FACTORS ASSOCIATED WITH TRENDS IN BARE GROUND IN HIGH COUNTRY

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Abstract

Soil erosion in the Canterbury high country has been a concern for many years, and Environment Canterbury wishes to encourage land management practices that will preserve soil quality and vegetative cover. Environment Canterbury brought to MISG2005 a data set spanning three decades of bare ground monitoring in the Canterbury high country, along with data on factors with potential to impact on the processes of revegetation. These include topographic and climate data, soil nutrient status and land management factors. The study group analysed these data with the aim of determining whether trends in bare ground can be predicted from the potential causative factors. Analysis was difficult due to the high level of confounding between many of the variables, such as soil quality with land management. However a predictive model of change in percent bare ground was derived (explaining 63% of the variation in the data) in which the most important factors were fertiliser application, percent bare ground at the start of the monitoring period, annual average temperature and winter rainfall. Removal of low intensity grazing (to no grazing) had no discernable effect on percent bare ground.

1. Introduction

Soil erosion in the Canterbury high country has been a concern for some decades. Maori and early European burning and grazing not only induced large tracts of tussock grassland in areas that were previously wooded [9], but also exposed areas of soil to further erosion by wind, rain and frost. Partially vegetated land with exposed and eroded soil is common above 900 m elevation, and has been the subject of much debate as to its causes. Regrowth of vegetation is slow in the harsh

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climatic conditions of the high country (above about 600 m elevation) where soils are generally shallow or impoverished.

In the 1960s to 1980s the government encouraged destocking on some properties, with the aim of restoring vegetative cover. This was implemented by catchment authorities through the Soil and Water Conservation Plan. In the late 1970s a monitoring programme was set up in the Canterbury high country to track the effects of lowered grazing levels. Further destocking in the poorer, steeper country is now occurring as a result of the Tenure Review process for Crown leasehold land. Rabbit numbers reached plague proportions in the late 1980s, resulting in the government-funded Rabbit and Land Management Programme (RLMP). The appearance of rabbit haemorrhagic disease (RHD) in 1997 caused rabbit numbers to plummet on the lower, flatter land of the Mackenzie Basin and Upper Waitaki catchment. The bare ground monitoring programme was extended to cover these areas in 1991.

Environment Canterbury (ECan) has responsibility for promoting sustainable management of the region's natural resources. An important aim is to prevent further loss of topsoil, and thus fertility, in the Canterbury high country [8]. The high country monitoring programme was initially carried out by South Canterbury Catchment Board but has been continued and expanded by ECan since its formation in 1989.

The aim of this programme is to monitor trends in percent bare ground, and, ideally, relate these to potential causative factors including changes in grazing pressure (farmed stock and rabbits), fertilisation and oversowing. In addition, knowledge of the climatic, soils and topographic conditions associated with either positive or negative change in vegetative cover would enable appropriate management recommendations for specific land areas. Data from this monitoring programme was brought by Environment Canterbury to the 2005 Mathematics-in-Industry Study Group, and the question was posed as to whether bare ground trends can be predicted from the potential causative factors.

2. Background studies and dataset

2.1. Previous studies

Gibbs et al. [6] mapped soil erosion throughout the eastern high country in the Southern Alps. At the time, the erosion was thought to be caused by ongoing pastoral mismanagement. Since that time there have been a large number of studies on the extent and causes of bare ground in the high country as well as on changes in vegetation species composition. O'Connor [10] suggests that the high country was heavily (and unsustainably) stocked in the early years of European pastoral farming with frequent burning so that shrub and tall tussock cover was much reduced. Stock numbers reached their maximum in about 1870 to 1880, but by 1952 had declined to a level only 10% of that in 1880.

