D. SCOTT

AgResearch, PO Box 60, Lincoln, New Zealand.

TIME SEGMENT ANALYSIS OF PERMANENT QUADRAT DATA: CHANGES IN *HIERACIUM* COVER IN THE WAIMAKARIRI IN 35 YEARS

Summary: A technique for inferring long term time trends in vegetation from permanent quadrat data using the different patterns in the scattergram of the mean and rates of change of attributes, e.g., cover, from individual quadrats over short periods is described. The technique is illustrated using point intercept cover data for *Hieracium* species from permanent transects in the Waimakariri measured at intervals over 35 years. There was an exponential increase of 8.6% of *Hieracium* spp. percentage cover once they appeared in a quadrat up to about 15% cover. The indications were that *Hieracium* may stabilize on these sites at an upper mean level of c. 34% cover.

Keywords: vegetation analysis; *Hieracium;* curve fitting.

Introduction

With the current concern of the invasion of the New Zealand high country by introduced hieracium species *(Hieracium* spp.), particularly *H. pilosella* L., attention has focused on available vegetation records as a guidance of their occurrence, rate of spread, and ecology as part of devising control measures (Hunter, Mason and Robertson, 1992). One of the longest and most accurate sets of records are those for ground cover from permanent transects initiated by Mr R. D. Dick within the then North Canterbury Catchment Board in the tussock grasslands of the central Waimakariri Valley, and measured for the period 1947 to 1963, and again in 1980, 1981 and 1993. The main features of those records have been reported by Scott, Dick and Hunter (1988) and Hunter and Scott (1993).

Hieracium species were not prominent in the early period studied but increased over time. By 1993 *H. praealtum* Gochant was the most common, followed by *H. pilosella, H. caespitosum* Durmort, and *H. lepidulum* (Stenstroem) Omang. In comparison to the other twelve common species, the principal features of *Hieracium* species' trends and distribution were: a mean cover over all transects of 6.1 %; the highest rate of increase in cover of any species; occurrences irregular over the full altitudinal range; concentration in samples with 70% or more plant cover, tendency to associate with *Agrostis capillaris* L., *Anthoxanthum odoratum* L., *Discaria toumatou* Raoul, *Hypochoeris radicata* L., and *Raoulia subsericea* Hook. f.; and only moderate increase in ground cover when *Hieracium* was dominant. These results led to a prediction that vegetation types dominated by *Hieracium* would increase. However, with the apparently increasing importance of *Hieracium* in these and other areas the data warranted further examination with particular reference to *Hieracium*.

Permanent transects or quadrats have particular advantages and disadvantages in the study of species and vegetation trends. Their main advantage is that they can give precise determinations of changes at particular points, and this is the usual reason given for quantitative techniques like point analysis, line transects, or photo-quadrats. Quadrat data, especially from small sampling areas, also commonly have the disadvantage of differing greatly in the measured values between different samples, e.g., in percentage cover of a particular species. This variability may be ecologically significant but generally becomes merged in the general variability of experimental error in many statistical techniques. Another limitation for the purposes of statistical analysis is that because measurements are repeated on the same quadrat they may not be independent in their errors and hence should not be subjected to the usual analysis of variance or regressions analysis which assumes independence. In considering this problem I believe it may be possible to rephrase such data in a manner so that the variability between quadrats is highlighted as having possible ecological interpretations and where the individual quadrat data can be transformed in a way which makes independence a more realistic assumption. This approach is first described and then used to examine the *Hieracium* trends in the central Waimakariri records.

Methods

Time segment analysis

Time segment analysis uses the data from the repeated measurements of each permanent quadrat to derive variables which are more likely to be independent. The appropriate variables are the mean level of each attribute in that quadrat (e.g., mean percent cover of *Hieracium),* and the rate of change of that attribute within that particular quadrat (e.g., rate of increase in cover of *Hieracium* per year). Depending on what the magnitude of changes were within a particular set of quadrats the variables may be a single derived mean and rate of change for each permanent quadrat over the whole sampling period if the magnitude of change is small, or separate pairs of mean and rate of change values derived from each pair of successive measurements, or group of successive measurements if the changes are larger. The first derives only a single pair of variables and hence that quadrat data is independent from other quadrats in any subsequent analysis. The other alternatives contain some degree of non-independence.

The mean level of the attributes can be determined as simple averages if the sampling was at regular or near regular intervals, but might require some form of weighting if the measurements were at very irregular intervals. The means and gradients can be determined by curve-fitting formulae. While these could be derived by regression techniques, they would only use the curve-fitting part of such techniques and do not depend on the statistical assumptions that would be required to make probability tests. In practice it is easier to derive the coefficients by using recoding formulae or matrix procedures rather than regression analysis on data for each quadrat.

