

A 1961–2000 DATABASE FOR

NEW ZEALAND  
TUSSOCK GRASSLAND  
MOTHS



E.G. WHITE

A 1961–2000 Database For

New Zealand Tussock Grassland Moths



Edwin Graeme White 2004

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## Foreword

As he approached his death Graeme White worked hard to assemble the records of moth trapping in the Mackenzie Basin in an accessible form. He envisioned a book based on printed out pages of spreadsheets. After his death, Manaaki Whenua Press decided this would be better realised as an Internet-accessible database, at once reducing the cost of publication and making the data more widely accessible in a form other researchers could more easily manipulate.

The financial support required to undertake this project was secured by Bruce Burns, then of Landcare Research, and its successful completion was facilitated by the excellent help and encouragement of Clare Churcher and of Ying (Sammi) Liu of Lincoln University; I would like to thank them all in the spirit of Graeme, and personally to thank Erika White for her patience and gentle prodding to ensure the establishment of Graeme's intellectual legacy.

Richard Sedcole

## Biographical details



Edwin Graeme White was born in 1938 and brought up in Dunedin. He attended Otago Boys' High School for his secondary schooling and, like a number of his contemporaries, moved on to Lincoln College (as it then was). He graduated from the University of New Zealand with a BAgrSc (Hort) in 1962. For his Masters degree he was supervised by Dr Roy Harrison and Graeme's interest in the insect fauna of the South Island high country became the focus of his thesis work and, indeed, his research career. After a short time with Entomology Division, Department of Scientific and Industrial Research, in Nelson, he moved to the University of California, Berkeley, to study for his PhD under the eminent quantitative ecologist Professor Carl Huffaker. The focus of that study was the moth *Anagasta kuehniella* (Zeller) and thus the second main strand of his research career was established. It was during this time that he met and married Erika.

On returning to New Zealand with his PhD, Graeme joined the Tussock Grasslands and Mountain Lands Institute at Lincoln College to investigate the invertebrate impact on tussock grasslands. Alpine grasshoppers formed the core part of the early programme but other monitoring, especially of moths, was also carried out. With the demise of TGMLI in 1988, Graeme was forced to set out as a private scientific contractor. He secured contracts from the Foundation for Research, Science and Technology, the Department of Conservation and Landcare Research. These contracts allowed him to pursue long-term studies on the fauna of the high country, primarily in the Craigieburn area and the Mackenzie Basin.

Graeme was an active member of the New Zealand Ecological Society and the Entomological Society of New Zealand, on the former serving as secretary in 1968–71 and as a Council member 1978–81. In 1992, he was awarded the Ecological Society's Te Tohu Taiao Award for Ecological Excellence.

In addition to his scientific work, Graeme was a deeply religious person and was an elder of Knox Presbyterian Church for many years. Graeme also had an interest in poetry and had a small collection of poems that he had written, some of which combined his love of the high country and his Christian beliefs.

Graeme considered himself an ecologist; insects were simply the group through which he sought to better our understanding of nature. However, one of Graeme's most significant contributions is undoubtedly his book on tussock grassland moths published in 2002, two years before his death. Now we have the database on which that book and other publications were based. These two, the book and the published database, will provide valuable resources for entomologists and ecologists for many years to come.

Dr RR Scott

## Details of database contents

ARCHIVED DATABASE OF E.G. WHITE MOTH STUDIES WAIMAKARIRI BASIN (1961–1963, 1987–1989) AND MACKENZIE BASIN (1991–1996, 1998–2000)

The tussock grassland database for 43 Canterbury sites extends to 61 spring-autumn trapping sequences (35 sites x 1 year each; 8 sites x 2-5 years each) based on standardised light-trapping methods.

The archived database comprises base-samples only (*refer New Zealand Grassland Tussock Moths*, E.G. White, 2002). In all selections it is important to recognise and respect ecological incompatibilities and the sampling restrictions of certain data, as noted by file structure and comment.

All study sites are permanently pegged and relevant site and vegetation data are also presented to permit future site comparisons. Several site photographs appear in the references. The index further includes a summary of the conventions and notations used throughout all phases of light-trapping 1961–2000.

## Standardisation of moth counts

*An example from Site X (trap number 18) to illustrate the calculation of an individual weighted moth count by evaluating a sample against its two neighbouring samples.*

All spring–autumn sampling sequences (sideways format tables) have been evaluated across all study sites using an approach similar to moving averages, and the Site X example of standardisation is selected here because it illustrates a range of calculation criteria within a single span of only three consecutive base-samples. Refer Site X samples 3 Nov, 18–21 Nov and 3 Dec. The central sample is a composite sample (see White, 2002) and the sample date has been determined as 21 Nov (21 = 3 Nov + 18-day interval).

In that central sample, the sampling conditions (final line) are rated as ‘Good’ for all three flight classes of moth (A = heavy fliers, B = medium fliers, C = light fliers) based on a scale of seven favourability ratings (ideal/good/good in part/moderate/fair/poor/failed – refer E.G.White, 1991. The changing abundance of moths in a tussock grassland, 1962-1989, and 50- to 70-year trends. *New Zealand Journal*

of Ecology 15: 5-22.). In contrast, there is a mix of different ratings between flight classes for each of the two neighbouring samples, 3 Nov and 3 Dec. All ratings apply to moth species entries to the left of the zero template columns of each sample. For those species recorded in a given sample, there is also a standardised entry in the template column. Elsewhere this column retains all '0' entries.

In the case of the 18-21 Nov central sample, only four species of flight class B moths were recorded, shown as *Orocrambus lewisi* (at row 39, page 1 of paired flight-class-B pages), x , x , *Helastia corcularia* (at row 58, page 2), and total sample size = 18 (page 2, inclusive of page 1 part total). Excluded from this total is an additional moth species, *Scoparia ejuncida*, shown as 'present' (page 1). Such entries are not members of base-samples and refer to known specimens when there was no sighting external to the trap). Given that the central sample index for class B does not have a favourability rating 'Ideal' (such samples always retain an index of 1.00), and index is calculated as

$$\begin{aligned} & \{[(3427)[12/(12+18 \text{ nights})]+27]/18 \text{ moths} \\ & = [7(12/30)+27]/18 \\ & = 1.65 \end{aligned}$$

as shown on the line below class totals, where

34 (3 Nov) and 27 (3 Dec) are total sample sizes (shown as page 2 class totals),

12 (21 Nov–3 Dec) and 18 (3 Nov–21 Nov) are sampling intervals (shown as headers), and where

the absolute value of the first expression (34–27) is never negative, i.e., the lesser neighbouring moth count is subtracted from the greater neighbouring count.

All upwards-adjusted species counts have been rounded to integer whole numbers to represent moth individuals, and the adjustments serve to recognise time-series patterns inherent in raw data but compromised by limiting sampling conditions that may apply to any central sample.

Recent extreme rains and local conditions (second last line) contributed to an overall decline from 332 moths on 3 Nov to 68 in the central sample (combined flight classes), but the conservative Class A index remains set = 1. A calculated index value of 2.97 was within the acceptable range of 1.00–3.00 for weighting adjustments but was rejected as too large because fewer Class A moths were trapped in the 'Ideal' conditions of 3 Dec than in the central sample (so indicating a true time-series trough).

