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## CHANGE IN *HIERACIUM* POPULATIONS IN EASTERN OTAGO OVER THE PERIOD 1982 - 1992

**Summary:** Changes in *Hieracium* abundance in Eastern Otago tussock grassland were examined by sampling 163 sites in 1982 and again in 1992. For *Hieracium pilosella*, *H. praealtum* and *H. lepidulum*, as well as *Agrostis capillaris* for comparison, colonisation of new sites was recorded, as well as extinction of species from sites over the 10 years, and changes in cover. *H. pilosella* colonised the majority of sites from which it had been absent in 1982; it disappeared from only a few sites where it had been present at very low cover. In sites where it remained over the decade, its cover increased by 50%. Its rate of increase was very similar to that recorded for North Canterbury, but with no indication of the 34% stabilisation point that has been hypothesised for the latter area. *H. praealtum* and *H. lepidulum*, in contrast, remained absent from most sites, and colonised only a few; in very few sites was their cover greater than 1%. *Agrostis capillaris* was widespread and abundant, but increased little over the period. The sites where *H. pilosella* colonised tended to be degraded, with a greater, and increasing, percentage of bare ground and low tussock cover. The few sites where it disappeared were ones where pasture improvement had occurred, as seen in the increase of species indicative of pasture development.

Several explanations are considered for the increase in *H. pilosella* in recent decades. The increase of this species in Eastern Otago has been greater than that of most other exotic species. Changes in land management have contributed to its increase, but probably changes caused indirectly by government policy, not gradual degradation. Genetic changes in the species, and metapopulation dynamics, have not been investigated, but they could well have contributed to *Hieracium* invasion.

**Keywords:** *Hieracium*; *Agrostis*; Eastern Otago; abundance; colonisation.

## Introduction

The invasion of exotic species is a major problem world-wide, both for rangeland production and for conservation (Baskin, 1996; Luken and Thieret, 1996). In New Zealand, one of the threats to pastoralism and to conservation is invasion by *Hieracium* species (Harris and Mark, 1992; Duncan Colhoun and Foran, 1997). The abundance of *H. pilosella* (= *Pilosella officinarum*, mouse-ear hawkweed) and *H. praealtum* (= *Pilosella praealta*, king devil hawkweed) (nomenclature follows Webb, Sykes and Garnock-Jones, 1988) in drier areas of South Island has increased dramatically in the past three decades. These species now form a considerable part of the cover through much of these regions, compromising the pastoral values of those areas (Rose, Platt and Frampton, 1995). In areas once bearing semi-arid short tussock grassland with high conservation values, the invasion of *Hieracium* species has been accompanied by a considerable decrease in the native component of the vegetation, most noticeably the dominant tussock grass *Festuca novae-zelandiae*. *Hieracium lepidulum* is becoming

a problem weed in wetter areas, such as Mount Aspiring National Park (Harris and Mark, 1992).

In spite of the widespread concern regarding the spread of *Hieracium* species there is a paucity of long-term studies from which the rates of increase in both frequency and abundance of the species can be determined. We investigated changes in *Hieracium* species in Eastern Otago, by repeating in 1992 a survey made ten years earlier. The aims were to document for the first time the changes in frequency and abundance of *Hieracium* species in this area, and to relate any changes to the condition of the vegetation including changes in *Agrostis capillaris*.

## Methods

### Study area

The study area lies between Roxburgh in the West, Naseby in the North, Karitane in the East, and Milton in the South (Fig. 1). It comprises a series of parallel ranges and intermontane basins, ranging from 70 m to 990 m above sea level. Soils are predominantly

schist-derived, or weathered quaternary gravels and sands. Yellow-grey earths predominate on the lower slopes of the intermontane basins and in the mid-altitude zone of the drier ranges, where annual rainfall is 500 - 700 mm, with a moisture deficit for up to 3 months of the year. Above an altitude of about 500 m, yellow-brown earths predominate. There are few climate stations above 500 m, but precipitation is assumed to be higher, with consequently higher leaching. Mean annual temperatures are between 5°C and 10°C with January and February being the warmest months of the year; July is the coldest. Up to 120 days per year experience screen frosts and up to 30 days per year experience maximum temperatures greater than 25°C. Much of the study area was covered by *Nothofagus* forest before human settlement, but burning by Polynesian immigrants from about 1200 A.D. converted most of this to tussock grassland. The native component of this

grassland has since been reduced, and in some areas eliminated, by burning, grazing, and in some areas fertilisation and oversowing by European pastoralists.