The approach has a number of advantages. Firstly, the quadrat measurements need not have been at regular time intervals, or even similar time intervals for the different permanent quadrats in the data set. Secondly, while the standard errors associated with the derived variables should not be used to make statistical tests, they can be used as weighting factors associated with the value when it is used in further analysis.

Consideration of processes like succession would suggest that vegetation at a site often goes through an orderly sequence of changes. The suggestion is that survey data from a set of permanent quadrats are a number of different 'snapshots' or 'time frame' views of different segments of a full response curve, and that the problem is to arrange the pairs of values of mean and rate of change from the quadrats into the sequence which shows the overall mean long term vegetation response.

Figure 1 shows that if one works back from segments of various assumed long term trends then they appear as distinctive scattergrams of the means (b_0) and gradient coefficients (b_l) derived from individual permanent quadrats. Several of the scattergrams mimic directly the time trends serving as convenient mnemonic, and this is the reason for using the gradient as the horizontal axis and the mean as the vertical axis in the initial assessment of the data, though this causes some dilemmas in later fittings of relationships. The scattergrams could also detect long term trends which have a maximum or minimum by the occurrence of both positive and negative values for rate of change from different quadrats of a similar mean level.

Thus, given a scattergram of means and gradients fitted to individual permanent quadrats, it is possible to determine long term trends. This involves fitting some general trend line through the scattergram using regression or freehand techniques. A difficulty would be for distributions that indicate maxima or minima where strictly the time spent at a gradient of zero is infinite. One would need to make some assumption, like that the rate of change of gradient through a zero value was similar to that for other periods. There is also difficulty in applying common regression techniques in that there are variances associated with both the mean and gradient values.

Sampling

A full description of the sites and the field sampling methods is given in Scott et *al*. (1988). In summary, permanent transects were established in 1947 at seven locations in the Porter River/Broken River area of the central Waimakariri Basin, on steep slopes in the 780-1300 m altitudinal range and on various aspects. Each transect extended 200 or 300 m up slope. Approximately 400 point samples at 50 mm intervals were taken per 20 m. Ground cover at each point was recorded as either living vegetation, dead material, or bare ground. Measurements were taken annually in January or February from 1947 to 1963 and again in 1980, 1981 and 1993. In 1956, 1959, 1962, 1980, and

1993 the species touched by every third point was also recorded to determine the cover contribution of each species.

The basic unit used for the present analysis was a 5 m interval along a transect for a particular year, compromising approximately 100 ground cover and 30 species' composition records, which were converted to percentages. The same 5 m intervals were used for samples in different years. There were 38-60 such samples per transect. The present paper is confined to the collective class of *Hieracium* species as individual species were only individually recorded in the last (1993) measurements.

Means and rates of change were determined for each successive time interval for *Hieracium* in each quadrat. Because of the low inherent number of species' records in each sample only some combinations of values were possible in the resultant cover estimates. In graphing this led to apparent linear trends in some series of points, and in others coincident points. For the purposes of showing frequency these coincident points were slightly dispersed into clumps in the diagrams presented.

Results

Hieracium species increased from rare occurrence in 1956 to a mean cover of 6.1 % in 1993 (Table 1). The stabilizing or decreasing cover on the Cloudy Knoll transects by 1993 was a new feature after the rapid increase from 1962 to 1980. The individual species were only distinguished in 1993 when *H. praealtum* made up 4.9% of the mean cover of 6.1 %, as compared to 0.6% for *H. pilosella,* 0.5% for *H. lepidulum* and 0.1 % for *H. caespitosum.* There were no major differences in proportions of the species between transects.

The expansion phase of *Hieracium* species is illustrated by samples from the combined transects where *Hieracium* was present and at less than 15% of ground cover in a sample. The scattergram of the gradient versus mean (Fig. 2), when initially plotted as mean versus gradient, shows the increasing trend of the top example in Fig. 1. While there was some scatter of points the trend was best approximated by a linear regression through the origin with a gradient of 0.0864 yr^{-1}. This linear relationship between rate of change and mean implies an exponential increase in *Hieracium* once it appears in a sample, with a compound interest growth rate (intrinsic growth rate) of 8.6%.