A null weighting of 1.00 is retained for all non-adjusted samples (see standardisation index entry line).

When all accepted weightings are applied to individual species counts within a flight class, two annual measures can be derived, and are shown on the upright format sheets:

- (a) weighted species data per site – the sum of residual unadjusted moth counts + upwards-adjusted moth counts
- (b) species estimates of annual 'moth-nights' per site – the area below a graph of the indexed species samples graphed against true time (calendar nights, as shown by the sampling intervals). This measure fully incorporates the variable intervals between samples (contrast the weighted summed counts).

In a special application, the data at seven sites (Sites C, L, Z, Chi, Phi, Psi and Theta) were also given additional adjustment. An index in the range of 1.1–1.4 (site-constant) replaced the base index 1 to compensate for reduced trap visibility horizons beyond 100 m in 1–2 radial quadrants of each site; and at Site L, the replacement index was further varied through summer-autumn (range 1.2→ 1.4→ 1.2) to account for partial loss of visibility due to seasonal grass growth. These adjustments are all conservative.

Occasional entries in white typeface (black background) are estimates for missing data when capture records are weak or missing due to known trapping failure (e.g. timer error) or due to recurrent flight interference for flight class C moths, e.g. outwash fan Sites V, J and X were located along a narrow pathway of NW winds that often did not die out until 3 hours trapping had been completed – in contrast, calming conditions tended to arrive earlier at other outwash fan sites. Missing data estimates are conservative and were only applied if consistent with the phenological record of the species for the given site, e.g. Site X, compare each of the three sampling dates with dates in normal typeface.

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A guide to the quantitative interpretation of data is given by White, 2002, pp. 26–28.

As a general precaution, care should be taken to not over-interpret differences between capture records when comparing sites. Different sampling conditions and sometimes moth behaviours (e.g. a strong flight of females at one site) may at times account for notable differences in the numbers of moths captured and yet lack any corroborative evidence of true site differences. Conversely, small but consistent differences in the numbers of moths captured throughout a moth phenology may provide acceptable evidence of true site differences.

## Appendix I

### **Quantitative sampling of flighted insects across a varied landscape**

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**Summary:** A quantitative method is presented to address the practice and interpretation of aerial sampling of flighted insects. Five principal sources of sample variability are recognised and a composite series of standardising practices is applied to their dominant components. The procedures are illustrated from a light-trapping study of moths (Lepidoptera) and seek to attain data compatibilities at three levels: biological, operational and analytical. The collective benefit is a time-series of biologically independent and standardised samples.

**Keywords:** aerial sampling; light-trapping; Lepidoptera; moths

### **Introduction**

The sampling of airborne populations by flight attraction and/or flight interception techniques is subject to a wide range of variables associated with flightedness. Flight is a temporary activity in the adult life-stage of many insects. As the greater part of adult longevities may be spent in non-flight activities, the practice of aerial sampling

is critically dependent on timing considerations. It needs to address the numerous variables pertaining to periodic flight events. The performance of a sampling technique likewise depends on variables that govern its sampling space, because the distances moved during flight may mask primary associations with particular habitats or locations. Aerial samples have a landscape context, and this is open to quantified definition.

While flight factors have long been recognised, there have been only limited attempts to devise aerial sampling technologies and strategies that standardise and/or minimise their variable influences. Rather, aerial samples have been recognised as measures of relative abundance that fall short of quantitative definition or rigorous comparison standards. The present objective is to redress this shortcoming in a context of light-trapping and moths (Lepidoptera), but the approach remains broadly applicable to all forms of aerial trapping and other target insect groups.

## **Methods**

The composite method recognises five principal sources of variability in the practice and interpretation of aerial sampling. Each source has its dominant components and these are interrelated via a series of standardising practices as set out below.

Table 1 presents the five principal sources of variability as column headers (read 'flighted insects' in place of 'moths' for wider applicability), and columns identify the dominant variables. The first three variables of each column are 'local' insofar as they relate to individual units of measurement or observation (the primary sample). In the bottom cells are 'grouped' variables, so named because they relate to composite units of measurement (the secondary sample). These latter units have been selected to clarify data patterns and trends that might otherwise be masked. Any pattern shown by a grouped variable should be able to be explained by considering the standardising practices adopted for its component local variables.

For the method to maximise quantity, all variables must be considered collectively. Some have been previously described in detail (see cell references, Table 1) and others are newly integrated. A full description and context for Landscape variables is presented elsewhere (White & Sedcole, this publication, Appendix II) and an overview of other variables follows.

## Trapping

Trapping variables (Table 1, column 2) are always governed by trap specifications (column 2, cell 1). The current study used automated Robinson light-traps of a portable design fitted with 60-W 12-V tungsten opaque lamps run from batteries (White 1996). Lamps were replaced every 2 years (before 500 hours of use) to minimise spectral shifts and decreasing lumen output over the study duration. Each specification was important in retaining long-term consistency (extending the database of White (1991)) and in the derivation of 'trap catchment' (cell 3, see below).

Trap deployment (cell 2) seeks to minimise operational variability between samples and sites. Light-trapping nights were selected to attain optimised conditions for moth flight (especially targeting nights with minimum winds) and trap locations were selected to optimise visibility across open space (the targeted minimum radius of visibility was 200–300 m). Traps were operated for 3 hours from dusk, and on occasions a second 3-hour sample (a.m.) was taken 5 m away, beginning 1 hour after the first trap cycle was completed.

'Trap catchment' (cell 3) is defined for a given trap location as the primary area from which nearly all trapped moths originate. This is governed by trap specifications and deployment (cells 1 and 2) but is primarily a function of flight behaviours (of cumulative net distances moved, whether on night of capture alone or over successive nights). It must not be confused with the (smaller) area of light-attraction behaviours. In order to estimate its size, a working definition was adopted, namely, the area over which correlations between faunal counts and foodplant abundances were highest when calculated across multiple sampling occasions. The foodplant abundances were estimated across incrementing radial distances from a trap (White & Sedcole, this publication, Appendix II).

The sampling frequency based on longevities (cell 4) and optimised sample timing (cell 2) yields a time-series of independent measures. The special character of this sampling strategy is its tight incorporation of biological factors (moth longevities and flight criteria). It thereby avoids some common sources of sampling bias. At the same time it affords a higher productivity per unit effort than does the nightly sampling frequency of conventional light-trapping practices, and no loss of vital information is implicated.

## Moths

Insect variables (Table 1, column 3) are always governed by light-response behaviours (read 'trap-response' in place of 'light-response' for wider applicability). The variety of species-specific behaviours (column 3, cell 1) is a given for any trapping technique, and hence cell 1 is less amenable to standardising practice than any other listed variable of Table 1. Measures can be standardised within a taxon across the full range of Table 1 variables, but in a broad faunal sense comparisons *between taxa* require caution and must be assessed case by case. The usual evidence for a valid (or invalid) comparison accrues with the incremental growth of a quantitative database and a routine of extended sampling across a varied landscape (refer cell 3).