Whitehouse [11] showed using repeat aerial photography in the Porters Pass area of Canterbury that, between about 1900 and 1980, the proportion of bare ground did not change significantly, suggesting that the pastoral management of the 1900s was not having as great an effect as initially thought. In a further study, Whitehouse et al. [12] showed no overall trend in bare ground in the prior 10-35 years over a range of Canterbury tussock grassland sites, though significant increases and decreases occurred year-to-year (depending on temperature and rainfall) and at certain localities. Barringer [1] notes that, in the Remarkables Range (Central Otago), the highest proportion of bare ground occurs between 1100 and 1500 m altitude and appears to be related to the zone of maximum freeze/thaw (at the snowline). Aerial photographs show that these areas of bare ground have persisted for at least 35 years, with no trend visible in that timeframe. The snow tussock species present is very slow growing and long-lived, so any revegetation of bare areas would be slow.

Hunter et al. [7] note that, although the original reduction in vegetative cover probably occurred many decades ago, the consequences may be ongoing and could be aggravated by current management. Though typical present-day stocking rates (< 1 stock unit per hectare) are probably not causing increasing bare ground, dry areas are at greatest risk of adverse impacts from grazing and burning, due to the slow revegetation rates in such areas.

Thus, as noted by Duncan et al. [5], there remains uncertainty about the extent to which recent changes in tussock grassland vegetation have been driven by pastoral impacts over the past 30 years. If other processes are more important in driving vegetation change then it may not be possible to manage the tussock grasslands by adjusting current pastoral use.

2.2. ECan bare ground dataset

As described in Cuff [4], monitoring transects have been set up at 80 sites in the high country (established between 1979 and 1988), and at 66 sites in the Mackenzie/Waitaki RLMP area (established between 1991 and 1992). Site locations are shown in Figure 1. The high country sites have been revisited at approximately 5-yearly intervals, while the RLMP sites have been revisited at approximately 2-yearly intervals. The sites were selected to include a range of land types and land uses for comparison.

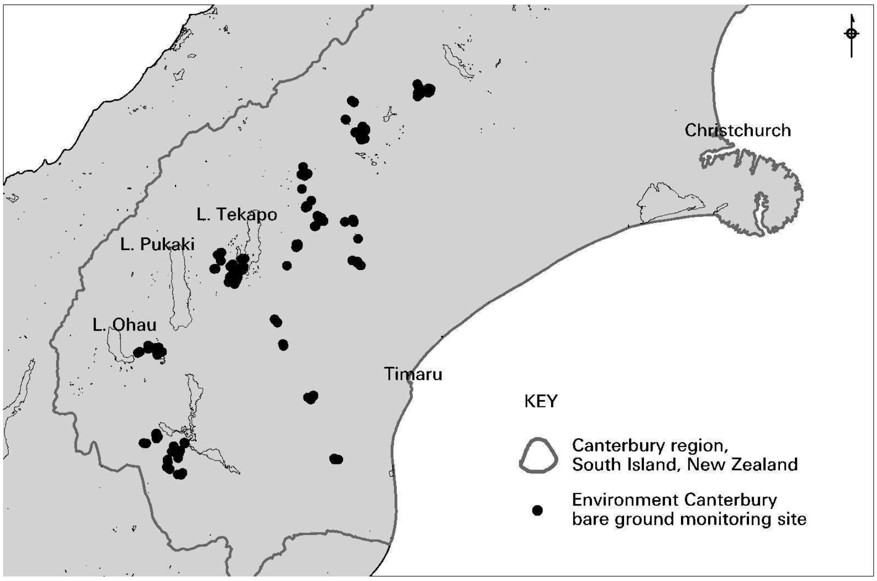

Figure 1. Locations of Environment Canterbury vegetation cover monitoring sites.

At each site, a stereo photograph monitoring transect has been laid out. This is a permanently marked line with 10 photo points at 3 m intervals along it. At each photo point, a stereo pair of vertical photographs is taken, with the camera positions 10 cm apart for the stereo pair. The camera is mounted on a tripod 1.3 m above the ground for these photographs. A 35 mm SLR camera with a 35 mm focal length is used, so the ground coverage of each photograph is approximately 0.85 × 1.25 m. The photo points are marked with an alloy pin so that they can be accurately repeated at each revisit of the transect [4].

Back in the office, the stereo pair is viewed with a grid of 4 × 5 rectangles marked across it. This gives a scale on which the analyst can estimate percent cover of bare soil, dead vegetation, *Hieracium pilosella* (a weed species also of interest to the Environment Canterbury monitoring programme, but not explicitly studied at MISG2005), and other live vegetation. For most analysis to date, the percentages have been averaged across the 10 photo points, to give estimates of the four cover types for the transect as a whole.

