

THE CHANGING ABUNDANCE OF MOTHS IN A TUSSOCK GRASSLAND, 1962-1989, AND 50- TO 70-YEAR TRENDS

Summary: Species-rich moth faunas at two sites in a montane tussock grassland at Cass show major declines in the abundance of many common species between 1961-63 and 1987-89, furthering a 50- to 70-year trend. The recent faunal record (202 species) is quantified by a 3-point light-trapping methodology based on independence of serial samples, minimised sample variability and *a posteriori* data standardisation. An historical record of vegetation change is also presented, pointing to a major decline in endemic herb species with the advances of an adventive grass, *Agrostis capillaris*. Site differences feature in the analysis of vegetation and faunal changes. At the site with the greater loss of herbs and the 93% grass cover (a doubling in 26 years), the respective abundances of common herb- and grass-feeding moth species have declined 88% and 74% since 1961-63. A greater residual floral diversity at the other site (13% herb cover, 71% grasses) has to date favoured a lesser decline in grass-feeders (56%). Data analyses suggest that few common endemic grassland moths can survive as oligophages, most depending on feeding diversity. In the face of reducing diversity, the thrust of faunal conservation in induced *Agrostis* associations should be to manage the vegetation using adventive animals as allies. The evidence of the study supports and extends the author's earlier conservation guidelines.

Keywords: Lepidoptera; moth fauna; abundance; population trends; light-trapping; grasslands; *Agrostis*; polyphagy; conservation.

Introduction

The long-term status of insect faunas in New Zealand's indigenous tussock grasslands has attracted minimal research. Time frames and processes of change are poorly understood and have received scant investigation. While some fragmentary evidence of declining insect trends has been noted (White, 1987), these are merely a pointer to faunal history over recent time. Quantitative measures are absent. The present study attempts to quantify change in faunal elements of tussock grasslands that have been invaded by the widespread adventive grass *Agrostis capillaris* L. (browntop). The choice of a 'representative' faunal element is desirable in ecosystems with rich faunas that can reach 1000 insect species alone (see Burrows, 1977). Of the primary insect taxa, Lepidoptera (notably moths) are a dominant herbivore group, and adults are readily sampled. Insofar as all life-stages comprise a major prey resource for invertebrates and birds, the taxon may also be a prime indicator of the likely dynamics of other faunal elements. The numerous difficulties in quantifying moth dynamics across species phenologies have tended, however, to hinder precise faunal monitoring, and thereby the recording of long-term changes in abundance. Light-trapping measures are dependent on moth behaviour and local flight variables (see Southwood, 1978; Bowden, 1982), and such data have two numerical weaknesses: catches are not unit-area

samples; and sampling bias is always present and seldom constant. To minimise these weaknesses and address the biases of continuous removal sampling (when population size itself is repeatedly modified by removals), a 3-point light-trapping methodology has been adopted:

probability theory is used to prescribe an optimal interval between samples (based on adult longevities) so that each sample in a series is drawn from population cohorts unmodified by previous removals (White, 1988, discontinuous sampling); sampling-area variability between sites and trapping occasions is minimised (as far as practical) by a 360° field of non-obstructed trap visibility to a distance of potential flight response (up to 700 m; Bowden, 1982); an *a posteriori* method is used to standardise samples for the collective impacts of weather variables (primarily wind), based on the serial sample compositions of different flight classes of moth.

Methods

The study area is a montane short-tussock grassland in the Cass Basin, Waimakariri River catchment, South Island (Figs. 1, 2). Climate is described by Greenland (1977). At Cass Field Station, 566m a.s.l. a mean annual rainfall of 1300 mm (1918-1965) is uniformly distributed throughout the year, and typical monthly mean air temperatures range from 1.6°C

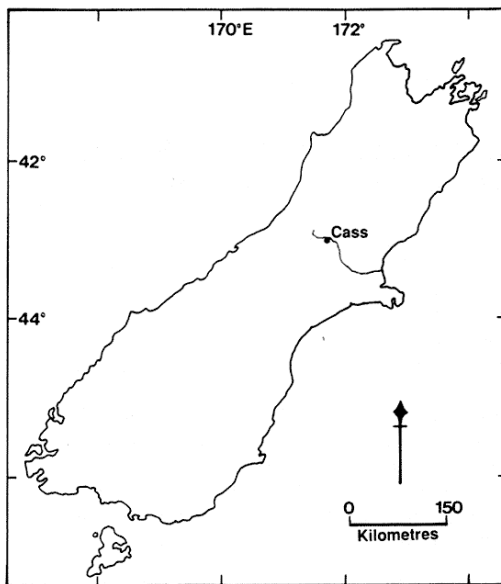


Figure 1: Study area location south of Waimakariri River, South Island, New Zealand.

(July) to 15.7°C (February). Frosts can occur in all months and weather patterns are dominated by north-westerly rain-bearing or desiccating föhn-like winds. Snow lies for some days each winter and the surrounding mountains feature a winter snowline at 1200-1400 m a.s.l. at midslope.

The study had two phases, 1961-63 and 1987-89, and two light-trapping sites, Ribbonwood Fan (site R) and Mt Sugarloaf Fan (site S). The sites are 4 km apart, and each is marked by a 7 cm tall wooden survey peg inscribed 'W62'. Respective grid references are 234124 and 234169 (NZMS1, S66). The site R peg is 65m approximately from a local supply power pole (towards the grid power line); and site S is 360m approximately from the smaller laboratory of the Cass Field Station, and 20m above the present Chilton Valley vehicle track. The latter peg marks the 1987-89 site only, but is close to the 1961-63 site (not re-located, but probably within ± 20 m upslope and ± 5 m across slope).

Sites R and S both lie on 5-10° slopes within large debris flow fans; respective aspects are 340° and 235°, with traps at altitudes of 640m and 610m a.s.l. Both fans have been grazed by sheep since settlement in the late 1850s, and sheep numbers in the region peaked at 92 000 in 1895 and then fell to two-thirds by 1919 ("Grasmere" data in Cumberland, 1944; Scott, Dick and Hunter, 1988). Stocking rates were especially high during snow periods at higher

altitudes. More recently, site management histories have diverged.

Site R was accidentally burnt in January, 1956. Within 6 months it was topdressed and oversown with white clover (*Trifolium repens* L), alsike (*T. hybridum* L) and Montgomery red clover (*T. pratense* L), and was thereafter managed more intensively (including increased numbers of cattle), with 2- or 3-yearly topdressings and light clover oversowings until the mid-1970s (D. and I. McLeod, *pers. comm.*). Traditional set-stocking became mob-stocking through the 1980s (after cattle removal) because of increases in browntop from the late 1970s, but reverted to set-stocking in 1987 with the removal of most stock throughout the moth-trapping period. An increase of rank sward followed. There was one topdressing in the mid-1980s (D. Harcourt, *pers. comm.*).

Site S was grazed in early years by sheep, and in the winter, by cattle (Malcolm, 1925), but there have been low stocking rates of sheep (and seldom any cattle) from about 1930. Recovery from an accidental fire in 1947 was slow (Burrows, 1977, p. 207) and there has never been topdressing or oversowing.

Early series of vegetation analyses exist for site R (unpublished North Canterbury Catchment Board annual records, February 1957-62), and for site S (Malcolm, 1925; Burrows, 1977). Site S was again assessed in February 1988 (Shanks *et al.*, 1990), and both sites in February 1990 (present study). The 1990 analysis re-surveyed 5 chains (100.6m) of the 1957-62 transect at site R (grid reference 238118), using the original point analysis method at 10-inch centres (25.4cm) and recording the basal node of the plant nearest to the needle point at ground level. The same method was used at site S on a 120m transect from the survey peg, in the direction of Chilton Valley at the apex of the fan (lower slopes shown Fig. 2B). The method emphasises species ground-cover rather than species mass.

Trapping

Light trapping at both sites was as far as possible identical in the two study periods. Robinson light traps (Fig. 2) with 60W 12V tungsten opaque lamps were positioned to give 360° visibility at each site, interrupted only by distant topography. Over one quadrant, local topography created interruption zones beyond 150m, but these were near ground level only. There were no competing light sources, and traps were operated for 3 hours from dusk, using battery or mains power. The effective cross-section area of baffles above the rim-line of the cone was 1000 cm² x 2 faces, including the lamp but excluding areas vertically beyond the 37.5cm rim diameter (1961-63 design). Baffle dimensions (but not cross-sectional areas) varied slightly between traps, and lamp



(A)



(B)

Figure 2: (A) Ribbonwood Fan site R in February, 1963. (B) Mt Sugarloaf Fan site S in March(?) 1988; note scattered *Cassinia* bushes.

elevation above the rim was comparable on traps of both study periods. Trapping was timed by automatic devices or manually, and both sites could be sampled simultaneously if desired.

In 1961-63, the collecting compartment was below ground and contained potassium cyanide crystals (KCN) in a protective chamber (White, 1964b; Southwood, 1978, Fig. 7.11). In 1981-89, the collecting compartment was above ground and the trap more elevated (mean sward heights were greater than in 1961-63). The safer substitute for KCN was Dichlorvos 200g Kg⁻¹ in the form of Shell 'Vapona' or 'Black Flag' pest strips. Two strips were placed in the compartment 1 hour before trapping, in addition to strips of paper sprayed with a pyrethroid contact insecticide 'Slay' (tetramethrin 3.3g l⁻¹, d-phenothrin 0.8g l⁻¹, piperonyl butoxide 7.7g l⁻¹ in aerosol form). Although 1987-89 knockdown time was slower than with the earlier KCN, observation of moth behaviour suggested a comparable capture efficiency. Moths alighting on baffles (like those impacting, entering and re-entering) tended to sink lower into the trap after

increasing exposure time to Dichlorvos emissions from below.

Trapping nights were selected according to elapsed time since last sample, operator availability, weather suitability and degree of vegetation wetness (dry conditions being preferred). On-site winds during the hour to dusk usually controlled the final choice of night, and sampling was at times terminated if flight conditions later deteriorated.

The sampling frequency target (White, 1989) was one representative sample every 14 days, with a minimum interval of 10 days and preferred upper limit of 18 days (based on a literature review of moth longevities, W.E. Miller, *pers. comm.*). When possible, sampling was repeated within three nights if flight conditions seriously limited a catch (see 'Data analysis'). Interference by cattle and automation failures shortened the site R sequences in 1961-63, and a substitution of spring 1989 sampling was made at site S for the absence of spring 1988 data (Table 1). Species abundances in the two Novembers were closely matching.

For future reference, nearly all voucher specimens of moth species recorded in the study are deposited in the Entomology Department collection, Lincoln University. The remaining few are held in the New Zealand Arthropod Collection.

Data analysis

Given an exposed montane environment in which wind velocities may fluctuate widely by the minute and shift dramatically by the hour, moth flight conditions are at times very changeable across a 3 h trapping period. Species catches, therefore, appear not only to be a function of wind velocity relative to moth size and manner of flight (e.g., Mizutani, 1984), but also of lag-time thresholds under pulsing flight conditions. Non-continuous wind records thereby fail to explain flight potentials over such periods, and continuous data were unavailable.

Catches themselves provide biological indicators of wind influence *a posteriori*, and data series were screened to select the samples representing the least-limiting sampling occasions (i.e., those nearest to unit-area samples; see 'Introduction'). Three screening criteria were adopted.

Sample composition

Three flight classes were recognised, and observation of body size x sample composition over many samples was used to assign every species to a class:

'heavy fliers' (typically Hepialidae and Noctuidae) were the faster-flying species, and the last to remain active with increasing wind velocities (class A); 'medium fliers' (primarily most Crambidae and Geometridae, with some Oecophoridae and Tortricidae) had intermediate flight powers and

Table 1: Site sampling dates and statistics for each flight year¹. The more favourable sampling periods are standardised (according to flight class) by a sample index of 1.00 (see text).