Flight onset and duration for the current night (cell 2) accounts for factors that sometimes advance or delay a periodic flight event (read 'day' in place of 'night' for applicability to some other trapping techniques). The most common factor causing delay is wind over the first sampling hour(s), and increase in altitude is possibly another factor. Should flight onset be too delayed, the 3-hour sampling routine of this study may have under-represented some taxa in some samples. With lesser delays, a compensating late surge in flight activity was sometimes observed when winds died and may offset the delay factor (a 'self-standardising' response).

Moth distribution patterns and biodiversity measures (cell 3) have a spatial context, and minimal criteria have been derived to standardise faunal sampling at a landscape scale (refer White & Sedcole, this publication, Appendix II). Moth flight classes A, B and C (cell 4) partition a fauna according to observed flight powers, and each class is always standardised independently (cell 4 of columns 3, 4 and 5). Flight powers are broadly indicated by body weight and wingspan, and sample composition over nights of limiting flight conditions was used to ratify classifications. In the trapped fauna of the present study, there were similar numbers of species in each flight class.

## Weather

Weather contributes the independent variables of aerial sampling (Table 1, column 4) but standardisation steps seek to minimise their effects by accommodation criteria, e.g. trap deployment (column 2) and moth flight classes (column 3). Recent weather conditions (column 4, cell 1) can sometimes have a significant influence on sample size, especially following extreme events such as snows, heavy rains, cold spells and prolonged drought. The record of prevailing weather patterns may be used in standardising procedures but only indirectly as background information.

Current night flight conditions (cell 2) are a key variable and local to every site. On-site observations of weather parameters and the progression of any changes during the night's sampling were used in the derivation of a flight favourability rating (cell 4). In the event of marginal flight prospects on a given night (cell 3), sampling decisions and practices conformed to a set of quantitative sampling rules (see White 1991). Should resampling be necessary, a single but non-additive composite sample is derived using the same rules.

The flight favourability rating of each flight class (cell 4) is derived from two sources: the weather parameters during sampling (cell 2) and the overall composition of the sample (i.e. its representation of each of the flight classes and also of other flighted insects, especially the presence of those with weaker flight powers). The scale of seven ratings ranged from *ideal* to *failed* (refer White 1991).

## Sample analyses

Sample analyses (Table 1, column 5) constitute variables insofar as the standardisation practice generates adjusted datasets. The raw data (column 5, cell 1) are themselves standardised in terms of trap deployment and sampling frequency (column 2) and are thereby unlike the raw data of conventional light-trapping practices. The current raw data provided the benchmark against which other derived datasets were tested. The primary test database was a consecutive 5-year trapping sequence, spring–autumn, at two outwash plain sites in the Mackenzie Basin, New Zealand (sites K and P of White & Sedcole, this publication, Appendix II). The traps were each visible from the other, 800 m apart and equidistant on either side of a rabbit-proofed fenceline separating degraded site K (*Hieracium*-dominated vegetation,  $n = 35$  plant species) from site P (a mixed *Festuca* sward,  $n = 92$  plant species).

One data subset of interest (cell 2) was the selection of annual totals of the more common sex, determined species-by-species for sites K and P independently ( $n = 40$  common species). This statistic was tested in an attempt to limit the assumed sex ratio biases of some moth species samples, and is based on the assumption that most species' true sex ratios are nearer to 50:50 than to 100:0 (as in some trapped samples). In cell 3, annual variation is a key variable, for wide variation has a capacity to negate the equivalence of standardised data across years (though not to preclude comparisons between years). The weather-in-common at contrasting sites K and P permitted a controlled assessment of the sources of annual variability.

Standardised data and 'moth-night' data (cell 4) incorporate all standardising procedures applied to the variables of Table 1. In brief, a full sequence of 16–17 sampling periods per year was evaluated in moving sequences of three (in the manner of moving averages), and at each step, only the central sample was assessed to yield the *standardising index* (Table 2, with worked example; further see White 1991). Moth-nights are then expressed as the summation of the *area* below the annual time-series graph of standardised samples (= generation numbers × natural longevity). The measured entity is the standardised trappable population of caught + non-caught individuals (those alive in the intervals between samples). If the natural longevity of a taxon is known, an estimate of trappable numbers = moth-nights / mean longevity.

## Test results

### Trap deployment

The adequacy of the 3-hour sample beginning at dusk was examined using the dataset of White & Sedcole (this publication, Appendix II). Of 339 moth species trapped at light (118 732 individuals,  $n = 810$  samples), 337 were represented in standard 3-hour samples (114 387 individuals,  $n = 672$ ). Only one of the 337 species was shown to be primarily active during *ante meridiem* hours ( $n = 24$  samples), and three other species may be so. It is concluded that the standard 3-hour sample beginning at dusk provided a comprehensive measure of the light-attracted moth fauna.

### Effective 'trap catchment'

Tests of the dataset of White & Sedcole (this publication, Appendix II) failed to define catchment size in terms of the working definition of trap catchment (see Methods). An almost total lack of significant correlations over comprehensive matrices of moth abundance × vegetation abundance analyses (concentric radii to 200 m from trap) prompted a search for incompatibilities between light-trap moth samples and vegetation measurements. Three lines of provisional evidence from the study suggest that trap catchment radius lies between 300 and 500 m, and that percent ground-cover measures and 200-m radii were inappropriately restrictive across the patchy vegetations. A fauna-compatible method of vegetation measurement is currently being explored.

Note that the provisional estimates of unobstructed 300–500-m radii for a 60-W 12-V tungsten incandescent lamp emitting 1000 lumens are in excess of the theoretical maximum radius of 233 m for invertebrate light-response (derived from Bowden

1982, tables II and IV, given  $385 \text{ m}$  for a 200-W tungsten incandescent lamp emitting 2720 lumens, hence  $385 \times \sqrt{(1000/2720)} \text{ lumens} = 233 \text{ m}$ ). Further note that this light-response radius is voltage-dependent because lumen output declines with increasing voltage (hence a 60-W 230-V tungsten lamp emitting 650 lumens has a lesser light-reponse radius of 188 m). But whatever the trap specifications, some moths will first enter the zone of light-attraction after flight from beyond it; so it should not be surprising that net distances moved will exceed even the maximum calculated distances of light attraction.

### Sampling performance

The performance of the sampling strategy was examined using the dataset of White & Sedcole (this publication, Appendix II) expressed as site-years, where a site-year is any one full year of trapping for any one site. Given a sampling frequency based on moth longevities, 810 samples yielded 42 site-years of data compared with only 3.5 site-years if sampling had been nightly over the same spring–autumn sequence of c. 230 nights per year. The benefits of a 12-fold increase in productivity (based on a unit trap-night yielding a unit sample) include an expanded logistical feasibility for landscape studies, and in addition, the enhanced measuring of mesoscale phenomena. The trapped population is also better conserved by fewer removals than would occur in nightly sampling.

### Annual variation

The weather-in-common at contrasting sites K and P confirmed tussock grassland moths as K-strategists with annual variation commonly 2- to 3-fold or less (also unpublished data of White, 1991). Two notable exceptions were the sodworm moth *Eudonia submarginalis* (Crambidae) and the lichen-feeding *Dichromodes* sp. nov. of Patrick (1992) (Geometridae). Annual variation suggests that the former may be vulnerable to high pre-emergence mortalities in exposed soils over wet summers (January–March rainfall correlations over 5 years were  $r = -0.996$  for site K,  $P < 0.001$ , and  $-0.981$  for site P,  $P < 0.01$ , 3 d.f.), but observed variability in other taxa had no demonstrable weather link. For spring-emerging taxa, rabbits were shown to explain much of the between-year variation (White & Sedcole, this publication, Appendix II), and such a demonstration gives prominence to a site-specific variable despite contrasting weather between years. Site comparisons across years are thereby validated.