ECan brought these data to MISG2005 in the form of a database containing records for each site, where the percent cover of each of the four ground covers was recorded for each visit date. Other files contained climate, soils, topographic and land management data associated with each site. Specific data available included classification of soil by soil series name (soil series are categories of soil classification), soil nutrient status (percent organic carbon content, percent available nitrogen, carbon:nitrogen ratio, pH, available phosphorus), site elevation, slope and aspect, rainfall (annual and growing season), an indication of stock grazing intensity (low, medium or high), fertiliser/seed application (yes or no), and survey data of rabbit numbers for the Mackenzie/Waitaki area as a whole.

2.3. Statistical modelling

An excellent reference for many aspects of statistical modelling is Box et al. [2]. Generally one tries to find a model to explain the behaviour of a response variable, Y, in terms of various explanatory or predictor variables $x_1, \ldots, x_p$, where some of these explanatory variables may be functions of other explanatory variables; e.g., $x_3 = x_1^2$ or $x_5 = x_1 x_2$. It is assumed that, no matter how complicated the function $y = f(x_1, \ldots, x_p)$, it can be approximated in a small $(x_1, \ldots, x_p)$-neighbourhood by the linear (in the parameters) relationship

$$Y = \beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p + E,$$

where $\beta_0, \ldots, \beta_p$ are unknown parameters and E represents random variation, or 'error'. Traditionally, this model has been called a regression model if all the x_i are continuous, and an Analysis of Variance (ANOVA) model if all the x_i are categorical (i.e., variables that take discrete values that are essentially labels rather than numbers; e.g., 0 = 'No', 1 = 'Yes'). Recent advances in statistical computer packages have blurred this distinction, and models with both continuous and categorical explanatory variables are often known as general linear models (GLMs).

For a given data set, the values of the β_i in a GLM are estimated. The proportion of the variation in the values of Y that is 'explained' by the model is given by the quantity known as r^2. As r^2 is usually increased by the inclusion in the model of one or more additional explanatory variables, no matter how uninformative, statisticians often consider instead adjusted r^2, $\mathrm{r}^2(\mathrm{adj})$, which takes into consideration the loss of parsimony through inclusion of the additional variables. Of two competing models, the one with greater $\mathrm{r}^2(\mathrm{adj})$ is preferred.

The worth of including an explanatory variable, x_i, in the model is assessed by testing whether the true value of its coefficient, β_i, is equal to zero. If β_i is not significantly different from zero, we omit x_i. Most statistical packages indicate the degree of significance of β_i by means of a 'P-value', the probability that — by chance alone — the estimated value of β_i would be at least as different from zero as we observed if β_i is truly zero. If the P-value is less than the significance level (usually chosen to be 0.05), we decide that β_i differs significantly from zero.

2.4. ECan existing analyses

As reported in Cuff [4], ECan had already carried out initial analysis of the data. The aim of this study was to determine what factors influence bare ground and *Hieracium* cover and, of these, which could be managed to improve vegetative cover on bare and eroded areas. We discuss only the bare ground work here. The response variable used was the rate of change of bare ground over time. Average rates of change were obtained by linear regression of percent bare ground versus date of photography. Cuff [4] acknowledges that this approach ignores fluctuations in percent bare ground due to seasonal variations in rainfall, management, pests, etc. However, the method does indicate, for each site, the general trend of increasing or decreasing bare ground (a positive or negative slope coefficient, respectively), or little change (a slope coefficient not significantly different from zero).

The ECan study tested the slope coefficients, as indicators of trends in percent bare soil, for their relationship to potentially influential factors, including soil, topographic, climatic and management variables. This was done by regression for continuous variables and by ANOVA for categorical variables. Interpretation of relationships and trends was problematic until the dataset was split into two parts: a subset of sites where slope is over 5° (mostly the high country sites) and the other of flatter land (mostly the Mackenzie Basin sites).