¹Statistics are in part influenced by weather differences between flight-years:

1961-62 - all seasons mild; rather dry August-April; hot summer; sampling nights often quite windy;

1962-63 - very wet October; dry but cool summer; greater sampling frequency of less windy nights;

1987-88 - very wet, cool and windy year; delayed spring; cold autumn nights; suitable sampling nights often widely spaced;

1988-89 - all seasons mild; dry, warm summer; higher frequency of suitable sampling nights than other years;

1989 - spring - mild; dry; sampling frequency as 1988-89.

	Ribbonwood Fan (R)					Mt Sugarloaf Fan (S)					Total
	Flight year (1961-62)	1962-63	1981-88	1988-89		1961-62	1962-63	1981-88	1988-89	1989(-90)	
Trapping dates: start	16 Jan	16 Nov	8 Dec	11 Nov		1 Dec	14 Sep	11 Nov	11 Nov	16 Sep	
finish	21 Apr	21 Mar	26Apr	16 May		16 May	21 Mar	26 Apr	11 May	25 Nov	
No. of sampling periods	8	9	8	13	38	13	14	10	14	5	56
No. of samples	9	11	9	18	47	19	20	17	23	5	84
No. of periods indexed 1.00											
*Heavy fliers (class A)	4	6	8	11	29	8	7	8	13		36
*Medium fliers (class B)	4	4	3	10	21	4	5	4	12		25
*Light fliers (class C)	4	4	2	8	18	3	4	2		10	19

body size, and remained active in light breezes (class B). Class B moths were frequently sampled with class A moths when light breezes persisted for the full sampling duration or were intermittent between windier conditions;

'light fliers' (small moths in a wide range of families) were only sampled with larger species in conditions of faint breezes or calm (class C).

All samples were screened by classes using a 3-step scale of trapping success (relative to time of year): class well represented / sub-standard / absent.

Sampling conditions

All available information was related to each sample. This included general observations of weather (wind patterns, temperatures, precipitation, moonlight, cloud cover and darkness), screen temperatures (on occasions), vegetation dampness over the duration of a sample, and the abundance of other 'class C' micro-insects in the sample and/or at the light. Where the joint evidence of the 3-step scaling (above) and the prevailing conditions suggested a favourable sampling of moth classes B and/or C, it was also concluded that the heavier classes A and/or B were favourably sampled, regardless of their moth numbers. Each moth class in the sample was then ranked on the following scale of trapping standards:

ideal/good / good in part / reasonable / fair / poor/failed

where 'ideal' and 'good' represent (respectively) no known limitations and low-impact limitations over 3h; 'good in part' is their equivalent over a partial duration of less than 3h; and 'reasonable' to 'failed' refers to limiting flight conditions of increasing severity and/or duration.

Class weighting factors for sub-standard samples

Weighting factors were then derived for each class in a sample to standardise class relativities between

sampling periods (in periods of repeated sampling, the '3 h sample' comprised the highest single count for each species in order to retain maximal information for the period). The classes were indexed in three steps:

- a) samples scaled 'ideal' - these were indexed 1.00;
- b) samples scaled 'good' or 'good in part' - these were indexed 1.00 only if the plotted sample would further maximise or extend the line joining consecutive plots in step (a) above; e.g., four plots in Fig. 3B are 'ideal' and two plots (16 November, 17 December) extend the line over time;
- c) all remaining samples - each was multiplied by a weighting factor to match the combined graph of steps (a) and (b) (e.g., Fig. 3B shows indices of 2.24 and 2.0 I), and the index was accepted as robust if its value did not exceed 3.00 (Classes A and C) or 3.50 (Class B).

All weighting factors were determined on the basis of total sample size, by classes, but are applied to individual species counts within classes. Non-accepted samples were rejected as measures of standardised abundance, but could be cited in evidence of species absence before and after the flight spans as identified by the accepted samples. Table 1 lists numbers of samples indexed 1.00, and the difference between these counts and the total number of sampling periods (same column, top row) represents the maximum number of indices greater than 1.00. In most sequences, rejected samples reduced this number; e.g., Fig. 3B includes only eight samples of the nine listed in Table 1 (site R, 1962-63) and both graph and table show there to be six class A plots indexed 1.00. The performance of the screening procedure identified closely with observed conditions, weighting or rejecting nights of prolonged moonlight, low temperatures and unfavourable winds.

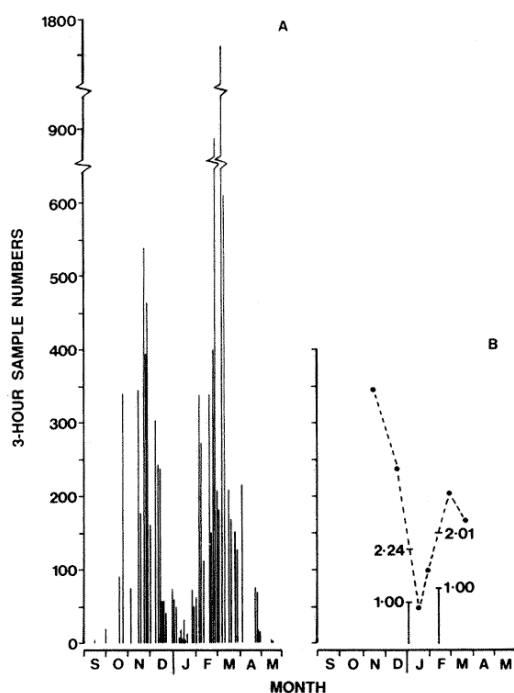


Figure 3: Class A moth flight periods. (A) Bimodality of Noctuidae alone as a composite of ideal nights for 2 sites x 3 flight years. (B) Indexing of all class A species at site R in 1962-1963, showing six ideal nights and two extrapolated indices (see text).

The independence of serial samples (when moths individually are shorter-lived than sampling intervals) means that estimates of abundance are unbiased by moth removals. Thus discontinuous removal sampling and data standardisation jointly compensate for major sources of sampling variability across species phenologies. The measured population is a sub-set of the full population, and comprises its trappable members only. These members are those responsive to the light source under 'ideal' trapping conditions if such were to be always attained, i.e., from throughout each species' maximised trapping range. (undefined but site-specific; White 1989). Graphs of indexed samples are the standardised estimates of moth frequencies x time, and define non-disrupted phenology distributions. Hence the integration of a species graph (i.e., the area under a graph) accounts for all trappable individuals, including uncaught members that are present on non-trapping nights. White (1989) defines the graph area as 'moth-nights', where moth-nights = generation numbers x natural longevities. Should a species include individuals that

are longer-lived than sampling intervals, the benefit of pseudo-independent samples is still a gain. White (1988, Fig 1) contrasts the outcomes of disruptive and non-disruptive sampling based on probability theory.

Results

Moth abundance (non-standardised)

Table 2 presents summary trapping statistics. The totals exclude a further 39 moth species (see White, 1964a), plus five 1987-89 species (*Asaphodes aegrota* (Butler), *Austrocidaria arenosa* (Howes), *Heterocrossa morbida* (Meyrick), *Orocrambus catacaustus* (Meyrick), *O. corruptus* (Butler)) recorded beyond the range of the two light traps or not attracted to light.

Appendix I lists species trapping records by families (after Dugdale, 1988) and flight-classes. Direct comparisons are merited within the majority of species as each study period had similar sampling spans apart from later autumn sampling in the final year (Table 1). Species clearly under-represented by lesser sampling effort are indicated by italicised numerals or captioned notations; e.g., if sampling was omitted, limiting or delayed over critical periods in a species' phenology. Most spring-occurring species are directly comparable for only one year per study period (Table 1).

Known larval foods are cited if recorded in vegetation analyses of the two sites (Appendix 2) or listed locally (Burrows, 1977). Estimates of minimum distances from very localised foods to a light-trap (Appendix I) are based on direct observations and do not imply that a food or habitat type is common or widespread. In some instances only single patches are present, such as aquatic herbs within riparian strips and two small *Nothofagus* forest patches at site S, greater than 300m from the trap. In other instances, no positive recording was made and therefore the minimum distances represent the limits of searching. Estimated distances are not intended as statements of moth response distances to light, and larval food citations are drawn from the 20 asterisked references, from specimen records in the New Zealand Arthropod Collection, J.S. Dugdale *pers. comm.*, or from B.H. Patrick *pers. comm.*

The important note of Appendix 2 emphasises differences in vegetation analyses. With the possible exception of Method V, no method was applied extensively enough to fully represent species diversity. In the grasses sampled in 1990, 'other species' refers wholly to the adventive *Festuca rubra* L. It is not listed separately to avoid confusion with Appendix I references to endemic *Festuca* species (principally *F. novae-zelandiae* Ckn.). In Method 1, note that 0.3% numerical cover for *Festuca* represents 15.2 tussocks m^{-2} (where total species = 4366 plants m^{-2}). An

Table 2: Comparison of trapping records over the two study periods.
* = some species in common to both periods.

	Total	1961-63	1987-89	Change
No. of moths trapped	44606	31032	13574	-56%
No. of species trapped	202	153*	160*	+5%
No. of species recorded in one period only	90	41	49	+20%
No. of species recorded at one site only	81	43*	55*	+28%
No. of species recorded with only 1 moth period-.	56	29*	40*	+38%
No. of species with nearest food plants >300 m from light	41	25*	30*	+20%

overall decrease of 56% in moth numbers between the two study periods (Table 2) does not occur uniformly across taxa. Contingency table analyses of Appendix 1 subtotals against collective residual totals (sites combined within periods) further indicates significant proportional declines in Geometridae, Crambidae - Crambinae and Scopariinae - and in Noctuidae when *Tmetolophota* spp. are excluded ($X^2=77.6, 4683.9, 623.7, 417.4$ respectively, $P<0.005, df=1$). *Tmetolophota* spp. are excluded because, collectively, they increase rather than decline, and the proportional change in their abundance is even more significant ($X^2=8906.0$). A few species are dominant in these changes, viz. *Helastia corcularia* (Geometridae), *Orocrambus cyclopicus*, *O. vittellus*, *Eudonia submarginalis* (Crambidae), *Graphania mutans* and *Tmetolophota propria* (Noctuidae). Two other notable declines are *Coleophora trifolii* (Coleophoridae) and *Capua semifera* (Tortricidae), and many less abundant species also conform to this overall trend.

The decline does not appear to be an artifact of sampling or chance variability between study periods. The 1988-89 flight year had the greatest sampling effort, and between-year variability across the 4 trap-years of each study period (2 sites x 2 flight years) was seldom great. Strongly differential changes among taxa (above) discount any suggestion of less effective killing agents in 1987-89, and it is unlikely that broad-spectrum pathogens and predators could account for the observed mix of site similarities and differences at species levels. The predatory adventive wasps *Vespula germanica* (F.) and *V. vulgaris* (L.) are not present.