## Derived data

In the tests of derived data against raw data (see Methods), the pooled  $r$  for summed 5-year raw data totals (0.900 back-transformed mean) was significantly different ( $P < 0.05$ , 117 d.f.) from the pooled  $r$  for the measure *commoner sex* totals (0.866), but not significantly different from *standardised data* totals (0.892) or *moth-nights* (0.888) (Fisher & Yates 1963). The latter two measures are shown to be robust despite the tests being performed on least favourable data (sites K and P had weather and trapping nights in common), and on occasions can be expected to significantly improve upon the raw data fit where sites have very different weather sequences or where the sampling routine is weather-impeded (as in White 1991).

Standardising statistics for the current study ( $n = 42$  site-years, White & Sedcole, this publication, Appendix 1) are as follows: standardising indices  $> 1.00$  were applied to 0–7 sampling periods per site-year (mean =  $2.17 \pm 1.34$  periods out of 16–17); mean weighted index =  $1.74 \pm 0.56$  ( $n = 273$  total weightings over three flight classes). The low means reflect predominantly good choices of sampling nights and relatively favourable (albeit variable) weather sequences over much of the sampling duration. As a result, many standardised site-year summations of species are little different from non-indexed (cf. White 1991).

## Discussion

Light-trapping data have been quantitatively suspect since early evaluations (e.g. Taylor & Carter 1961). Comparative and analytical light-trapping (refer Lödl 1987) have by tradition been synonymous with non-independent samples that confound and limit data analysis (Wolda & Marek 1994); and commonly used sampling intervals (e.g. nightly) lack meaningful biological and time-series rationales (White 1988, 1989). As a result, sample size on any one occasion is confounded by sampling on prior occasions, for the trappable population is in an ongoing state of depletion and/or behavioural interference, even when trapped samples are released.

In order to be quantitatively robust, the present method seeks to tightly define data compatibilities at three levels: biological, operational and analytical. The collective benefit is a time-series of biologically independent samples that are optimised at source by operational controls, and then internally standardised as necessary (each sample against its neighbour samples) by weighting indices. The indexation procedure is conservative because the observed (raw) data of the neighbour sample are used as the standard for comparison.

Similar benefits cannot be transferred to the non-independent data of traditional light-trapping because close sampling intervals already compensate for the limitations of any one sample via multi-sampling over the natural longevity of the individual. The summing of samples (e.g. weekly and annual totals) remains the only available means of addressing such data.

The present method further derives benefit over traditional databases by circumventing claims of negligible bias from repeated removals (e.g. Williams et al. 1955) as often supposed by commonplace citing of low capture success and short light-response distances, e.g. the data of Baker & Sadovy (1978) and Bucher & Bracken (1979). This argument is circular because traditional testing has relied on the very routines of repeated sampling that introduce the bias. Tests reliant on competing multiple light sources may also be suspect, and independent measures (e.g. Hartstack et al. 1971; McGeachie 1988; White 1989) provide the only valid means of assessing removal-trapping bias. Moreover, the only critical tests of flight attraction and flight interception techniques can be those carried out in open country (e.g. Hartstack et al. 1968). The tussock grasslands of White & Sedcole (this publication, Appendix II) are thereby appropriate to demonstrating quantitative capability and rigour, as claimed for the present method.

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Wolda, H.; Marek, J. 1994. Measuring variation in abundance, the problem with zeros. *European Journal of Entomology* 91: 145–161. Table 1: Schema for quantitative sampling and analysis of flighted insect data across a varied landscape.

VARIABLE	LANDSCAPE	TRAPPING
LOCAL (PRIMARY)	Management areas	Trap specifications
	<i>White &amp; Sedcole</i> <sup>1</sup>	<i>White 1991, 1996</i>
	Topography (altitude, aspect, slope, water)	Trap deployment (optimised timing and location relative to weather and terrain coverage)
	<i>White &amp; Sedcole</i> <sup>1</sup>	<i>White 1991</i>
	Vegetation classes	Effective "Trap catchment" (derived as a correlate of foodplant distributions)
	<i>White &amp; Sedcole</i> <sup>1</sup>	refer present text
GROUPED	Site pairs and Landform zones and Management classes	Sampling frequency based on longevities (for most moths, an interval of $14 \pm 4$ days avoids the renowned serial bias of removal-trapping studies)
	<i>White &amp; Sedcole</i> <sup>1</sup>	<i>White 1988, 1989, 1991</i>

<sup>1</sup> See elsewhere in this issue

<sup>2</sup> The Class B maximum weighting factor is reduced from 3.5 to 3.0 in the present study (thus matching Class A and C maxima), and non-robust samples are retained (unmodified) and seldom replaced by estimates of White 1991

**Table 1** A schema for quantitative sampling and analysis of flighted insect data across a varied landscape

MOTHS	WEATHER	SAMPLE ANALYSES
Light-response behaviours (species-specific)	Recent conditions (context for survival and current flight activity)	Raw Data
<i>refer present text</i>	<i>refer present text</i>	<i>refer present text</i>
Flight onset and duration for current night	Current night flight conditions (wind temperature, cloud cover, moonlight, plant wetness, precipitation)	Selective data (e.g. the more common sex)
<i>refer present text</i>	<i>White 1991</i>	<i>refer present text</i>
Distribution patterns and biodiversity (minimal criteria for sampling a landscape)	Marginal flight prospects (sampling options: delay to next night, or sample and later re-sample)	Annual variation
White & Sedcole <sup>1</sup>	White 1991	<i>refer present text</i>
Flight classes A, B, C (species-specific ranked flight powers based on observed responses to wind conditions)	Flight favourability rating (for every trapped sample, one of seven ratings is assigned to each Flight class)	Standardised data And "Moth-night" data (Flight class weighting factors are applied to suboptimal samples that meet test criteria)
<i>White 1991</i>	<i>White 1991</i>	<i>White 1991</i> <sup>2</sup>

Table 2: An illustration of standardisation steps (in bold type) over three consecutive spring sampling periods. The selection shows sample composition and totals for Class B, a composite sample (18–21 Nov), flight favourability ratings, and different indexing across the three flight classes. The 3-hour data are from Site X in 1994 (refer White & Sedcole, this publication, Appendix II), and the central sample index for Class B is calculated from bold-type figures as  $\{ \{ (34-27) [12 / (12+18 \text{ nights})] \} / 27 \} / 18 \text{ moths} = 1.65$ . Recent extreme rains and cool conditions (line 3) contributed to an overall decline from 332 moths on 3 November to 68 in the central sample (combined flight classes), but the conservative Class A index for the central sample remains set (= 1). A calculated value of 2.97 was rejected as too large because fewer Class A moths were trapped in the 'ideal' conditions of 3 December than in the central sample (so indicating a true time-series trough).