For the subset of steeper sites, increasing bare ground was negatively correlated with increasing pH, available phosphorus, growing season temperature, and addition of fertiliser, while increasing bare ground was positively correlated with increasing carbon:nitrogen ratio, altitude and rainfall. It was also noted that sites in a "good" condition (little bare ground) at the start of monitoring showed little change over time, while sites in a "poor" starting condition generally showed improvement. There was no significant difference in bare ground trend between sites that were destocked or lightly grazed. There were fewer significant relationships for the flatter sites in the Mackenzie Basin. Only fertiliser application and available phosphorus were significantly correlated with decreasing bare ground.

The most significant of these factors were combined in a GLM with an r^2 of 0.8. This was applicable just to those sites where soil analysis information is available: approximately half the sites. Cuff (2002) acknowledges that interactions are likely between several of the variables but the initial work did not include analysis of these interactions. Conclusions were that harsher climatic conditions and poorer soils tended to be associated with increasing bare ground, while land use (extensive grazing) did not appear to be significant. Fertiliser application was the main factor associated with decreasing bare ground.

3. Data analysis

The participants at MISG were asked to analyse the monitoring data, with the aims of exploring alternative methods, carefully checking statistical assumptions and ideally taking the analysis further than the original ECan work.

3.1. Selection of response variable

The phenomena we are interested in are those processes that allow revegetation of existing bare areas and those causing the formation or enlargement of bare soil areas. Thus the response variable is not the absolute amount of bare soil at any given time, but its change over time (in units of percent bare ground per year). We do not know the exact processes of bare soil formation that may have occurred before the monitoring programme started, so cannot easily determine the factors contributing to the absolute amount of bare soil. However we do know many of the factors operating during the monitoring programme, and wish to determine which of these factors influence either positive or negative change in percent bare ground.

The MISG group began by checking whether a linear regression of percent bare ground against photography date provided a reasonable representation of trend in bare ground. Sites with less than three points (observation dates) were excluded and other datasets were assessed visually and by their r^2 values. The rate of change of bare ground over time (from a linear regression) was confirmed as an appropriate response variable.

3.2. Data exploration

The group's initial data exploration included regression tree analysis; see Breiman [3]. This first selects the independent variable that explains most variation in the response variable, and then clusters the values of this independent variable. The analysis produced clusters of soil series, where two clusters were associated with reduction in bare ground, one with increase, one with stable amounts of excessive bare ground, and one with stable amounts of minimal bare ground. The clusters of soil series are shown in Figure 2.

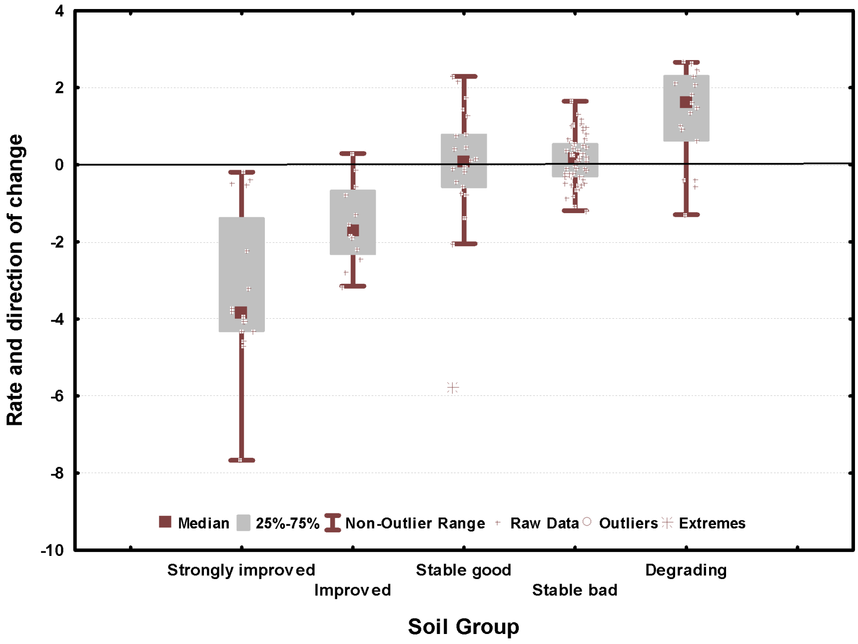

Figure 2. Result of regression tree analysis, which found that soil series explained most variation in percent bare ground change, and clustered the soil series into groups. Positive rate-of-change values indicate increasing bare ground (bad), and negative values indicate revegetation (good).