### Site selection

Within the study area, sites were selected to give a representative coverage of tussock grasslands and undeveloped rangeland. These sites were identified from Landsat false colour satellite images. A 1:250,000 topographical map was then superimposed to show the network of roading and tracks, and also the 1000 m contour. Areas above 1000 m in altitude were eliminated, and an attempt was made to uniformly cover the remaining areas with sites at approximately 2 km intervals along any tracks or roads that happened to traverse them. The sites were usually taken about 50 m from the road or track on alternate sides. The requirement for sites to



Figure 1: Location of study area in Eastern Otago, South Island, New Zealand.

have vehicular access was due to the need during the first sampling to take fairly weighty soil samples for faunal analysis. The location of each site was fixed to within 50 m by surveying with a theodolite.

During the summer 1981/82 (hereafter referred to as 1982), 202 sites were sampled. In 1991/92 (referred to as 1992) all sites were revisited. The 163 sites remaining as tussock grassland and undeveloped rangeland were resampled by the same operator (AGB) as in 1982. Ninety five of the sites were identified in 1992 from the pattern of holes left by soil sampling in 1982. Where soil sampling holes could not be relocated during the 1992 survey, relocation was based on the original theodolite bearings and the measurements made at the time of the first survey. It is therefore likely that all these 38 "inexactly relocated" sites were within 50 m of the original site. There were eight sites ungrazed by farmed livestock in the 95 exactly relocated sites and two in the 38 inexactly relocated sites.

### Sampling

At each site, a sampling plot of 10 m x 10 m was laid out. Both enumerative and visual methods were used to assess the cover of all species. Visual estimates were on the scale of 0%, 0.1%, 1%, 5%, 10% and then multiples of 10% and/or 25%. In 1982, visual estimates of cover were made in all plots. For calibration and as a guide to visual estimation, enumerative estimates were made in a subset of plots. In 1992, both visual and enumerative surveys were made on all plots.

In enumerative sampling, in 1992, the basal circumference of all individual tussocks falling within the plot was measured. For shrubs, canopy circumference was measured at 100 mm height. Where tussocks or shrubs were very numerous, typically greater than 100, only those falling into a randomly chosen half of the square were measured, and the result doubled to convert to a whole plot measurement. For smaller species, cover in a randomly selected part of the plot not covered by tussocks and shrubs was recorded with point quadrats. The points were arranged in frames of 10 points, the points being 50 mm apart. Each point was effected by a sharp needle taken all the way down through the canopy, only contacts with the very tip being recorded (Greig-Smith, 1983). Ten frames were placed where practicable, giving 100 points. The percent cover over the whole plot for each species was then calculated as follows:

$$\%S_i = P_i [100 - \sum_i B_i] + B_i$$

where:  $\%S_i$  is percent cover for species  $i$  (Bare ground was treated as a species)

$P_i$  is proportion of points for species  $i$  (0 for measured tussocks and shrubs)

$B_i$  is the measured basal area of species  $i$ . It is zero for all but the measured tussocks and small trees.

$\sum_i B_i$  is the sum of the basal area of measured tussocks and shrubs.

Other data recorded included altitude in the hope of finding a correlation with *Hieracium* invasion.

### Calculation of indices

The sum of the percent cover by the species *Trifolium pratense*, *T. repens*, *Lolium perenne*, *Dactylis glomerata* and *Cynosurus cristatus* was taken as an index of pasture development, these being the most common pasture species in the area. Similarly, the sum of the percent cover by the species *Chionochloa macra*, *C. rigida*, *C. rubra*, *Festuca novae-zelandiae*, *Poa cita* and *Poa colensoi* were taken as an index of lack of development, called here a tussock index.

### Annual rates of change

Rates of change for percent cover of *Hieracium pilosella* was calculated as  $\exp[\log_e(\text{mean percent cover 1992}) - \log_e(\text{mean percent cover 1982})]/10$ . That is, it is the exponential of the slope of the change in the logarithm of the mean percent cover over the ten year period.