Despite declining abundance, Table 2 indicates that species richness has not lessened (row 2) even if species composition appears changed (row 3). Two recent adventives were present in 1987-89, *Leucoptera spartifoliella* (Lyonetiidae) and *Chloroclystis filata* (Geometridae) but no other 1987-89 species can be affirmed as definitely absent in 1961-63. A good example is *Eudonia luminatrix* (Crambidae), known in 1961-63 only from a forest margin, its traditionally recognised habitat, but now strongly intrusive at both grassland sites (site R is 1.2 km from the nearest forest). Seven other non-adventive species recorded at

both sites for the first time in 1987-89 were *Anisoplaca* n.sp. (Gelechiidae), *Leptocroca* sp. (Oecophoridae), *Bactra noteraula* (Tortricidae), *Eudonia octophora* (Crambidae), *Helastia cymozeucta*, *H. expolita* and *Hydriomena purpurifera* (Geometridae). Some of the 15 species no longer evident at either site in 1987-89 are cited later (see 'Trends in abundance'). Other species making up row 3 (Table 2) are known from one site only and from few specimens. Rows 4 and 5 present statistics for low-frequency species, and most of these data are fully independent. Thus in row 4, 59 species were recorded exclusively at one or other site and in only one or other period (excluding species without adequate sampling at site R), and 50 of these species also belonged to the grouping listed in row 5. Contingency table analyses of both sub-sets, 2 periods x 2 sites for 59 species and 50 species, show non-significance ($X^2 = 0.798, 0.363$ respectively, $df = 1$). Because the sub-sets account for two-thirds of all species in the groupings of rows 3-6, the very low X^2 values infer that none of the % species changes in Table 2 can be significant. The greater number of 1987-89 species might only reflect increased sampling effort, and both study periods undoubtedly had non-recorded scarce species.

Thus species richness has been maintained over 26 years (Table 2, row 2) despite apparent shifts in the faunal composition of scarcer species, and a fall in moth abundance (row 1). The fall itself is highly significant between sites (test of Appendix I grand totals), with the proportional decline at site R exceeding site S ($X^2=44.38, P<0.005, df=1; X^2=479.8$ when *Tmetolophota* spp. are removed). A lesser site R difference is shown when moth totals are tested for species caught in one period only ($X^2=6.26, P<0.025$).

In seeking an explanation for these changes, it is important to note that both of the sites and their surrounding grasslands and shrublands have remained extensive and essentially non-fragmented since the first study period.

Trends in abundance (standardised)

An example of standardised faunal phenologies (Fig. 3A) shows a strong bimodality of class A moths in Noctuidae, the dominant family in this class. Six data

sets are superimposed (2 sites x 3 flight years) to show the 49 samples with index 1.00 (= class A summation in Table 1, excepting 1987-88 because the delayed spring moved the earlier modality to the right, narrowing the normal January trough). While some species are bimodal, most fly within one modality alone. In contrast, the standardised abundance of class B moths (dominated by Crambidae, flying November to March) shows a unimodal peak towards late February. Unlike Noctuidae above, the annual pattern is dependent on relative species abundances rather than on inherent biology. Class C phenology patterns from October to March are without any consistent peaks (taxa are diverse), and good data are fewer because flight is so wind-restricted.

Figure 4 illustrates standardised abundance data for 6 species, and the 2-year summations may be directly compared with the trapping records for each study period in Appendix 1. Such comparisons demonstrate that trapping records do not always reflect the relative abundances obtained by data standardisation. For example, by summing *Tmetolophota propria* moth-nights (Fig. 4) to match the column sequence from left to right of "Numbers trapped" in Appendix I data, the raw data ratio (1 : 8 : 2 : 3) is halved by standardisation (1 : 4 : 1 : 1.5). Similar shifts of -50% to +100% over one, two or three ratio values in other Fig. 4 species point to some sizeable changes in site and trapping period relativities. Because such trapping period comparisons are based on the means of 2-year summations, standardised comparisons between individual years include shifts exceeding -50% and + 100% in some years.

All species are open to sizeable shifts by standardisation because the same serial catches over a time continuum of variable trapping conditions can be phased differently for different species, each responding in its own way to the continuum variables. Hence, while one peak coincides with an 'ideal' trapping sample, another species' peak may coincide with a sub-standard sample and be substantially weighted by an index > 1.00. Figure 4 includes species with the greatest shifts based on 2-year summations. .

Table 3: Changes in abundance of 40 common species from 1961-63 to 1987-89 grouped according to feeding categories. Percentages are based on moth-nights.

	Site R	Site S
Known grass feeders (n= 14)	-74%	-56%
Known herb feeders (n=8)	-88%	-84%
Shrub feeders (n=2) and unknown (n= 16)	-72%	-82%
Mean (n=40)	-74%	-70%

Table 3 presents an analysis of standardised species abundance according to major feeding categories (see Appendix I for specific known foods). The 40 species account for 96.8% of all site R moths and 93.4% of site S, and their respective declines of 74% and 70% (n=40) contrast with the earlier non-standardised mean of 56% (Table 2, 100% samples). The additional margin of 14-18% is attributable to data standardisation.

A log-linear model analysis of moth-nights for the three-way table (Fienberg, 1980), sites x study periods x feeding classes, shows first- and second-order interactions to be highly significant ($P < 0.0001$). Of the first-order interactions, site x feeding class contributed most to the deviance, and the largest contribution was by the grass feeders (Table 3, row 1), including five *Orocrambus* spp. (*O. cydopicus*, *O. flexuosellus*, *O. ramosellus*, *O. vittellus*, *O. vulgaris*). Row 3 species, including shrub feeders (n=2), also contributed strongly and could include further species of all three feeding classes. The least contribution to the deviance (but the greatest change between study periods) is observed for herb feeders (row 2).

When Table 3 and Appendix 2 are taken together, long-term increases in % grass composition reaching 93% (site R) and 71% (site S) by 1990 show a highly negative correlation with observed decreases in grass feeders. Although site S grass feeders declined less, this site retains a moderate abundance of endemic herb species despite their strong decline from 1972 (Method V, Appendix 2; note the species that were not recorded subsequently). In contrast, only adventive herbs are now conspicuous at site R (especially clover species), and % herb cover is only one-third of the site S level.

Of the 40 species, the known herb feeders are *Aludonia cataxesta*, *Graphania mutans*, *Helastia corcularia* and *Hydriomena deltoidata*. Three have seemingly disappeared (Appendix 1) along with other grassland species known to be herb feeders (*Orocrambus xanthogrammus*, *Scopula rubraria* and *Aletia cuneata*) or known to be likely so (*Kiwaia schematica*). Thus at least half of the 15 non-recorded species of 1987-89 are herb feeders.

Of shrub feeders and forest species (Appendix I), *Harmoloma* spp. (Tortricidae) have increased in abundance with their food plant *Discaria*, but *Mnesictyna flavidalis* (Crambidae) and the winter moth *Zermizinga indocilisaria* (Geometridae) have noticeably decreased. At site S, fewer *Graphania homosda* (Noctuidae) were recorded than in 1961-63, yet the known food plant *Cassinia* is surely increasing (c.f. site R). Of forest' species, the most notable 1987-89 absence was the noctuid *Meterana dotata*, and herein is a caution that faunal diversity changes in extensive

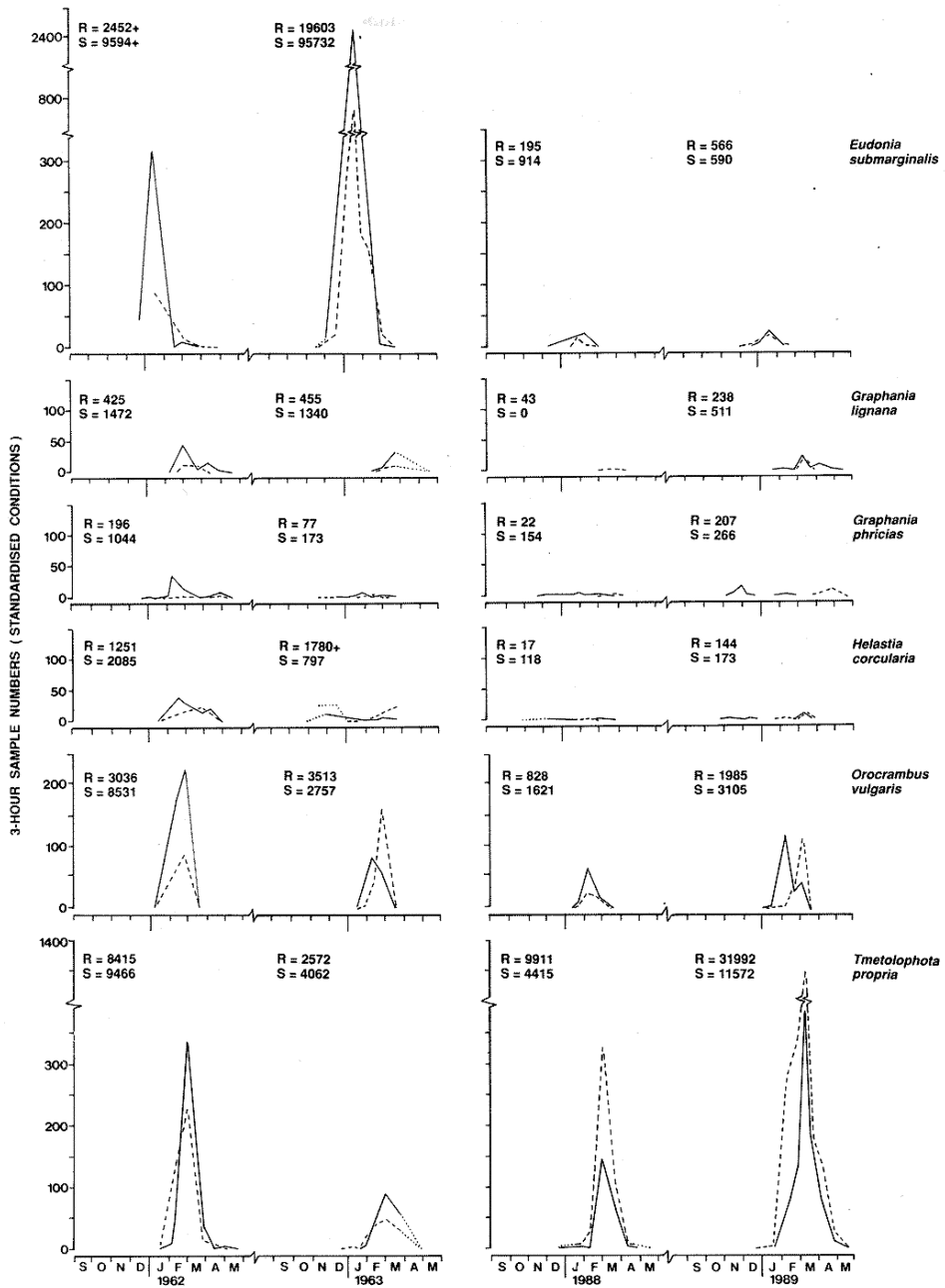


Figure 4: Standardised abundance of 6 common species in alphabetic sequence, showing moth nights for each flight year (annual total = area below graph; totals given for both flight years) and each site (dashed line = site R; solid line = site S; dotted line = data values approximate; + = incomplete records). 1989 spring data are polled as September-November 1988 (see text).

WHITE: CHANGES IN GRASSLAND MOTH ABUNDANCE

grasslands may in part represent changes in adjacent vegetation (note distances greater than 1 km to nearest known food sources, Appendix 1).