Thus the MISG group identified early that soil type is important (soil cluster alone explained 55% of the variation in bare ground change). An initial predictive model containing soil series names, level of available phosphorus (an important soil nutrient), and the percent bare ground at the start of the monitoring period explained 77% of the variation in bare ground change.

Interpretation remained difficult, however, as soil series is strongly confounded with topographic position and land use (e.g., it tends to be the better soils at lower altitude that receive fertiliser and oversowing). So it was unclear whether bare ground change was being affected by the inherent chemistry and physical properties of the soil, by the climate and topography in which that soil tends to occur, or by the land use management practices common on that soil type. In addition, the group recognised that:

- Not all soil series are represented in the dataset, so a model based on these names would not be sufficiently general to be applied throughout the Canterbury high country.
- The model needed to answer questions about what land management practices are appropriate in what areas, and thus the effects of land management needed to be untangled from the effects of landform, soils and climate.

3.3. Experimentation

Therefore efforts were focused in two areas. One was to characterise the soil series in terms of their chemistry, topographic position and climatic zone. The other was to isolate the effects of individual management practices, specifically those of fertiliser application and oversowing, stocking intensity and rabbit control.

The cluster of soils with the greatest decrease in bare ground included areas that had extremely high rabbit numbers in the past (these numbers are now much reduced) while the cluster of soils with the smaller decrease in bare ground occurred in areas than had fewer rabbits to start with. The improving and “stable good” soils also have pH and Carbon:Nitrogen ratios that are favourable for vegetation growth. The cluster with the increase in bare ground was a set of very poor, shallow soils occurring in areas that also had very high rabbit populations in the past. Of the stable clusters, one was a set of good soils (having little bare ground to start with) and and the other a set of poorer soils at high altitude (having extensive bare ground to start with).

The four soil clusters where bare ground was decreasing or remaining stable were well characterised by soil nutrient status and general plant growing conditions. But the fifth cluster, where bare ground was increasing, was not well characterised in the available data. These Mackenzie Basin soils are at relatively low altitude and flat. Though these soils are known to be poor, the data available did not explain this. Across all the clusters, soil chemistry data were available for 74 of the 143 sites.

Each management factor was studied separately. For each, records were selected from the database where both levels of the factor were present in the same environment, e.g., sites with and without fertiliser application in a similar geographic area and on the same soil type. Five data blocks (regions/soil types) were available for fertiliser analysis and two for grazing analysis.

A two-way ANOVA was performed, with change in percent bare ground as the response variable, and with fertiliser (applied, not applied) and altitude (low, high) as the two factors. The ANOVA showed that fertilising/oversowing was effective in increasing vegetative cover on all soil types, though the magnitude of that change was greater at low altitude than at high (Figure 3). As shown in Figure 4, no difference in revegetation rate could be detected between low intensity grazing (< 1 stock unit/ha) and no grazing. No comparison was available between “high” intensity grazing (1-4 stock units/ha) and no grazing, as insufficient data were available.

The effects of rabbit management had to be investigated in a different way, as this treatment is applied over broad areas, meaning no side-by-side comparison of treatment versus no treatment is available. In a simple comparison of mean change in bare ground, revegetation proceeded more quickly when rabbits were controlled on sites that were also fertilised (Figure 5). However, of the non-fertilised sites, degradation of vegetation cover appeared to be faster on sites where rabbits were controlled. The areas that had no fertiliser input but were within the RLMP control programme are probably the poor Mackenzie Basin soils (where bare ground is increasing), and those with neither fertiliser nor rabbit control are likely to be the high altitude sites (where bare ground is fairly stable). No definite conclusion could be reached on the effects of rabbit control though it did appear to help on some sites.

