Ministry for Primary Industries
Manatū Ahu Matua

Improved measurements of hill country soil carbon – to assist carbon change studies

Final Report

MPI Technical Paper No: 2018/35

Prepared for Gerald Rys, Principal Science Advisor, Science Policy Group

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ISBN No: 978-1-77665-899-2 (online)
ISSN No:

February 2015

New Zealand Government

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Executive Summary

A purpose-built sampling and monitoring protocol is required to estimate soil organic carbon stocks (SOCS) and stock changes in hill country. It must provide information with accuracy and precision at spatial and temporal scales that matches the aim of the project.

Methods used in the past have not adequately accounted for spatial variability, which is known to be a major (often the major) uncertainty relating to SOCS estimations, especially in the complex hill country terrains that characterise a large part (37%) of New Zealand's landscape.

Key findings from our literature review are that SOCS follow a distinctive topographically related gradient in hill country terrain. Higher SOCS typically occur in more stable areas, such as ridge lines, summits, and valley floors. They tend to increase downslope (simple hillslopes) and this trend is disrupted on complex hillslopes, dominated by erosion processes. In addition, grazing animals recycle nutrients non-uniformly across hill sides, for example onto camp sites and tracks, influencing C cycling.

A comprehensive analysis was undertaken to test the representativeness of 23 National Soil Database (NSD) sites resampled by Schipper et al. (2010, 2013, 2014), which on average showed a significant increase in soil organic C. Findings are that further stratified sampling is required to more thoroughly represent the whole of pastoral New Zealand hill country for the assessment of soil carbon stock changes.

New data have been collected from around three of the 23 NSD sites of Schipper et al., (2010, 2013, 2014) using a stratified sampling protocol, and these data support the literature that argues that SOCS are highly variable within a hill country catchment. The difference between the minimum and maximum SOCS estimates within two 2-km^2 areas was more than three-fold. The coefficient of variation (CV) of SOCS estimates on hillslopes (lower, mid and upper slopes) was 28% and 23% at Okoia and Te Whanga, respectively. The uncertainty (reproducibility) associated with resampling within 10 m of one position to obtain the same estimate of SOCS was estimated to be 22.02% using data (n=3) collected around three NSD sites.

The formation and stabilisation of soil carbon in hill country soils is affected by hill slope position, and more research is required to understand how it varies in different parts of the landscape. It is likely that any endeavour to sequester carbon should be targeted at specific parts of the landscape, using precision agriculture management practices.

Project and Client

- A literature review was conducted to determine how geomorphology and management in hill country pastoral systems influences stocks and rates of change in soil C.
- A comprehensive analysis was conducted to assess the representativeness of existing resampled positions of (i) the immediate surrounding 'hill country' landscape, and (ii) nationally.
- Investigative fieldwork was undertaken in challenging, complex hill country terrain to measure SOCS at different positions around existing resampled NSD sites.
- A final report is provided to MPI summarising our findings and proposing a refined method to assess changes in SOCS through time.

- The Ministry for Primary Industries funded the study under the Sustainable Land Management and Climate Change programme.

Objectives

- Assess the uncertainty of using measurements from one position in a hill country landscape for extrapolation to wider areas.
- Use digital soil mapping (DSM) methods and propose refined methodologies for future research projects.

Methods

- Literature review: search the literature to find all relevant information on topography-driven spatial variability of soil organic carbon stocks and stock changes in hill country soils.
- Spatial and statistical analysis: to examine the representativeness of the 23 resampled sites (Schipper et al. 2010, 2013, 2014) at local and at national scale.
- NSD search and field campaign: to examine the National Soils Database to find hill country localities that might be used in future studies, and collect new samples from two of these sites to account more fully for spatial variability.
- Provide a report to MPI summarising findings of this work, with recommendations for future work.

Results

- SOCS follow a distinctive topographically related gradient in hill country terrain.
- Management practices, such as grazing intensity, influences the spatial distribution of nutrients and soil C cycling within hill country terrains.
- The 23 resampled NSD sites do not fully represent the whole of pastoral New Zealand hill country, and further stratified sampling is required to address this limitation.
- A stratified sampling method, which proportionally samples soils from all facets of the landscape, was applied at 2 locations (near Wanganui and Masterton) and the difference between minimum and maximum SOCS within two 2-km^2 areas was more than three-fold.
- North-facing slopes had higher SOCS than south-facing slopes, at the Wanganui and Masterton sites.
- The mean reproducibility of SOCS estimates (n=3) within 10 m was 22.02% at the Wanganui and Masterton sites.

Recommendations and future research

- Design a stratified soil carbon sampling and monitoring protocol by statistically interrogating environmental data layers to assess SOCS and SOCS changes in New Zealand hill country more accurately and precisely.
- Where it is impractical to sample soils, as a result of time and cost constraints, then process models, using sufficient validation data, can be usefully employed to investigate SOCS and SOCS changes through time; and to investigate management effects such as grazing intensity and land-use change.

- Research is required to identify potential positions in the landscape where soil C sequestration is most likely to be achievable.
- SOCS change trend assessments can be used to inform land management, to maintain or enhance soil C stores, provision ecosystems, maintain food supply, increase resilience to degradation, and mitigate climate change impacts.

1 Introduction

The global maintenance or, preferably, the sequestration of soil organic carbon is imperative to address threatening issues of food security and climate change (Lal 2014). Carbon (C) sequestration offsets anthropogenic emissions, with multiple co-benefits, such as yield increases, water quality improvements, and enhanced biodiversity. Lal (2014) therefore recommends that US farmers be compensated (US$40/ha/y for sequestration rates of 300 kg C/ha/year) for adoption of best management practices to sequester C. Globally, governments and industry are pursuing effective and realistic climate change mitigation options, and soil carbon sequestration is one example of these options (Powlson et al. 2011).

In parallel with global initiatives, the New Zealand Ministry for Primary Industries (MPI) has stated, “understanding how soil carbon is changing may be critical for both national accounting and long-term land-use management decisions if soil carbon is included under any future commitments.”

They also state, “A number of previous SLMACC reports and currently funded projects address changes in soil carbon stocks under different land classes and land uses. Work is currently being done in the pastoral sector through the NZAGRC on ways to enhance soil carbon. Pastoral hill country is an area where current work has indicated that carbon stocks are increasing. The reason why is not well known. However, to investigate causes will likely rely on also finding cost-effective sampling protocols for hill country. This research would be used by policy advisors in developing policy options for soil carbon management”.

In response, we investigated how soil carbon changes, both in time and space, in hill country terrains, and proposed a refined method to assess soil carbon stocks and stock changes by using stratified sampling based on statistical analysis of spatial datasets (data layers).

The project had three main work components. First, a literature review investigated processes affecting soil organic carbon stocks and stock changes in pastoral hill country.

Second, a spatial and statistical exercise investigated the representativeness of hill country sites used in previous studies (Schipper et al. 2010, 2013, 2014) by assessing the landscape and paddock-scale representativeness of these sites, and interpreting digital elevation data layers for these locations using automated landform classification methods.

Thirdly, a data-gathering exercise tabulated National Soil Database (NSD) hill country pastoral sites, and we undertook new field work to investigate the spatial variability of soil organic carbon stocks (SOCS) around existing NSD sampling sites at two locations by sampling different topographic positions in the hill country terrain.

The project builds on work completed in other SLMACC projects, which include:

1. “Soil order and land-use effects on changes in soil C and N under different grazing management practices, New Zealand” (Schipper et al. 2013)
2. “Soil carbon stocks and changes: carbon losses from erosion” (Basher et al. 2013)
3. “Refinement of the framework for up-scaling nitrous oxide emissions from hill country” (de Klein et al. 2009).

The project links to the Landcare Research “Filling the Research Gap” Global Research Alliance projects (2013–2016), which aim to develop soil proximal sensing technologies (including electromagnetic soil surveys and field visible near-infrared spectroscopy) with spatial modelling of soil carbon, at the farm-scale:

1. ”An innovative solution for accurate and affordable estimates of soil carbon” (with CSIRO, Australia)
2. “Farm scale assessment of SOC from disaggregated national/regional scale models” (with University of Sydney, Australia)

2 Background

New Zealand "hill country" is defined as the more rugged parts of our landscape, with slopes >15° and located below an altitude of 1,000 m above sea level (MfE 2007; Jones et al. 2008; Basher et al. 2008). It occupies an estimated 9.9 million hectares or 37% of New Zealand's total land area, and is classified as Land Use Capability (LUC) class 5, 6 and 7, as described in the New Zealand Land Resource Inventory (Lynn et al. 2009). Grazed pastoral hill country, using the Landcover Database v.4 (LCDB4) grassland and short rotational cropping classes, is estimated at 4.2 million hectares (42% of hill country; 38% of all grazed land in NZ).

These pastoral hill country soils are extremely variable; much more so than soils on flat to gently rolling topography, because of short-range differences in topography, age, geology, microclimate, and vegetation (Molloy 1988). SOCS might easily vary two-fold over a distance of a few metres due to a number of factors such as differences in slope, soil depth, and the existence of old tree roots. Spatial variability therefore needs to be accounted for in any assessment of soil carbon stocks and associated processes of soil formation in this complex hill country terrain, supporting nearly half of New Zealand's livestock population (Statistics NZ 2012).

Recent work suggests soil organic carbon may be increasing at stable mid- to upper-slope positions in pastoral hill country, although the processes involved are not understood (Schipper et al. 2010, 2013, 2014); and this contrasts with findings in lowland pastoral terrains (Schipper et al. 2010, 2013, 2014). The method used to obtain this result was to resample in close proximity to one fixed position (in a relatively stable mid- to upper-slope position) over time to assess any change in soil organic carbon. It is therefore desirable to assess the uncertainty of this method because it is well documented that a major component of uncertainty in any estimation of soil organic carbon stocks is spatial variability (Stolbovoy et al. 2007; Goidts et al. 2009; Frogbrook et al. 2009).

The study by Schipper et al. (2010, 2013, 2014) resampled 23 NSD sites in hill country after a period of about twenty years. These sites are referred to as "**the 23 NSD sites**" in this report.

The European Union soil-sampling protocol, created to certify changes of SOC stocks in mineral soil over time, acknowledges the existence of short-range spatial variability of SOC by assessing the reproducibility of trying to resample the exact same position at two times (e.g. using a GPS device with 10-m accuracy) (Stolbovoy et al. 2007). This is achieved by taking samples along parallel transects 10 m apart to estimate the range of SOC stocks within this short distance. This method was adopted in a NZ Soil Carbon Monitoring System Cell Validation study, and results were that soil samples collected from within a 20 × 20 m plot had a reproducibility of 24–61% and coefficient of variation of 11–47% for low-producing grassland soils on hillslopes > 10° (Hedley et al. 2012). Goidts et al. (2009) also report that large errors occur when attempting to re-sample in the same position and these relate to short-range changes in soil bulk density, % stones, and horizon depth changes.

The effect of short-range variability on soil organic carbon stocks is likely to be enhanced in hilly terrains compared with flat land, due to hillslope processes such as mobilisation, translocation, and redeposition of soil materials (Conacher & Dalrymple 1977; Park et al. 2001), which are accelerated during erosion events. Park et al. (2001) found that topsoil (where organic matter accumulates) thickness is controlled by hillslope processes, with thickness in a shoulder position varying between 11 and 47 cm, whereas in the toeslope position, it varied between 25 and 95 cm. Similarly, topsoil depth has been observed to increase downslope in the North Otago rolling downlands, being 5 cm on the summit increasing to 76 cm on the valley floor (Hedley et al. 2013). The hillslope position from which soils are sampled is therefore likely to have a very strong effect on the resulting SOC stock assessment (as also noted by Goidts et al. 2009).

We therefore hypothesise that the spatial variability of SOCS in hill country is large and needs to be assessed and accounted for in studies of soil stocks and stock changes.

This background summary has illustrated that spatial variability of SOCS in hill country is likely to be large due to the effect that differences in slope and aspect have on: (1) soil formation processes, including erosion and deposition processes; (2) pasture production (thus total C inputs to the system); and (3) grazing animal behaviour. Tate (1992) and Tate et al. (2000) also found land use history to be an important factor influencing soil carbon stocks, finding C turnover rates slower in southern beech forests compared to tussock grasslands

In the recent research by Schipper et al. (2010, 2013, 2014), which showed increases in SOCS in hill country, sampling sites were generally located in relatively stable mid- to upper-slope positions, and therefore the reported increases in C may not be representative of the wider landscape. The aim of this study is to address this issue, and key objectives are:

1. Conduct a literature review to determine how topographic position influences soil C stocks and change in stocks, and if possible, do targeted sampling to fill gaps in knowledge, and inform future designs of sampling strategies to best account for variability (Section 4).
2. Determine how well the 23 re-sampled NSD sites represent the range of soils, drainage classes, climatic regions, productivities, slope and aspect classes, and extent of erosion in New Zealand's approximate 4.2 Mha of productive hill country pastures, which is important for upscaling for inventory purposes, and identifying data gaps (Sections 5 and 6).
3. Recommend key areas for further research, and particularly the most cost-effective sampling strategy to determine soil C stocks and stock changes in hill country pasture systems (Section 10).

In summary, we propose to investigate the uncertainties associated with existing SOCS estimation methods, by literature review, spatial and statistical investigation of NSD sites, with new field campaigns, to inform any future national accounting requirements, and long-term land-use management decisions. In addition, we propose to recommend a refined method to predict soil organic carbon stocks and stock changes spatially, with a cost-effective sampling protocol, and to develop evidence-based hypotheses of soil organic carbon change processes in hill country.

3 Work undertaken

- Literature review to determine how geomorphology and management in hill country pastoral systems influences soil C stocks and their rates of change through time.
- Spatial and statistical analysis of digital elevation maps of a 2-km^2 grid around the 23 resampled NSD sites of Schipper et al. (2014).
- NSD search for existing hillslope sites which may be useful for future studies of SOCS in pastoral hill country.
- Collection of new data to assess spatial variability around the 23 NSD sites, where resampling has previously occurred to assess temporal changes in SOC stocks.
- Final report on findings, with recommendation for future opportunities to apply research knowledge to improve our accounting of SOCS, and understanding of processes that affect change through time.

