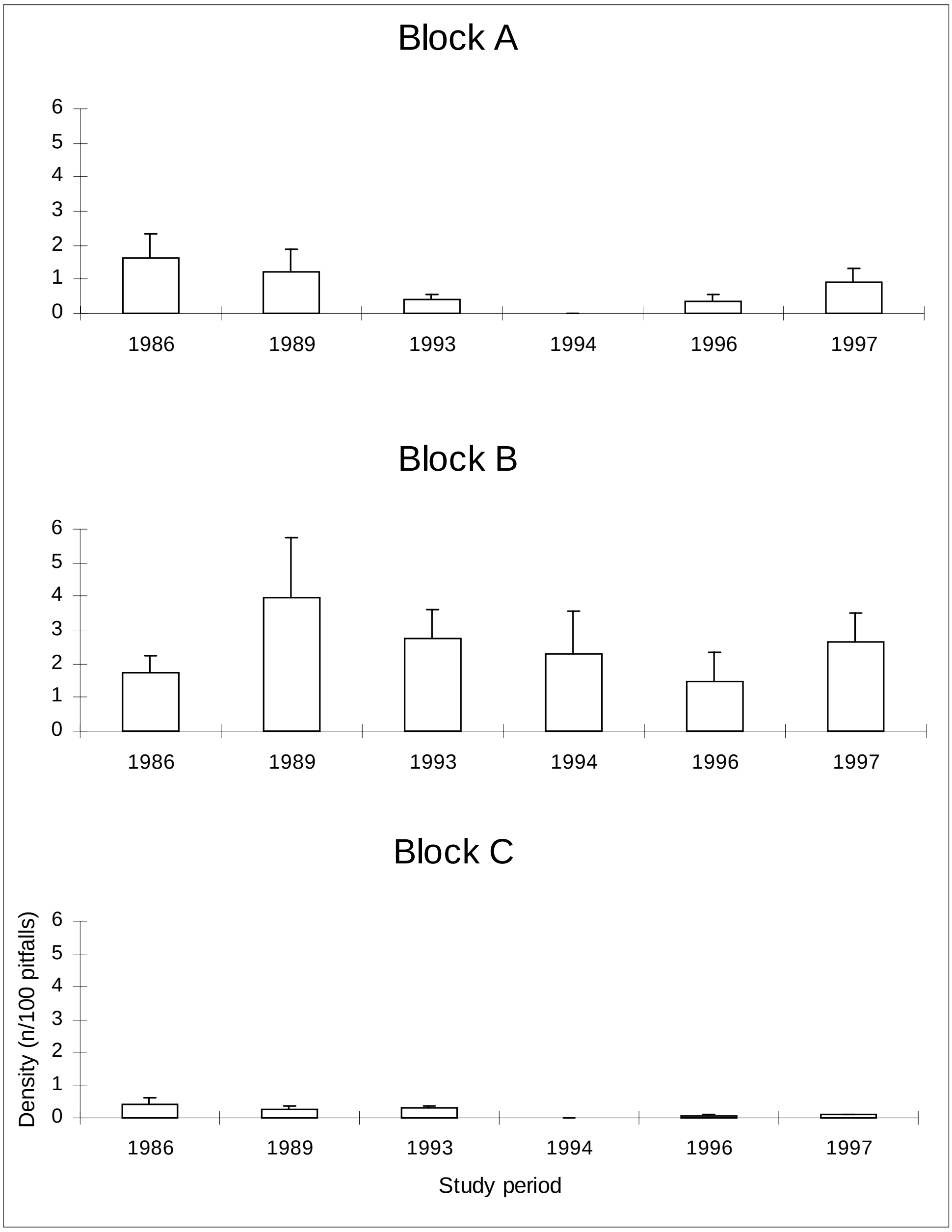