3.4. Modelling

A final model was developed (Table 1) that depended on fertiliser application, percent bare ground at the start of the monitoring period, annual average temperature (strongly correlated with altitude) and winter rain (probably supplying moisture for the spring growth flush). Several interactions of variables were also significant. The model prediction is shown in Figure 6.

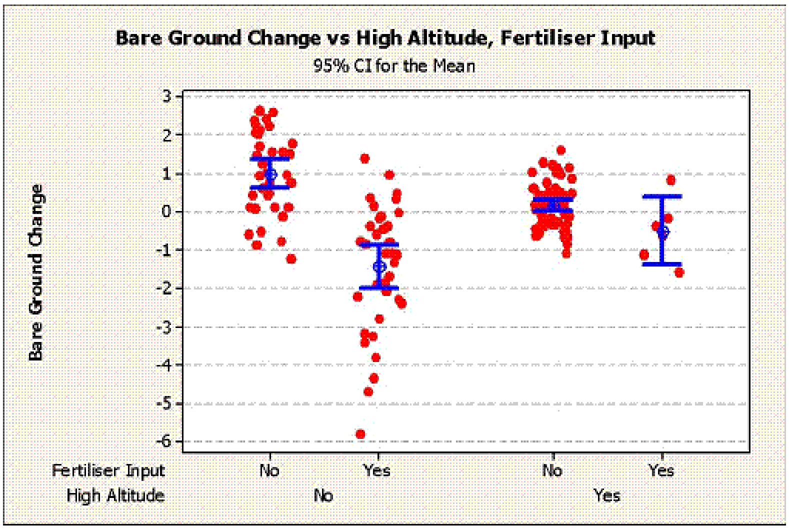

Figure 3. Effect of fertiliser/oversowing on change in bare ground (percent bare ground per year) for both high and low altitude sites.

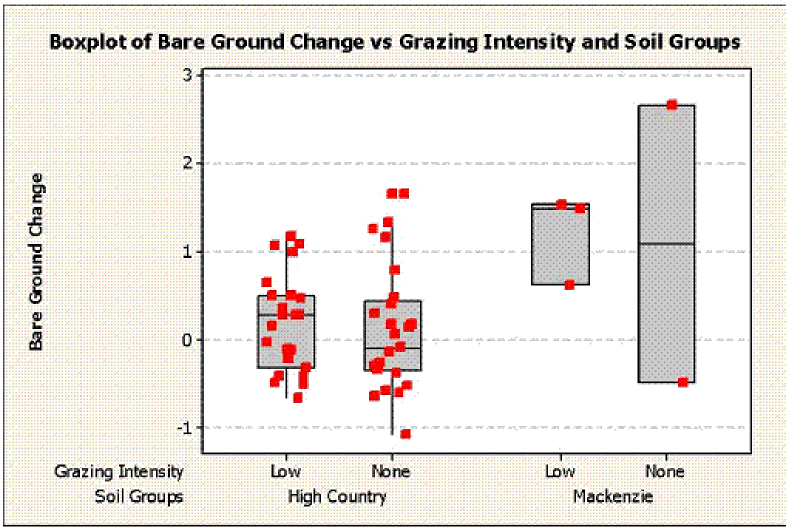

Figure 4. Effect of grazing intensity on change in bare ground (percent bare ground per year), for both high country and Mackenzie sites.