4 Literature Review

4.1 Introduction

Recent research by Schipper et al. (2010, 2013, 2014) revealed that soil carbon (C) stocks increased significantly across 23 hill country sampling sites under grazed pastures in New Zealand. Sites were resampled on average 30 years after the initial sampling (~1978), and the mean rate of increase between samplings was 520 kg C ha^{-1} y^{-1}. Schipper et al. (2014) extrapolated these results to the whole country and stated "If these sites are considered representative of grazed hill country in New Zealand (total area of about 5.1 million ha not including tussock grassland) this represents a substantial sink of C (69 Tg C) and N (8.2 Tg N) for the top 0.3 m between soil samplings. However, as for flat land, these estimates need to be viewed with considerable caution as the representativeness of the sampled sites for grazed hill country in New Zealand is not well understood" (p.73). It is unknown whether the observed increases in soil C are ongoing, or whether soil C stocks are stabilising at a new equilibrium. Any new equilibrium may take many decades or centuries (Johnston et al. 2009) to achieve, and it is imperative to understand that one observed equilibrium is part of an on-going dynamic process controlled by natural (e.g. storm event, tectonics) and human-induced influences (e.g. land use change). Clearly, a better understanding of the representativeness of the resampled sites is required to provide more confidence in the estimates of soil C stock changes for the large area of hill country in New Zealand. In addition, improved understanding of the cause(s) for the observed increases may allow manipulation of management practices to further enhance C sequestration. While the 'representativeness' of the sites sampled by Schipper et al. (2014) can be determined relatively easily in terms of underlying geology, slope, and aspect (e.g. from a GIS analysis), we will still not know whether changes in soil C measured at these sites were representative of rates of change in soil C for other areas on hill country. Therefore, the primary aim of this review was to determine how geomorphology and management in hill country pastoral systems influences stocks and rates of change in soil C.

The review commences by first providing an overview of the underlying influence of hill slope processes on soil C stocks. Attention then focuses on three key drivers of soil C stocks across differing landscape positions in hilly terrain: (1) the long term effects of land conversion to pasture, (2) the effects of erosion, and (3) the influence of grazing management and animal behaviour. Interactions between these drivers is also addressed (Fig. 1).

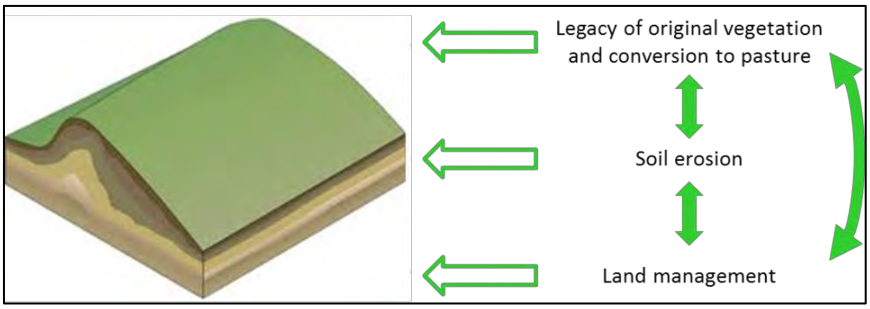


Figure 1: Conceptual diagram outlining the key drivers of soil C stocks, and stock changes, in hill country pastoral systems.
Land conversion, erosion and management have direct effects on soil C stocks (open arrows), but interactions between the drivers (solid arrows), and their position in the landscape influences the overall impact.

A further aim of the review is to evaluate different sampling strategies that could be employed to best detect changes in soil C stocks for whole hill country systems, for example incorporating both hilly terrain and the downslope terrain that is affected by processes occurring on the hills (Dymond et al. 2010).

4.2 Overview of the influence of hill slope processes on soil C stocks

Numerous studies have demonstrated the effect of topography on soil C stocks and sequestration potential, as well as the response of soil C to management interventions in hill country (e.g. Hao et al. 2002; Vitharana et al. 2008; Davy & Koen 2013). The predominant outcome is the development of greater soil C stocks on lower hill slopes and valley floors than on crests and steeper hill slopes. Various processes drive this effect, including the effect of slope angle on the redistribution of soil particles with water (and accompanying nutrient) movement (Bryan 2000; Aksoy & Kavvas 2005), the effect of slope on the erosion of material available for soil formation (Ghani et al. 2003; Schipper et al., 2011) and the effect of increasing moisture availability with decreasing slope on plant litter production and decomposition (Belnap et al. 2005).

An examination of the various geomorphological processes occurring on hill slopes that can affect the spatial distribution of soil is given by Park et al. (2001). This information was used to develop a model to predict the thickness of soil layers (which can be used as a crude qualitative proxy for soil C stocks in most cases) based on the geomorphological processes that are associated with different defined classes of landscape unit (Fig. 2), such as slumping, colluvial deposition, alluvial deposition and throughflow. Comparison of modelled and measured data have shown that these geomorphological processes interact across hill slopes to produce significant, and relatively predictable, effects on soil thickness (Park et al. 2001), indicating that they must also be considered with regards to the distribution of soil C stocks over the same landscape (see pp. 8–9).

However, general trends in the spatial distribution of soil C stocks are not consistently observed both at the landscape level, i.e. comparison of hills to valleys (see Senthilkumar et al. 2009) or at the hill slope level, i.e. comparisons of different positions on a slope (see Sigua & Coleman 2010; Schwanghart & Jarmer 2011). This variation is due to the influence of a range of site specific factors, including differences in underlying parent material on soil properties (Ghani et al. 2003; Schipper et al. 2011), greater clay content in some landscape positions enhancing soil C storage (Blanco-Canqui & Lal 2004), the influence of slope on C allocation to roots (Saggar et al. 1999), and the impact of shading on rates of photosynthesis and the soil processes (e.g. moisture availability) that drive C mineralisation (Wan & Luo 2003; Bahn et al. 2013).

Aspect (predominantly north facing versus south facing in New Zealand) is a driving factor in shading, and it has been reported that although overall photosynthate production is reduced with shading, the relative proportion of C allocated belowground is increased, maintaining C input to soil (Bahn et al. 2013; Schmitt et al. 2013). Coupled with decreased rates of C mineralisation due to lower temperatures, shading has the potential to increase C storage relative to unshaded soils. However, other site factors that influence C storage can readily overwhelm any effect of aspect. For example, Radcliffe et al. (1974) found that pasture productivity (and likely photosynthate production) was greater on north facing slopes in the North Island, but was the reverse in the South Island. Lambert et al. (1983) reported lower pasture production on south westerly facing slopes than east or northwest slopes at the

Ballantrae Research Station. However, Lambert et al. (2000) analysed soils from the same site, and found that aspect had no significant effect on soil C concentrations.

Gillingham (1974) found a significant negative relationship between land slope and pasture production in North Island hill country, with land slope accounting for 22% of the variability in pasture growth rate on both north and south aspects over the major part of the year excluding late autumn and winter. Saggar et al. (1999) measured greater respiration rates from soils pulse labelled with $^{14}C\text{-}CO_2$ on low slopes (1–12°) compared with steep slopes (>26°) on a North Island hill country farm; suggesting faster turnover of soil carbon at these lower slope angles.

Another issue of relevance is the legacy of erosion on the stability of soil carbon in different hill slope positions (Fig. 2). Erosion predominantly redistributes topsoil, which contains a higher proportion of labile C than soil from greater depth (Lorenz & Lal 2005). Therefore, post-erosion, proportionally more labile C is present in lower hill slopes and valley floors than crests and steeper hill slopes, while proportionally more recalcitrant C is present in the soil further up the slope (Wiaux et al. 2014). This is likely to impact on the trajectory of hill slope C stocks over time, as although total post-erosion stocks will be depleted, the C that is present is much less likely to be mineralised. This may result in extended gains in soil C stocks with the cessation of erosion until the pool of more labile C is rebuilt to the extent that inputs match the losses due to mineralisation.

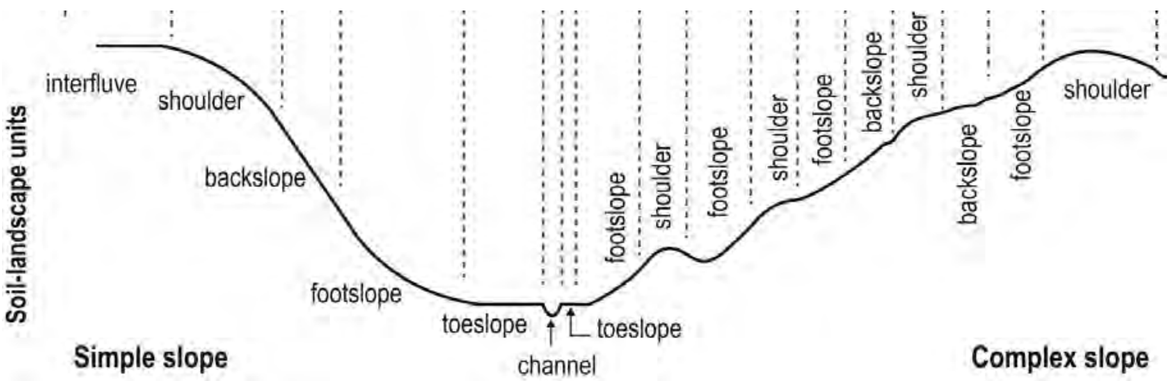


Figure 2: Schematic diagram outlining hillslope positions (modified from Park et al. 2001).

4.3 Key processes affecting soil C stocks and stock changes in pastoral hill country

4.3.1 Soil C stock changes following conversion to pastoral systems in hill country

It is necessary to determine if the conversion from native vegetation to pastoral systems is producing legacy effects on the trajectory of soil C stocks that are contributing to the observed increases in soil C stocks described by Schipper et al. (2014). Comparison of global data reviews indicates that the trajectory of soil C stocks following conversion from native vegetation to pasture is largely unpredictable due to the importance of site specific factors (Conant et al. 2001; Guo & Gifford 2002; Murty et al. 2002). A more recent review has argued for reduced soil C storage following clearance of native vegetation for pasture (Poeplau et al. 2011), but as this work does not explore the impacts of landscape position or post-conversion disturbance (most likely due to the lack of a sufficient dataset), the value of the estimates provided are negligible for the specific situation under discussion here.

On flat to gently rolling land in New Zealand, conversion from native forest or scrub to pasture has been shown to cause either no change or significant increases in soil C (Walker et al. 1959; Jackman 1964; Tate et al. 2005: Schipper & Sparling 2011; Mudge 2012). Similar results have been observed following conversion of plantation forests (mainly pines) to pasture (Hedley et al. 2009; Sparling et al. 2014), and paired site studies have also found greater soil C stocks under pasture than pine forests (Hewitt et al. 2012). Hedley et al. (2009) discussed that increased fertility, due to the capital dressing of fertiliser applied immediately after land conversion assisted pasture growth and below-ground allocation of carbon. However, the study did not assess change with time, and it is likely that new carbon introduced to the soil under productive pastoral systems, will decompose more rapidly than older carbon originating from native vegetation and plantation forest.

Few data are available describing the impact of the conversion of native vegetation to pastoral systems on the trajectory of soil C stocks in New Zealand hill country. This is predominantly because the vast majority of conversions occurred without any collection of longitudinal data to determine short and long- term effects.

Post-conversion erosion has been widespread in New Zealand hill country. Based on a long term study of soil C stocks across multiple sites in Te Whanga station, Wairarapa, it has been reported that the reduced soil C stocks in eroded areas are unlikely to recover to pre-disturbance levels with human timescales (Sparling et al. 2003; Rosser & Ross 2011). Other relevant effects influencing the variation in post-conversion soil C stocks and trajectories are the long term effects of the chemistry of soil that developed under the native vegetation (Beets et al. 2002), as well as the nature of the native vegetation and how it was cleared, which affects the extent and spatial distribution of woody debris in the soil (Oliver et al. 2004).

4.3.2 The effect of erosion on soil C stocks and stock changes

Schipper et al. (2010, 2014) speculated that the most likely cause for increases in soil C under hill country pastures was topsoil regeneration following erosion (caused by forest clearance 70–150 years before sampling). This suggestion was somewhat supported by Parfitt et al. (2013), who measured ^{137}Cs at a subset of sites in the North Island, and found that only about 20–30% of the observed increases in soil C could be attributed to soil deposition from slopes above the sampling sites, with the remainder of the C derived from plant inputs.

The sites resampled by Schipper et al. (2014) were located on relatively stable mid-slope positions, and therefore were not representative of areas where mass movement erosion (e.g. landslides, earthflows, and gully erosion) had occurred. In the soft rock hill country of the North Island, up to about 45% of the landscape may have been affected by mass movement erosion (Basher et al. 2013b). Clearly, the effect of such erosion must be accounted for if trying to determine soil C stocks and stock changes for entire hill country systems.

The influence of mass movement erosion on soil C stocks in New Zealand has been extensively researched in a previous SLMACC project (Basher et al. 2011, 2013a,b), and therefore will only be summarized here.

A number of studies have investigated how erosion influences soil C in hill country pastures in the eastern North Island of New Zealand (Lambert et al. 1984; Sparling et al. 2003; Page et al. 2004; Rosser & Ross 2011; Basher et al. 2013b; De Rose 2013). Soil C recovery on shallow landslide scars has received the most research attention, and was initially investigated due to interest in recovery of pasture production in these areas (Lambert et al. 1984). These studies have largely used the chronosequence approach (space for time substitution), by sampling slip scars of differing ages, although Sparling et al. (2003) also resampled sites though time which provided validation of the chronosequence method.

The most intensively researched site has been Te Whanga near Masterton in the Wairarapa. Recently De Rose (2013) compiled soil C data from all previous studies at Te Whanga and developed a model (see Table 1) that could be used to predict surface soil (0–10 cm) C stocks for slip scars of different ages. Using this model, De Rose (2013) predicted that C stocks in the top 10 cm of slip scars would recover to 74 % of stocks at un-eroded sites after about 70 years, which was similar to the models developed in previous studies (Lambert et al. 1984; Sparling et al. 2003; Rosser & Ross. 2011). Interestingly, pasture production on slip scars at Te Whanga also recovered to 70–80% of production on un-eroded sites (Lambert et al. 1984; Rosser & Ross 2011).

Both soil C stocks and pasture production recovered rapidly at first and then slowed considerably, following the pattern of a negative exponential increase (Table 1). Basher et al. (2011) did additional sampling of slip scars at Te Whanga, and also at Tutira (in Hawke's Bay), and found that data from both sites fitted the original model of Lambert et al. (1984) well. This suggested that one model might be able to be used across sites. Further support for this suggestion is provided by a study in Taranaki (Trustrum & De Rose 1988), which found topsoil depth (usually closely related to soil C) followed a similar pattern of increase. Pasture production on slip scars in Taranaki (De Rose et al., 1995) and near Wairoa (Douglas *et al.*, 1986) also showed a similar pattern of increase with time to what was observed at Te Whanga.