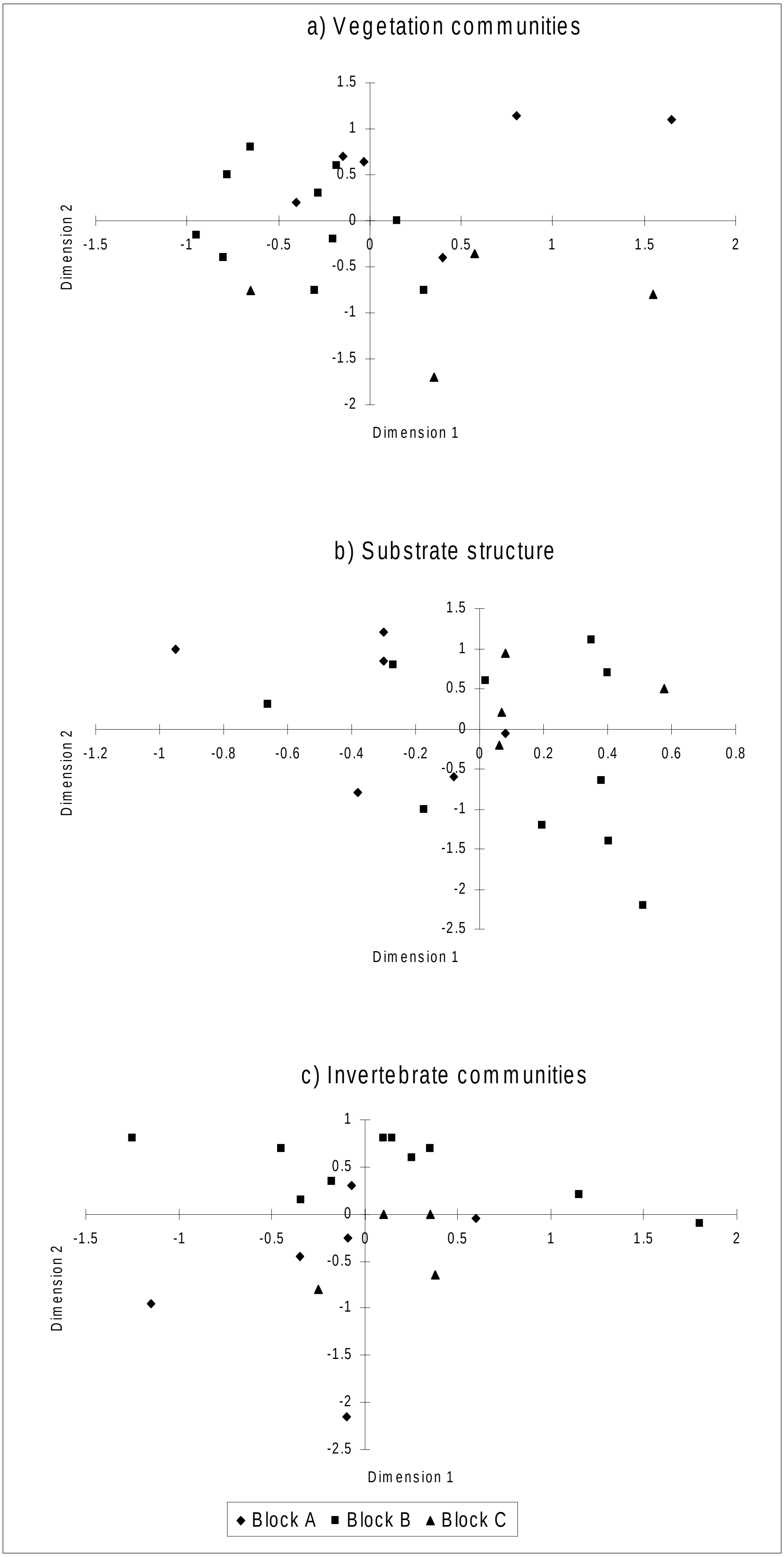