Longer-term evidence of grassland faunal trends is given in Fig. 5. The observations of Hilgendorf (1918) and Dick (1940) in the environs of site S are indexed against present site S data, assuming that faunal abundance in 1917 and 1939 equalled (rather than exceeded) 1961-63 abundance. This assumption is believed to be highly conservative and an example illustrates the conversion of 1939 data (collected in late February; R.D. Dick, *pers. comm.*) from a 1-5 scale to 1961-63 light-trap equivalents. Species with February phenologies were present in 1962 and 1963 catches as follows (summed by families, figures rounded):

Geometridae 200
Noctuidae 2700
Crambidae 4750

Of the 4750 Crambidae specimens, 3190 were *Orocrambus vittellus*, and of these, late February 3 h catches (one in each year) totalled 1650 moths ($\bar{X} = 825$, Fig. 5). Corresponding moth numbers for 1939 were approximated by allocating 4750 crambids (see assumption above) among the three site S species which Dick recorded. The allocations, adjusted for phenological timing, were based on an indexing of his 1-5 scaling for each family against a 1:7:15 family weighting (Geometridae:Noctuidae:Crambidae) derived from the 1961-63 trapping ratios (Appendix 1). Thus, by adopting an expanded 1-15 scale for the crambids, the first species, *O. vittellus*, was estimated as 15/31 of the crambid total (where 31 equals the summation of the values for the three species on the expanded scale), and a 1939 '3 h catch' as

$$\left[\frac{4750 \times 15}{31} \right] \left[\frac{1650}{2 \times 3190} \right] \\ = 594 \text{ moths (Fig.5)}$$

In this way, 50- and 70-year trends of late-summer species were plotted as mean seasonal indices of abundance, using assumed family abundances pre-1961. In Crambidae, the large declines in *Orocrambus flexuosellus* and *O. 'simplex'* (= *O. lewisi/O. ordishi* complex, Appendix 1) may be an outcome of the 1947 fire, but fire impacts on any given species are unknown (d. site R after the 1956 fire). Two patterns are evident among the grass moths: major early declines have occurred in some species while others (*O. vittellus*, *O. vulgaris*, and probably *O. cyclopicus*, not shown) have more recently peaked and declined. The majority of species, however, emphasise earlier declines, even if some 1917 observations include taxonomic errors; e.g., Hilgendorf did not record *O. vittellus* (not necessarily

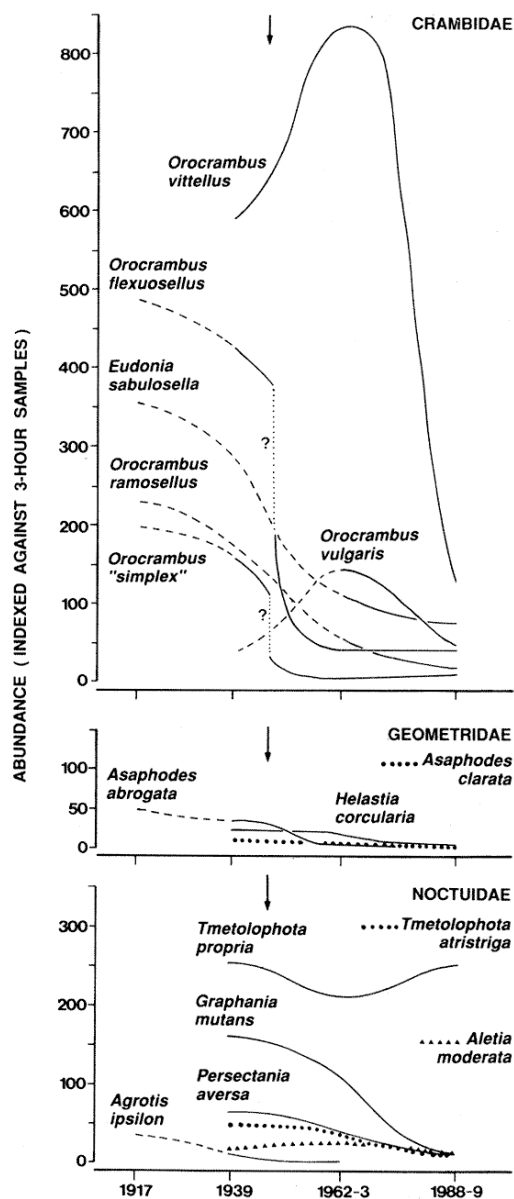


Figure 5: Site S trends in the abundance of some late-summer species projected over 50 to 70 years (see text for assumptions). The 1917 projections are based on an interpretation of non-quantitative data. The arrow refers to the fire of 1947.

an error - see species above with peaking abundance) and his *Venusia undosata* = *Asaphodes abrogata* (see White, 1987). The prolonged decline of known herb feeders is pronounced (note geometrid species and *Graphania mutans*, though less so for *Aletia moderata*), and is paralleled by many grass feeders (the four crambid species of 1917 and the noctuids *Persectania aversa*, *Tmetolophota atristriga* and *Agrotis ipsilon aneituma*). The notable exception is *T. propria*, adapting well to dominantly grassed swards (also Fig. 4, site R).

Discussion

The fauna-sward dynamic

The local record of sward changes (Appendix 2) fits in a long-term context of spreading adventive species (Dobson, 1977). Detailed descriptions of habitat associations in the Cass district (Cockayne and Foweraker, 1915; Burrows, 1977) amplify the quantitative grassland record of the region (Sewell, 1947; Wilton, 1948; Moffat, 1957; Rose, 1983; Scott *et al.*, 1988). A dominant species in widespread change is *Agrostis capillaris*, not recorded at site S in 1925, but noted nearby by 1944 and by the 1970s a dominant inter-tussock species (Dobson, 1977). Since that time the increase has been dramatic (Appendix 2, both sites; also see 'Methods'), and given the rhizomatous habit, few localised patches now remain without its smothering dominance. The 70% *Agrostis* frequency recorded in 1972 (Appendix 2, Method V) had reached 99%+ by 1990 (visual assessment). In earlier stages of invasion, the inter-tussock sward remains open (see Fig. 2A) but in later dominant stages, there is a heavy reduction in endemic species, especially herbs.

Qualitative changes in grasses, e.g., shifts in the apparent vitality of *Festuca* swards, offer at best a partial explanation for decreases in grass feeders (Table 3, Fig. 5). Disappearance of the semi-moribund tussocks of 1961-63 (site S) may reflect a gradual loss of larval habitat and food quality/diversity during the widespread decline of *F. novae-zelandiae* over 30+ years (see Scott *et al.*, 1988). Explanations of disease and predation have been discounted (see 'Moth abundance') and climate changes can only be small. By induction, it would appear that there is only one adequate hypothesis to explain observed declines: few of the common endemic grassland moths can survive as oligophages, most depending rather on feeding diversity as obligate polyphages (e.g., see White, 1978, p. 39). In support (Appendix 1), it is significant to note that species known to feed on *Agrostis* (*Wiseana mimica* (Hepialidae); *Orocrambus enchophorus*, *O. flexuosellus*, *O. vittellus* (Crambidae); and *Persectania aversa* (Noctuidae)) have themselves declined.

Enforced browntop monophagy is not their adaptation for survival (d. endemic monophagy; Dugdale, 1975). Nor does the observed maintenance of moth species diversity (despite heavily reduced herb populations) fit a classic explanation of faunal decline with losses of specialist feeders. Scarce moth species, some almost certainly 'specialists', have survived without apparent change to their abundance while populations of common 'generalist' feeders (note polyphagy, Appendix 1) have collapsed.

An explanation is seen to lie in the dynamics of plant invasions and the statistics of plant abundance frequency distributions (e.g., see Hengeveld, 1989). Heavy invasions of *Agrostis* depress the densities of most pre-invasion plant species. The emerging *Agrostis/grass* dominance has been further aided by other 'disturbance' factors at site R (a regime of oversowing and topdressing) lowering many herb frequencies toward zero. At site S, in contrast, no major secondary disturbances have been evident, and few if any herbs are likely to have reached zero abundance. Here, both specialist and generalist feeders may still find their food plants (even if scarce) and survive.

An explanation of the general collapse of common moth species is therefore suggested as follows. With increasing food scarcity, the searching ranges of feeding polyphagous larvae are increasingly extended to locate adequate food mixes (at times 'concealed' among the invasive plants), whereas food-specific larvae need only remain with located food-plants. Polyphagy (especially if obligate in the above sense of precluding enforced oligophagy or monophagy) may therefore ultimately become a liability with the progress of plant invasions, leading to the collapse of many generalist moth species. Specialists, on the other hand, remain more directly limited by food supplies *per se* than by proximities between food plants, and their relative abundances may be sustained for longer.

The roles of other fauna are also relevant here. Lord (1990) has demonstrated the selective impact of stock grazing (principally sheep) on the floristic composition of a semi-natural short-tussock grassland. A cessation of grazing promotes fewer sward species (indigenous and adventive) but higher adventive cover. Many surviving indigenous species tend to decrease in abundance, and a few adventive species assume dominance.

The permanently low sheep numbers at site S have long favoured trends in this direction, and thereby exert an indirect but strong influence on the availability of food plants for the endemic moth fauna. Adventive grasses are best contained by adventive animals, as illustrated by mob-stocking management at site R in the early 1980s (see 'Methods'). Yet domestic stock may not be the sole

adventive agents of browntop management, therein 'assisting' the moth fauna. At site S, scattered vegetation patches of 1-3m², with well-defined margins, are without rank *Agrostis* and offer a greater frequency of low herbs and low shrubs than in surrounding rank areas (visual assessment). Hare faecal pellets are frequently conspicuous in these 'hare gardens', and similar open patches are found with Canada goose pellets. (Rabbits are not present.) Faecal cuticle analysis of small random samples (recent pellets taken in February 1989) showed a high frequency of *Agrostis*: hares - 62% of cuticle frequencies; Canada geese - 100%. The seasonal territoriality of such herbivores at site S, also given an increase in sheep numbers, might yet act as a residual buffer against total *Agrostis* dominance and the pervasive losses of Lepidoptera foods.

Conservation

Invasive *Agrostis* is widespread in many low-tussock montane grasslands and study findings point to four conclusions pertinent to conservation:

- a) ongoing vegetation changes are directly modifying the prevalence of the endemic moth fauna;
- b) more intensive pastoralism, as at site R, hastens the changes;
- c) the more abundant moth species are in general the first to be noticeably affected by changing vegetation composition when invasive sward species displace endemic species;
- d) the increasing scarcity of some endemic food-plants, and especially of herbs, ultimately implies species loss to local faunas dependent on them.

The conclusions confirm and amplify earlier evidence and conservation theory drawn from tussock grassland insects (White, 1987). Three of the four earlier conclusions on conservation management are directly endorsed by this study, whereby:

- a) monitoring of common species is shown to give early signals (and more sensitive measures) of possible shifts in the abundances of scarce species;
- b) a goal of maintaining systems rather than scarce species is shown to favour species' chances of survival while species-specific knowledge of management requirements remains uncertain;
- c) a changing species abundance (and ultimately the risk of local extinction) is shown to be unrelated to scarcity status *per se*, but rather to habitat changes that select between survival strategies (such as monophagy versus oligophagy versus polyphagy).

From current evidence, a further management conclusion is also offered: conservation management should draw on the impacts of *all* grazing animals for the better management of conserved species or of endemic local faunas.

Some herbs have been all but lost from grasslands through selective grazing in the historic past. Those losses cannot be now redeemed. But other herbs in induced *Agrostis* swards may yet be retained by direct management in specific habitats of conservation interest. The prime objective is to optimise the grazing of *Agrostis* (to keep the sward open) while limiting other losses due to the over-grazing of endemic species.

Note that an opposite conclusion (maximum protection against all grazing) may be equally valid for other grassland types and for other invading species, e.g., *Hieracium* in some tall-tussock grasslands (Treskonova, 1991). The controlling processes of ecosystem change must be specifically characterised before conservation management initiatives can be clarified.

Improved *Agrostis* management at the two study sites (and especially site S) would favour future retention of current species-richness in the moth fauna. Unless new disturbances or site fragmentation pose earlier threats, another sampling of the long-term faunal record by 2010 appears warranted, and the potential value of re-sampling within 10 years might be considered, taking full account of elapsed changes in *Agrostis* dominance. The results of simple vegetation monitoring might thus become the prime basis for decisions on critical faunal sampling.