The recent sampling of Basher et al. (2011) at Te Whanga and Tutira was to 30 cm depth, in 10-cm increments. From this a 'correction' factor (0.51) was developed whereby soil C stocks to 30 cm could be predicted from 10-cm samples. Applying this correction factor to predictions from the model of De Rose (2013) revealed that predicted rates of C recovery were 3.68 Mg/C/ha/y during the first 10 years after a landslide, slowing to 0.075 Mg/C/ha/y between 60 and 70 years, and averaging 1.09 Mg/C/ha/y between 0 and 70 years (Table 1). Similar, but slower rates of C recovery were predicted using the equation of Lambert et al. (1984) (Table 1). The average rate of C accumulation from the model of De Rose (2013) was about twice the average rate of 0.52 Mg/C/ha/y reported by Schipper et al. (2014) for more stable hill slopes around New Zealand (23 sites). The average rate of change reported in

Schipper et al. (2014) might have been expected to be similar to the slower rate predicted for old scars (e.g. 60–70 year rate), because any major erosion events (and thus rapid C recovery) would have likely occurred soon after the original forest was removed, ~40–150 years before the initial sampling. Further, because the sites sampled by Schipper et al. (2014) were relatively unaffected by mass movement erosion, it would have been expected that rates of recovery would be slower, because initial C contents would not have been as low as on slip scars. This suggestion is supported by the slower rates of C accumulation on debris tails, where initial C content was higher than on scars (Basher et al. 2011; Table 1). However, the comparison between rates of C change reported by Schipper et al. (2014), with those on landslide scars (and debris tails), must be viewed with caution because there was only landslide data for two sites. In addition, the comparison assumes that the increases in soil C reported by Schipper et al. (2014) were due to recovery following erosion, but other factors may have been important (e.g. ongoing C accumulation following conversion of forest to pasture; and hierarchical C saturation of small to larger aggregate-size pools (Kool et al. 2007).

While C recovery on slip scars is relatively well understood (at two sites), slip scars typically make up only a relatively small proportion of the overall landscape even in slip prone areas. Eroded material deposited in debris tails generally covers an area ~3–5 times the size of the actual slip scar (Hancox & Wright 2005; Basher et al. 2011). Despite the larger aerial extent of debris tails compared with slip scars, little research has been conducted on debris tails. This is largely because vegetation recovers more quickly than on slip scars, making debris tails more difficult to identify from aerial photographs (Basher et al. 2011). At Te Whanga and Tutira, Basher et al. (2011) found that C stocks (0–30 cm depth) on debris tails were higher than on slip scars, but lower than on un-eroded ground. Soil C stocks on debris tails increased with time in similar manner to what occurred on scars, although the initial starting point was higher, and rate of change slower for comparable time periods (Table 1). Basher et al. (2011) emphasised that although measured C stocks in debris tails were lower than un-eroded plots, there was considerable C in topsoils buried below 30 cm in the debris tails. Therefore greater sampling depths would be required to accurately determine the net effect of landslides on soil C stocks (although it could be argued that the C in buried topsoils would gradually be lost via mineralisation, and would not be replaced by fresh C derived from plants).

A few studies in New Zealand have tried to quantify the overall net effect of landslide erosion on soil C stocks. Basher et al. (2011) concluded that landslides caused a significant net decline in soil C stocks compared to uneroded areas, with the decrease being ~13% at Te Whanga and 21% at Tutira. De Rose (2013) combined data on landside occurrence (e.g. timing and area) with C recovery rates on slip scars, and calculated that topsoil (0–10 cm) C stocks for the whole Te Whanga study area (e.g. a range of slopes, including un-eroded areas) decreased by 7.5% in the ~135 years since forest clearance. This value should be treated with caution due to the shallow sampling depth, and because debris tails were treated as 'un-eroded' areas (i.e. C accumulation in debris tails was not included in calculations). However, the 'saw-tooth' theory put forward by de Rose (2013) to explain the cumulative impact of erosion events on soil carbon stocks since deforestation is a plausible explanation of the likely impacts of natural and human-induced events on soil C stocks on hillslopes (Fig. 3).

Page et al. (2004) used a similar approach at Tutira, and concluded that landslide erosion led an increase in soil C of 9% on landslide prone areas, due to C recovery on landslide scars and deposition of 57% of eroded C on slopes and valley floors. This value would have been higher if C accumulation on debris tails was included in the calculation. Dymond (2010) calculated the net effect of erosion on soil C at regional and national scales by combining a national erosion model with slip scar C recovery data from Page et al. (2004), calculations of C recovery on debris tails, and C decomposition in buried soils. For North Island areas where landsliding was the dominant erosion process (e.g. mudstone geology under pasture), erosion led to a net increase in soil C stocks. In contrast, erosion at sites dominated by earthflows and gully erosion in the North Island led to a net loss of soil C, because there was no C recovery on eroded areas. Erosion in the South Island was dominated by natural processes in the Southern Alps, and therefore C losses via erosion were assumed to be balanced by C accumulation on eroded sites (see Wiaux et al. 2014). Assuming most exported C was buried at sea (Brackley et al. 2010) with an efficiency of 80%, New Zealand would then be a net C sink of 3.1 million tonnes per year (Dymond 2010). Wiaux et al. (2014) selected soil cores from four topographic positions (summit, shoulder, backslope, and footslope) and showed that labile C increased downslope, and that unweathered material in eroded backslopes have less ability to stabilise C.

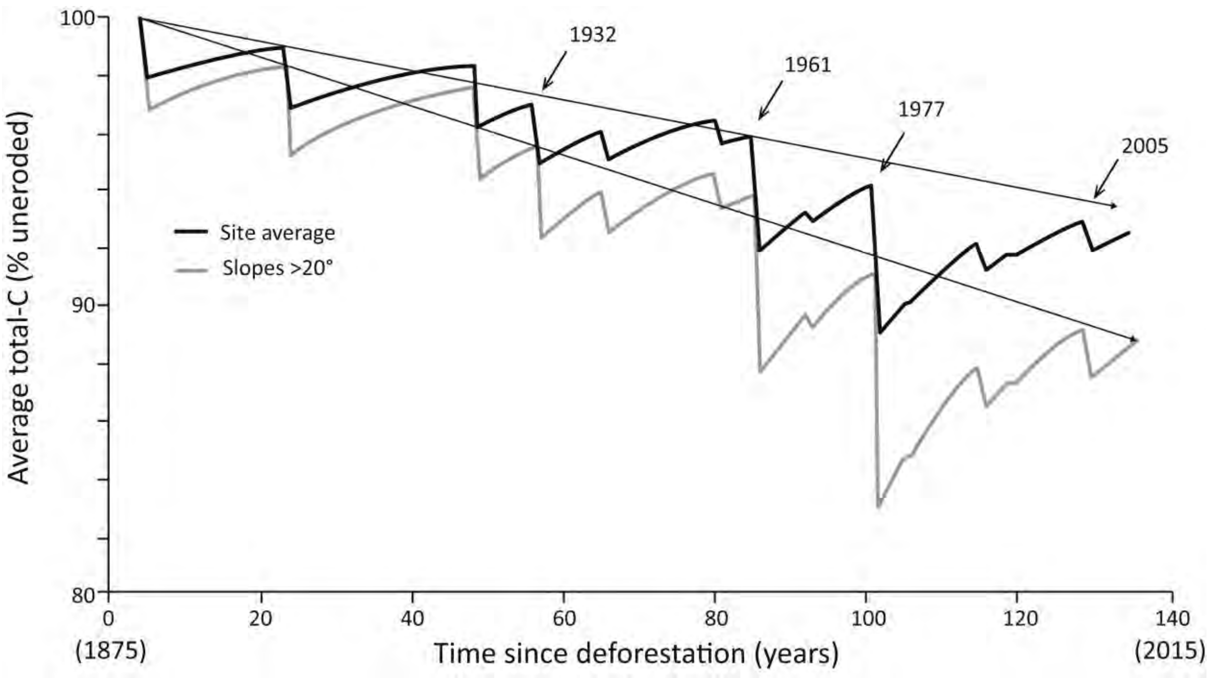


Figure 3: Change in average total C (0–10 cm) since deforestation (1875) at Te Whanga Station. Solid line is for all slopes at the site and the lower grey line is for slopes >20° (de Rose 2013). Calculation does not include C accumulation or burial in debris tails.

Basher et al. (2011) calculated C stocks for the full study areas of Te Whanga and Tutira in 1990 and 2011, with these dates roughly coinciding with the initial and final samplings in the study of Schipper et al. (2014). At Te Whanga there was virtually no change in soil C stocks between 1990 (88.7 Mg/ha) and 2011 (88.9 Mg/ha), because C losses from post 1990 landslides were about balanced by C gains on scars and debris tails (both pre and post-1990 ages). At Tutira, soil C stocks increased by 5 Mg/ha (0.24 Mg/ha/year) between 1990 (83.2 Mg/ha) and 2011 (88.2 Mg/ha). This increase was largely due to rapid C accumulation on the large area of 1988 slip scars and debris tails caused by Cyclone Bola, and because there were few new landslides between 1990 and 2011. The large influence of a single storm event on soil C stocks and subsequent stock changes highlights how sampling at only two points in time could provide quite different rates of change depending on when sampling occurred in relation to major storms. For example, at Tutira, predicted C stocks in 1988 before Cyclone Bola were 100.2 Mg/ha compared with 83.3 Mg/ha in 1990. Therefore, if samples were taken in 1988 and 2011 there would be a C loss of 12 Mg/ha between samplings, while there would be a gain of 5 Mg/ha if sampling occurred in 1990 and 2011. The timing of other events in relation to sampling, such as a sequence of wet winters or a drought, also needs to be considered with respect to their effect on perceived soil C trajectories (see Table 1). For example, at another hill country site, Schipper et al. (2011) found that soil C stocks increased for a few years and then decreased, with the change in C trajectory largely attributed to differences in climatic conditions during two time periods.

Basher et al. (2011; 2013a; 2013b) also investigated the effect of gully and earthflow erosion on soil C stocks. They concluded that although gully erosion caused a net decrease in soil C, the gullies limited overall areal extent means their effect can be ignored. Soil C stocks on earthflows were lower than adjacent areas, but this was "likely to be a persistent and constant characteristic of the landscape (affecting baseline soil C stocks) rather than a time-varying characteristic" (p. ??). Therefore earthflow erosion may not need to be considered when change in soil C stocks on decadal scales is the main question.

Although mass movement erosion (particularly landslides) can have a large impact on soil C stocks at localised sites, affected areas are proportionally small at regional or national scales. For example, the severe February 2004 storm that hit the Manawatu Region caused extensive landsliding, but landslide scars and debris tails rarely covered more than 10% of the land in 1 km squares for the hill country area in the region, and coverage was often less than 0.5% (Dymond et al. 2006). The Manawatu Region contains a large amount of sandstone and mudstone geology that is susceptible to erosion, so the area affected by erosion would probably be lower in other regions. Given the proportionally small land area affected by mass movement erosion at the national scale, future research should initially focus on determining changes in soil C on more stable facets of hill country landscapes. Quantifying the net effect of surficial erosion in these areas is one particular priority, because losses via this form of erosion are currently assumed to be in balance with C inputs from plants (Dymond 2010).

Table 1: Equations derived in different studies that were used to predict C stocks on landslide scars and debris tails.
Also shown are rates of change in C stocks for selected time periods (derived using the equations)

Reference	Erosion element	Equation	Time period (y)	C change 0–10 cm depth (kg/ha/y)	C change 0–30 cm depth* (kg/ha/y)
Lambert et al. (1984)	Slip scar	C0-10 = 32-26*exp(-scar age/12.5)	0–10	1432	2807
			60–70	12	23
			0–70	370	726
De Rose (2013)	Slip scar	C0-10 = 0.4+3.93* (1-exp-0.0649*scar age)	0–10	1876	3679
			60–70	38	75
			0–70	555	1089
Basher et al. (2011)	Debris tail	C0-10 = 40.7-14.93*exp(-tail age/21.1)	0–10	564	1105
			60–70	33	64
			0–70	206	403

* Calculated using a 'scaling factor' of 0.51 developed by Basher *et al.* (2011) to predict soil C stocks to 30 cm from stocks in the top 10 cm.

4.3.3 The effect of pastoral management on soil C stocks in hill country

A range of management practices occur on hill country farms, but key practices likely to affect soil C stocks could be narrowed down to: 1) fertiliser use, 2) grazing intensity (e.g. overall stocking rate) and regime (set stocking vs. rotational grazing), and 3) stock type (e.g. sheep or cattle), and 4) spaced tree planting. Interactions between these different practices will also occur (e.g. if more fertiliser is applied, overall stocking rates generally increase).

Fertiliser application

Three studies that investigated the effect of long-term superphosphate fertiliser application on soil carbon in North Island hill country (Lambert et al. 2000; Ghani et al. 2003; Schipper et al. 2011) found that the rate of superphosphate had no significant effect on surface soil (0–7.5 cm) C stocks or the rate of change in C stocks (on both easy and steep slopes). The observed absence of a superphosphate effect on surface soil C stocks (and stock changes) in hill country pastures is consistent with a long-term (~50 year) superphosphate trial under irrigated flatland pasture in Canterbury (Schipper et al. 2013). Condron et al. (2012) also found no significant difference in C stocks to 1 m depth in the Winchmore superphosphate trial from a one off sampling. In contrast to the previous studies, P and S fertiliser application and oversowing of high country grasslands in the South Island led to significant increases in soil C stocks (McIntosh et al. 1997, 1999). It was not possible to separate the effect of oversowing from fertilisation in these studies.

Two medium-term (4–5 year) nitrogen (N) fertiliser trials that started in 2004 at the Ballantrae Hill Country Research Station showed no significant effect of N rate (0 to 750 kg ha^{-1} y^{-1}) on soil C (Mudge 2012; Parfitt et al. 2012). There have been no long-term (i.e. >10 year) nitrogen (N) trials in New Zealand hill country pasture systems (or flat land for that matter), and N fertiliser use on commercial hill country farms is relatively low (particularly on steeper hill country). A number of international studies have also found that the rate of C accumulation in grassland soils was not related to fertiliser N input (Clement & Williams 1967; Hassink & Neeteson 1991; Hassink 1994; Watzka et al. 2006; Kriszan et al. 2009), although other studies have found that soil C increased with increasing N fertiliser inputs (Watson et al. 2007; Fornara & Tilman 2012).