TABLE 5. FREQUENCY OF MALES AND FEMALES IN CHAFER POPULATIONS SAMPLED DURING SIX STUDY PERIODS USING PITFALL SAMPLING.

STUDY PERIOD	MALES	FEMALES	χ_1-statistic	p-value
1986	145	50	χ_1=46.28	<0.05
1989	-	-	-	-
1993	-	-	-	-
1994	167	89	χ_1=23.77	<0.05
1996	281	58	χ_1=146.69	<0.05
1997	185	59	χ_1=65.06	<0.05

Figure 8. Scatterplots of quadrats distributed within two-dimensional space using three data sets.
a) Vegetation communities. Dimension 1 represents a positive gradient of the densities of *Anthoxanthum odoratum* and *Taraxacum officinale*, and a negative gradient of moss. Dimension 2 represents positive gradients of *Chondropsis* spp. and *Echium vulgare*, and negative gradients of *Linum catharticus* spp. and *Rauolia parkii*.
b) Substrate structure. Dimension 1 represents positive gradient of the amount of bare soil, while dimension 2 represents positive gradients of sand and negative gradients of Gravel 1–5 mm, Gravel 5–10 mm and Gravel > 10 mm.
c) Invertebrate communities. Dimension 1 is a positive gradient of small collembolids and negative gradients of weta, darkling beetle larvae, St. Johns wort beetles, wolf spiders and a larger collembolid. Dimension 2 represents a negative gradient of Carabid beetles and mites.



Vegetation, substrate structure and invertebrate communities on quadrats: Vegetation composition differed between quadrats, except for five comparisons between quadrats (out of 190) where the vegetation was similar. These were quadrats A1 and A2, A1 and B4, A1 and B5, A2 and B5, and B4 and B5 (detailed analysis available from authors). The comparison of substrate between quadrats showed that 25% had similar substrate characteristics. Most quadrats were also different from each other in terms of invertebrate communities, with the exception of B3 and B4, B4 and B5, B4 and B8, B7 and C1, and B7 and C3. These differences did not result in a predictable gradient in terms of beetle activity on quadrats for vegetation (Stress = 0.11), substrate structure (Stress = 0.06) and invertebrates (Stress = 0.15) (Fig. 8). Vegetation communities and substrate structures were closely associated with each other ($\sigma = 0.10$; $p = 0.19$), whereas invertebrates were not associated with either vegetation ($\sigma = 0.38$; $p = 0.01$) or substrate structure ($\sigma = 0.22$; $p = 0.04$).

Vegetation composition within 1 m of pitfalls with beetles did not differ significantly from that around pitfalls with none Block A ($\sigma = -0.006$; $p = 0.52$), B ($\sigma = -0.006$; $p = 0.55$) and C ($\sigma = -0.118$; $p = 0.70$). This was confirmed with analyses for each quadrat respectively (detailed analyses available from authors). Four variables were included in a multiple regression model to investigate the effect of vegetation communities on chafer beetle captures, but it explained only 27.85% of the variation ($y = 0.29pm + 0.13to - 0.05ta + 0.06hp$; pm = *Poa maniototo*, to = *Taraxacum officinale*, ta = *Trifolium arvense*, hp = *Hypericum perforatum*).

Substrate structure differed between pitfalls which recorded beetles and those which did not on Block B ($\sigma = 0.17$; $p = 0.01$), while no differences were recorded on Block A ($\sigma = -0.06$; $p = 0.92$) and C ($\sigma = -0.18$; $p = 0.80$). However, no differences were recorded for substrate structure on each quadrat respectively. A multiple regression model for substrate variables had very poor explanatory power.

Invertebrate communities differed between pitfalls with beetles and those with none on Block B ($\sigma = 0.12$; $p = 0.01$), but there were no differences for Block A ($\sigma = -0.05$; $p = 0.87$) and C ($\sigma = 0.07$; $p = 0.33$). No differences were recorded on each quadrat respectively. Three variables: weta (Anostostomatidae), Collembola species and St Johns Wort Beetle larvae (*Chrysomela hyperici*) were included in a multiple regression model to investigate the effect of invertebrate communities on chafer beetle captures. This model explained only 24.5% of the variation ($y = -10.34st + 2.13sjl + 0.65weta + 485.93$; st = Collembola species, sjl = St Johns wort beetle larvae).

Habitat selection and available habitat: Chafer beetles had a wide range of preferred vegetation. This resulted in large variations on sites where beetles were captured (euclidean distance = 52.18 ± 20.71, $n = 86$). This wide variation resulted in 73.6% of the reserve (which will include 95% of the existing variation in preferred beetle habitat) being suitable for beetles. On a smaller scale, 41.1% of the reserve would be very good beetle habitat (euclidean distance larger than the mean plus one standard deviation). However, only 9% of the reserve has beetles, which means that beetles occupy only 12.6% of the available habitat.