The expectation that, in the longer term, a

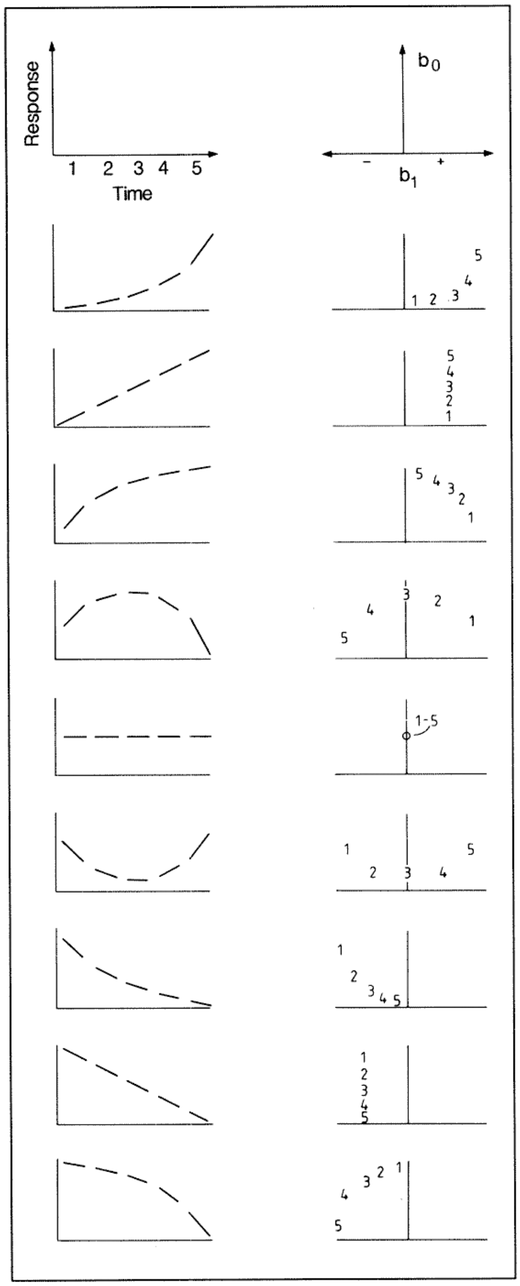

Figure 1: *Relationship between possible long term time trends (left) and regression coefficients of mean (b_0) and slope (b_1) fitted to short term time trends from individual quadrats (right).*

Table I: *Changes in percentage ground cover of Hieracium (combined species) on seven transects in the central Waimakariri Basin,*

	Cover in each year (%)					Intrinsic growth
Transect	1956	1959	1962	1980	1993	rate (%)
Cloudy Knoll South	1.2	2.1	2.9	19.1	15.8	9
Cloudy Knoll Middle	0.7	0.4	2.0	15.2	15.2	8
Leith Hill	0	0	0.3	0.3	6.1	10
Lyndon Lower	0	0.1	0	0.9	7.5	9
Lyndon Upper	0	0	0	0	0.1	11
Constitution Hill	0.1	0	0	0.2	0.5	8
Purple Hill	0	0	0	0	0	0

species would reach an upper asymptote is illustrated by the second example. The scattergram (Fig. 3) with the inclusion of all data, which included ninety seven samples exceeding 15% *Hieracium* cover, indicates a curvilinear relationship, which when plotted as mean versus rate was a combination of the bottom, and third to bottom, examples of Figure 1. This distribution indicates a sigmoid or logistic type growth curve with the fitted relationship showing that *Hieracium* cover stabilising at about 34% cover.

The effect of other characteristics of the individual quadrats on rate of change of *Hieracium,* namely percentages of living, dead, and bare ground cover, altitude, and cover of seventeen principal species, were investigated by forward stepwise multiple regression. In both cases the mean *Hieracium* cover remained the most significant factor influencing rate of change. In the cover data set with *Hieracium* below 15% cover the next three most important factors, in order of significance, were percentage cover of Agrostis capillaris L. (+ve association), *Anthoxanthum odoratum* L. (-ve), and total living cover (+ve). For the second set, including all *Hieracium* data, the corresponding factors were *Cyathodes colensoi* (Hook.f.) Hook.f. (-ve), total living cover (+ve), and total dead cover (-ve).