The absence of significant differences in soil C stocks between treatments in most New Zealand P and N fertiliser trials was not consistent with the large increases in pasture production that were observed when fertiliser was applied. There are a few possible explanations for this. Pasture plants in low fertility soils tend to allocate proportionally more resource below-ground (presumably for the acquisition of nutrients) compared with plants in high fertility soils (Saggar et al. 1997; Stewart & Metherell 1999; Scott et al. 2012). The quality of plant roots and litter in low fertility pastures also tends to be lower than in high fertility pastures, and this would have likely slowed microbial decomposition, the main C loss pathway from pastoral soils (Saggar et al. 1997; Stewart & Metherell 1999; Scott et al. 2012). Therefore, while total C inputs would likely be greater in those pastures receiving high fertiliser inputs than in pastures receiving no or low fertiliser inputs, total C outputs (primarily though microbial respiration) would also be higher, so net effects of fertiliser on soil C stocks were negligible.

Grazing intensity, regime, and animal type and behaviour

In the long-term superphosphate trials described above, treatments receiving more fertiliser had considerably higher pasture production and thus stocking rates, yet there were still no significant differences in soil C stocks. In these studies, grazing intensity was adjusted for comparable pasture utilisation, and therefore a large proportion of the extra above ground C in the fertilised treatments would have been consumed and lost via animal respiration, and, to a lesser degree, in animal products (e.g. meat and fibre); however, greater amounts of dung and urine would be added to the soil. Increasing grazing intensity in the absence of increased pasture production would lead to increased pasture utilisation, and possibly to decreased C inputs via plant litter but increased C input via excreta, with consequent flow-on effects to soil C. However, the majority of C inputs to soils are thought to be derived from roots (Rasse et al. 2005), and therefore any stocking rate effect on soil C via effects on above ground litter and excreta inputs is likely to be small.

Barnett (2012) and Barnett et al. (2014) reviewed the literature and found that grazing intensity either had no effect on soil C stocks, or soil C was lower under higher grazing intensities. However, the majority of the reviewed studies were in ‘rangelands’ in cold dry environments (e.g. Mongolia), and therefore not very comparable to pastoral hill country in New Zealand.

Although research to date suggests that absolute grazing intensity appears to have little effect on soil C stocks in New Zealand hill country, the behaviour of grazing ruminants could have a considerable effect on the spatial distribution of soil C. In hill country, livestock generally spend more time and deposit more excreta on areas of low slope (particularly at campsite areas where animals rest), around trees, gateways, and water sources (Saggar et al. 1990, 1999; Haynes & Williams 1999; de Klein et al. 2009; Betteridge et al. 2010, 2012). Such behaviour typically leads to a transfer of C and nutrients from steep slopes to low slopes, particularly to campsites. Greater deposition of excreta on low slope/campsite areas could increase soil C from direct incorporation of deposited C (mainly in dung), and higher nutrient deposition could also increase pasture production and thus C inputs to the soil. Whether these effects lead to a net increase in soil C depends on whether the increased C inputs are greater than outputs via, for example, respiration and leaching.

Slope and aspect in relation to prevailing wind has also been shown to influence animal behaviour. At the Ballantrae Hill Country Research Station, the strong prevailing north-west wind caused sheep to spend more time on sheltered east-facing slopes, which resulted in greater dung and urine deposition and a trend for higher fertility on these slopes (Lambert & Roberts 1978; Lambert et al. 1983; Saggar et al. 1990). Interestingly, pasture production on east and north-west slopes at Ballantrae was virtually the same, and aspect had no detectable effect on soil C concentrations (Lambert et al. 1983, 2000).

Differences in grazing regime can also influence animal behaviour. For example, under set stocking regimes (where the density of grazers is matched to pasture production so animals can be left in the same area for a long period of time), camping behaviour could be accentuated because animals will always camp in prime localised campsites. These campsites will receive high rates of animal excreta deposition relative to other parts of the landscape. In contrast, rotational grazing with large mobs will mean that animals and excreta deposition will be spread more evenly over the landscape. In New Zealand hill country pastures, soil C stocks are typically higher on easy slopes than steep slopes (Lambert et al. 2000; Ghani et al. 2003; Schipper et al. 2011), but it is unclear whether these differences were due to differences in animal behaviour and excreta deposition, other hill slope processes (e.g. erosion), or a combination of the two.

Two New Zealand studies have reported higher soil C in campsite areas relative to non-campsite areas in both hill country and flatland pastures (e.g. Nguyen & Goh 1992; Haynes &

Williams 1999), but no studies have specifically tracked how soil C stocks change over time in campsite compared with non-campsite areas of hill country. Campsite areas typically occupy <15% of hill country pastures (Rowarth et al. 1992; Betteridge et al. 2010), and although little is known about C changes relative to non-campsite areas, these positions warrant further study to better understand their impact within the landscape, e.g. movement of dissolved organic carbon through the profile and down the hill slope. There are several studies that show the major contribution of stock camps and stock tracks to pasture production, nutrient and C cycling, as detailed below

For example, McDowell et al. (2014) explain the important contribution that such 'critical source areas' make to nutrient runoff or subsurface flow. The accompanying dissolved carbon leaching from these campsites (Jansen et al. 2014) is likely to contribute to carbon and nutrient cycling across a greater areal extent than the camp site.

Betteridge et al. (2010) used GPS urine-sensors to map urine-return patterns for both sheep and cattle in hill country. They found that 50% of cattle urination events occurred on stock camp areas representing 6–14% of total paddock area, and 50% of sheep urination events occurred on 15% and 30% of total paddock area.

Some stock camps could be regarded as already achieving the *production potential* for a given hill country farm (Grant et al. 1973). Such areas can yield between 10 and 25 t DM/ha/yr for unimproved hill pastures, and up to 13–28 t DM/ha/yr for improved pastures. Hill country stock camp productivity levels are similar to maximums obtained from adjacent lowland pastures (Grant et al. 1973; Chapman & Macfarlane 1985), and double the yields from surrounding hillsides (Grant et al. 1973). Saggar et al. (1990) reported mean annual pasture yields from Ballantrae. Yields from camp areas were 28%, 45% and 58% respectively higher than surrounding easy (11–20°), moderate (21–30°) and steep slopes (31–40°). Gillingham (1980) and Gillingham et al. (1980) reported stock camping on slopes 0–10° at Whatawhata. Perennial ryegrass dominated these areas, while annual pasture production was more than double the yields from steep 45° slopes (11 t/ha cf. 5 t DM/ha/yr). The difference was equivalent to a reduction of approximately 850 kg DM/ha for every 5° increase in slope.

Estimates for stock tracks include 11% coverage for a 24° slope with loess soils (Radcliffe et al. 1968) and up to 40% for a 37° slope on a steepland mudstone soil (During & Radcliffe 1962). However, at Te Awa, Suckling (1960) considered the combined area of stock camps, tracks, and valley bottoms to be only a small proportion of total area.

Stock tracks have distinctly different soil properties than surrounding slopes. During and Radcliffe (1962) measured higher concentrations of total C, N, and available P and K on slopes of two steepland soils; however, caution is required when interpreting concentrations instead of volume-weight, because bulk densities can change dramatically over short distances, especially where erosion has occurred. Radcliffe (1968) in a study of four tracked sites on Banks Peninsula found track paths to be wetter, higher in organic C and total N, and slightly higher in P and K. Cowley (1982) reported that the inter-track region between tracks was 5–10% drier than the track area as part of a Waikato study. In a cattle grazing trial at Ballantrae stock tracks and flat areas grew 13 200 kg DM/ha/yr compared with only 8440 kg DM/ha/yr on inter-track slope areas (Betteridge et al. 2012).

Stock type

There appears to have been no work specifically comparing soil C stocks under pastures grazed by different stock types in New Zealand. Deer behaviour (e.g. fence pacing), however, can lead to increased erosion from deer grazed pastures relative to sheep and cattle grazed pastures (McDowell & Wilcock 2008), which would likely lead to a loss of soil C. Cattle also tend to disturb the soil surface more than sheep, which could lead to increased erosion and thus loss of soil C (Nguyen et al., 1998). Lambie et al. (2012, 2013) demonstrated that cattle urine can cause positive priming of microbial respiration in soils, and also solubilisation and leaching of soil C. Cattle deposit more intense urine patches than sheep, and therefore C losses via these pathways will likely be greater from cattle- than from sheep-grazed pastures. However, the net effect of urine on soil C stocks needs to be determined under field conditions (i.e. including the influence of increased pasture production) before firm conclusions can be drawn.

4.4 Summary of soil C stocks and stock changes in New Zealand hill country pastures

Table 2 presents a summary of soil C stocks and stock changes in New Zealand hill country pastoral soils, derived from published papers and reports. Two large-scale surveys based on resampling multiple sites at two points in time, have reported that on average, there were large increases (0.5–1.2 Mg/C/ha/y) in soil C stocks between these sampling dates (Parfitt et al. 2014; Schipper et al. 2014).

Three studies have resampled sites at a single location multiple times. In a long-term superphosphate trial at the Whatawhata Research Station, Schipper et al. (2011) found that surface soil C increased during the first 6 years (on both steep and easy slopes) and then subsequently decreased, with the decrease primarily attributed to a series of dry summers. Rate of fertiliser addition had no influence on C stocks or stock changes. In a similar trial, Lambert et al. (2000) found soil C (averaged across three slope classes) decreased by ~0.2 Mg/ha/y in both high and low fertility pastures at the Ballantrae Research Station. In a small plot N trial on the same farm (on gentle slopes), Parfitt et al. (2010) reported a significant decline in soil C (in all treatments) within just one year. This was attributed to an infestation of porina moth caterpillars (*Wiseana* spp.), which severely reduced pasture production and presumably C inputs, and at the same time probably increased respiratory losses. Soil C had recovered to pre-caterpillar infestation levels after 2 years, and there was no significant change between the initial sampling and a sampling after 5 years (Parfitt et al. 2010, 2012).

Soil C stocks and changes in relation to erosion have been discussed in the erosion section, but values derived from equations for slip scars and debris tails are presented in Table 2 to allow easy comparison with the other studies. In addition, calculated C stocks (and stock changes) for the whole study areas (e.g. eroded and not eroded) at Te Whanga and Tutira have been shown for 1988, 1990 and 2011 (calculated using the equations of Lambert et al. (1984) and Basher et al. (2011)).

Soil C stocks from different slopes and aspects reported in studies where only one sampling occurred are also presented in Table 2, to allow further comparison of the effect of topographic position on soil C stocks.

Table 2: Summary of soil C stocks and stock changes in New Zealand hill country pastoral soils, derived from published papers and reports. Bold rates of change were reported to be significantly different from zero by the original authors

Reference	Study description	Number of locations	Sample depth (mm)	Year of first sampling	Year of second sampling	Interval (y)	Slope (deg)	Slope position	Aspect	C1 (Mg/ha)	C2 (Mg/ha)	C change (Mg/ha/y)
Schipper et al. (2014)	NSD resampling	23	0–300	1977.8	2007.9	30.1	9--35	Stable midslopes	Various	101.3	114.8	**0.52**
Parfitt et al. (2014)	Soil quality resampling	18	0–100	2001.1	2006.3	5.2	15-40	Various	Various	49.1	55.3	**1.20**
Schipper et al. (2011)	Whatawhata P trial (Period 1)	1	0–75	1983	1989	6	10--20	Shoulder	NW	43.89	53.71	**1.64**
		1	0–75	1983	1989	6	30-40	Midslope	NW	42.32	49.14	**1.14**
Schipper et al. (2011)	Whatawhata P trial (Period 2)	1	0–75	1989	2006	17	10--20	Shoulder	NW	53.71	50.24	–0.20
		1	0–75	1989	2006	17	30-40	Midslope	NW	49.14	40.95	**–0.48**
Lambert et al. (2000)	Ballantrae high fert	1	0–75	1975	1987	12	1–>25	Various	E,SW,NW	-	-	**–0.21**
	Ballantrae low fert	1	0–75	1975	1987	12	1–>25	Various	E,SW,NW	-	-	**–0.19**
Parfitt et al. (2012)	Ballantrae N trial – control	1	0–100	2004	2009	5	<5	Shoulder	NE	52.39	50.03	–0.47
	Ballantrae N trial – herbicid	1	0–100	2004	2009	5	<5	Shoulder	NE	50.37	47.48	–0.58
	Ballantrae N trial - 300N	1	0–100	2004	2009	5	<5	Shoulder	NE	50.75	47.85	–0.58
De Rose (2013)*	Te Whanga scar C recovery equation	1	0–300*	0	10	10	-	Slip scar	Various	7.84	44.63	3.68
		1	0–300*	60	70	10	-	Slip scar	Various	83.33	84.08	0.07
		1	0–300*	0	70	70	-	Slip scar	Various	7.84	84.08	1.09
Lambert et al. (1984)*	Te Whanga scar C recovery equation	1	0–300*	0	10	10	-	Slip scar	Various	11.76	39.84	2.81
		1	0–300*	60	70	10	-	Slip scar	Various	62.33	62.56	0.02
		1	0–300*	0	70	70	-	Slip scar	Various	11.76	62.56	0.73
Basher et al. (2011)*	Te Whanga and Tutira debris tail C recovery equation	1	0–300*	0	10	10	-	Debris tail	Various	50.53	61.58	1.10
		1	0–300*	60	70	10	-	Debris tail	Various	78.10	78.74	0.06
		1	0–300*	0	70	70	-	Debris tail	Various	50.53	78.74	0.40
Basher et al. (2011)**	Te Whanga landscape stocks from equations	1	0–300*	1990	2011	21	-	Landscape	Various	88.67	88.89	0.01
		1	0–300*	1988	2011	23	-	Landscape	Various	88.25	88.89	0.03
Basher et al. (2011)**	Tutira whole landscape stocks from equations	1	0–300*	1990	2011	21	-	Landscape	Various	88.67	88.89	0.24
		1	0–300*	1988	2011	23	-	Landscape	Various	100.16	88.16	-0.52

Ghani et al. (2003)	Te Kuiti P trial	1	0–75	1998	-	-	10–20	Shoulder?	Various	10.50%	-	-
		1	0–75	1998	-	-	25–35	Midslope?	Various	6.10%	-	-
Lambert et al. (2000)	Ballantrae P trial Slope effects	1	0–75	1976-1978	-	-	1–12	Shoulder?	E,SW,NW	38.12	-	-
		1	0–75	1976-1978	-	-	13–25	Midslope?	E,SW,NW	35.78	-	-
		1	0–75	1976-1978	-	-	>25	Bank?	E,SW,NW	32.70	-	-
Lambert et al. (2000)	Ballantrae P trial Aspect effects	1	0–75	1976-1978	-	-	1–>25	Various	E	35.31	-	-
		1	0–75	1976-1978	-	-	1–>25	Various	SW	35.91	-	-
		1	0–75	1976-1978	-	-	1–>25	Various	NW	36.29	-	-

* Calculated using a 'scaling factor' of 0.51 developed by Basher et al. (2011) to predict soil C stocks to 30 cm from stocks in the top 10 cm.