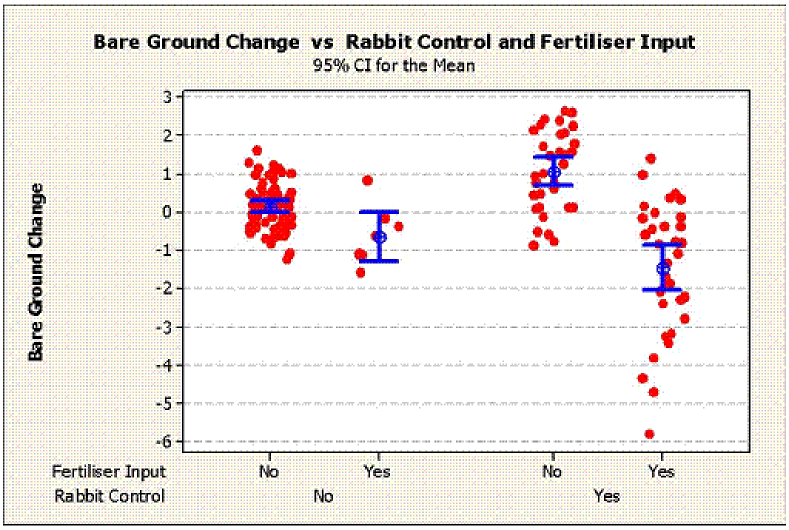

Figure 5. Effect of rabbit control on change in bare ground (percent bare ground per year) for fertilised and non-fertilised sites.

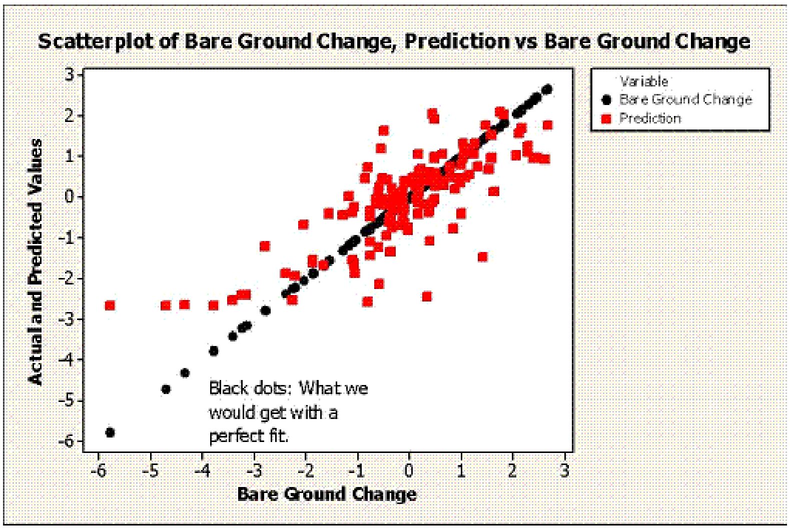

Figure 6. Actual and predicted values of change in bare ground.

The model of Table 1 explained 63% of the variation in bare ground change, compared with the earlier model that contained the soil series

Table 1. Model factors and their significance for predicting change in percent bare ground (negative change is good/revegetation, and positive change is increasing bare ground). S = 2.06111, r^2= 62.7%, r^2(adj) = 60.5%

Predictor	Coefficient	P-value
Constant	8.825	0.000
Fertiliser input/oversowing	-2.4738	0.000
Average temperature	-0.6935	0.000
Percent bare ground at start	-0.024722	0.000
Winter rainfall	-0.006202	0.002
Interactions		
Rabbit control on flat ground	1.2286	0.000
High altitude	-0.6310	0.232
Fertiliser/oversowing at high altitude	1.6048	0.003
Perecent bare ground at start at high altitude	0.019952	0.029

names, available phosphorus and starting level of bare ground, that explained 77% of the variation. However, the final model was generic (not dependent on soil names). In addition, the group is aware that soil chemistry and physical properties are important, but this information was not available for all sites so it was not included in the model.

4. Conclusions and future work

The aim of this project was to determine whether bare ground trends can be predicted from the suggested explanatory variables.

- A general model was developed for change in percent bare ground, where the significant factors include fertiliser application, starting percent bare ground, annual average temperature and winter rainfall.
- Soil chemistry and physical properties also appear to be important. Further data gathering and analysis are needed to include these properties in the model.
- Fertiliser application and oversowing has a strong positive effect on revegetation on all soils tested, with the effect strongest at low altitude.
- Little effect on revegetation was observed from destocking (from low intensity grazing to none).

- The effects of rabbit control were difficult to interpret, though there seemed to be some extra positive effect on the better soils that were also fertilised.

There is a very high degree of confounding between variables in this dataset, which has made analysis difficult. Climate variables are confounded with topographic position, and land management strongly confounded with soil quality. The suggested next step would be to assess relationships between year-to-year fluctuations in bare ground and the fluctuations of climate variables, to determine whether climate is a major driver in bare ground change.

Acknowledgments

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