4. Discussion

Although the history of human occupancy in New Zealand is relatively short (Prickett 1982), the impacts on native flora and fauna have been great, particularly since the arrival of Europeans in the 1800s (McGlone 1983; McGlone 1989). Clearance of land and invasion by alien biota have resulted in the decline of numerous indigenous biota (King 1984; Ragg 1992). The decreasing range of apparently suitable substrates (McKinlay 1997) and habitats (Watt 1979) for Cromwell chafers because of agricultural development was the main reason for the establishment of the Cromwell Chafer Beetle Nature Reserve. The establishment of this reserve does not in itself guarantee the continued survival of the Cromwell chafer, and identifying the factors which affect the beetle either negatively or positively is critical to ensuring the survival of this species. Quantifying these factors may be particularly challenging in view of the restricted distribution and rarity of chafers (Watt 1979) and their life history traits.

The present analysis showed that new chafers entered the population continually during all sampling periods. This may be a result of inefficient sampling techniques and/or variability in emergence of chafers. Low capture probabilities indicated that most chafers would not be captured and those that were would only be captured once (with a few exceptions). An alternative explanation is that marked differences in weekly activity could have led to a cumulative increase in the number of new individuals as sampling duration increased. In other words, chafers active at the end of the season were different individuals from those active at the beginning of the season. The 1986/87 trapping effort continued throughout the season, with an asymptote reached towards the end of the breeding season, and this tends to support the latter scenario. Corrected for differences in trapping effort, Cromwell chafer population densities appear to be variable, with no specific trend evident at this stage.

Let us assume that chafer sampling techniques do not produce a source of bias in the data. The results illustrate variable weekly activity during the spring and summer months, with no clear trend of increase towards a peak. This is contrary to the findings for the striped chafer, for which peak flight activity was recorded during the summer months (Barratt & Campbell 1982). If individual chafers emerged and disappeared at different times, individual activity budgets would have to be equal to maintain activity indices recorded during the spring and summer months. Alternatively, chafers would have to emerge all at the same time and maintain individual activity throughout the spring and summer. We have already highlighted the continual emergence of new individuals during the various sampling periods. Furthermore, our results, considering the variation recorded, suggest that individual chafers may not be active longer than 3–4 weeks. If the above assumptions are valid, the continuous accumulation of new individuals during all study periods is therefore not related to significant differences between weekly activity patterns during the summer and spring months, but to individual emergence and disappearance rates.

Cromwell chafer activity patterns were further complicated by apparently different activity regimes between the sexes. The mean date of activity for males during late October appeared to be 20 days earlier than for females. This variation in sex-specific activity did not have an effect on the weekly activity patterns of the sexes. For individual beetles this result has a significant implication, as some males might be active during times when there is a relative shortage of females, while females might be active when there is a relative shortage of males.The critical period for the population would be towards the end of the activity period when eggs might go unfertilised. However, the greater distances that males moved might compensate for any shortage, as one male could get to many females.

The earlier activity of males suggested males might be active longer than females to ensure reproductive success, but no significant results were obtained. Individual chafer beetles emerged and disappeared at different times during the spring and summer months, resulting in the continual appearance of new individuals in the population. As a further result, total activity showed large variation during the spring and summer months and it is due to this variation that no differences in activity were recorded between weeks or years. The within-weekly variation appeared to be related to prevailing environmental conditions, a pattern which has been recorded for other taxa (Barratt & Campbell 1982; Ehrlich 1984; Thomas 1984). Emerson (1993) and Mudford (1996) illustrated that wind and temperature played an important role in determining beetle activity. Combining their data with those of Armstrong (1987) allowed us to conclude that beetle activity was a function of the combination of temperature and humidity. Windspeed is auto correlated to these two variables which resulted in its exclusion from the present model. Beetle activity increased during warm and humid conditions, which is in accordance with Watt's (1979) suggestions.