** Calculated after Basher et al. (2011) using: the debris tail model of Basher et al. (2011), the slip scar model of Lambert et al. (1984), and areas of eroded and uneroded land, and C stocks from Basher et al. (2011).

4.5 Sampling strategies

To determine changes in soil C stocks, sampling programmes need to be designed that account for both spatial and temporal variation. An appropriate sampling protocol must be established that can be applied at each sampling location and time. The design must address the questions that the user of the data poses, and provide information with accuracy and precision at the spatial and temporal scales that match the user's needs (Arrouays et al. 2014; Morton et al. 2000; Gehl & Rice 2007; Goidts et al. 2009; Hedley et al. 2012, 2014a). Examples are provided by Schulp and Verburg (2009) for land-use history and by de Rose (2013) for sampling sequential erosion events.

4.5.1 Background

Research has accelerated in recent years to evaluate the effectiveness of various sampling strategies (e.g. modal soil profiles, representative sites, transects, randomly located plots, stratified plots) to measure soil C stocks in terms of the accuracy of results, and the expenses associated with the methodology (e.g. Vanden Bygaart & Angers 2006; Conant et al. 2011; Singh et al. 2012; Whitehead et al. 2012). Key issues identified by this work include the necessity for proportional representation of landscape positions and types to account for spatial variability; appropriate longitudinal measurement or modelling approaches to determine the trajectory of soil C stock changes; and appropriate estimates of uncertainty with sufficient sampling density.

4.5.2 Current Practice

Current practice used in New Zealand for soil C sampling is evaluated in Whitehead et al. (2012), as are issues around the production of compound error terms that encompass the uncertainty associated with site selection, sampling procedure and sample analysis. Comprehensive estimations of the uncertainty associated with soil C storage data are essential, as these values are required to evaluate the reliability of projected soil C storage and trajectory, but are often not adequately quantified in the literature (Goidts et al. 2009).

Following the protocol of Stolbovoy et al. (2007), Whitehead et al. (2012) suggest that the greatest source of error is likely derived from undetected differences between sites that are presumed to be similar due to inadequate site descriptions. Therefore, detailed knowledge of climate, pedology, erosion, and management history across the sampled sites is essential to determine, and reduce, uncertainty.

Sampling strategy has a significant impact on the threshold for changes in soil C storage that can be reliably detected (e.g. Yanai et al. 2003). Whitehead et al. (2012) discuss the use of power analysis to determine the number of sites required to calculate whether a mean change in soil C stocks is significant at set levels of probability, and based on case studies, demonstrate that smaller changes in C stocks require proportionally much greater numbers of sample points than larger changes in C stocks to identify statistically significant differences. This statistics method does not account for the uncertainty related to spatial variability, for example the error associated with resampling at the same position over time.

Power analysis is used for determining numbers of replicates required at any one sampling time for measuring stocks, and also for determining whether sufficient time has elapsed between samplings to be able to detect temporal stock changes. An incorrect conclusion that no change has occurred can be drawn when power analysis would demonstrate that insufficient time has elapsed between samplings to allow detection of reasonable changes in soil C stocks. This is illustrated using the data from Schipper et al. (2014). If it was assumed that the C change that occurred between samplings continued at the same average rate for the next 10 years, and then sites were re-sampled, there would only be about a 35% chance of correctly signalling a continued change (Ray Littler, University of Waikato, pers. comm. 12 July 2013). To increase the chances of detecting a significant change to 80%, there would have had to have been 63 sites (rather than 23). Alternatively, a longer time interval would increase the size of the C stock change (assuming the changes were continuing), thus increasing the chances of detection. Using a similar approach, Hedley et al. (2009) showed that sample size would need to be increased from 5 to between 66 and 103 samples at three different forest-to-farm conversion sites, for the measured changes to be significantly different.

Power analysis is therefore a useful statistical approach to assist decisions about sampling density for validating SOC stock changes.

Statistical stratification of SOC covariates can reduce sampling intensity and costs, to achieve the same accuracy as random sampling at any given site. "Covariates" are variables that show some degree of correlation with the soil attribute that needs to be measured, in this case SOC. The covariate can be measured more easily with exhaustive coverage, compared with the soil attribute of interest.

Stratification by covariate datalayers includes, for example, legacy soil maps and any other relevant environmental datalayers. Digital elevation models (DEMs) and derived terrain attributes (e.g. elevation, slope, aspect) are particularly useful for hill country studies where topography is a major driver of soil C variability. DEMs are likely to be less useful in lowland cropping situations, for example where there is a complex soil pattern which does not relate strongly to topography (Singh et al. 2012).

Spatial prediction models for soil C using point data with this auxiliary information (e.g. soil type, climate, parent material, landform position) reduces the uncertainty in predictions of soil C stocks across landscapes compared with traditional aspatial approaches (e.g. Dlugoss et al. 2010; Minasny et al. 2013; Hedley et al. 2014b; Adhikari et al. 2014). This 'digital soil mapping' approach is defined by the International Working Group on Digital Soil Mapping (WG-DSM) as the creation and population of a geographically referenced soil database generated at a given spatial resolution by using field and laboratory observation methods coupled with environmental data through quantitative relationships (Lagacherie et al. 2006).

DSM therefore enables quantitative soil mapping, and is described in the context of this project below. DSM provides a measure of uncertainty related to the prediction using e.g. Monte Carlo simulation, bootstrapping or Bayesian approaches. Goidts et al. (2009) used an error propagation method, cross-checked against a Monte Carlo simulation, to quantify the relative contribution of each variable and their interactions in assessing SOCS (SOC concentration, sampling depth, bulk density, stone content), finding that spatial variability is a major source of uncertainty.

4.5.3 Digital soil carbon mapping

The political drive to refine approaches for assessing SOCS and stock changes has focussed scientific research endeavour to develop new methods to represent variations of SOCS across the landscape.

This interest arises from the fact that mapping SOC:

- provides a baseline carbon level
- helps to understand and localise the variables controlling soil C and therefore to reduce the uncertainty attributed to the SOC spatial variability
- assists in natural resource management and monitoring
- identifies potential project locations for soil based carbon sequestration, and
- serves as an input into mechanistic simulation models (e.g. to model change with time)

(based on Minasny et al. 2013)

Traditional soil mapping defines areas, largely by homogenous qualitative criteria.

To quantitatively map a soil attribute, such as soil carbon, a digital soil mapping approach has been developed which divides a region into a regular grid and assigns a SOC value to each grid cell, in a GIS framework (McBratney et al. 2003). The method uses a prediction function based on the classic soil formation equation (Jenny 1941):

$$Soil = f\,(c, o, p, r, t)$$

C = climate
o = living organisms, including vegetation
P = parent material
r = relief or topography of the area
T = time

This equation has been adapted to quantitatively express a soil attribute at a spatial position as a function of a set of covariates. The new equation is known as the *scorpan* spatial prediction function (McBratney et al. 2003), and for soil carbon the expression is as follows (Minasny et al., 2013):

$$C_x = f\,(s, c, o, r, p, a, n) + e$$

Where:

C_x: soil carbon at a spatial position
s: soil factors
c: climate
o: organisms, vegetation or fauna or human activity
r: relief
p: parent material
a: age or time
n: spatial position
e: spatially correlated errors

The *scorpan* mapping method follows these steps:

1. *Collection of a database of SOC observations:*

This step defines the ***s*** factor of the scorpan function. It provides the SOC information to calibrate the spatial prediction model. Though some studies work with soil legacy data, most studies collect new samples and measure the SOC concentration at different depths. There is no rule to indicate how many samples to collect, but Minasny and McBratney (2006) argue that the sampling should hypothetically result in observations covering the whole range of covariates so that the prediction model can be applied to the whole area. Sampling positions are selected to account for the spatial variabilities of the covariates, with the use of a conditioned Latin Hypercube sampling method (cLHS) (Minasny & McBratney, 2006). This procedure maximizes the stratification of the marginal distribution of the covariates and ensures a better coverage of the range of each covariate than a simple stratification (Minasny & McBratney 2006; Minasny et al. 2013).

2. *Compiling the relevant SOC covariates:*

The covariates are usually linked to soil carbon because they are involved in soil formation processes, and/or in the production and decomposition of biomass, e.g. moisture content, fertility, solar energy. Vegetation related covariates such as land cover, land use and spectral images provide good predictions (Marchetti et al. 2010; Stevens et al. 2010; Mendonca-Santos et al. 2010). Native vegetation relates to regional soil C stocks (Schulp & Veldkamp 2008), and local terrain attributes are good predictors at resolutions < 100 m. Legacy data are commonly used because of their easy availability; however, researchers caution about its use (e.g. Powers et al. 2011; Hedley et al. 2012). Powers argue that if the sampling procedure that produced the data does not follow statistical criteria, the legacy data can under- or over-represent a certain area and then bias the predictions.

Climatic variables are critical for regional to global mapping (Guo & Gifford 2002; Powers et al. 2011; Bui et al. 2009). At farm scale, current land use mainly influences SOC at the top 20 cm, e.g. nitrogen fertilizer application.

3. *Training of a spatial prediction function and interpolation/extrapolation:*

The scorpan function is applied using, e.g. (i) linear models, (ii) geostatistics (Webster & Oliver 2007), and (iii) machine learning methods. The prediction function is then implemented on each cell of the grid of the whole area to create the soil carbon digital map.

4. *Validation and estimation of uncertainties*

Internal validation is used to calibrate the model using a specified proportion of the dataset, generally 70% and checking the accuracy on the rest of the dataset. The same principle is carried out in cross-validation but the process is repeated so that each observation is predicted once. The measurements of the performance of the predictions are then averaged on all the calibration runs.

4.5.4 Stratified soil sampling

Any sampling strategy needs to consider how to best capture variability at the relevant scale (e.g. 0.1–1000 ha), and also how to sample enough distinct sites with different soils and environments to allow meaningful extrapolation to the national scale. The conditioned Latin Hypercube Sampling method (cLHS) automates this approach using a statistical stratification of the available datalayers (Minasny and McBratney, 2006).

The statistical power of any sampling design should also be evaluated to provide confidence that any meaningful changes in soil C stocks will be detected. A cLHS sampling strategy in combination with GIS analysis enables the user to optimise sampling to meet these criteria using a statistically robust procedure.

The core methodology of the cLHS, as described above (Section 4.5.3.1) was developed to enable rigorous sampling from multidimensional distributions (McKay et al. 1979). This has subsequently been adapted to soil sampling regimes by utilising digital soil mapping surfaces and search algorithms to identify the positions of the least numbers of sampling locations required to satisfactorily account for all known variations in site factors (Minasny & McBratney 2006).

Further developments have enabled location selection to be constrained to optimise the degree of stratification and operational expenses, which is necessary to provide cost-effective data collection over hilly and rugged terrain (Roudier et al. 2012). Given the nature of the terrain in question, this operationally constrained variant of the cLHS strategy will likely be a suitable framework for further quantifying soil C stocks and stock changes in New Zealand hill country pastures.

4.5.5 Future directions

The use of non-traditional methodology will reduce sampling costs to obtain accurate results with satisfactory levels of confidence. DSM methods with detailed site information have the potential to greatly reduce the cost of soil C sampling.

New technologies, for example near infra-red spectroscopy (NIRS), are available to speed soil C analysis, (Chang & Laird 2002; Stenberg et al. 2010; Soriana-Disla et al. 2014). Portable VNIR instruments can be used in field settings, and although further evaluation is required, this is a promising option for tracking changes in soil C stocks following land conversion or disturbance (Whitehead et al. 2012). NIRS can enable the number of samples analysed to be increased (thus spatial representativeness), for the same cost, and requires traditional combustion based C analysis methods to ensure calibrations are correct (e.g. Hedley et al. 2014a; Soriana-Disla et al. 2014).

Any soil C sampling strategy that will be used to further investigate the findings described in Schipper et al. (2014) will need to be developed according to the issues described above, and also account for the various factors that affect the variability of soil C stocks in grazed hill country outlined in the previous sections. Given the likely sites used for this extended analysis, critical factors to consider when determining the method, distribution, and intensity of sampling include:

- the extent of soil C storage change over the wider hill country unit (i.e. hill slope and associated flat land)
- eroded versus non-eroded hill slope positions

- extent of colluvial soil deposition over the landscape
- influence of aspect
  - farm management and animal behaviour (e.g. compaction and stock campsites)
  - the expected rates of change and appropriate sampling density (both in time and space) to avoid incorrect conclusions about apparent changes in soil carbon stocks

To account for these issues, it is proposed that assessments of hill country soil C stocks implement a conditioned Latin hypercube sampling (cLHS) strategy to enable robust stratification based on available ancillary information.

4.6 Summary and recommendations from the literature review

4.6.1 Hill slope processes and conversion to pasture

- Slope, aspect, underlying geology, soil type, vegetation assemblages and rainfall will set baseline soil C stocks and variation in the landscape under the original native vegetation.
- In general, soil C stocks in hill country tend to be greater on flatter areas, and increase downslope.
- There is little information on changes in hill country soil C stocks following conversion from native vegetation to pasture in New Zealand. Data for flat to rolling land show conversion caused either no change or significant increases in soil C. However, in hill country, conversion would have likely increased erosion, so the net effect is unknown.
- Geology and slope strongly affect susceptibility to mass movement erosion following conversion from original native vegetation (e.g. mudstones are more predisposed to erosion).

4.6.2 The effect of erosion on soil C stocks and stock changes

- Although gully erosion causes a net decrease in soil C stocks, the limited overall areal extent means their effect can be ignored.
- Reported soil C stocks on earthflows were lower than adjacent areas, but this was likely to be a persistent and constant characteristic of the landscape (affecting baseline soil C stocks) rather than a time-varying characteristic". Therefore earthflow erosion may not need to be considered when change in soil C stocks on decadal scales is the main question.
- Under grazed pastures, landslide erosion can have a large effect on soil C stocks with large declines occurring during major storm events such as Cyclone Bola.
- Gradual C accumulation on slip scars and debris tails can offset losses, and some studies have argued that landslide erosion could lead to a net gain in soil C when considering the whole landscape (e.g. including C buried in debris tails).
- The timing of sampling in relation to major landslide inducing storm events can have a large impact on measured soil C stocks and the trajectory of stock changes.
- Although landslide erosion can have a large impact on soil C stocks at localised sites, affected areas are proportionally small at regional or national scales.
- The more subtle (but widespread) effect of surface erosion (e.g. by water and wind) on soil C stocks is difficult to quantify and has received less research attention in New Zealand.