### Calibration of cover estimates

In order to calibrate between the enumerative and visual estimates, and to check on the validity of analysis based on visual estimates, a comparative technique due to Altman and Bland (1983) was used, in which the difference between pairs of measurements, one by each technique on the same site, is plotted against the mean of the pair. The mean of the differences between pairs gives an estimate of bias between the techniques, and the slope of the differences between pairs plotted against their mean gives an estimate of systematic differences in the techniques which are related to the magnitude of the measurements.

The cover of *Hieracium pilosella* estimated visually in 1992 was on average 1.33% (S.E. 0.035%) higher than the value estimated by enumeration. The slope of the differences between estimates from the two techniques on their mean was 0.037 (S.E. 0.0221). For the development index,

visual estimates were on average 0.94% (S.E. 0.438%) higher than enumeration with the individual differences having a slope of 0.0102 (S.E. 0.0353) on the means. The average difference for the tussock index was 0.81% (S.E. 0.417) and the slope 0.1197 (S.E. 0.0521). For bare ground the average difference was 0.22% (S.E. 0.593) with a slope of 0.0660 (S.E. 0.0416).

Thus, the differences between enumerative and visual estimates of cover were small in relation to the magnitude of the differences being studied. This close agreement, combined with the fact that sampling was performed by the same operator in both 1982 and 1992, indicates that the 1982 values obtained by visual assessment are comparable to the visual values recorded in 1992. Thus the visual data can be relied upon to reflect the changes that actually took place.

### Statistical methods

In order to justify considering the exactly and inexactly relocated sites together, differences between the frequency of *Hieracium* spp. and *Agrostis capillaris* in exactly and inexactly relocated sites were estimated by generalised linear models (Nelder and Wedderburn, 1972) using the Poisson distribution and canonical link.

The significance of the differences in 1982 between reported mean percentage cover and the indices described above, and their changes between 1982 and 1992, were assessed using Student's *t* test.

Simple and multiple linear and non-linear regression methods and scatter plots were used to investigate relationships between cover and altitude.

## Results

### Changes in *Hieracium* frequency and abundance between 1982 and 1992

For each species, differences between the frequency of *Hieracium* species and *Agrostis capillaris* in exactly and inexactly relocated sites were not

significant in 1982 or 1992. In view of the similarity in the results from these sites, data from both classes of site have been combined. The frequencies of *Hieracium* spp. and *Agrostis capillaris* in 163 sites in 1982 and 1992 are presented in Table 1. Because of the small number of ungrazed sites, the effect of grazing management could not be usefully estimated.

In 1982, *Hieracium pilosella* occurred at 66 sites; by 1992 it had disappeared from only five of these sites. All five of these sites had less than 1% cover of *H. pilosella* in 1982. In contrast, on the 61 sites where *H. pilosella* had persisted, there was an average of 12.6 % cover (S.E. 2.10; range 1% - 80%) in 1982, which, by 1992, had increased to 18.6% (S.E. 2.32; range 0.1% - 70%). This is an annual rate of change of 4.0%. The mean cover in 1992 of the areas colonised after 1982 was 8.0% (S.E. 1.75; range 0.1% - 70%). The annual rate of change over all colonised sites, including the sites colonised after 1982, is 8.0%. At the 1992 assessment, 19 sites had greater than 35% cover of *H. pilosella*. There was no evidence of a relationship of altitude with cover of *H. pilosella* in 1982 or in 1992, nor with the increase in cover over the 10 years. During the period 1982 to 1992, *H. pilosella* became established in 67 out of the 97 sites which had previously been *H. pilosella* free.

*Hieracium lepidulum* and *H. praealtum* were much less widespread, less abundant, and less invasive than *H. pilosella* although the frequency of both increased over the study period. In 1992 the cover of *H. lepidulum* and *H. praealtum* exceeded 1% on only two of the 163 sites.

### Changes in *Agrostis capillaris* frequency and abundance between 1982 and 1992

Over the period 1982 to 1992, *Agrostis capillaris* became established in 17 sites, and disappeared from 20. The mean cover in sites where it was present in both 1982 and 1992 was 14.8% (S.E. 0.99%; range 1% - 50%) in 1982 and 14.5% (S.E. 1.13; range 0.1% - 50%) in 1992. In sites colonised after 1982, the average cover by 1992 had reached 9.2% (S.E. 2.01%; range 0.1% - 20%).