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References

- * = reference source for the listing of known larval foods in Appendix 1.
- Allan, H.H. 1982. *Flora of New Zealand. Vol. 1. Indigenous Tracheophyta*. Government Printer, Wellington, New Zealand. 1085 pp.
- *Anon, 1985 (unpublished). *Entomological survey of the Garvie Mountains*. Otago section of the Entomological Society of New Zealand, Inc, Dunedin. 31 pp.
- *Barratt, B.I.P.; Patrick, R.H. 1987. Insects of snow tussock grassland on the East Otago Plateau. *New Zealand Entomologist* 10: 69-98.
- Bowden, J. 1982. An analysis of factors affecting catches of insects in light-traps. *Bulletin of Entomological Research* 72: 535-556.
- Burrows, C.J. 1977. *Cass: History and science in the Cass district, Canterbury, New Zealand*. Department of Botany, University of Canterbury, Christchurch, New Zealand. 418 pp.
- Cheeseman, T.F. 1925. *Manual of the New Zealand flora*. 2nd edition. Government Printer, Wellington, New Zealand. 1163 pp.
- Cockayne, L.; Foweraker, C.E. 1915. Notes from the Canterbury College Mountain Biological Station. No.4 - The principal plant associations in the immediate vicinity of the station. *Transactions of the New Zealand Institute* 48: 166-186.
- Connor, H.E.; Egdar, E. 1987. Name changes in the indigenous New Zealand flora. *New Zealand Journal of Botany* 25: 115-170.
- *Cowley, J.M. 1982. Preliminary observations on sod webworms (Lepidoptera: Pyralidae) of hill country pasture. *New Zealand Entomologist* 7: 293-295.
- *Craw, R.C. 1987. Revision of the genus *Helastia sensu stricto* with description of a new genus (Lepidoptera: Geometridae: Larentiinae). *New Zealand Journal of Zoology* 14: 269-293. :
- Cumberland, K.B. 1944. High-country 'Run'. The geography of extensive pastoralism in New Zealand. *Economic Geography* 20: 204-220.
- *Dick, R.D. 1940. Observations on insect-life in relation to tussock-grassland deterioration. *New Zealand Journal of Science and Technology* 22A: 19-29.
- Dobson, A.T. 1977. Adventive plants. In: Burrows, C.I. (Editor), *Cass: History and science in the Cass district, Canterbury, New Zealand*, pp. 271-278. Department of Botany, University of Canterbury, Christchurch, New Zealand. 418 pp.
- *Dugdale, J.S. 1966. A revision of New Zealand Schoenotenini and Cnephasiini (Lepidoptera: Tortricidae: Tortricinae). *New Zealand Journal of Science* 9: 731-775.
- Dugdale, J.S. 1975. The insects in relation to plants. In: Kuschel, G. (Editor), *Biogeography and ecology in New Zealand*, pp. 561-589. Junk, The Hague, The Netherlands. 689 pp.
- Dugdale, J.S. 1988. Lepidoptera - annotated catalogue, and keys to family-group taxa. *Fauna of New Zealand* 14: 1-262.
- Fienberg, S.E. 1980. *The analysis of cross-classified categorical data*. MIT Press, Cambridge, Massachusetts, U.S.A. 198 pp.
- *Gaskin, D.E. 1966. New Zealand Noctuidae (Lepidoptera): summary of known host plants and a bibliography relevant to the biology of the group. *New Zealand Entomologist* 3: 19-27.
- *Gaskin, D.E. 1970. Analysis of light trap catches of Lepidoptera from Palmerston North, New Zealand in 1966-68. *New Zealand Journal of Science* 13: 482-499.
- *Gaskin, D.E. 1975. Revision of the New Zealand Crambini (Lepidoptera: Pyralidae: Crambinae). *New Zealand Journal of Zoology* 2: 265-363.
- *Gaskin, D.E. 1987. Supplement to New Zealand Crambinae (Lepidoptera: Pyralidae) - corrections description of females of two species, and notes on structure, biology, and distribution. *New Zealand Journal of Zoology* 14: 113-121.
- Greenland, D.E. 1977. Weather and climate at Casso In: Burrows, C.J. (Editor), *Cass: History and science in the Cass district, Canterbury, New Zealand*, pp. 93-113. Department of Botany, University of Canterbury, Christchurch, New Zealand. 418 pp.
- Hengeveld, R. 1989. *Dynamics of biological invasions*. Chapman and Hall, London, U.K. 160 pp.
- Hilgendorf, F.W. 1918. Notes from Canterbury Mountain Biological Station. No.6 - The insect-life. *Transactions of the New Zealand Institute* 50: 135-144.
- *Kelsey, J.M. 1957. Insects attacking tussock. *New Zealand Journal of Science* 38A: 638-643.
- Lambrechtsen, N.C. 1986. *What grass is that? A guide to identification of some introduced grasses in New Zealand by vegetative characters*. Department of Scientific and Industrial Research, Government Printing Office, Wellington, New Zealand. 151 pp.
- Lord, J.M. 1990. The maintenance of *Poa cita* grassland by grazing. *New Zealand Journal of Ecology* 13: 43-49.
- Malcolm, N.A. 1925 (unpublished). *Montane tussock grassland, with special reference to the effect of spelling*. M.Sc. thesis, University of Canterbury Library, Christchurch, New Zealand.
- *Mark, A.F. Dickinson, K.I.M.; Patrick, R.H.; Barratt, B.I.P.; Loh, G.; McSweeney, G.D.; Meurk, C.D.; Timmins, S.; Simpson, N.C. 1987

- (unpublished). *Eyre ecological district. Mavora ecological region. An ecological survey of the central part.* Report to the New Zealand Protected Natural Areas Programme, Department of Conservation, Wellington, New Zealand. 59 pp.
- Mizutani, M. 1984. The influences of weather and moonlight on the light trap catches of moths. *Applied Entomology and Zoology* 19: 133-141.
- Moffat, R.W. 1957 (unpublished). *Ecological studies on montane tussock grassland* M.Agr.Sc. Thesis, Lincoln University Library, Canterbury, N.Z.
- Myers, S.c.; Park, G.N.; Overmars, F.B. 1987. A guidebook for the rapid ecological survey of natural areas. *New Zealand Biological Resources Centre Publication No.6*, Wellington, New Zealand. 113 pp. .
- *Patrick, B.H. 1989 (unpublished). *Lepidoptera, Cicadidae. Acrididae of the Manorburn ecological district.* Science and Research internal Report No. 60, Department of Conservation, Wellington, New Zealand. 16 pp.
- *Patrick, B.H.; Barratt, B.I.P.; Rance, B.; Heads, M.; Tangney, R. 1986. Entomological survey of the Siopedown Range. *New Zealand Forest Service Miscellaneous Report No.3.*
- *Patrick, B.H.; Rance, B.D.; Barratt, B.I.P.; Tangney, R. 1987 (unpublished). *Entomological survey of the Longwood Range. Longwood ecological region. Te Wae Wae ecological region.* Report of the Department of Conservation, New Zealand. 86 pp.
- *Patrick, B.H.; Rance, B.; Lyford, B.; Barratt, B. 1987. *Entomological survey of Snowdon Peak State Forest, Livingstone ecological district. Mavora ecological region.* Report to the Department of Conservation, Invercargill, N.Z.
- Rose, A.B. 1983. Succession in fescue (*Festuca novae-zelandiae*) grasslands of the Harper-Avoca catchment, Canterbury, New Zealand. *New Zealand Forest Research Institute Bulletin No. 16.* 35 pp.
- Sainsbury, G.O.K. 1955. *A handbook of the New Zealand mosses.* Royal Society of New Zealand, Wellington, New Zealand. 490 pp.
- Scott, D.; Dick, R.D.; Hunter, G.G. 1988. Changes in the tussock grasslands in the central Waimakariri River basin, Canterbury, New Zealand, 1947-1981. *New Zealand Journal of Botany* 26: 197-222.
- Sewell, T.G. 1947 (unpublished). *A study of montane tussock grassland with special reference to the growth, seeding and behaviour of the principal tussocks and grasses.* M.Agr.Sc. thesis, Lincoln University Library, Canterbury, N.Z.
- Shanks, A.; Glenn, D.; Gibson, R.; Rosser, K.; Roozen, D.; Phillipson, S.; Steven, J.; Arand, J. 1990 (unpublished). *Coleridge. Craigieburn and Cass ecological districts.* Survey Report for the New Zealand Protected Natural Areas Programme, No. 10, Department of Conservation, Wellington, New Zealand. 306 pp.
- Southwood, T.R.E. 1978. *Ecological methods with particular reference to the study of insect populations.* Chapman and Hall, London. 524 pp.
- *Spiller, D.; Wise, K.A.J. 1982. A catalogue (1860-1960) of New Zealand insects and their host plants. *Department of Scientific and Industrial Research. Bulletin 231*, Wellington, New Zealand. 260 pp.
- *Sweeney, w.J. 1980 (unpublished). *Insects of Mount Cook National Park.* M.Agr.Sc. thesis, Lincoln University Library, Canterbury, New Zealand.
- Treskonova, M. 1991. Changes in the structure of tall-tussock grasslands and infestation by species of *Hieracium* in the Mackenzie Country, New Zealand. *New Zealand Journal of Ecology*, 15(1).
- Webb, C.J.; Sykes, W.R.; Garnock-Jones; P.J. 1988. *Flora of New Zealand Vol. IV. Naturalised pteridophytes. gymnosperms, dicotyledons.* Botany Division, Department of Scientific and Industrial Research, Christchurch, New Zealand. 1365 pp.
- *White, E.G. 1964a (unpublished). *A survey and investigation of the insect fauna associated with some tussock grasslands.* M.Agr.Sc. (Hort.) thesis, Lincoln University Library, Canterbury, New Zealand.
- White, E.G. 1964b. A design for the effective killing of insects caught in light traps. *New Zealand Entomologist* 3: 25-27.
- White, E.G. 1978. Energetics and consumption rates of alpine grasshoppers (Orthoptera: Acrididae) in New Zealand. *Oecologia* 33: 17-44.
- White, E.G. 1987. Ecological time frames and the conservation of grassland insects. *New Zealand Entomologist* 10: 146-145.
- White, E.G. 1988. Sampling efficiency and the analysis of light-trapping data. *New Zealand Entomologist* 11: 81-84.
- White, E.G. 1989. Light-trapping frequency and data analysis - a reply. *New Zealand Entomologist* 12: 91-94.
- Wilton, H.J. 1948 (unpublished). *A critical study of comparative methods of botanical analysis of pastures with special reference to their mathematical reliability: The application of these methods to selected grassland associations in New Zealand* M.Sc. thesis, Victoria University Library, Wellington, New Zealand.
- *Wood, J. 1977. *Arthropoda collected in light traps at Winchmore.* Winchmore Irrigation Research Station Technical Report No. 10, Ministry of Agriculture and Fisheries, Ashburton, New Zealand. 59 pp.

Appendix 1: Species list and cumulative site trapping records for each study period. Also shown are species flight class (see text), recorded flight months (including observations additional to trap records), known larval foods (if locally present) and ecological comment (including minimum distances from localised foods to light - see text). . = adventive species; n/a = data not available for the known flight period; c = circa; italic numerals = data under-represented by lesser sampling effort; t = species not trapped but observed in trapping vicinity; so. D J f. . . = serial months September-May, main flight months in upper case, other records lower case; A = Appendix 2.