4.6.3 The effect of pastoral management on soil C stocks in hill country

- Existing data from hill country pasture studies in New Zealand indicate that soil C stocks are not significantly affected by long-term phosphorus fertiliser application (excluding South Island tussock grasslands). The effect of nitrogen application is not known due to lack of longer term studies.
- Grazing intensity also appears to have no net effect on soil C stocks, and there is little to no data on the effect of different grazing regimes (e.g. set stocking vs. rotational grazing), or stock types (e.g. sheep or cattle) on soil carbon stocks.
- The current lack of any obvious fertiliser or grazing management effects on soil C stocks in hill country suggests it is possible to ignore these factors when extrapolating results across the wider landscape – but this position may change with new data.
- Animal behaviour can influence the spatial distribution of soil C within hill country landscapes, with higher C stocks reported for campsites compared with non-campsites. Campsites typically occupy only a relatively small area (<15%) of hill country pastures, and therefore the effect on soil C stocks (and stock changes) at the landscape scale may be relatively small. However, the effects of these ‘hot spots” or “critical source areas” should not be overlooked as they become conduits for carbon and nutrient transfer mechanisms within the catchment. Also effects such as pugging and compaction are widespread and should be considered.

4.6.4 Rates of change in soil C stocks in hill country

- Few studies have measured changes in soil C stocks in pastoral hill country (see Table 2).
- Two large-scale surveys based on resampling multiple sites at two points in time have reported large increases (0.5–1.2 Mg/C/ha/y) in soil C stocks. Whether ongoing changes are occurring is not known.
- Other studies resampling multiple times at single sites have reported both large increases (up to 1.64 Mg/C/ha/y) and large decreases (–0.48 Mg/C/ha/y) in soil C stocks. Increases and decreases can occur at the same sites, but during different time periods (i.e. changes are not unidirectional). This means that sampling times should either be a few decades apart to determine overall trends or more frequent if the trajectory and timing of any C changes are important.
- The most rapid increases in soil C stocks were observed on recent slip scars (e.g. 3.68 Mg/C/ha/y during the first 10 years), but rates slowed considerably on older scars (e.g. 0.07 Mg/C/ha/y between 60 and 70 years).
- Very rapid and large decreases in soil C stocks can occur during major storm events which cause extensive landsliding. However, at the landscape scale a portion of the mobilised C will be redeposited in debris tails, and the proportion of C completely removed from the landscape by landsliding requires further research. In such studies sampling needs to be deeper than 30 cm to account for C buried under debris tails (particularly in the old top soil).

4.6.5 Sampling strategies

- The non-unidirectional trends in soil C stocks observed at Whatawhata (on both steep and easy slopes), and in relation to the timing of large landside inducing storms (at Tutira and Te Whanga), suggest that samples may need to be collected on many occasions if accurate gauging of the trajectory of soil C stock changes is important. Because of the complexity of soil C change through time, a modelling approach might be preferred instead of, or together with, repeated measurement campaigns.
- An operationally feasible stratified sampling framework provides a new method to integrate the various site factors that influence soil C stocks over time in hill country in a cost-effective manner. This method addresses the need to proportionally sample the expected range of soil C across a landscape, and uses an unbiased statistical analysis of available datalayers (e.g. DEMs) and categorical layers (e.g. legacy soil maps).
- A method to pre-assess an appropriate sampling density needs more research. Post hoc power analysis or a similar approach is currently required to determine whether any sampling scheme will allow detection of rates of change considered important for prescribed levels of significance and power.

5 GIS and statistical analysis of site representativeness

5.1 Summary

Schipper et al. (2010, 2013, 2014) sampled soil carbon for 23 sites in grazed NZ hill country and tentatively concluded that soil organic carbon stocks in hill country under pasture were increasing. The purpose of this spatial and statistical analysis is to retrospectively examine how representative those 23 sites are of pastoral hill country in New Zealand, by statistically interrogating relevant datasets (digital elevation models and derived terrain attributes, soil, climate, pasture productivity, drainage class, erosion, hill country type).

Characteristics for each of the 23 sites have been compared against distributions and populations of similar values obtained from spatial data sources, using an "Interquartile Range (IQR) Representativeness" method (see Section 5.3 and 5.4.1). IQR representativeness is examined at several hill country scales, including the immediate hill face or facet, the type of landform element within a 2-km^2 extent, soil type, hill country type, and all grazed hill country in NZ. Site values are deemed to be representative if they fall within 50% of the population (with proximity to the most central value indicating how representative), or in the case of categorical data, if the classes represented a substantial area of grazed area.

Results for individual sites were highly variable (Table 3). No quantitative method to summarise collective representativeness could be identified. Generalised results in Table A are based firstly on the count of representative variables, but also include a degree of weighting (e.g. slope is more important than elevation) and a consideration of distance from the median.

Table 3: IQR representativeness of each site at different hill country scales

	Hill side	Landform	Soil type	Hill type	All hill
Site 1	Marginal	Fair	Marginal	Marginal	Marginal
Site 2	Marginal	Fair	Fair	Fair	Fair
Site 3	Marginal	Fair	Marginal	Marginal	Marginal
Site 4	Fair	Fair	Marginal	Marginal	Marginal
Site 5	Fair	Fair	na	Fair	Marginal
Site 6	Marginal	Fair	na	Marginal	Fair
Site 7	Fair	Marginal	na	Fair	Marginal
Site 8	Marginal	Fair	Marginal	Marginal	Marginal
Site 9	Fair	Marginal	Marginal	Marginal	Poor
Site 10	Fair	Fair	Fair	Marginal	Marginal
Site 11	Fair	Marginal	Marginal	Marginal	Fair
Site 12	Fair	Fair	Marginal	Fair	Fair
Site 13	Marginal	Fair	Fair	Marginal	Marginal
Site 14	Fair	Marginal	Marginal	Marginal	Marginal
Site 15	Fair	Marginal	Marginal	Marginal	Marginal to poor
Site 16	Fair	Fair	Marginal	Fair	Marginal
Site 17	Marginal	Fair	Marginal	Marginal	Marginal
Site 18	Fair	Fair	Fair	Fair	Marginal
Site 19	Fair	Fair	Marginal	Marginal	Marginal
Site 20	Fair	Marginal	na	Marginal	Marginal
Site 21	Fair	Fair	na	Marginal	Marginal
Site 22	Fair	Fair	na	Fair	Fair to marginal
Site 23	Marginal	Fair	Fair to marginal	Fair	Fair

Results have also been compared against the ideal number of sites required to achieve full representation for all NZ pastoral hill country (Tables 4 & 5). For site variables recorded as numerical data (Table 4), and using the devised IQR representativeness method, about one third qualify as representative, over half as marginal, and approximately 10% are definitely not representative. In terms of variables, elevation is particularly well represented, but the important variable of slope is not (only 3 sites qualify as representative).

Table 4: Number of sites required to achieve ideal representation of numerical variables for all NZ pastoral hill country vs. number of actual sites falling within the inter-quartile range (IQR)

	Ideal number of sites falling within the IQR	Actual number of sites falling within the IQR (representative)	Actual number of sites falling outside the IQR (marginal)	Actual number of sites that qualify as outliers (definitely not representative)
Elevation	23	**12**	**8**	**3**
Slope	23	**3**	**17**	**3**
Erosion	23	**9**	**12**	**2**
Rainfall	23	**8**	**13**	**2**
Temperature	23	**4**	**18**	**1**
Average (rounded)		**7 (31%)**	**14 (59%)**	**2 (10%)**

Table 5: Number of sites required to achieve ideal representation of categorical variables for all NZ pastoral hill country vs number of actual sites in each category.
('Ideal' is the percent area of each class multiplied by the total number of sites (23) rounded to the closest whole number. Rounding results in some tallies summing to 22 or 24). For example, if 10% of hill country is flat land, then 10% of the 23 sites should represent this flat land class (i.e. 2.3 sites rounded to 2 sites). Pasture production is expressed by categories because the values are derived from Land Use Capability (LUC) classes

Aspect	Ideal	Actual
Flat	0	**0**
North	3	**5**
Northeast	3	**4**
East	3	**5**
Southeast	3	**3**
South	3	**2**
Southwest	3	**1**
West	3	**2**
Northwest	3	**1**

Pasture Tn DM/ha/yr	Ideal	Actual
0	0	**0**
0–2	2	**0**
2–4	0	**0**
4–6	2	**0**
6–8	4	**9**
8–10	4	**6**
10–12	4	**2**
12–14	5	**5**
>14	1	**1**

Soil order	Ideal	Actual
Anthropic	0	**0**
Brown	9	**6**
Melanic	1	**3**
Gley	0	**0**
Allophanic	2	**2**
Pumice	2	**0**
Granular	0	**0**
Organic	0	**0**
Pallic	5	**9**
Recent	2	**2**
Semi arid	0	**0**
Ultic	1	**1**
Raw	0	**0**
Oxidic	0	**0**
Podzol	1	**0**

Slope	Ideal	Actual
Flat	2	**1**
Undulating	4	**0**
Rolling	7	**3**
Strongly rolling	4	**1**
Mod. steep	3	**8**
Steep	3	**10**
Very steep	1	**0**

Drainage	Ideal	Actual
Very poor	0	**0**
Poor	0	**0**
Imperfect	4	**6**
Mod. well	7	**9**
Well drained	12	**8**

Hill country type	Ideal	Actual
1. Crushed soft rock hill country with mod. to severe erosion	2	1
2. Deeply weathered hill country	1	1
3. Hard igneous rock hill country	0	0
4. Hard rock hill country	4	0
5. Loess hill country	1	5
6. Morainic hill country	0	0
7. Soft rock hill country (including soft Limestone)	5	7
8. Steep crushed soft rock hill country	0	0
9. Steep deeply weathered hill country	0	0
10. Steep hard igneous rock hill country	0	0
11. Steep hard rock hill country	3	0
12. Steep soft rock hill country	2	4
13. Steep tephric (ash) hill country	0	0
14. Steep weathered hill country	0	0
15. Steep weathered igneous rock hill country	0	0
16. Tephric (ash) hill country	4	5

For site variables recorded as categorical data (Table 4) the match between the ideal and actual number of sites falling within a given category is imperfect. With aspect, north to north-eastern facing slopes are over-represented, while the south to north-west sector is under represented. Slope types are strongly biased towards the steeper slope categories, while the 6–8 t DM/ha/yr pasture production category is similarly over-represented. Melanic and Pallic soil orders are over-represented; Brown soils are under-represented; Pumice and Podzol soils are not represented at all. Representation of hill country types is also variable; of special note are the nil representation of Hard rock hill country (4) and considerable over-representation of Loess hill country (5), particularly in South Island.

These results should not be particularly surprising, given the substantial level of variability that characterises hill country landscapes. Further, we acknowledge the difficulties and constraints of having a limited number of fixed historical sites from which to draw a sample, and the associated risk of bias these constraints may or may not introduce to a study. We also temper our own results by noting that while the hill country layer used in this study is perhaps the best data source available, it is far from being a perfect representation of all NZ hill country. Likewise, existing spatial data sources constrain our choice of variables used to compare site representativeness. Despite these constraints, the results presented here are considered valid for better informing the interpretation of other pan-hill country research studies, and should hopefully contribute to the improvement of future research study designs.

We did not analyse if 23 sites represent a sufficient sample size to adequately resolve the levels of variability found in hill country environments. This is recommended further work to be completed.

5.2 Objectives of the GIS analysis

Schipper et al. (2010, 2013, 2014) sampled soil carbon for 23 sites in grazed NZ hill country and concluded that soil organic carbon stocks in hill country under pasture were increasing. The purpose of this study is to examine:

- how well the 23 sites represent the range of soils, drainage classes, climate, slope, productivities, aspect, and extent of erosion in NZ's grazed hill country landscapes (national scale).
- what proportion of the local landscape (2 km^2) is represented by individual pit locations (local scale).

It is important to emphasise that this study is concerned with how well the sites represent hill country, rather than how well they may or may not represent landscape differences in soil carbon stocks.

5.3 Method

Values and ranges for hill country site variables recorded for the 23 point locations were compared against the populations for similar values found in pastoral NZ hill country using environmental datalayers, interrogated by descriptive and summary statistics in a Geographic Information Systems (GIS) framework. Digital elevation models were derived for this project using photogrammetry (23 sites) and Lidar data where available (6 sites) (see Section 3.1). Sites were deemed to be representative if they fell within 50% of the population (with proximity to the most central value indicating how representative), or in the case of categorical data, if the classes represented a substantial area of grazed hill country, determined using quantiles and frequency distributions. Zonal data were extracted using

ArcGIS software and imported into Excel to conduct the statistical analyses. This "Interquartile Representativeness" method assesses the representativeness of a position based in whether it falls within 50% of the total population, using quantiles and frequency distributions, (see Section 5.4.1 for more Method details).

5.3.1 Photogrammetric derivation of digital elevation models (DEMs)

Stereo aerial photography covering each site was purchased from New Zealand Aerial Mapping Ltd and supplied as digital captures (Sites 1–19) or digital scans of film negatives (Sites 20–23). Full details of aerial imagery used are given in Table 6. All images were purchased with triangulation data (in SOCET SET format) and full camera calibration data.

Table 6: Details of aerial imagery used in this study

Site	Survey No.	Date of photography	Nominal ground resolution (metres/pixel)
1	SN50992	05/03/12	0.4
2	SN50992	19/04/12	0.4
3	SN50986	24/10/12	0.4
4	SN50992	10/11/12	0.4
5	SN50986	06/01/12	0.4
6	SN50986	29/01/12	0.4
7	SN50986	12/10/12	0.4
8	SN50921D	10/01/2011	0.4
9	SN50921D	25/11/2010 & 30/03/2011	0.4
10	SN50921D	10/01/2011	0.4
11	SN50921D	02/01/2011	0.4
12	SN50921D	02/01/2011	0.4
13	SN50921D	02/01/2011	0.4
14	SN50921D	02/01/2011 & 10/01/2011	0.4
15	SN50921D	31/03/2011	0.4
16	SN50921D	31/03/2011	0.4
17	SN50921D	26/01/11	0.4
18	SN51023D	16/12/12	0.4
19	SN51023D	16/12/12	0.4
20	SN12854	2004	0.75
21	SN12854	2004	0.75
22	SN12854	2004	0.75
23	SN12854	2004	0.75

DEM construction

DEMs were built for each site using LPS eATE (ERDAS Imagine 2011), using the digital aerial imagery and the supplied triangulation and camera calibration data. Several pairs of sites were located in close proximity to each other and these pairs (Sites 11–12, 18–19, and 19–20) were covered by a single DEM for each. The projection used was the New Zealand Transverse Mercator projection (GRS 1980 spheroid, NZGD2000 datum), and the DEM resolution was 5 m. This resolution was considered to be a suitable trade-off between the overgeneralisation inherent in lower-resolution DEMs, and the over-representation of microrelief features that often confounds DEM derivatives such as slope and aspect when using higher DEM resolutions.