Was our assumption that the sampling technique was effective in this study valid? The sampling technique (pitfall trapping) recorded only a few of the beetles active, and some individuals had a better chance of being captured than others, as exemplified by the skewed sex ratios recorded during all study periods. More males than females were recorded, although the sex ratios during field surveys at night revealed no significant differences (Males: 41, Females: 37, $\chi_1 = 0.21$, $p > 0.05$; pers. obs.). Furthermore, the simulation of the effect of pitfall density on the number of beetles captured suggests that in most instances too few pitfalls were used for the area covered by each quadrat. The shortcomings of pitfall trapping for the purpose of estimating population sizes has been highlighted by numerous other authors, e.g. Mitchell (1963) and Greenslade (1964). The sampling technique therefore undersampled the population and the results should be interpreted in this context.

Let us further assume that the inefficiency of the sampling methods was at least of equal magnitude during the various study periods. This assumption is supported by the closeness of the range of capture probabilities. The highest densities occurred on Block B with the lowest on Block C. However, the only temporal differences recorded were on Block C where densities recorded during the last two sampling periods were significantly lower than the first sampling period. However, this block was consistently characterised by low densities. At low densities, the non-capture of beetles may not give a true reflection of presence or absence of beetles let alone density trends. Within the limitations of the data highlighted already, it appears that Chafer beetle densities exhibit expected population fluctuations, with 1989 being an exceptional sampling period on Block B.

The variation in activity recorded between quadrats in the same block is of concern, as significant differences between nearly all quadrats in terms of vegetation and invertebrate communities as well as substrate structure have been recorded. The variation does not shape into a predictable gradient of beetle activity with quadrats being located randomly within multi-dimensional spaces, whichever analysis is undertaken. It should be noted that substrate structure and vegetation composition were associated, whereas the composition of invertebrate communities was independent of substrate or vegetation composition. As no differences were found between habitat characteristics surrounding pitfalls that did record beetles and those that did not, it seems likely that beetles live in a wide range of habitats.

Watt (1979) described an association of chafers with silver tussock (*P. cita)* and scabweed (*R. australis*), but also noted that several apparently suitable areas were devoid of chafers. Chafers appear to select for habitat features other than *P. cita* and *R. australis*. The present analysis indicates that the beetles only use 12% of the suitable habitat available on the reserve (described in terms of vegetation characteristics).

The lack of use of habitat could be a result of limitations to larvae and not to adults. Adults are most likely to be observed close to where eggs were laid and larvae hatched and matured. The failure of three components of habitat features to distinguish between sites of chafer presence and absence supports the suggestion that adults and larvae utilise a similar set of habitat features. Further support comes from the association of the classification of above ground habitat features based on vegetation characteristics which influence adults and substrate structural gradients which influence larvae. Chafer larvae probably also occur on only a fraction of the area that could potentially be utilised.

Alternatively, the constraint on chafer distribution or the cause of the restricted distribution of larvae and adults may be the dispersal ability of females. Females appeared to be more sedentary than males, obtaining all resources close to where they emerged, whereas the males did all the exploration to find females and mate with them. Females did not have to move far because the range of habitat features they prefer never presented a limiting resource within their immediate vicinity, and they were able to lay eggs close to where they initially emerged.

5. Conservation status of the Cromwell chafer beetle

An evaluation of the conservation status of Cromwell chafer beetles has been undertaken by the Department of Conservation as part of its priority setting requirements. In 1994 it was ranked as a Category A species (Tisdall 1994; Table 6). A re-evaluation of the ranking criteria indicates that it should still be classified as a Category A species, although its status in several categories has improved markedly. The conservation status score declined from 62 to 49 (Category A when score is greater than 47) as a result of conservation actions reported on in this study (Table 6).

TABLE 6. SUMMARY OF THE CHANGE IN CONSERVATION STATUS OF CROMWELL CHAFER BEETLE SINCE 1994 BASED ON THE CRITERIA STIPULATED BY TISDALL (1994).