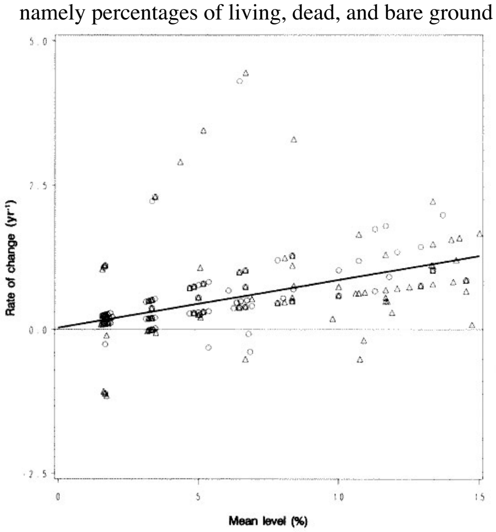

Figure 2: *Scattergram and fitted line of a relationship between rate of change and mean cover for combined* Hieracium *cover. Values are for each time period and each quadrat in which* Hieracium *was present and with less than* 15% *cover (n=289). Symbols: circles = living cover less than 70%; triangles = living cover ≥70%.*

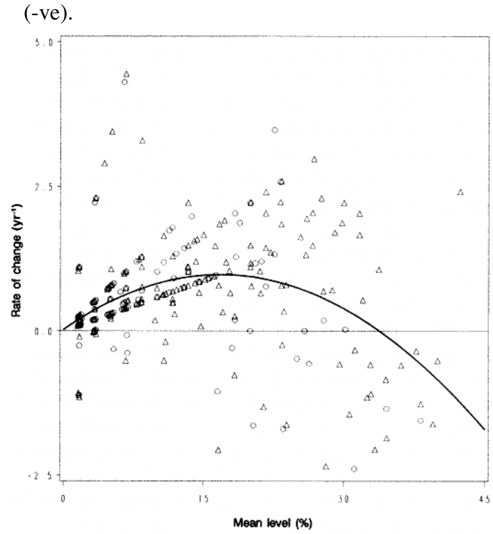

Figure 3: *Scattergram and fitted line for all time periods and quadrats in which* Hieracium *was present, (n=386). Symbols as in Fig.* 2.

Discussion

There are many inherent dilemmas and compromises in the analysis of species' cover data from permanent quadrats, with the intuitive inherent value of repeated measurements on the same quadrats being at variance with the assumptions required for rigorous statistical analysis.

The paper has demonstrated a method of handling short term permanent quadrat data for determining long term trends of vegetation. It does this by separating the accuracy inherent in re-measurement of change for individual samples, from the variation between samples. It has made the successive measurements from one sample more independent for subsequent statistical analysis, and allowed the differences between samples to be used for determining time trends, or other ecological relationships.

In vegetation cover data there is a number of ways in which the rate of change of a particular component can be determined. This can range from simple regression of the combined data set considering each cover observation as independent, through using the rate of change first determined for the data for each quadrat with the rate values meaned for all quadrats, to using the rates determined for each time interval for each quadrat with the values then meaned. The final values while similar in general magnitude will differ in detail.

The finer subdivision of data in the later approaches has the advantage of being more statistically independent and the potential of associating rates of change with other factors associated with particular quadrats or periods. But such fine subdivision also has the risk that results could be unduly influenced by particular observations, e.g., in an extreme case, if rates of change were determined from regular successive measurements, the mean rate would be determined by only the first and last observations with no influence by any number of intermediate measurements.

There was a dilemma in choosing the plotting axis for the scattergram for first detecting the type of long term time trend relative to subsequent fitting of relationships. The attraction of the rate of change versus the mean used in Fig. 1 was that in many cases the scattergram mimicked the long term trends. However, in fitting a relationship it was more likely that the rates of change would be functionally related to the mean levels rather than *vice versa*. There was also the usual statistical dilemma of the regression of y on x being different from x on y (for the first example the gradient being 8.6% versus 17.8%). As there were measurement or estimation errors in both the mean cover and rates of change there is probably no fully acceptable test of the reliability of the estimates.

The significant ecological feature of the present example has been the near linear relationship between mean levels and rates of change of cover when *Hieracium* cover was low. This is a demonstrable test of the exponential increase of *Hieracium* in the high country. This is more consistent with the view that *Hieracium* is an invasive weed into a new environment with few environmental constraints, at least at the early stages, rather than a symptom of some changing environment. The difficulty with claiming that *Hieracium* is a symptom of a degrading environment, such as nutrient depletion, is that I would have expected, in that scenario, there would have been much more patchiness in the *Hieracium* increase, related to the patchiness of, say, nutrient depletion. That is not my impression; the increase in *Hieracium* seems to have been widespread and general.

However, the second feature of the results was the indication of *Hieracium* reaching an upper mean level of about 34% cover, though as Fig. 3 shows, individual areas can have much higher levels. While to some observers this may seem to be a relatively low value, it must be remembered that the estimates are based on point intercept data, which because of its close observation at ground level, generally records a greater proportion of dead vegetative cover than other methods. The extent of this trend for average *Hieracium* cover to stabilise at moderate levels remains to be seen. While this trend is apparent in the present data from a particular environment and time period, the time segment method described offer the ability to detect trends in data from other areas.

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