We compared the DEMs against available Lidar data which gave partial coverage for six of the photogrammetric DEMs (covering eight sites). For each photogrammetric DEM that was compared against Lidar we extracted elevations for a set of check points that were scattered quasi-randomly over the photogrammetric DEM such that heavily vegetated areas were avoided. This gave us an estimate of the vertical accuracy of the photogrammetric DEMs versus Lidar for open areas (Table 7). Lidar coverage of the other study sites was unavailable.

Table 7: Comparisons of check point elevations from photogrammetric DEMs against available Lidar coverage

Site/s	Mean (m)	Max (m)	Min (m)	Range (m)	SD (m)	Number of check points
1	–1.01	0.94	–2.69	3.62	0.11	134
2	1.24	7.49	–0.65	8.14	1.00	98
11–12	1.22	3.01	–0.98	–4.00	0.60	53
13	1.01	5.49	1.54	3.94	1.54	139
14	0.73	3.23	–0.88	4.11	0.84	49
18–19	–0.70	3.19	–5.36	8.55	1.41	142

5.3.2 Pastoral NZ hill country defined

Hill country is classified from the NZ Land Resource Inventory (NZLRI) spatial database according to the definition of Basher et al. (2008): Hill country is defined as all lowland and montane hill and steeplands (slope >15°), classified as LUC class 5, 6 or 7, and being described in the unit descriptions in the NZLRI as hill country. Hill country includes some flat to rolling land mixed with the steeper slopes, as described by de Klein et al. (2009).

This method differentiates hill country into sixteen categories according to rock type and erosion susceptibility (Table 8). Total area of hill country is estimated at 9.9 million hectares (37% of NZ).

Pastoral land is classified from the Landcover Database v.4 (LCDB4) using high, low and depleted grassland, along with short rotational cropping (on the basis that if it occurs in hill country, it is most likely to be for fodder and thus quickly returned to pasture). Grazed hill country is estimated at 4.2 million hectares (42% of hill country; 38% of all grazed land in NZ) (Fig. 4).

Table 8: Area of pastoral hill country in NZ

Hill country type	North Island		North Total	South Island		South Total	Total pasture	Total NZ
	Pastoral	Non pas.		Pastoral	Non pas.			
1. Crushed soft rock hill country with mod. to severe erosion	334,114	254,286	588,401				334,114	588,401
2. Deeply weathered hill country	193,831	382,777	576,608				193,831	576,608
3. Hard igneous rock hill country	9,320	6,279	15,599				9,320	15,599
4. Hard rock hill country	135,555	164,162	299,716	594,182	565,785	1,159,966	729,736	1,459,683
5. Loess hill country	92,023	20,826	112,849	165,770	78,626	244,395	257,793	357,245
6. Morainic hill country				36,919	132,428	169,347	36,919	169,347
7. Soft rock hill country (including soft Limestone)	756,437	255,679	1,012,116	201,826	330,407	532,233	958,264	1,544,349
8. Steep crushed soft rock hill country	11,249	45,169	56,419				11,249	56,419
9. Steep deeply weathered hill country	17,595	166,077	183,672				17,595	183,672
10. Steep hard igneous rock hill country	5,155	45,881	51,036				5,155	51,036
11. Steep hard rock hill country	67,762	552,438	620,200	384,326	473,696	858,022	452,088	1,478,223
12. Steep soft rock hill country	407,527	762,358	1,169,885	7,756	358,818	366,574	415,283	1,536,459
13. Steep tephric (ash) hill country	51,952	269,606	321,557				51,952	321,557
14. Steep weathered hill country				19,841	218,006	237,847	19,841	237,847
15. Steep weathered igneous rock hill country				2,671	15,340	18,012	2,671	18,012
16. Tephric (ash) hill country	657,149	687,281	1,344,430				657,149	1,344,430
Not hill country	*2,847,128*	*2,255,597*	*5,102,725*	*4,035,197*	*7,490,710*	*11,525,907*	*6,882,325*	*16,628,632*
Total hill country	**2,739,671**	**3,612,818**	**6,352,489**	**1,413,291**	**2,173,106**	**3,586,396**	**4,152,961**	**9,938,885**
Total all NZ	5,586,799	5,868,416	11,455,214	5,448,488	9,663,815	15,112,303	15,188,247	26,567,517

5.3.3 Hill country characteristics of the 23 sites

NSD site characteristics

The 23 sites were originally selected from the National Soils Database (NSD). This is a comprehensive database of approximately 1500 soil descriptions and measurements held and maintained by Landcare Research. Each of the 23 locations were referenced back to the NSD to extract site characteristics, including soil type, NZ Soil Classification (NZSC), profile drainage class, slope (degrees), aspect (degrees or compass category), elevation (height above sea level), annual rainfall, and annual temperature. In some cases descriptions of landscape position were also available.

Representative Local Areas (RLA) site characteristics

A number of sites had incomplete NSD site records, or contained values of uncertain accuracy. Higher confidence was assigned to values that can be readily observed or easily measured in the field (e.g. slope angle, aspect orientation), while lesser confidence is assumed where field measurement was unlikely (e.g. elevation, rainfall, temperature). Lastly, several variables of interest are not recorded in the NSD (e.g. pasture production, erosion rate).

Representative Local Areas (RLAs) were constructed to overcome these limitations. An RLA is the immediately surrounding area that most closely matches slope, aspect, and landform element (and to a lesser extent elevation), to that recorded in the NSD. It is based on the concept and dimensions of the 'soil profile site':

> *"The 'site' refers to the element of the landform on which the profile is positioned. It must not encompass areas more than 50m away from the point of description. It should not include multiple elements or geomorphic surfaces, but it may include several mircrotopographical features. On hill and steep land the site may be much less than 50m in radius if the topographic elements are small."*
>
> *Milne et al. (1995, p. 9)*

RLAs were manually digitised for each site, as areas <0.2 ha that have the most similar slope and aspect to that recorded for the site in the NSD, and either encompass or sit adjacent to the site point location (within 10 m as per Schipper et al. 2010) as identified with GPS during Schipper et al.'s (2010) soil carbon re-sampling.

Zonal statistics were performed, in a GIS framework, over each site RLA to identify median slope, aspect, elevation, rainfall, temperature, and erosion rate. Zonal statistics is a technique used to calculate summary and descriptive statistics from multiple point or cell values that fall within a specified target zone (in this case the RLA). RLA medians were used in lieu of NSD values where NSD values were either missing or suspect.

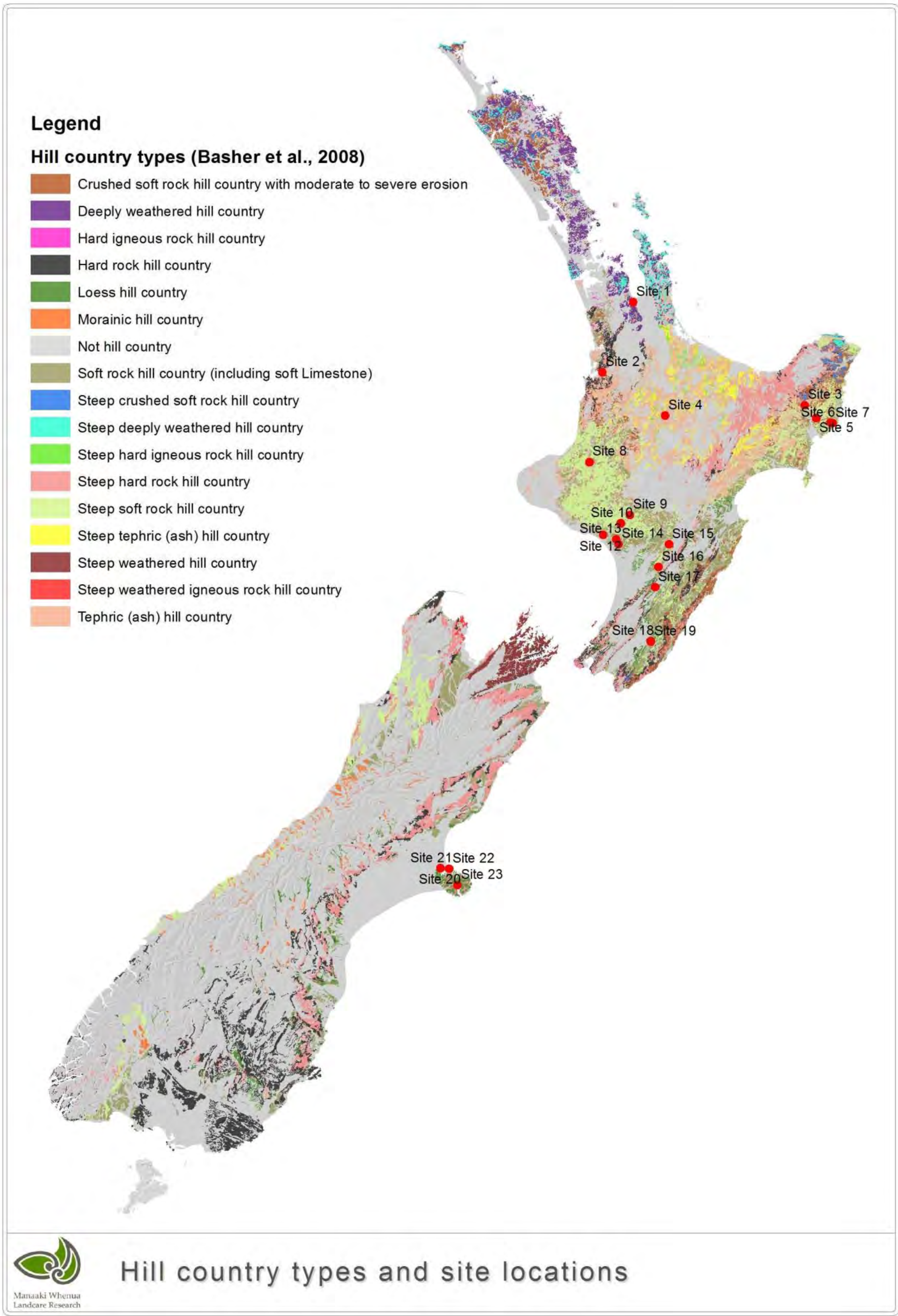


Figure 4: Hill country types and site locations.

Site characteristics as categories

Some data are categorical by nature (e.g. soils), and categorical classification systems are commonly used to help simplify interpretation of continuous data. Slope is classified into seven NZLRI slope groups, while aspect is classed according to eight compass orientations (Table 3).

Table 9 & 10: Slope and aspect categories

NZLRI slope group	Values
A	0–3°
B	3–7°
C	7–15°
D	15–20°
E	20–25°
F	25–35°
G	>35°

Compass orientations	Values
North	337.5–22.5°
Northeast	22.5–67.5°
East	67.5–112.5°
Southeast	112.5–157.5°
South	157.5–202.5°
Southwest	202.5–247.5°
West	247.5–292.5°
Northwest	292.5–337.5°

Note: Care is required with the interpretation of pre-set categories as no indication is given as to where the value may sit within a class. If the value sits close to a class boundary, it may not be fairly represented (e.g. a slope of 15.2°). Where a site value straddles a boundary, the dominant values from the surrounding area are used to determine the appropriate class.

5.4 Determining representativeness (method)

5.4.1 For continuous numerical data

The test of representativeness for continuous data sets is how closely a site value fits within a target population of values. For this study, the population size is defined by the grid-resolution of a spatial dataset. For example, a grid cell resolution of 15 m^2 over the 4.2 million hectares of grazed hill country will produce a population of approximately 184 million individual values. A grid resolution of 2.5 m for a 2-km^2 extent equates to a potential population size of 64 000 values.

If a site value fits within 50% of the population it is deemed to be representative, while proximity to the centre of a distribution indicates the degree of representation.

While a 50% threshold is somewhat arbitrary, it is not uncommon. For example, a population threshold of 50% is used to determine the toxicity of a substance (median lethal dose or LD50) (OECD, 2001).

Quantiles and frequency distributions are used as an appropriate method to determine population distributions, as the datasets mostly had asymmetric distributions.

An index of *distance from the median* (DM) is constructed to indicate the strength of representativeness. This is based on 100 percentile categories calculated for a given dataset using Grass GIS r.quantile, with each 1% change away from the median in either direction being assigned a value of 1.

Thus, an index value of 0 (the median) indicates the strongest possible representativeness, a value between 0and 25 indicates strong representation, while values >25 indicate increasingly marginal representativeness (the 25th and 75th percentiles are synonymous with the upper and lower quartiles of boxplots – Fig. 2).

Index values are symbolised as numbers (1, 2, 3, etc.,…100) while outliers are highlighted in red.

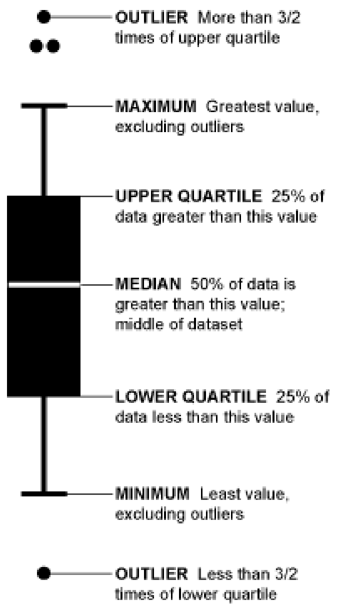


Figure 5: Boxplot terminology.

For categorical data

Percent area is used to provide an indication of representativeness. If the class covers a substantial or dominant area, then it is deemed to be representative. Aspect is analysed by category despite being recorded as a numerical value (0–360°), because north covers both low and high values (337.5–360° & 0–22.5°) and is thus not suitable for spread/distribution type of analysis.