FACTORS AND CRITERIA	CONSERVATION STATUS 1994			CONSERVATION STATUS 1998		
	SCORE		REFERENCE	SCORE		REFERENCE
DISTINCTIVENESS						
Taxonomic distinctiveness	**3**	Recognised at species level; genetically or morphologically highly distinct from other members of the genus	Broun 1904	**3**	Recognised at species level; genetically or morphologically highly distinct from other members of the genus	Emerson 1995
STATUS						
Number of populations	**5**	Only one known	Watt 1979	**5**	Only one known	Present study
Mean population size	**3**	From 100 to 500, or **area 1–10 ha**	Watt 1979	**3**	From 100 to 500, or **area 1–10 ha**	Present study
Largest population	**3**	From 100 to 500, or **area 1–10 ha**	Watt 1979	**3**	From 100 to 500, or **area 1–10 ha**	Present study
Geographic distribution	**5**	Total range <10 km^2	Watt 1979	**5**	Total range <10km^2	Emerson 1995
Condition of largest population	**5**	Very poor	Watt 1979, Armstrong 1987, Emerson 1993	**1**	Healthy	Present study
Population decline rate	**4**	Total wild population presently declining at a rate which is likely to cause the taxon to become extinct in the medium-term (15–25 years), or **unknown but suspected to be declining rapidly**	Armstrong 1990, Emerson 1993	**1**	**Total wild population stable** or increasing	Present study
THREATS						
Legal protection of habitat	**3**	Long-term legal protection for at least one site	Department of Lands and Survey 1985	**3**	Long-term protection for at least one site	Department of Lands and Survey 1985
Habitat loss rate	**5**	All remaining breeding grounds/occupied habitat likely to be destroyed in less than 10 years	Watt 1979	**1**	Less than 10 of the remaining breeding grounds/occupied likely to be destroyed in the next 10 years	Present study
Predator/harvest impact	**4**	Predation/harvest having high impact on the survival of the taxon, or **impact unknown but suspected to be high**	Watt 1979	**4**	Predation/harvest having high impact on the survival of the taxon, or **impact unknown but suspected to be high**	Watt 1979, M. Brignall-Theyer, Otago University
Competition	**4**	Competition having considerable impact on the survival of the taxon, or **impact unknown but suspected to be high**	–	**4**	Competition having considerable impact on the survival of the taxon, or **impact unknown but suspected to be high**	–
Other factors affecting survival	**1**	No other factors known	–	**1**	No other factors known	–

FACTORS AND CRITERIA	CONSERVATION STATUS 1994 SCORE		REFERENCE	CONSERVATION STATUS 1998 SCORE		REFERENCE
VULNERABILITY						
Habitat and/or diet specificity	**5**	Displays extreme habitat and/or diet specificity	Watt 1979	**3**	Displays moderate **habitat** and/or diet specificity	Present study
Reproductive and/or behavioural specialisations	**5**	Displays reproductive and/or behavioural specialisations which severely limit the recovery ability of the taxon	Watt 1979	**5**	Displays reproductive and/or behavioural specialisations which severely limit the recovery ability of the taxon	Present study
Cultivation/captive breeding	**5**	Not known to be in captivity/cultivation or germ plasm bank, and/or **breeding in captivity**/propagation **unsuccessful**	Ministry of Works and Development 1975, Armstrong 1987	**5**	Not known to be in captivity/cultivation or germ plasm bank, and/or **breeding in captivity**/propagation **unsuccessful**	Ministry of Works and Development 1975, Armstrong 1986
VALUES						
Maori Cultural Values	**1**	Minor significance	–	**1**	Minor significance	–
Pakeha Cultural Values	**1**	Regarded as important by a few people	–	**1**	Regarded as important by a few people	–
CONSERVATION STATUS SCORE	**62**	**Category A: Highest Priority Threatened Species**	Tisdall 1994	**49**	**Category A: Highest Priority Threatened Species**	Present study

The largest contributions to the improved conservation status of this species since 1994 come from an improved understanding of the population status, with chafer populations seeming relatively healthy and stable. Evaluation of habitat preferences and available habitat have also contributed to the improvement.

This re-evaluation pinpoints areas of work that should be targeted to enhance the conservation status of this species. Ferreira & McKinlay (1999) support the current taxonomic status. Other moderate priority actions include addressing some of Tisdall's (1994) criteria (see Table 6) such as the number of populations, mean population size, largest population, and geographic criteria within the vulnerability factor (Table 6).