Family and species	Flight class	Numbers trapped				Flight period (months)	Known larval foods and ecological comment
		Site R 1961-3	1987-9	Site S 1961-3	1987-9		
HEPIALIDAE							
<i>Wiseana copularis</i> (Meyrick)	A	107	62	11	22	. . n d J f . . .	LEAVES. "PORINA MOTHS"
<i>W. mimica</i> (Philpott)	A	n/a	17	c390	151	. . ON	Polyphagous on sward spp.
<i>W. umbraculata</i> (Guenée)	A	3		3	1	. . n D J	As above, including ^A <i>Agrostis</i>
SUBTOTAL		110	79	c404	174		Damp swards >300m from light
TINEIDAE							
<i>Archyala erranea</i> (Butler)	B	1				. . . . i	SAPROPHAGES
* <i>Monopis ethelella</i> (Newman)	C	4	1	6	4	. . . d j f m a .	?dry plant debris
GRACILLARIIDAE							
<i>Caloptilia elaeas</i> (Meyrick)	C	n/a	73	7	22	. . ON . . f	Animal fibres, including soiled wool
<i>C. linearis</i> (Butler)	C	1	3	14	5	. . On . i f	"LEAF MINERS"
<i>C. selenitis</i> (Meyrick)	C				1	. . n	<i>Coriaria</i> , site R >500m
<i>C. n.sp.</i>	C		1			. . n	<i>Coriaria</i> , site R > 500m
YPONOMEUTIDAE							
<i>Orthenes porphyritis</i> Meyrick	C	n/a	n/a		1	. . o	<i>Nothofagus</i> >300m
<i>Plutella psammochroa</i> (Meyrick)	C	16	1	22	2	. . ON . . i f . . .	^A <i>Gaultheria</i>
<i>P. xylostella</i> (L.)	C	n/a	3	t	14	. . On d i f	<i>LEA VES</i>
<i>Rhigognostis sera</i> (Meyrick)	C			1	1	. . o . . . f	<i>Podocarpus. Phyllocladus</i> > 300m
GLYPHIPTERIGIDAE							
<i>Glyphiphrix acrothecta</i> (Meyrick)	C	t		2		. . . . j F m	MINERS IN TILLERS
<i>G. cionophora</i> (Meyrick)	C		1	t	1	. . . . j f m	Monocotyledons
<i>G. oxymachaera</i> (Meyrick)	C			1		. . n D J F	As above) Moths rarely
<i>G. triselenia</i> (Meyrick)	C		1			. . . . f	As above) attracted to light
L YONETIIDAE							
* <i>Leucoptera spartifoliella</i> (Hubner)	C		63		1	. . . . J	MINERS
SUBTOTAL		22	147	53	52		* <i>Cytisus</i> >500m, site R > 1.5km
GELECHIIDAE							
<i>Anisopla ptyoptera</i> (Meyrick)	B	5	3	2	3	. . n d i F m	SPUN LEAVES. SHOOTS
<i>A. n.sp.</i>	C		1		1	. . . . . m a	^A <i>Carmelhaelia</i> [<i>Ulex</i> >500m]
<i>Kiwia lithodes</i> (Meyrick)	C	14	4	12	10	. . o n d j f m	<i>Hoheria</i> >800m, site S >3km
<i>K. monophragma</i> (Meyrick)	C	2		2	2	. . . . n d i	^A <i>Raoulia</i> , site R >800m 1987-9
<i>K. porapleura</i> (Meyrick)	C	4		12	2	. . . . d J F	
<i>K. schematica</i> (Meyrick)	C	5		5		. . . . d J F m	Cushion herbs
BA TRACHEDRIDAE							
<i>Batrachedra tristictica</i> Meyrick	C	t			1	. . . . i	SAPROPHAGES
COLEOPHORIDAE							
* <i>Coleophora spissicornis</i> (Haworth)	C	5	46	1	11	. . . . D J	<i>Juncus</i> seedheads, >300m
* <i>C. trifolii</i> (Curtis)	C	205		53		. . . . n . J f m	"CASEBEARERS"
* <i>C. vcrsurella</i> (Zeller)	C				1	. . . . d	^A <i>Trifolium</i>
MOMPHIDAE							
<i>Zilpyrastra stellata</i> (Philpott)	C		1			. . . . i	^A <i>Trifolium</i>
SUBTOTAL		240	55	87	31		Chenopodiaceae >?600m
OECOPHORIDAE - Oecophorinae							
<i>Atomotracha ommatias</i> Meyrick	B	n/a	n/a		3	. . o n	MINERS
* <i>Endrosis sarcitrella</i> (L.)	C	1			2	. . s . n . . f	MINERS
<i>Gymnobathra sarcoantha</i> Meyrick	B			1		. . . . . f	Dried vegetation, domestic refuse (Leaf) litter
<i>Hierodoris n.sp.</i> , nr <i>eleetria</i> (Meyrick)	C				1	. . . . . j	Litter under shrubs
* <i>Hofmannophila pseudosprella</i> (Stainton)	B			t	1	. . . . . j f	Bird nests, domestic items
<i>Leptocroca sp.</i> , nr <i>lindsayi</i> Philpott	C	2			1	. . . . . i	Litter
<i>Tingena sp.</i> , <i>T. chloradelpha</i> sp. group	C	1				. . . . n	Litter
<i>T. chloritis</i> (Meyrick)	C			1		. . . . n	Litter
<i>T. macarella</i> (Meyrick)	C	1	1	1		. . . . n d i f	Litter (?including ^A <i>Festuca</i>)
<i>T. ombrodella</i> (Hudson)	B		1			. . . . . j	Litter
<i>T. oporaea</i> (Meyrick)	B	1		3		. . . . . j f	Litter
<i>T. seelusa</i> (Philpott)	C		1			. . . . . f	Litter
<i>Trachypepla conspicuella</i> (Walker)	C			1		. . . . . j	Litter
OECOPHORIDAE - Depressariinae							
<i>Phaeosaces apocrypta</i> Meyrick	B		6	1	5	. . . . . j f	PHYTOPHAGES
<i>Proteodes earnifex</i> (Butler)	B	3		1		. . . . . f m	Lichens on shrubs
ELACHISTIDAE							
<i>Cosmioles helonoma</i> (Meyrick)	C	1		1		. . . . . j F M a	<i>Nothofagus</i> >300m, site R > 1.2km
<i>C. ochroleuL'a</i> (Meyrick)	C				2	. . . . . j	LEAVES, STEMS, SEEDS. MINERS
<i>Elachista gerasmia</i> Meyrick	C	1				. . . . . j	Grasses. Moths rarely at light
SUBTOTAL		8	12	10	15		^A <i>Festuca</i> (?also above sp.), <i>Poa</i>
							<i>Juncus</i> > 300m

Appendix 1 (contd)

Family and species	Flight class	Numbers trapped				Flight period (months)	Known larval foods and ecological comment
		Site R		Site S			
		1961-3	1987-9	1961-3	1987-9		
TORTRICIDAE							"LEAF-ROLLERS"
<i>Acroclita discariana</i> Philpott	B	1				. . . o n	^A <i>Discaria</i>
<i>Bactra noteraula</i> Walsingham	C		1		4	. . . . . j	<i>Carex</i> , site R >500m
<i>Capua semifera</i> (Walker)	C	558	9	53	10	. . . n d j F m a .	Sward tiller
<i>Catantacta alopecana</i> (Meyrick)	B		1			. . . . . m	<i>Phyllocladus</i> >800m
<i>Crociosema plebejana</i> Zeller	C		1			. . . . . j	Malvaceae > 1 km
<i>Epichorista aspisana</i> (Meyrick)	C	1			2	. . . . . f	Damp swards >300m
<i>E. emphanes</i> (Meyrick)	C				1	. . . . . f	<i>Nothofagus</i> > 300m
<i>E. hemionana</i> (Meyrick)	C				3	. . . . . m	^A <i>Acaena</i> , low herbs
<i>Harmologa oblongana</i> (Walker)	B	2	14	16	30	. . n d J F M a .	^A <i>Muehlenbeckia</i> , <i>Disearia</i>
<i>H. scoliasis</i> (Meyrick)	B				1	. . . . . j	^A <i>Muehlenbeckia</i> >500m
<i>H. sisyrana</i> (Meyrick)	B	1	2	1	20	. . n D J F M . .	^A <i>Cassinia</i> , site R >400m
<i>Merophyas leuaniana</i> (Walker)	C	13	1	7	3	. . . . . J . m a .	^A <i>Pimelea</i> , herbs
<i>Planolorix condilana</i> (Walker)	B	1				. . . . . m	Polyphagous on shrubs
<i>P. picloriana</i> (Felder & Rogenhofer)	B	8		1		. . . . . m a .	<i>Nothofagus</i> >300m, site R >1.2km
<i>Prolhymna niphosrola</i> (Meyrick)	C		1			. . . . . f	<i>Hebe</i> twigs >800m
CARPOSINIDAE							SHOOTS, FRUITS
<i>Heleroxrossa canescens</i> (Philpott)	C			4	1	. . . n . j f m .	^A <i>Gaultheria</i> flowers, fruits
<i>H. philpotti hudsoni</i> Dugdale	C				1	. . . n	
PTEROPHORIDAE							"PLUME MOTHS"
<i>Platyphilia falcalalis</i> (Walker)	C	4	2	5		. . . d . F	<i>Hebe</i> leaves, flowers, site R >800m
<i>Slenophilta oriles</i> (Meyrick)	C		1	1	10	. . n d j f m . .	^A <i>Brachyglottis</i> , also <i>Gentiana</i>
PYRALIDAE							PHYTOPHAGES
<i>Delogenes limodoxa</i> Meyrick	B	1				. . . . . f	Short swards
<i>Homoeosoma anaspila</i> Meyrick	B				8	. . . n	^A <i>Cassinia</i> , <i>Gnaphalium</i> , <i>Vittadinia</i>
SUBTOTAL		590	33	90	94		
CRAMBIDAE - Crambinae							MOST ARE "GRASS MOTHS"
<i>Gadira acerella</i> Walker	C	1	2	2		. . . . . j f	Lichens
<i>Glaucocharis interrupta</i> (Felder & Rogenhofer)	C		1			. . . . . f	Mosses
<i>Orocrambus callirrhous</i> (Meyrick)	B	0	1	2	1	. . . . . f	^A <i>Festuca</i> ?, <i>Poa</i> , often Stony areas
<i>O. cyclopicus</i> (Meyrick)	B	734	4	305	7	. . . . . f M	Grasses, endemic + adventive
<i>O. enchophorus</i> (Meyrick)	B	15	1	17	2	. . . . . j F M a .	As above, ^A <i>Agrostis</i> , ? <i>Poa</i>
<i>O. flexuosellus</i> (Doubleday)	B	296	83	179	156	. . n d J F m . . .	As above, ^A <i>Agrostis</i> , <i>Festuca</i> / <i>Poa</i>
<i>O. lectus</i> (Philpott)	B		1	4	18	. . n D j f	?Damp swards
? <i>O. lewisi</i> Gaskin	:1	16	34	56	24	. . n D J f	^A <i>Festuca</i> , <i>Poa</i>
<i>O. ordishi</i> Gaskin	B			2	4	. . . D j	1 Damp swards
<i>O. philpotti</i> Gaskin	B	84	144	171	90	. . n D J F m a .	As below, ? <i>Festuca</i> ?/ <i>Poa</i>
<i>O. ramosellus</i> (Doubleday)	B	9242	456	3191	418	. . n d J F m . . .	As below, A <i>Agrostis</i>
<i>O. vittellus</i> (Doubleday)	B	306	218	488	314	. . . . . j f	Fig. 4 Grasses, endemic + adventive
<i>O. vulgaris</i> (Buller)	B	7		23		. . . N . j f	^A <i>Raoulia</i>
<i>O. xanthogrammus</i> (Meyrick)	B					. . . . . f m	
<i>Tawhilia penladaclyla</i> (Zeller)	B	5					
SUBTOTAL		10706	944	4440	1035		
CRAMBIDAE - Scopariinae							"SOD WEBWORM MOTHS"
<i>Antiscopa elaphra</i> (Meyrick)	C			2	1	. . o . . f	
<i>Eudomia aspidota</i> (Meyrick)	B	2		3	2	. . . . . f	Forest sp. >300m, site R > 1.2km
<i>E. aslerisca</i> (Meyrick)	B				5	. . . . . d j f	
<i>E. cataxesta</i> (Meyrick)	B	162	27	162	47	. . o n d j f m a .	Cushion herbs
<i>E. dochmia</i> (Meyrick)	B		1			. . . . . f	
<i>E. feredayi</i> (Knaggs)	B	52	68	168	61	. . n d J F m a .	Short swards
<i>E. leplalaeo</i> (Meyrick)	B	128	20	23	56	. . n d j F m . . .	Dry swards
<i>E. luminatrix</i> (Meyrick)	B		13		58	. . . N D	
<i>E. melanaeigis</i> (Meyrick)	B		2	5		. . . . . j f	Forest margins >300m, R>1.2km
<i>E. oclophora</i> (Meyrick)	B		1		5	. . . . . f m a .	Damp areas, R >300m
<i>E. oculala</i> (Philpott)	B	7	1	60	8	. . n d j f m . . .	
<i>E. paltomacha</i> (Meyrick)	B	19	2	178	13	. . . N D j	
<i>E. philerga</i> (Meyrick)	B	30	11	30	21	. . n d J F M . . .	
<i>E. sabulosella</i> (Walker)	B	251	236	394	411	. . n D J f m . . .	Grasses, herbs, ^A <i>Trifolium</i> , moss
<i>E. steropaea</i> (Meyrick)	C	13	9	180	207	. . . d j f m . . .	Shrubland
<i>E. submarginalis</i> (Walker)	B	1311	44	3112	65	. . . . . f m . . .	Fig. 4
<i>E. trivirgata</i> (Felder & Rogenhofer)	B	27	7	31	13	. . o N d j	Dry swards
<i>Scoparia animosa</i> Meyrick	B				1	. . . . . f	
<i>S. asaleula</i> Meyrick	B	1	5	1	1	. . . . . j f	Stony areas >400m
<i>S. sp. nr autumnae</i> Philpott	B	2		1		. . . . . f m	
<i>S. cyameuta</i> (Meyrick)	B	1	1			. . . . . d j	Forest sp. > 1.2km
<i>S. ejuncida</i> Knaggs	B	87	3	301	13	. . . d j F m . . .	
<i>S. exilis</i> Knaggs	B	29	9	78	10	. . . N d	Dry swards
<i>S. indistinctalis</i> (Walker)	B	1	1			. . . . . j f	
<i>S. minusculalis</i> Walker	B	16	2	104	6	. . . . . j F m a .	Moss
<i>S. monochroma</i> Salmon	B	3	1	5		. . . . . j F	
<i>S. niphospora</i> (Meyrick)	B	4	1	3	1	. . . d j f m . . .	Dry swards
<i>S. roluela</i> (Felder & Rogenhofer)	B	2				. . . . . . . . . . a .	^A <i>Epilobium</i>
<i>S. scripla</i> Philpott	B	1	3			. . . . . f m a .	
<i>S. trapezophora</i> Meyrick	B	1				. . . . . f	Damp shrubland >800m
<i>S. lurneri</i> Philpott	B	25	1	21	214	. . . . . j F M a .	
Unidentified (damaged)	B		1		3		
SUBTOTAL		2175	470	4862	1224		