[note 'Ericotenes' is ms name only]

Sample date
Sampling interval (nights)
Recent weather
Sample
<b>Class B (medium fliers)</b>
<i>Epyaxa rosearia</i>
"Ericotenes" sp.
<i>Eudonia cataxesta</i>
<i>Eudonia leptalaea</i>
<i>Eudonia paltomacha</i>
<i>Eudonia sabulosella</i>
<i>Eudonia</i> sp.
<i>Helastia corcularia</i>
'Homoeosoma' <i>anaspila</i>
<i>Orocrambus lewisi</i>
<i>Scoparia exilis</i>
'Scoparia' sp. nr <i>subita</i>
Total
standardising index
flight favourability rating
<b>Class A (heavy fliers)</b>
standardising index
flight favourability rating
<b>Class C (light fliers)</b>
standardising index
flight favourability rating

3 Nov		18-21 Nov		3 Dec	
	18		12		14
settled		rain, cool		warming	
Trapped	Standardised	Trapped	Standardised	Trapped	Standardised
1	1	-	-	-	-
-	-	-	-	1	1
4	4	-	-	-	-
2	2	-	-	-	-
-	-	-	-	1	1
12	12	14	23	23	28
1	1	-	-	-	-
3	3	1	2	1	1
1	1	-	-	-	-
1	1	2	3	-	-
8	8	1	2	1	1
1	1	-	-	-	-
<b>34</b>		<b>18</b>		<b>27</b>	
	<b>1</b>		<b>1.65</b>		<b>1.2</b>
<b>Good in part</b>		<b>Good</b>		<b>Good</b>	
	<b>1</b>		<b>1</b>		<b>1</b>
<b>Good</b>		<b>Good</b>		<b>Ideal</b>	
	<b>1</b>		<b>2.14</b>		<b>1</b>
<b>Good in part</b>		<b>Good</b>		<b>Reasonable</b>	

### Effects of tussock grassland management on a moth fauna (Lepidoptera) across a varied landscape (Mackenzie Basin, New Zealand)

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**Summary:** The southern Mackenzie Basin, New Zealand, is a tussock grassland landscape of varied pastoral histories and biophysical gradients. The study aim was to assess the effects of land management on the sustainability of a native invertebrate fauna. Thirty light-trapping sites were chosen to represent jointly pastoral and biophysical gradients, and an analysis of Lepidoptera samples is presented (339 species and 118 732 individuals, range 360–8624 per site, spring–autumn). Correlations were calculated to assess moth associations with temporal and spatial gradients. Some physical gradient groupings (e.g. landform, aspect) showed significant associations independently of land management. Oversown and topdressed sites had higher moth numbers, and dryland sites in better pastoral condition averaged 70% more moths of those species feeding on living vegetation (excluding principally detritivores) and also had more species than relatively undeveloped sites. Faunal diversity was retained with intensified management when sufficient vegetation diversity was also maintained, and two key management goals are identified. Where faunal reductions occur, moth numbers usually fall first and then species may be lost. Four key agents associated with such reductions are adventive species: hawkweed (*Hieracium* spp.), sorrel (*Rumex* spp.), clovers (*Trifolium* spp.) and rabbits (*Oryctolagus cuniculus*). High autumn rabbit numbers are associated with lower abundances of spring-flying moth species, especially at sites already degraded. Few direct associations between moths and vegetation could be established and a new compatible method of vegetation measurement is shown to be necessary.

**Keywords:** abundance; adventives; *Hieracium*; Lepidoptera; management; rabbits; sustainability

## Introduction

Whatever their sources, historical changes in the botanical composition and vegetative states of tussock grasslands in New Zealand have had a modifying influence on their insect faunas. Recorded faunal histories are few (White 1991) but pointers to the effects of change may be recognised by comparing the current faunas of co-existing but different historical states of land use. Yet such comparisons are seldom straightforward. Faunas are composite entities, and any one measure tends to be imprecise because some members may be notably mobile (crossing land-use boundaries) and insect phenologies lack unified time sequences. Should a significant faunal difference exist, its demonstration is therefore dependent on serial measures and is most likely achieved across a strong gradient. A strong landscape gradient is one in which a variable changes substantially across a space that is free from the confounding changes of other variables. The definition requires an optimal matching between study space (the landscape scale of measurable gradients) and sampled space (the unit of measurement).

The montane landscape of the Mackenzie Basin affords a patchy space of measurable gradients, and is topographically a self-contained area. In the broadest sense of land management, its history is known. Since European settlement in the 1850s, all land has been pastorally grazed by sheep (*Ovis aries* L.), and from the 1870s by rabbits (*Oryctolagus cuniculus* L.). Dry, wet and moist regions of the basin are compared by Harris and O'Connor (in preparation) for livestock numbers 1850–1982, dry matter consumption trends for sheep and rabbits (to 1982), fertiliser applications, land development trends and effective rabbit control (from the 1950s). Connor (1992) and Treskonova (1991) review vegetation changes from the early 1960s.

## Methods

### A landscape strategy

The 1991–1996 study area was a 40-km east–west broad transect across the southern Mackenzie Basin, South Island, New Zealand (Figs 1 and 2). Thirty light-trapping sites were selected to represent strong gradients in climate (semi-arid east to subhumid west), landform (outwash plains to mountain slopes), altitude (380–1320 m a.s.l.), aspect (N-E to S-W), grassland types (short- and tall-tussock), grassland management (range: semi-natural unimproved to intensively improved), and vegetation condition (range: semi-pristine to highly degraded) (Fig. 3). The transect contained areas of severe depletion

by rabbits and weeds (especially hawkweed, *Hieracium* spp.), and a new outbreak in rabbit numbers was peaking at the start of the study.

The moth fauna (Lepidoptera) was elected for study as an abundant and diverse group of native consumers responsive to the effects of tussock grassland management (White 1991). A quantitative application of light-trapping (White & Sedcole, this publication, Appendix I) yielded biologically independent and standardised samples spring–autumn, and the inclusive radius around a trap from which nearly all trapped moths originate (the effective ‘trap catchment’) was provisionally estimated as 300–500 m. A premise of optimal matching between study space and sampled space (see Introduction) was thus based on the adequacy of 30 sites each with unit sampling areas of up to 28–78 ha (300–500-m radII).

Sampling adequacy was not defined solely in terms of site numbers. Firstly, a site-pairing strategy enhanced the data utility of every site. All sites were placed not only to represent the primary landscape gradients (above) but to provide proximate pairs to represent strong local gradients at the same time. Local gradients included management (e.g. strong vegetation differences across fencelines), topography (e.g. contrasting aspect), and water regime (e.g. wet and dry). Secondly, sites were also collectively allocated to test for any differences in aggregate site groupings, such as landform zones and management classes (White & Sedcole, this publication, Appendix I, table 1). In these ways, it was feasible to represent and sample landscape variables at different scales. All 30 trap positions are permanently pegged.