However, four areas are considered of high priority, primarily because of lack of knowledge required to make judgements about them. These are:

- the impact of predators,
- competition from other herbivorous insects on the reserve,
- an understanding of reproductive and behavioural specialisations,
- captive breeding potential.

Finally, a word of caution. We have listed a great number of conservation actions that have taken place on the Cromwell Chafer Beetle Reserve. Some of these were directed at attaining secondary objectives, often without investigating and quantifying the potential impact on the primary objective, i.e. conservation of chafers. An example was the eradication of rabbits because of the threat they posed to the reserve by digging up and destroying soil horizons on which beetles were believed to be dependent; as well as creating a fertile site for adventive plants to become established (Bruce McKinlay pers. obs.). The prevention of soil destruction was achieved, but despite this it would appear that vegetation communities are now more dominated by invasive species than the natives on which chafers were believed to be dependent at the time (Watt 1979). The impacts of rabbit removal were negligible or even positive on the adult beetles primarily as a result of general habitat requirements previously not known. We urge that future conservation actions be considered in an experimental manner prior to large-scale implementation.

6. Conclusions

Knowledge of the current status of Cromwell chafer beetle populations is restricted by the inefficiency of the sampling techniques that generated the existing database. Apparent seasonal patterns in activity are characterised by large between-week variation, with the mean date of activity of males being 20 days earlier than that of females. Activity is also influenced by temperature and humidity, resulting in the variation observed. Apparent sex-related differences in activity are most likely the result of sex-related differences in capture probability, as sex ratios determined using other sampling methods were 1:1. Within the constraints of the sampling problems highlighted, it would appear that Cromwell chafer beetle densities are characterised by inherent fluctuations and that the patterns observed are within the normal range of fluctuation. However, Cromwell chafer beetles could potentially occupy much larger areas within the reserve. Our results also reflect positively on conservation actions and highlight areas of priority for the continued success of Cromwell chafer beetle conservation.

7. Recommendations

CONTINUED MONITORING

We suggest a new sampling method to be used, initially in conjunction with existing monitoring methods to provide a continuation of comparable data until the database is sufficient to exclude pitfall trapping. We suggest fixed-width transects (3×20 m) located on existing known 'hotspots' and sampling done at night between 2200 and 0200 hours using strong torches and lamps. Each beetle recorded on the transects can be marked as before. Measure local environmental conditions at the start of each transect as well as at the conclusion of a transect. This technique will allow additional information to be collected, such as the type of activity, food items if feeding, etc. Each transect can be repetitively sampled for vegetation composition and various other variables that may be related to beetle densities. Vegetation surveys may be best done during the last two weeks of November.

Sampling for comparative purposes should be done during the last two weeks of October and the first two weeks of November. This period overlaps the mean activity dates of males and females. Sampling on a yearly basis during these periods will yield data that are essential in quantifying the factors influencing year-to-year fluctuation in population densities.

In addition, two or three seasons of sampling using the above method throughout the activity period (September to March) may be useful in clarifying the within-season variation described above.

A regular vegetation monitoring system should be installed to quantify vegetation changes outside the present distribution of chafers. We recommend a method similar to that used in the present study during the last two weeks of November when most vegetative growth has ceased. Substrate, soil and invertebrate composition could be quantified at the same time, providing information for future decision-making.

A yearly evaluation process through which continuous accumulation of information is assessed and used to plan fieldwork for the next year should be established.

HIGH PRIORITY RESEARCH AND MANAGEMENT TOPICS

The following criteria based on the procedure of Tisdall (1994) are areas where we presently have insufficient information for Cromwell chafer beetles and which should have high priority when research needs are assessed:

- threats: predator/harvest impact,
- threats: competition,
- vulnerability: reproductive and/or behavioural specialisations,
- vulnerability: cultivation/captive breeding.

The first three criteria have a high priority ranking because of lack of knowledge. The fourth criterion is one where some information is available (Armstrong 1987), and therefore is less important.