Table 1: *The presence and absence of Hieracium spp. and Agrostis capillaris in 163 sites in 1982 and 1992.*

	Present in 1982 and in 1992	Absent in 1982 Present in 1992	Present in 1982 Absent in 1992	Absent in 1982 and in 1992
<i>H. pilosella</i>	61	67	5	30
<i>H. praealtum</i>	0	5	0	158
<i>H. lepidulum</i>	1	12	1	149
<i>A. capillaris</i>	108	17	20	18

Table 2: Percentages of bare ground, development index and tussock index in 1982, and changes in the next ten years, in four classes of sites based on presence and absence of *H. pilosella*. Negative values indicate a decrease. The values in brackets are the standard errors.

	Present in 1982 and in 1992	Absent in 1982 Present in 1992	Present in 1982 Absent in 1992	Absent in 1982 and in 1992
Number of sites	61	67	5	30
% bare 1982	6.4 (1.40)	7.4 (1.60)	4.0 (4.00)	6.7 (2.89)
Change in % bare 1982-1992	-1.2 (1.51)	5.7 (1.60)	-1.9 (4.89)	0.7 (2.19)
Development index 1982	6.9 (0.95)	13.2 (1.89)	6.2 (3.93)	24.9 (3.80)
Change in development index 1982-1992	2.0 (1.46)	-6.1 (1.75)	9.9 (7.82)	-7.6 (3.75)
Tussock index 1982	19.9 (1.79)	15.2 (1.44)	46.8 (12.1)	18.8 (3.11)
Change in tussock index 1982-1992	-11.0 (1.56)	-7.3 (1.40)	-37.9 (11.40)	-9.5 (2.75)

## Bare ground

In the sites which were colonised by *Hieracium pilosella* during the years 1982 to 1992, the amount of bare ground increased significantly during the period (Table 2); this increase is significantly greater ( $P < 0.01$ ) than the change at the sites which *H. pilosella* had colonised prior to 1982.

## Development and tussock indices in 1982

The development index in 1982 was significantly lower ( $P < 0.05$ ) in the sites which *Hieracium pilosella* colonised after 1982, than in sites where *H. pilosella* remained absent (Table 2). However, sites which had already been colonised by *H. pilosella* prior to 1982 had an even lower development index ( $P < 0.001$ ).

In 1982 the tussock index was significantly higher ( $P < 0.05$ ) in the sites which had already been invaded by *Hieracium pilosella* but from which it had subsequently disappeared, than in other sites. It was also significantly higher ( $P < 0.05$ ) in the sites which had been previously invaded, than in the sites which were to be invaded over the next decade.

## Changes in indices between 1982 and 1992

In those sites where *Hieracium pilosella* was absent in 1982, the development index was significantly reduced ( $P < 0.05$ ) during the decade to 1992 (Table 2). In all classes of sites, the tussock index significantly ( $P < 0.001$ ) decreased during the period 1982 to 1992, but the reduction was greatest in the sites from which *H. pilosella* had disappeared during the period. In 1992, the tussock index had an overall average value of 8.8% (S.E. 0.69%) with no significant difference amongst the four classes of sites.

## Discussion

### Time trends in *Hieracium* species

*Hieracium* species were sparse in tussock grasslands in the 1960's (Connor, 1992; Scott, 1993a). Since then, they have increased in Canterbury (Scott, Dick and Hunter, 1988; Scott, 1993a, b; Rose *et al.*, 1995). For example, in one area of North Canterbury, Scott (1993a) estimated the increase in cover of *Hieracium* species to represent an instantaneous rate of increase of 8.6% per year. In the area of Otago that we surveyed, the annual rate of increase of cover in those sites remaining occupied from 1982 was 4.0%. Over all sites (i.e., including new site colonisation) the increase was 8.0%, remarkably similar to the 8.6% in North Canterbury. Scott (1993a), suggested that the rate of increase in his North Canterbury area was lower, or even negative, in sites with higher *Hieracium* cover. A regression of rate of change on mean cover suggested that this effect would lead to stabilisation with an upper asymptote of about 34% cover. However, the graph on which Scott based his claim of 34% has so much scatter that the true value could be anywhere between 7% and 25%, and beyond this range if the relation was because of indirect correlations, which it certainly would be to some degree. Moreover, Scott's claim of 34% is not borne out even by his own data; the two areas of his that stabilised in cover in 1980 and 1993 did so at 15% and 16% cover respectively, not 34%. Had Scott's 34% been supported by his own analyses and his own data, we might ask whether it applied also in East Otago, but since it did not, it is not surprising that we recorded 10 sites which had attained more than 34% cover by 1992; indeed Duncan *et al.* (1997) reported several sites in Otago and southern Canterbury with *Hieracium* species cover of 50% or more.