### **Additional measures**

Six sites were trapped for more than one year to obtain measures of annual variation as follows: five consecutive years were trapped at paired sites K and P, two consecutive years at sites S and T, and two non-consecutive years at sites D and U (Fig. 1). Thus 30 sites yielded a database of  $18 + 24 = 42$  site-years, and a summary of site details is listed by White 2002, table 1). A pegged benchmark site near Mt John in the upper Mackenzie Basin (Fig. 1 inset) was also sampled on 18 and 28 February 1996 to provide an indication of 33-year change since light-trapping in the same proximity on 21 February 1963. No other comparative early site is known to exist in the Mackenzie Basin.

In each year of trapping at a given site, the early-summer percentage ground cover of all vascular plant species and prominent cryptogams was visually estimated by an experienced observer using a modified standard grassland reconnaissance technique

(Allen et al. 1983; cf. Espie et al. 1984). The technique was adapted to light-trapping by recording comparative measures in concentric radial bands to 30 m, 100 m and 200 m from a trap (12 ha per site). It was expected that more trapped moths would originate from within 200 m than from beyond; cf. the provisional trap catchment measures of White & Sedcole, A 1961–2000 Database for New Zealand Tussock Grassland Moths (cited above).

## Data analysis

Iterative correlation analysis was used to test moth associations (species richness and the abundance of individuals) across gradients, and many tests were performed at several levels of data grouping (i.e. total fauna; selected sub-groupings; individual species). Most moth data were tested as annual totals for both raw and standardised data forms (refer White & Sedcole, this publication, Appendix I), and some spring, summer and autumn data were separately analysed. In order that the six sites with multi-year sampling not be over-represented in landscape analyses across all 30 sites, a single data year was chosen to represent each of these sites. The selections were determined by noting sampling conditions between years, rabbit history (avoiding high impact years where possible) and site pairing priorities. A total of 315 moth species out of 339 (118 732 individuals) was recorded in the combined 30-site-year selection of standard 3-hour samples (refer White & Sedcole, this publication, Appendix I).

In such faunal analyses, some taxa invariably occur in small numbers. These records may often apply to incidental and/or transitory species, and a data truncation method was used (as appropriate) to minimise their undue weight and possible masking effects on analyses. The robustness of a data grouping was tested by examining the pattern of 10 successive  $r$  values when species numbers were progressively truncated, using the test statistic  $M > m > 0$  ( $m = 1 \dots 10$ ) where  $M$  = the number of moths recorded for a species, and  $m$  = the minimum number of moths to retain that species within a given test. All sites in the grouping were each assessed independently for each value of  $m$ . If significance of fit increased to a maximum and then decreased across increasing values of  $m$ , group robustness was confirmed for the maximum  $r$  value.

## Results

The term 'moths' is used throughout the paper to mean numbers of individuals ( $N$ , not  $n$ ) and refers to raw data totals in the context of White & Sedcole, this publication, Appendix I. The distinction 'moth species' is always spelled out.

In text notation, \* =  $P < 0.01$ , \*\* =  $P < 0.001$ , otherwise  $P < 0.05$ .

## Species numbers

Correlation analysis by aspect (degrees from North,  $n = 30$  sites) showed decreasing species richness towards southern (shaded) slopes,  $n = 315$  species (range 46–135 species per site),  $r = -0.481^*$ , 28 d.f. Slope (degrees,  $n = 30$  sites) and altitude (metres,  $n = 30$  sites) lacked significance, but species richness was enhanced by the presence of running or surface water within 200 m of a trap location (presence/absence),  $n = 315$  species,  $t = 2.59^*$ , 28 d.f. Surface water occurred on three 'wet' sites and running water on 10 of the 27 non-wet sites. When the three wet sites and their paired non-wet sites were omitted, a significant management effect on species richness was shown when the two sites of all remaining pairs were ranked 1 and 2 based on pastoral condition,  $n = 46$ –107 species per site,  $t = 6.80^{**}$ , 12 d.f. The significance of fit increased to  $t = 10.90^{**}$  for the selection  $M > m = 5$  ( $m = 1, \dots, 10$  individuals per species), and the corresponding truncated  $n = 11$ –58 species per site.

The 30 sites were further analysed as three landform zones: outwash plains, valleys + footslopes, and higher slopes (Table 1, left columns). Valleys + footslopes were distinctly richer in species than outwash plains ( $t = 5.67^{**}$ , 20 d.f.) and higher slopes ( $t = 3.43^*$ , 17 d.f.). Outwash plains and higher slopes did not differ significantly.

In tests of vegetation classes over 30 sites, ground cover abundance was linked directly with moth species numbers for shrub feeders ( $n = 43$  species,  $r = 0.627^{**}$ , 28 d.f.), but not for grass feeders and herb feeders. When the naturalised herb *Hieracium* was tested alone (ground cover range 0.1–85.5%), outwash plains showed significance,  $r = -0.641$ , 8 d.f. The negative correlation increased when all naturalised herbs of outwash plains were grouped (range 4.03–91.23% ground cover including *Hieracium* spp.,  $r = -0.722$ ) and was maximised ( $r = -0.853^*$ ) for the selection  $M > m = 3$  ( $m = 1, \dots, 10$  individuals per species), truncated  $n = 18$ –46 species per site. The fitted regression is  $y = 45.26 - 0.308x$  where  $y$  is species number per site and  $x$  is percent ground cover of naturalised herbs ( $r^2 = 0.729$ ). Neither grasses nor native herbs were similarly correlated, and the naturalised herb correlation was not increased by excluding detritivore moth species.

## Moth numbers

Annual sample totals of moths per site,  $N$ , showed no significant correlation with aspect, slope and free water presence/absence (tested as above,  $n = 30$  sites). However, sites with intensive oversowing and topdressing ( $n = 4$ ,  $N = 3732\text{--}8624$  moths per site, mean =  $6630 \pm 2319$  SD) differed from other sites ( $n = 26$ ,  $N = 360\text{--}3951$  moths per site, mean =  $1866 \pm 177$ ) as follows:  $n = 315$  species,  $t = 7.44^{**}$ , 28 d.f. The difference does not hold for species numbers (above) but means that most analyses of moth numbers should be restricted to 26 sites. This restriction shifts the site designations of landscape zones (Table 1, right columns). Valleys + footslopes ( $N = 973\text{--}3951$  moths per site) had more moths than higher slopes ( $N = 360\text{--}1482$ ),  $t = 3.51^*$ , 14 d.f., but did not differ significantly from outwash plains ( $N = 1495\text{--}3685$ ). Moth numbers on the plains also exceeded those on the higher slopes,  $t = 4.44^{**}$ , 16 d.f.

The 26-site restriction enhanced a negative correlation of numbers with altitude (metres a.s.l.,  $n = 26$  sites:  $r = -0.653^{**}$ , 24 d.f.), and this increased to  $r = -0.703^{**}$  when adjusted for the climatic effects of a W–E-tilted landscape by re-expressing altitude as metres above proximate basin (i.e. outwash plains sites set to 0 m baseline). The 26-site restriction was lifted for management analyses because improved sites lie within the compass of management. However, wet sites do not lie within the compass of dryland management, and exclusion of the three wet/non-wet site pairings (refer species numbers above, 14 site pairs  $\times$  2 ranks) enhanced the significance of the effect of management:  $N = 360\text{--}8624$ ,  $t = 6.65^{**}$ , 12 d.f. When the total moth (raw) data are replaced by standardised ‘moth-night’ data (refer White & Sedcole, this publication, Appendix I),  $t = 8.31^{**}$ , which further improved to  $10.21^{**}$  by restricting analyses to those species with larvae feeding on living vegetation, i.e. omitting known detritivores, feeders on keratin and carrion, and one predatory species. The fitted moth-nights regression is  $y = 4966 + 0.539x$  where  $x$  is the standardised moth nights for the first-ranked site of each pair and  $y$  is that for the second-ranked site.