Project 1. Predation and rates of parasite infection of Cromwell chafer beetles

Brignall-Theyer (1998) investigated the possible effects that vertebrate predators might have on Cromwell chafer beetles. Contrary to Armstrong (1987) Brignall-Theyer did not rank little owl (*Athene noctua*) as the primary vertebrate predator. She noted that hedgehogs (*Erinaceus europaeus occidentalis*) were more likely to be present for more time, and were more likely than owls to target chafers. Rates of parasite infection remain unknown. Both these factors have been suggested as potential limiting factors on chafer densities (Watt 1979). This project should consist of two sections:

1) Predation. Building on the work by Brignall-Theyer (1998), the highest priority should focus on identifying the distribution and habitat use of hedgehogs in and around the reserve. This should be followed by projects on magpies (*Gymnorhina hypoleuca*) and mice (*Mus musculus*). Potential native predators include the native tunnel-web spider *Porrhothele antipodiana*, but the study of native predators is not a high priority as similar evolutionary constraints are likely to have resulted in stable predator-prey relationships. Nonetheless, incidental observations during monitoring should be noted.

2) Rates of parasite infestation. To obtain life-history information concerning predation and host-parasite relationships associated with Cromwell chafer beetles, we suggest a three-step investigation into potential parasites (including pathogens) for which chafers could be hosts. *Proscissio valida*, a parasite of several Melolonthinae, occurs commonly on the reserve (Watt 1979). Additionally, most Melolonthinae are infected by tachinid flies (Tony Harris pers. comm.). A database of potential parasites of the Scarabaeidae and the Melolonthinae should be developed using published information and local expertise on coleopteran parasites. Using this database as a guide, the second step should be to assess a closely related beetle species on the reserve (e.g. *Pericoptus* spp.) as a surrogate species to expand the information base. Finally, the levels of parasite infestation of Cromwell chafers should be established by sacrificing a number of individuals (say 1%) based on the population size recorded at the time.

Project 2. Potential competitors of Cromwell chafer beetles

The role of potential competitors is particularly important in light of the invasion ecology of New Zealand (Ragg 1992; Mooney & Drake 1989). The effects of competition are often subtle and may directly affect only one species (Mooney et al. 1986). The Cromwell Chafer Beetle Reserve has a number of introduced invertebrate species such as St John's wort beetle. We therefore propose a literature survey of existing knowledge of potential competitors followed by an investigation of correlations and associations of these candidates with chafers using invertebrate data collected during yearly monitoring.

Project 3. Life-history characteristics, habitat requirements, environmental limitations and distribution of larvae

Knowledge about chafer larvae is extremely limited and is the greatest source of uncertainty in defining changes in chafer densities and distribution. This project should aim to quantify developmental stages of chafer larvae; determine which vegetation and soil characteristics are associated with larval presence; quantify the population density of larvae; and determine the existing distribution of larvae. Again, the project may best be approached by using a surrogate species, such as one of the *Prodontria* spp. occurring in the Alexandra area. To address larvae life-history characteristics, we suggest soil core sampling or trench sampling in selected areas of the reserve (see Barratt (1982) for details) known to have high chafer densities. We also suggest simultaneous measurement of vegetation composition, soil profiles, substrate structure, and soil biochemistry.

MODERATE PRIORITY RESEARCH AND MANAGEMENT TOPICS

The following criteria, based on the procedure of Tisdall (1994), have a moderate priority for research and management:

- status: mean population size,
- status: largest population,
- status: geographic distribution,
- vulnerability: habitat and/or diet specificity.

Project 1. Experimental dispersal of adult chafers

One suggested limiting factor on chafer distribution was female dispersal ability. To investigate this we suggest experimental removal of mating pairs and placement on suitable habitat within the reserve and then monitoring survival of the new population.

Project 2. Diet of Cromwell chafer beetles

Design of this project should be done in conjunction with the monitoring programme above and, for larval diet, with the above project on larval life-history features.

LOW PRIORITY RESEARCH AND MANAGEMENT TOPICS

The remaining criteria have all been assigned low priority status and are listed in no particular order:

- distinctiveness: taxonomic distinctiveness,
- status: number of populations,
- status: condition of largest population,
- status: population decline,
- threats: legal protection of habitat,
- threats: habitat loss rate,
- threats: other factors affecting survival,
- values: Maori cultural values,
- values: Pakeha cultural values.

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