Appendix I (contd)

Family and species	Flight class	Numbers trapped				Flight period (months)	Known larval foods and ecological comment
		Site R 1961-3	1987-9	Site S 1961-3	1987-9		
CRAMBIDAE - other subfamilies							
<i>Diasemia grammalis</i> (Doubleday)	C		1	8	2	. . . n . J F . . m	PHYTOPHAGES
<i>Hygraula nitens</i> (Butler)	C	4	36	9	42	. . . . d J F M . .	Short dry swards, diurnal moth
<i>Mnesictena adverso</i> (Philpott)	B	1		2	1	. . . . . f m . .	Aquatic weeds, site R >800m
<i>M. flavidalis</i> (Doubleday)	B	21	1	18	5	. . . . j F M a .	? Damp areas, diurnal moth
SUBTOTAL		16	38	37	50		^A <i>Muehlenbeckia</i> , <i>Rubus</i> , diurnal
GEOMETRIDAE							
<i>Anachloris subochraria</i> (Doubleday)	B			7	4	. . . . j f m a .	LARVAE ARE "LOOPERS"
<i>Asaphodes abrogata</i> (Walker)	B	2		10	9	. . . . . F m . .	Herb flowers
<i>A. chlamydata</i> (Meyrick)	B	1				. . . . . j	Herbs, diurnal moth
<i>A. clarata</i> (Walker)	B	1		64	t	. . . . d J F . . .	Shrubland > 1 km
<i>Austrocidaria anguligera</i> (Butler)	B				1	. . . . d . f . . .	Herbs, <i>Ranunculus</i> , diurnal moth
<i>A. prionota</i> (Meylick)	B	n/a	n/a	1		. . . . . o	^A <i>Coprosma</i>
* <i>Chloroclystis filata</i> (Guenee)	B				1	. . . . . n	^A <i>Coprosma</i>
<i>Declana junctilinea</i> (Walker)	A	4	7	19	5	. . . n d j f . a .	Shrub nowers, <i>Hebe</i>
<i>D. leptomera</i> (Walker)	A				1	. . . . d	As below, ^A <i>Cassinia</i> , site R >400m
<i>Dichromodes sphaeriata</i> (Felder & Rosenhofer)	B	2	2	11		. . . . d j f m a .	^A <i>Discaria</i> , <i>Leptospermum</i> , <i>Myrsine</i>
<i>Epiphyrene xanthaspis</i> (Meyrick)	B				1	. . . . . m	Lichens on rocks, diurnal moth
<i>Epyxoa rosearia</i> (Doubleday)	B	6	2	20	3	. o n d j f m a .	<i>Aristotelia</i>
<i>Gingidiobora subobscurata</i> (Walker)	B			1		. . . . . j	Herbs, ^A <i>Rumex</i> , stream <i>Nasturtium</i>
<i>Helastia cinerearia</i> (Doubleday)	B	1		5	1	. . . . d . f m . .	<i>Gingidium</i>
<i>H. corcularia</i> (Guenee)	B	128	12	95	IS	. . . . . Fig. 4	Mosses, lichens
<i>H. cymozoeuta</i> (Meyrick)	B		1		2	. . . . . d j	Herbs, lichens
<i>H. exposita</i> (Philpott)	B		1		2	. . . . n d	Shrubland
<i>Hydriomena deltoidata</i> (Walker)	B	18		77		. . . . . J f	Herbs, ^A <i>Plantago</i>
<i>H. purpurifera</i> (Fereday)	B		1		1	. . . . . j	^A <i>Epilobium</i>
<i>H. rixata</i> (Felder & Rogoehofer)	B	2	2	3	3	. . . . . j f m . .	Herbs, ^A <i>Epiobium</i> , <i>Plantago</i>
<i>Microdes quadristrigata</i> (Walker)	B				2	. . . . . m a . .	
<i>Orthoelydon chlorias</i> (Meyrick)	B	1				. . . . . m	^A <i>Gaultheria</i>
<i>Pasiphila acompta</i> (Prout)	B				2	. . . . . d	<i>Hebe</i>
<i>P. bilineolata</i> (Walker)	B	1				. . . . . m	^A <i>Carmichaelia</i> , <i>Muehlenbeckia</i> , <i>Rubus</i>
<i>P. lunata</i> (Philpott)	B		1	1	1	. . . . . f m a .	<i>Hebe</i> , site R >800m
<i>Pleudocoremia rolpogramma</i> (Meyrick)	B			1		. . . . . f	^A <i>Cassinia</i>
<i>P. productata</i> (Walker)	B				1	s f	<i>Podocarpus</i> , <i>Nothofagus</i> >300m
<i>Scopula rubraria</i> (Doubleday)	B	32		1		. . n d j f m . .	Herbs, <i>Plantago</i>
<i>Xanthorhoe orophylla</i> (Meyrick)	B			1		. . . . . f	Herbs
<i>X. semijfissata</i> (Walker)	B			9	2	. . n d j f m a .	<i>Cardamine</i> , stream <i>Nasturtium</i>
<i>Zermizinga indocilisario</i> Walker	B	12	1	10	t	. o n . j f . . .	^A <i>Cassinia</i> , <i>Discaria</i> , <i>Rosa</i>
SUBTOTAL		211	30	316	60		
ARCTIIDAE							
<i>Metacrias strategica</i> (Hudson)	A			4	1	. . . d j f . . .	"TIGER MOTHS"
NOCTUIDAE							
<i>A. letia cucullina</i> (Guenée)	A	154	16	c225	236	. o N d j	Polyphagous on grasses, herbs
<i>A. cuneata</i> Philpott	A	3		13		. . . o . F m a .	"OWLETS", "CUTWORMS"
<i>A. longstaffi</i> (Howes)	A			4	1	. . . . . f m . .	Herbs
<i>A. mitis</i> (Butler)	A	167	648	150	168	. . . . . f M a .	<i>Dracophyllum</i> , herbs
<i>A. moderata</i> (Walker)	A	153	53	c246	12S	. o N d j f m a .	Polyphagous on herbs, ^A <i>Raoulia</i>
<i>A. nobilia</i> Howes	A		1			. . . . . f	
<i>A. sollenis</i> (Meyrick)	A				1	. . . n	
<i>A. virescens</i> (Butler)	A		2	2	1	. . . n . . f m . .	^A <i>Epilobium</i> , <i>Coriaria</i>
<i>Andestia pessota</i> (Meyrick)	A		4		1	. . . . . i f m . .	^A <i>Melicivtus</i>

Appendix I (contd)