No single test of vegetation classes showed ground cover to be clearly correlated with moth numbers, despite testing moths as a range of classes and sub-classes based on larval foods. Some gains were made by scaling moth numbers (and log moth numbers) as percent total moths per site to correspond to percent ground cover measures, but all testing collectively suggested that current methods of vegetation analysis are not fauna-compatible for light-trapping data (also see White & Sedcole, this publication, Appendix I).

At paired sites K and P, testing of seasonal data over five consecutive years (with moth lag = 0, 1, and 2 years, 3 d.f.) revealed a strong negative correlation of autumn rabbit numbers with spring-flying moth numbers. A rabbit-proofed fenceline separated degraded site K (*Hieracium*-dominated vegetation,  $n = 35$  plant species) from site P (a mixed *Festuca* sward,  $n = 92$  plant species), and the rabbit data were Canterbury Regional Council night-counts 1989–95 for the 1-km length of fixed route closest to each light-trap location. The correlation is not fully understood and is therefore expressed via two moth groupings (non-independent) as follows: (1) for spring-flying moths *excluding* bimodal species with spring + later generations ( $n = 17$  species),  $r = -0.986^*$  against rabbits of the *previous* autumn for the better site P, and  $-0.997^{**}$  against the prior autumn of *year-1* for site K; (2) for spring-flying moths *excluding* species with non-vascular food plants *but including* the spring generation of bimodal species ( $n = 34$  species),  $r = -0.992^{**}$  and  $-0.984^*$  respectively for the same rabbit correlates;  $n_{1+2} = 36$  species.

At Site P also, the abundances of two grass moths *Orocrambus vittellus* and *O. vulgaris* (Crambidae) lagged by 1 year the changing abundances of hard tussock (*Festuca novae-zelandiae*), with  $r = 0.973^*$  and  $0.959^*$  respectively. In contrast, the same site's abundance of spring-flying moths belonging to rabbit correlation groups (1) and (2) above had no lag component in their correlation with current *F. novae-zelandiae* abundance,  $r = 0.962^*$  and  $r = 0.971^*$ .

## Discussion

### Landscape gradients

Multiple linear regressions of soil temperature against altitude, aspect and slope imply finely stratified polygonal patterns across Mackenzie Basin slopes, with elevation and aspect the dominant variables (Barringer 1997). So it also proved for moths. The significant decrease in moth species richness towards cooler shaded slopes (while showing no significance with slope degrees) is fully consistent with this temperature dominance of aspect over temperature  $\times$  slope interactions. The negative correlation of moth numbers (but not of species) with increasing altitude is likewise consistent with temperature  $\times$  altitude interactions, and the W–E-tilted landscape analysis points to altitude  $\times$  aridity interactions. Major shifts in fauna and flora compositions above 850 m a.s.l. (refer White, 2002) clearly confound the species relationship.

Only one aquatic moth species was recorded in the study (*Nymphula nitens*) (Crambidae) and hence the positive correlation between water presence and moth species numbers is indirect. Water tables influence flora composition and in turn faunal richness, and the presence of even narrow moisture gradients in the vicinity of running waterways appears to significantly favour biotic diversity. The broad moisture gradients of the three 'wet' sites similarly favoured diversity, and one (a permanent string-bog) had a partly specialised fauna. There was neither a specialist fauna nor any moth species adapted to the vagaries of periodic wetness and dryness at the other two, and wet sites were too few for separate analysis.

Of the three landform zones, valleys + footslopes offered the most diverse range of microhabitats (including wet sites), and it is not surprising that both species numbers and moth numbers were higher here, matched only by moth numbers of the less diverse outwash plains. Site variables and the limitations of vegetation data (White & Sedcole, this publication, Appendix I) precluded robust tests of correlation between plant species richness and moth species richness.

### **Land management impacts**

In paired-site management analyses (omitting wet-site pairings), sites ranked 1 for pastoral condition had a significantly greater moth presence. The analysis based on moth-nights for species feeding on living vegetation indicates an average of 70% more moths on the preferred sites. Thus dryland management has a measurable direct impact on faunal abundance. A prominent factor at some sites is the extent to which adventive plants invade (e.g. *Hieracium* spp., *Rumex* spp.) or are introduced (e.g. *Trifolium* spp.) because these genera dominated the negative regression of naturalised herbs on moth species richness across outwash plains.

Similarly, rabbits can place a seasonal ceiling on collective moth numbers (species were not individually correlated with rabbits) and the lagged correlations of two common grass moths with *Festuca novae-zelandiae* abundance suggest that the effect may be indirect (or at least partly so) through the reduction of food supplies. Seasonal rabbit peaks in autumn coincide with the larval feeding stages of spring-flying moths and a non-growth period for most plants. High rabbit numbers peaking at 9.5 per kilometre (site K) and 60 per kilometre (site P) led to greater absolute moth reductions in the more resilient site P sward (a 2- to 3-fold decrease of large populations), but resulted in more severe and more protracted reductions (a 4- to 5-fold decrease of smaller populations) at degraded

site K (cover: bare ground + rock 31%, *Hieracium* spp. 65%, other species 4%). Thus it would appear that moth recovery was delayed in *Hieracium*-dominated vegetation due to lower absolute abundances and a limiting food supply. The data suggest a full moth recovery period of up to 3 years (site P) and 4+ years (site K) following a major rabbit outbreak.

Thus naturalised species, plant and animal, may limit either moth abundance (see White (1991) for limitation by a grass, *Agrostis capillaris*) or species richness. Such distinction, however, is more apparent than real. Time-series analyses (rabbits and *Agrostis*) identified the initial phase of decreasing moth numbers (based on  $M > m = 0$ ) whereas the naturalised herb regression identified the current state of reducing faunal richness (based on  $M > m > 0$  discounts occasional species, including species now becoming incidental through declining abundance). A moth species' resilience to change and a potential to recover numerically is not disputed by such analysis, but permanent loss always remains a possible outcome if critical ceilings remain enforced. The outwash plains have a history of rabbit outbreaks, *Rumex* and *Hieracium* (see Methods; Connor 1992).

The nutrient cycling role of detritivores (22% of all trapped moths but principally *Capua semifera*, Tortricidae) is less clearly related to management because the five records of greatest *C. semifera* abundance included the most intensively improved site with high summer biomass (site A below,  $N = 4028$  individuals) as well as two of the most degraded sites with scant biomass in any season ( $N = 2343, 1562$ ). At one of these, site K, a sudden 4.5-fold detritivore increase in the fifth year (after years of only slight increase) illustrates the non-static nature of *Hieracium* swards when little appears to be changing. The bimodality of *C. semifera* (spring + summer/autumn generations) presumably enhanced the numeric response to changes in detritus levels.