*Hieracium praealtum* and *H. lepidulum* are less common in Eastern Otago than is *H. pilosella*, as in some other lower-altitude areas (Connor, 1992; Rose *et al.*, 1995; Duncan *et al.*, 1997). Scott *et al.* (1990) reported slightly greater increases for *H. praealtum* than for *H. pilosella* at a site in the Mackenzie country. *H. praealtum* was not appreciably present in the area surveyed by Rose *et al.* (1995) and Scott *et al.* (1988) did not report it separately from *H. pilosella*, as it was not separately identified in the early part of the study. Our data indicate *H. praealtum* to be increasing, but slowly. *H. lepidulum*, for which Rose *et al.* (1995) report a slow increase (2.8% per year), has such a low baseline that a reliable estimate of annual increase for Eastern Otago cannot be made.

The increase in *Hieracium* species in South Island grasslands in the past few decades has drawn considerable comment with suggestions that it is remarkable that such a large increase should occur in this species at this time. However, other exotics have increased in the same period, e.g., *Agrostis capillaris* increased over 25 years at an instantaneous rate of 12% per year in the area of North Canterbury surveyed by Rose *et al.* (1995). It is normal for invasive species to show a lag period, then to increase rapidly (Hobbs and Humphries, 1995).

#### ***Hieracium* and the interaction between tussock cover, development index and bare ground**

In the period 1982 to 1992, the tussock index decreased for all four site classifications, regardless of starting value, to an overall average value of less than 10%. Fan and Harris (1996) suggest that competition from *Hieracium* spp. is the cause of "weakening of the tussocks". However, the decrease in tussock cover in sites where *H. pilosella* was absent indicates that interference from *Hieracium* cannot have been the primary cause of the tussock decline.

The same conclusion, that *Hieracium* spp. are not the cause of degradation in tussock grassland and undeveloped rangeland, is reached by examining the bare ground. There was indeed an increase in bare ground in those sites invaded by *H. pilosella* between 1982 and 1992, but this was probably not a result of invasion by *H. pilosella*, because in 1982 those sites with *H. pilosella* present had a similar showing of bare ground to those sites without it. Therefore, whilst a halo of bare soil can sometimes be seen around patches of *H. pilosella* (McIntosh, Loeseke and Bechler, 1995), *H. pilosella* cannot be seen as a cause of degradation of vegetation cover.

An alternative suggestion has been that *Hieracium pilosella* increases more rapidly in areas

that already have reduced tussock cover and more bare soil (Treskonova, 1991). This is partially supported by our data: sites where *H. pilosella* invaded in the decade 1982/92 were those with the lowest tussock cover and lowest development index at the beginning of that period, and the largest increase in bare ground in the period 1982/92. Bare ground does not seem to be essential for *Hieracium* invasion: Scott (1993a) reported that in an area of North Canterbury *Hieracium* species were increasing most in those areas with higher plant cover.