Family and species	Flight class	Numbers trapped				Flight period (months)	Known larval foods and ecological comment
		Site R		Site S			
		1961-3	1987.9	1961-3	1987.9		
<i>Bityla defigurata</i> (Walker)	A	n/a	n/a	2	t	. o m	^A <i>Muehlenbeckia</i> leaves, site S >500m
<i>B. sericea</i> Butler	A			1	t	. . . . . m . .	^A <i>Muehlenbeckia</i> leaves, site S >500m
<i>Eucoxa admirabilionis</i> (Guenée)	A	18	3	18	46	. . N d j	
<i>Graphania agoraslis</i> (Meyrick)	A	10	43	72	253	. . . d j F M a .	
<i>G. averilla</i> (Hudson)	A	1		4	1	. . . n . j f . . .	Herbs, ^A <i>Plantago</i>
<i>G. disjungens</i> (Walker)	A	436	291	967	653	. . . N D j f . . .	^A <i>Festuca</i> / <i>Poa</i>
<i>G. homoscia</i> (Meyrick)	A	1	10	33	4	. . o n d . f m A m	^A <i>Cassinia</i> , site R >400m
<i>G. infensa</i> (Walker)	A			1	2	. . . n d	<i>Carex</i> , <i>Uncinia</i> . [[*] <i>Bromus</i>]
<i>G. sp., nr insignis</i> (Walker)	A			3		. . o f . . .	Herbs, ^A <i>Rumex</i>
<i>G. lignana</i> (Walker)	A	34	22	102	30		Fig. 4
<i>G. lithias</i> (Meyrick)	A	41	39	105	50	. . . N D . . F M a .	^A <i>Meliccytus</i>
<i>G. morasa</i> (Butler)	A	2		6		. . . . . f m . . .	Adventive grasses, ^A <i>Holcus</i>
<i>G. mutans</i> (Walker)	A	186	17	c554	92	. . o N D j F M a m	Herbs, ^A <i>Plantago</i>
<i>G. nullifera</i> (Walker)	A		1	3	2	. . . . . d j f m a .	^A <i>Aciphylla</i> roots
<i>G. olivea</i> (Watt)	A				1	. . . . . j	
<i>G. omicron</i> (Hudson)	A	2	3	2	5	. . . n d j	
<i>G. omoplaca</i> (Meyrick)	A	2	2	4	28	. . . N D j	^A <i>Plantago</i> , <i>Poa</i>
<i>G. paracausla</i> (Meyrick)	A	4	4	3	33	. . o N	Adventive grasses
<i>G. phricias</i> (Meyrick)	A	12	11	84	33		Fig. 4
<i>G. plena</i> (Walker)	A			1	1	. . o . d . f	Forest margins, <i>Fuchsia</i> >?1 km
<i>G. prionistis</i> (Meyrick)	A			1	1	. . . . . d . f . . .	
<i>G. rubescens</i> (Butler)	A	5	1	19	2	. . . . . j F m a . .	Herbs, ^A <i>Luzula</i> , sedges
<i>G. sculala</i> (Meyrick)	A	2	2	16	3	. . . . . . . A . .	^A <i>Plantago</i>
<i>G. ustislriga</i> (Walker)	A	1	1	5	3	. . o n . . . f m a .	Polyphagous, ^A <i>Muehlenbeckia</i>
<i>Ichneutica marmorata</i> (Hudson)	A			2		. . . n	<i>Chionochloa</i> >600m
<i>Melerana roeleno</i> (Hudson)	A	n/a	n/a		3	s o	<i>Muehlenbeckia</i> >300m
<i>M. dolala</i> (Walker)	A	6		7		. . . . . j f m . . .	<i>Nothofagus</i> >300m, site R >1.2km
<i>M. meyricki</i> (Hampson)	A			1		. . . . . . . m a m	^A <i>Pimelea</i>
<i>M. ochlhislis</i> (Meyrick)	A		1	2	2	. . o n d	Polyphagous, <i>Hebe</i> , <i>Rubus</i>
<i>M. larlarea</i> (Butler)	A		1	3		. . . . . . . m a .	^A <i>Coprosma</i>
<i>M. viliasa</i> (Butler)	A		1			. . . . . . . a . .	^A <i>Coprosma</i>
<i>Perseclania avera</i> (Walker)	A	181	21	c283	53	. . o N d j F M a m	Grasses, ^A <i>Agrostis</i> , <i>Festuca</i> , ? <i>Poa</i>
<i>Physetica caerulea</i> (Guenée)	A	11	1	92	13	. . o N D J F m . . .	
<i>Rictonis comma</i> (Walker)	A	1	6	7	33	. . . n D	^A <i>Brachyglollis</i> , <i>Taraxacum</i> , grasses
<i>Schrankia costaestrigalis</i> (Stephens)	A				1	. . . . . j	Litter
Unidentified (damaged 26-10-62)	A			c75			
PART SUBTOTAL		1433	1201	c3160	1885		
<i>Tmelolopha aeonlislis</i> (Meyrick)	A	115	301	c163	885	. . o N d	^A <i>Elymus</i> , <i>Festuca</i> , ? <i>Poa</i>
<i>T. alopa</i> (Meyrick)	A	1		3		. . . . . f m . . .	
<i>T. arolis</i> (Meyrick)	A	n/a	n/a	1	6	. . o n	<i>Phormium</i> >300m
<i>T. alrislriga</i> (Walker)	A	81	37	367	64	. . n d j F M a .	Grasses, ^A <i>Festuca</i> / <i>Poa</i>
<i>T. propria</i> (Walker)	A	404	3221	795	1272		Fig. 4
<i>T. semivillala</i> (Walker)	A	1		28	2	. . . n . j F m . . .	^A <i>Festuca</i> / <i>Poa</i> , <i>Carex</i> , <i>Juncus</i>
<i>T. sleropasjfs</i> (Meyrick)	A			1	t	. . . . . d j f . . .	<i>Phormium</i> >300m
<i>T. unica</i> (Walker)	A	19	33	53	127	. . . n D j	Grasses
PART SUBTOTAL		631	3592	c1411	2356		
SUBTOTAL		2064	4793	c4571	4141		
GRAND TOTAL		16152	6601	c14880	6976		

Appendix 2: Site histories of vegetation species composition, based on five recording methods.¹ The numbering sequence I - V represents a gradation from the most local to the most extensive sampling of a debris flow fan.* = adventive species; n/a = data not available; t = species observed but not recorded. Nomenclature follows Allan (1982), Cheeseman (1925), Connor and Edgar (1987), Lambrechtsen (1986), Sainsbury (1955), and Webb et al. (1988).

¹The five methods are not directly comparable but the sampling sequence provides strong evidence in support of major trends.

Method I (numerical cover): Quadrat analysis by species classes, all plants recorded by basal sections at ground level over ten 1 x 1 m quadrats (for *Festuca novae-zelandiae*), two 1 x 0.02 m quadrats (other frequent species) and a 2 x 1 m enlargement of one quadrat (infrequent species), total plants = 4366 m² (Malcolm, 1925. data recalculated).

Method II (canopy cover): Point analysis, first hits of needle, five needles per frame at 5 cm intervals, randomly-placed frames, 200 points per sample, mean of two site S samples (Burrows, 1977, Table 13G, selected data only).

Method III (basal cover): Point analysis, basal node of the plant nearest to the needle point at ground level, three needles per frame at 25.4 cm intervals along a transect, site R mean sample 438 points, site S 495 points (present study, see Methods).

Method IV (cover-abundance, subjective): All species observed within a 13-minute search of a representative area, records allocated to height tiers (0-30 cm, 30 cm-1 m, 1-2 m above ground), tiers and species within tiers assigned to cover abundance classes where < 1 = present and rare, 1 = present and common, 2 = 1.5%, 3 = 5-15%, 4 = 15-30% (Myers, Park and Overmars, 1987, Appendix III; Shanks et al. (1990), unpublished plot sheets (Department of Conservation, Canterbury Conservancy)).

Method V (extent of occurrence): Quadrat analysis, all species recorded within 1 x 1 m quadrat, 30 randomly-placed quadrats, mean frequencies of occurrence over total sample (Burrows, 1977, Table 13F).

Appendix 2 (contd)

Site	R	R	R	R	S	S	S	S	S
Method ¹	III	III	III	III	I	II	III	IV	V
	1958	1960	1961	1990	1915	1971	1990	1988	1971
Species	%	*1,	%	%	%	%	%	Class	Frequency %
GRASSES									
* <i>Agrostis capillaris</i>	3.6	5.6	11.8	43.0		9.5	38.7	3	70
* <i>Anthoxanthum odoratum</i>	17.1	16.7	10.1	19.3	1.9	9.5	6.9	3	76
<i>Deyeuxia avenoides</i>	0.5	0.7	2.3			n/a	t	1	13
<i>Elymus rectisetus</i>	1.8	t	1.9	6.4		n/a	t	2	10
<i>Festuca novae-zelandiae</i>	t	t	1.2	3.2	0.3	7	7.7	4	96
* <i>Holcus lanatus</i>					1.1	n/a		1	13
<i>Poa colensoi</i>	2.0	3.2	5.6	14.0	17.2	12	16.2	3	96
<i>Pyrranthera exigua</i>	1.6	3.2	3.3						
<i>Rytidosperma gracile</i>						n/a			10
<i>Rytidosperma</i> spp. (others)	0.2	0.2	3.7	2.3					
Other species	0.5	0.2	t	*4.8		n/a	*1.6	1	
SUBTOTAL	17.3	19.8	41.0	93.0	11.5	38+	71.1	-	-
HERBS									
<i>Acaena</i> spp.	0.2					n/a		1	10
<i>Adphylla subflabellata</i>						n/a			<10
<i>Anisotome</i> spp.		t	0.5			n/a		1	33
<i>Brachycome sinclairii</i>	0.7	0.2	0.2			n/a			<10
<i>Brachyglottis bellidioides</i>	2.5	2.7	3.0		t	n/a	t		73
<i>Celmisia gracilentia</i>	2.9	4.7	2.8		4.6	n/a	t	1	50
<i>Celmisia</i> spp. (others)								1	
* <i>Cerastium</i> spp.	2.3	0.9	0.5					1	
* <i>Crepis capillaris</i>					4.6			1	
<i>Epilobium</i> spp.					t	n/a		1	<10
<i>Geranium sessiliflorum</i>	t		t		3.4	n/a	0.2	1	50
<i>Gnaphalium traversii</i>	t	t	0.2						
<i>Helichrysum</i> spp.	0.5	2.7	1.4						<10
* <i>Hieradum pilosella</i>							0.8	<1	
<i>Hydrocotyle novae-zelandiae</i>	t	t	t		2.9				
* <i>Hypochoeris radicata</i>	13.5	13.8	7.9	0.2	4.0	4	5.1	3	100
<i>Leptinella</i> spp.	0.2	0.7	0.5		4.0	n/a			20
* <i>Linum catharticum</i>	7.0	0.5	t			n/a			<10
<i>Luzula</i> spp.	t	t	t		25.8	n/a	0.2	1	60
<i>Oreomyrrhis colensoi</i>						n/a			16
* <i>Plantago major</i>					0.6				
<i>Raoulia subsericea</i>	t	0.5	t		4.0	6	6.7	3	76
* <i>Rumex acetosella</i>	5.0	2.0	1.6	0.2	t	n/a			23
<i>Taraxacum magellanicum</i>					t				
* <i>Trifolium</i> spp.	16.7	4.1	3.3	3.9		n/a			<10
<i>Viola cunninghamii</i>	t		t					1	10
<i>Wahlenbergia albomarginata</i>	2.9	1.6	0.7	t	6.9	n/a	0.2	1	66
Other spp.	1.1	t	2.3			n/a			<10
SUBTOTAL	55.5	34.4	24.9	4.3	60.8	10+	13.2	-	-
SHRUBS									
<i>Cormichaelia monroi</i>						n/a			<10
<i>Cassinia</i> spp.							1.0	3	53
<i>Coprosma petriei</i>	3.4	7.7	4.0	0.2	5.2	12	8.5	1	70
<i>Discaria toumatou</i>	t	0.5	1.2	0.9	0.02	5	0.6	3	53
<i>Gaultheria depressa</i>		t				n/a	1.0		16
<i>Leptospermum scoparium</i>								<1	
<i>Leucopogon fraseri</i>	3.6	6.8	9.5	0.5	2.9	n/a	2.2	2	96
<i>Meliclytus alpinus</i>			0.2			n/a			10
<i>Muehlenbeckia axillaris</i>					1.1				
<i>Pentachondra pumila</i>							2.2		
<i>Pimelea</i> spp.	t	0.7	2.3	0.2	t	n/a	0.2	1	66
Other species						n/a			<10
SUBTOTAL	7.0	15.7	17.1	1.8	9.11	17+	15.7	-	-
FERNS, LICHENS, MOSSES									
<i>Blechnum penna-marina</i>	fern					n/a			<10
<i>Cladonia</i> spp.	lichen	n/a	n/a	n/a	n/a	n/a	n/a	1	60
<i>Hypnum cupressiforme</i>	moss	n/a	n/a	n/a	n/a	3.5	n/a	1	
<i>Lembophyllum divulsum</i>	moss	n/a	n/a	n/a	n/a		n/a	1	
<i>Polytrichum juniperinum</i>	moss	n/a	n/a	n/a	n/a		n/a		60
<i>Racomitrium lanuginosum</i>	moss	n/a	n/a	n/a	n/a	1	n/a	1	13
Unidentified spp.	moss	n/a	n/a	n/a	8.6		n/a		
SUBTOTAL	-	-	-	-	8.6	4.5+	-	-	-
TOTAL LIVING	89.8	79.9	83.1	99.1	100.1	69.5+	100.0	-	-
LITTER	1.5	3.6	6.3	0.7	-	13.5	0.1	-	-