Of the four improved sites, site A was the most intensively improved (cover: alsike clover *Trifolium hybridum* 50%, white clover *T. repens* 10%, sweet vernal grass *Anthoxanthum odoratum* 40%, other species 1%) and had eight moth species account for 95% of the fauna ( $n = 51$  species,  $N = 8377$  moths per site) compared with 88% for the paired site (an unimproved degrading *Festuca novae-zelandiae* sward,  $n = 55$  species,  $N = 3685$ ). Thus a narrower species base of dominant moths was evident with intensive improvement, but the same did not hold for the commonest eight species at each of the other three improved sites (respective ranges: 63–83% of the fauna,  $n = 90$ –129 species,  $N = 3732$ –8624). These latter sites had retained a greater plant diversity than site A.

## Faunal sustainability

As discussed above, some land areas have retained (from former times) a more favourable moth presence than have adjacent lands. But key agents of change (rabbits, *Hieracium* spp., *Rumex* spp., *Trifolium* spp.) cannot explain all observed site differences. A 70% higher presence of moths on sites in better pastoral condition is also attributable to oversowing and topdressing histories (improved sites) and stocking histories (non-quantified but evident from contrasting vegetation compositions). Lack of a fauna-compatible vegetation analysis (see Results) precluded an assessment of stocking impacts.

Because the ceilings to moth abundance and diversity have also been shown to differ across landscape gradients (e.g. valleys + footslopes had the greatest species richness) and in response to natural dryland features (e.g. aspect, altitude and proximity to water), the fauna is inherently stratified. Degrees of landscape patchiness may either enhance faunal diversity and abundance (e.g. via floral richness) or in some circumstances suppress it (as in periodically wet sites subject to extreme vagaries of wetness and dryness). An assessment of faunal sustainability must therefore seek to discriminate between such inherent variables and the imposed land management variables.

To that end, this study and White (1991) have demonstrated that a progressive limitation of moth numbers (but not of species) is commonly the first step in moving towards a lowered faunal sustainability. Should a reduction of species richness be in progress but not yet fully attained, a transition (or stable state that includes rare species) can be demonstrated by analyses of the form  $M > m > 0$  removes occasional species to yield a more robust analysis. Measuring the impacts of management on faunal sustainability is otherwise dependent on long-term monitoring data.

The 33-year Mt John data point to some pronounced changes since 1963: (1) declines in the grass moth *Orocrambus ordishi* and a moss feeder *Helastia corcularia* (Geometridae); (2) increases in lichen feeders (*Dichromodes* spp., Geometridae), detritivores (*Trachypepla* sp. nov. (Oecophoridae) and *Capua semiferana*), and a herbivore associated with exposed soils and sands (the grass moth *O. callirrhous*); (3) arrival of an adventive species, the clover case-bearer *Coleophora alcyonipennella* (Coleophoridae); (4) apparent loss of a locally common but elsewhere rare moth, *Tortrix demiana* (Tortricidae). Such changes are consistent with known reductions of inter-tussock species (mosses and native herbs), increases in exposed stone surfaces (lichen growth), increased soil stabilisation (litter now less wind-blown), spreading *Hieracium*, and introductions of clover.

Similarities of Mt John data with the 30 study sites exist to varying degrees, and it is probable that some share comparable histories of species declines and losses (feeders on native plants) and of species gains (especially lichen feeders and detritivores). If a gain in lichen feeders and detritivores has been widespread, it appears to reflect the changing flora composition and lessened sustainability of tussock grasslands as such, for many have degraded in recent time (Rose et al. 1995).

## Conclusions

The benefits of field standardisation procedures, sample standardisation and multi-gradient site pairings are cumulative (White & Sedcole, this publication, Appendix I), and without these attentions to detail, less conclusive study results would have been reached. The following conclusions are drawn:

- A science of land-use sustainability, inclusive of native fauna, requires quantified and explanatory measurements of both biotic and abiotic variables, i.e. it is too simplistic to measure faunal indices in isolation (as has often been attempted).
- A minimum database size for landscape analysis is reached when: (1) the incrementing record of species diversity becomes asymptotic (i.e. when the sampling of further sites adds little new to the faunal list); and (2) when stratified patterns emerge for the occurrences of major species and at least some minor species; both of these conditions were met by this study.
- There is no place in observational science for a non-discriminating analysis of 'total available data' (e.g. all site-years) because ecological resolution of multivariable effects may reside in different data subsets for different variables, as shown by this study.
- This study in tandem with White (1991) shows decisively that dominating adventive plants and animals can become the greatest modifiers of tussock grassland faunas.
- The faunal changes in New Zealand's tussock grasslands are shown to be gradual and generally depleting, and may be irreversible where habitat is permanently modified.
- At the same time the study demonstrates that faunal diversity can be retained at sites with intensified land management practices (e.g. moderate oversowing and topdressing) provided that native vegetation diversity is itself sufficiently sustained.

- The key management goals to sustain a local fauna are: (1) to preclude modification of the biotically richer and more specialised areas of any management unit, no matter how negligible their conservation values may appear; and (2) to retain native vegetation patchiness (diversity) across modified sites as above, or to retain by block management a natural vegetation mix across adjacent blocks.
- The study highlights the importance of compatibility between faunal and floral databases, and the development of a fauna-compatible method of vegetation measurement is a pre-requisite for future moth × plant species analyses.
- It is suggested that the conclusions for moths are substantially representative of other tussock grassland invertebrates because Lepidoptera respond directly to vegetation changes (as primary consumers and decomposers) and comprise a key prey resource in the dynamics of many parasitoids and predators (both vertebrate and invertebrate).

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Table 1: Total moth species numbers in trapping areas identified as significantly different by one or more tests, based on a selection of one year's data for each of 30 sites (315 species). Some species are unique to each configuration of the trapping areas.

SITE GROUPING SELECTIONS	Selection based on species numbers per site		Selection based on moth numbers per site	
	No. sites	Total species	No. sites	Total species
1. Outwash plains	11	156	10	154
2. Valleys + footslopes	11	255	8	227
3. Higher slopes	8	217	8	217
Areas 1 + 2	22	276	18	256
Areas 1 + 3	19	256	18	254
Areas 2 + 3	19	301	16	279
Oversown + topdressed	-	-	4	161
Remaining 26 sites	-	-	26	296

[Refer to Database]

Figure 2: Study transect, including the distant western mountains and extending across the Mackenzie Basin outwash plains (visible in part at centre right) to the Benmore Range (centre left) and eastern low ranges (foreground). The foreground vegetation is dominated by the short tussock *Festuca* and the adventive flatweed *Hieracium*, and two trapping sites are located nearby to compare north and south aspect faunas. On this sampling occasion, a helicopter drop of trapping gear was the only means of accessing upper slopes.



Figure 3: Two representations of gradient extremes: (A) a semi-arid outwash plain site of degraded short-tussock grassland dominated by adventive *Rumex acetosella* and bare ground, with pegged trapping location (foreground) and Ben Ohau Range in the distance; (B) a subhumid Ben Ohau Range mountain site of semi-pristine tall-tussock grassland (predominantly *Chionochloa rigida* and stone with the native shrub *Dracophyllum uniflorum* among snow on the distant south face, 1200–1300 m a.s.l.), foreground light-trap located on a 35° west-facing slope.

A



B