#### ***Hieracium* decrease in some sites**

Although there has been a general tendency for *Hieracium* species to increase, Scott (1993b) demonstrated that *Hieracium pilosella*+*praealtum* (not distinguished in that work) can decrease or even disappear under high fertiliser or sowing inputs. We recorded sites in Eastern Otago where *H. pilosella* disappeared between 1982 and 1992. Whilst a species could conceivably be overlooked in the 10 x 10 m plots that we used, Johnstone, Espie and Allan (1994) report the elimination of *H. pilosella* from small plots where it could not have been overlooked. In sites where we observed elimination of *H. pilosella*, tussock cover was high in 1982, but decreased over the next decade with a concomitant increase in development index. The most likely explanation is that these sites received fertiliser input; indeed *H. pilosella* normally decreases where fertiliser has been applied (Scott and Covacevich, 1987; Scott, Robertson and Burgess, 1989; Scott, 1993b; Scott and Sutherland, 1993). However, the opportunity for elimination of *H. pilosella* is limited: there was not one instance in our data of *H. pilosella* disappearing from a site where it was present as more than a trace.

#### **Invasion processes**

*Hieracium* spp., and *H. pilosella* in particular, have increased considerably in range and abundance in tussock grassland communities in New Zealand in the past three decades (e.g., Treskonova, 1991; Rose *et al.*, 1995).

We should not be surprised by invasions such as those by *Hieracium* species and by *Agrostis capillaris*. Rangelands under low rainfall world-wide have been subject to invasion by exotic species (Young and Longland, 1996). Such invasion does not need continuing disturbance (Mack, 1985). It has to be seen as a normal process in view of the continuous vegetation change that is typical of such systems even without human influence (Johnson and Mayeux, 1992).

There are five likely explanations for the increase in *Hieracium* species:

1. The abundance of *Hieracium* species has increased, but perhaps no more than that of other exotic species, which have been gradually expanding their range in New Zealand; increases in *Hieracium* species have been noticed more because of their conspicuous flowers, and the lack of agronomic value and impact on pasture quality of *H. pilosella*. The increase in frequency recorded in *Agrostis capillaris* by Rose *et al.* (1995), which was greater than that of *H. pilosella*, indicates there is some truth in this. Under this explanation, the increase in *Hieracium* species is simply a part of the general continuing invasion of exotic species into New Zealand. However, our data show that in Eastern Otago *H. pilosella* has been increasing in a period when the range and abundance of *A. capillaris* has been almost constant.
2. Accumulation of the effects of management changes in the last two decades may have resulted in the conditions for *Hieracium* species to invade. Treskonova (1991) suggested this was via 'degradation'/'depletion'/'deterioration', related to burning and grazing. Harris and Mark (1992) suggested that "general nutrient deficiency" facilitated the spread of *Hieracium*. However, it seems quite unlikely that the threshold 'degraded' state, e.g. in terms of nutrient depletion, would be reached at about the same time on a wide range of sites.
3. Changes in land management caused by political decisions, such as the removal of agricultural subsidies in the mid 1980s, could have facilitated an increase in *Hieracium* species. During periods of high fertiliser application with oversowing, the growth of the sown exotic species would cause competitive suppression of the native cover (Fan and Harris, 1996). In subsequent periods with lower fertiliser application, those species would die back, leaving bare soil gaps which *Hieracium* species could invade. However, *Hieracium* species seem to have increased on sites with very little agricultural management (Rose *et al.*, 1995). An increase in access roads in the 1970's could have facilitated invasion.
4. The species may have changed genetically (*cf.* Rejmanek, Thomsen and Peters, 1991; Williamson, 1996) with the emergence of genotypes more suited to New Zealand conditions. The genetic material may have been present from the beginning, it may have appeared in more recent introductions, or it may

have resulted from chromosomal or allelic mutations, in any case emerging by selection. This possibility does not seem to have been considered.

5. A metapopulation threshold may have been crossed, above which metapopulation growth is more rapid. Carter and Prince (1981) demonstrated a model with such a threshold. This could explain the increase in *Hieracium* species on sites on which management had not changed – a larger metapopulation would result in a larger propagule rain on those areas. However, it would be a coincidence for this threshold to have been reached in three species of *Hieracium* at the same time. Indeed, the lumping of several species of *Hieracium* as if they had the same ecology (e.g., Scott 1993a, b) has confused the literature.

Probably, the real cause is a combination of and interaction between general exotic invasion (explanation '1'), changes in land management ('3') and metapopulation dynamics ('5'), possibly with genetic change ('4').

## Acknowledgements

We thank Dr W.L. Lowther for providing the list of plants used to construct the development and tussock indices and Dr D. Scott, Dr W.G. Lee, and research students, for comments on a draft.

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