5.5 Datasets

A variety of spatial datasets are used in this study (Table 11). In several cases, spatial datasets at appropriate resolutions or scales were not available (indicated with an X). Areas of representation include only pastoral land (*Eligible total area*).

Table 11: Data sources tabulated by site characteristics and areas being represented

Characteristics	Site values	RLA values	Areas being represented (populations)					
			Hill slope facet	Landscape class	Full 2km² grid	Hill soil type	Hill country type	Hill country all
Eligible total area	-	-	-	-	-	-	-	-
Elevation		1–5 m DEM	1–5 m DEM	1–5 m DEM	x	15 m DEM	15 m DEM	15 m DEM
Slope	NSD	1–5 m DEM	1–5 m DEM	1–5 m DEM	x	15 m DEM	15 m DEM	15 m DEM
Aspect	NSD	1–5 m DEM	1–5 m DEM	1–5 m DEM	x	15 m DEM	15 m DEM	15 m DEM
Erosion	x	NZEEM	x	x	x	NZEEM 15 m	NZEEM 15 m	NZEEM 15 m
Precipitation	NSD	NIWA 500 m	x	x	x	x	NIWA 500 m	NIWA 500 m
Temperature	NSD	NIWA 500m	x	x	x	x	NIWA 500 m	NIWA 500 m
Slope position	NSD	1–5 m DEM	1–5 m DEM	1–5 m DEM	1–5 m DEM	x	x	X
Hill country type	x	Basher et al.	X	X	x	x	x	Basher et al.
Soil type	NSD	X	X	X	x	FSL	FSL	FSL
Soil subgroup	NSD	X	X	X	x	FSL	FSL	FSL
Soil order	NSD	X	X	X	x	FSL	FSL	FSL
Slope groups	(NZLRI)	X	1–5 m DEM	1–5 m DEM	x	15 m DEM	15 m DEM	15 m DEM
Aspect groups	(compass)	X	1–5 m DEM	1–5 m DEM	x	15 m DEM	15 m DEM	15 m DEM
Pasture	x	NZLRI	x	x	x	x	NZLRI	NZLRI
Drainage	NSD	X	x	x	x	x	FSL	FSL

5.5.1 Areas of representation

Site representativeness is examined at several hill country scales:

1. How well does the site represent the immediate hill face or facet? [local]
2. How well does the site represent its landscape position (or landform type) relative to surrounding hill country? [local]
3. How well does the site represent its soil type? [local]
4. How well does the site represent its hill country type? [national]
5. How well does the site represent all grazed hill country in NZ? [national]

Hill country and hill country types are discussed in Section 5.3.2. Local hill slope faces or facets are manually interpreted off hill shaded DEMs to represent the proportion of a landform that could be considered as an individual unit. The extent of a site's soil type within hill country is used as an area of representation to reflect the original reason why the site was actually selected (i.e. as part of the original soil survey it would have been nominated as being representative site for the given soil type). All areas being represented are for grazed pastoral land only.

Landform classification is applied to the surrounding 2 km^2 of a site, using either 1m Lidar elevation if available, or photogrammetry-based 5m DEMs processed especially for this study (See Section 5.3.1). We initially used the Terrain Position Index (TPI) method of classifying landform slope types according to slope classes (De Reu et al. 2013) to identify categories. Thresholds particular to the sites of interest were determined from transects across key landscape positions to identify profiles (Fig. 6).

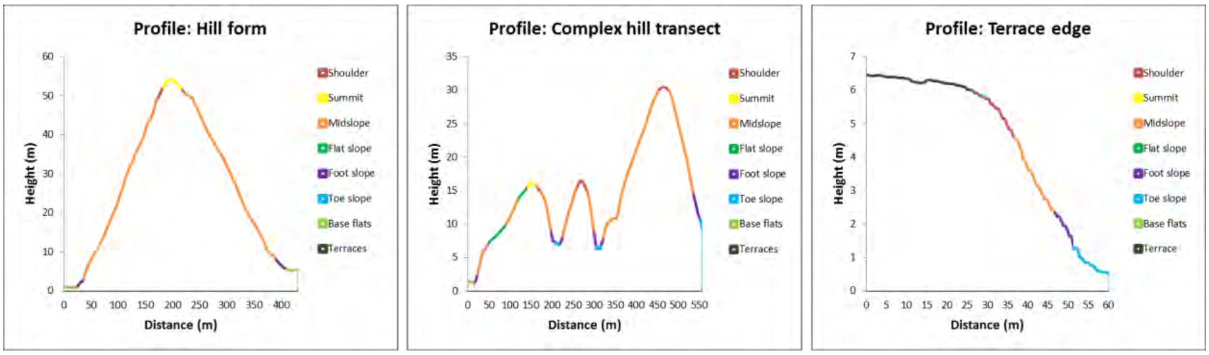


Figure 6: Elevation and landform profiles taken across three transects for Site 1.
Note that height scale of the hill and complex hill transects are exaggerated (which distorts the visual representation of flat slopes). See Figure 7 for location of transects.

This was later simplified as classification of relative slope types, whereby terrain position is normalised according to slope length (each position is assigned a value of 0–100). Landform profiles (Fig. 2) were used to help determine classification thresholds (<7 = valleys and drainages; 7–25 = lower slopes; 25–75 = midslopes; 75–93 = upper slopes; >93 = ridgelines and spurs). This more closely matches the field definitions and thresholds used in Milne et al. (1995) for toe slopes (valleys and drainages), foot slopes (lower slopes), midslopes, and upper slopes. Typically, Milne et al. (1995) specify up to a maximum of 30% of slope length or vertical height for upper and lower slopes, while the normalised slope classification method uses 25% but integrates the effects of changing slope pitch along a slope length.

Non-pastoral vegetation types (trees, roads, buildings) were manually digitised off orthophotography and masked from the analysis (to maintain the focus on grazed hill country only). Extensive areas of flats that are obviously not hill country were manually digitised and classed separately (e.g. flats of high terraces, alluvial river flats).

5.6 Results

The results for the three resampled sites are provided below, and results for all 23 sites are presented in Appendix 4.

5.6.1 Site 13 (SB08318) Okoia

Site 13 is located in Wanganui steep hill country (Kaukatea Valley, Okoia) near the edge of a spur in a midslope postion (Fig. 7). Aspect appears to be incorrectly recorded in the NSD (W) – there are no west facing slopes in the immediate area, although strong NW slopes feature within the same hill facet. Soil type – Okoia steepland soil is classified as EPJ in the NSD, but as PJM in the FSL database. There are no EPJ classifications in the hill country component of the FSL database.

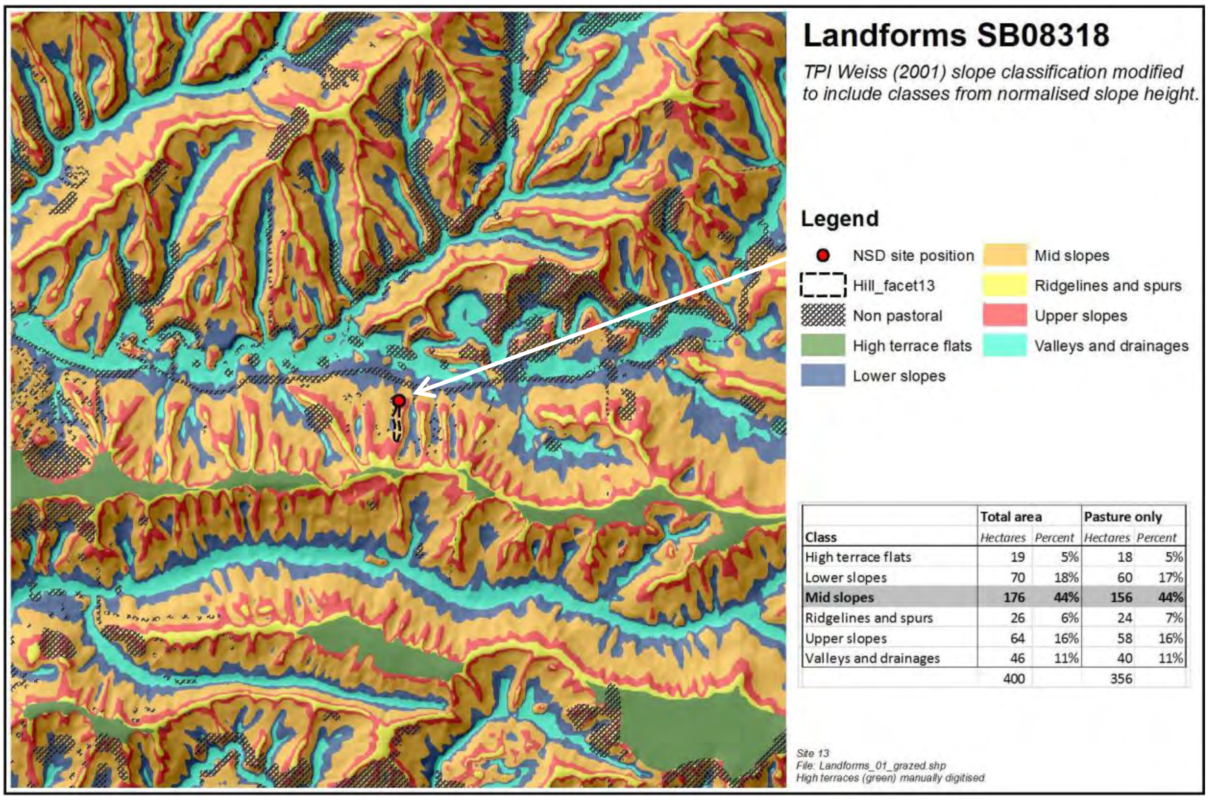


Figure 7: Classification of land forms for site 13 within a 2-km² grid.

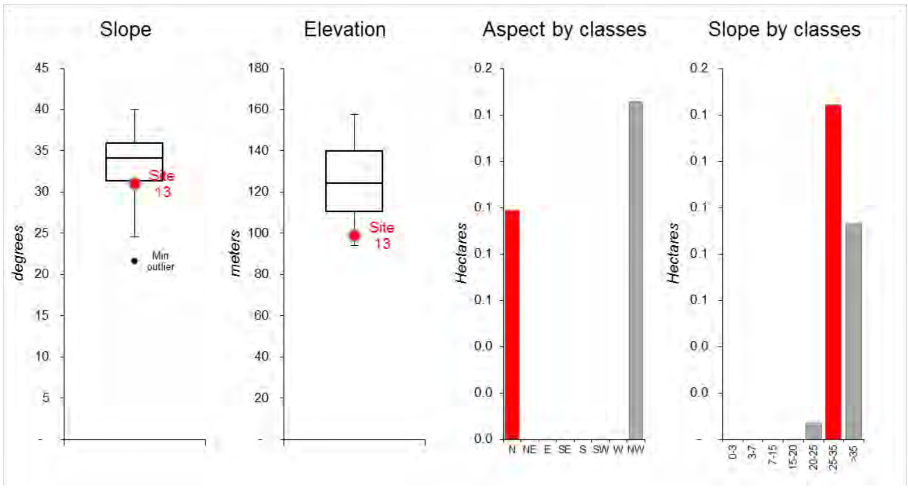


Figure 8: Representativeness of site 13 within the immediate hill facet.

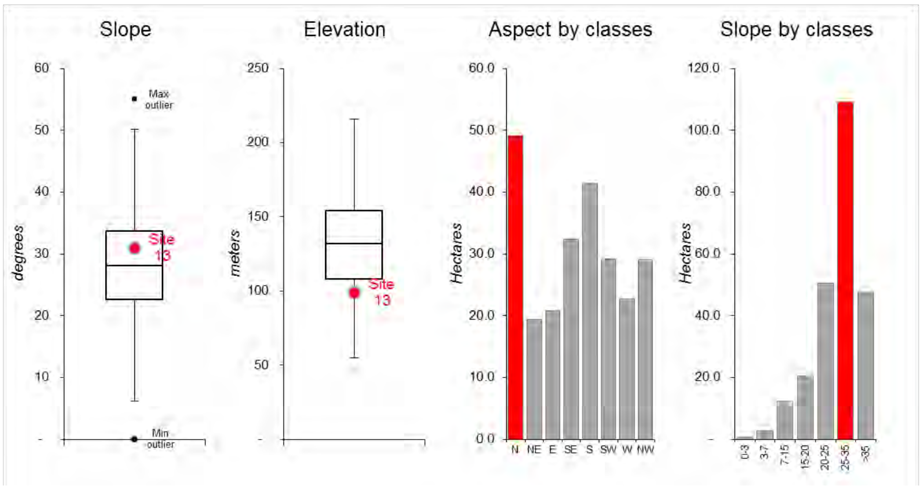


Figure 9: Representativeness of site 13 within midslopes located within a 2-km² grid.

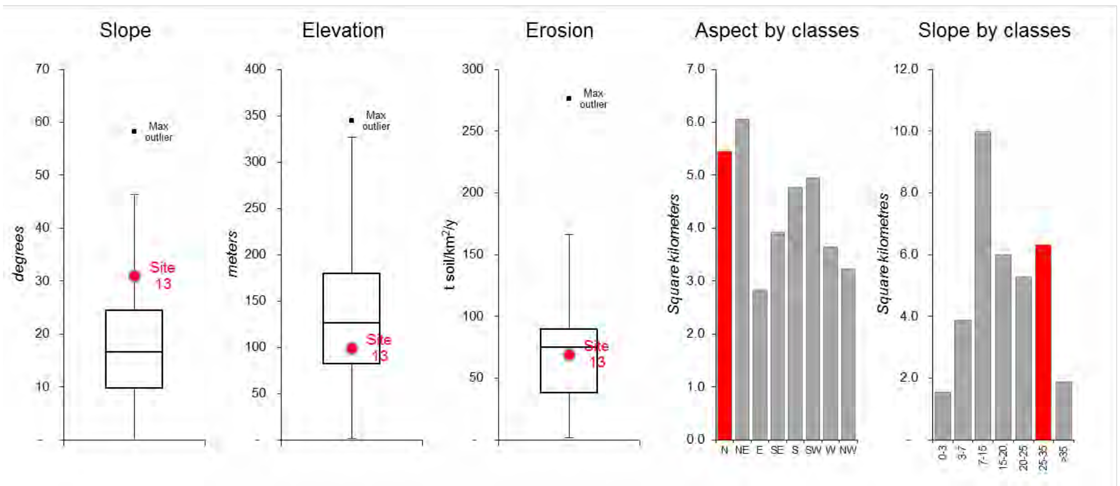
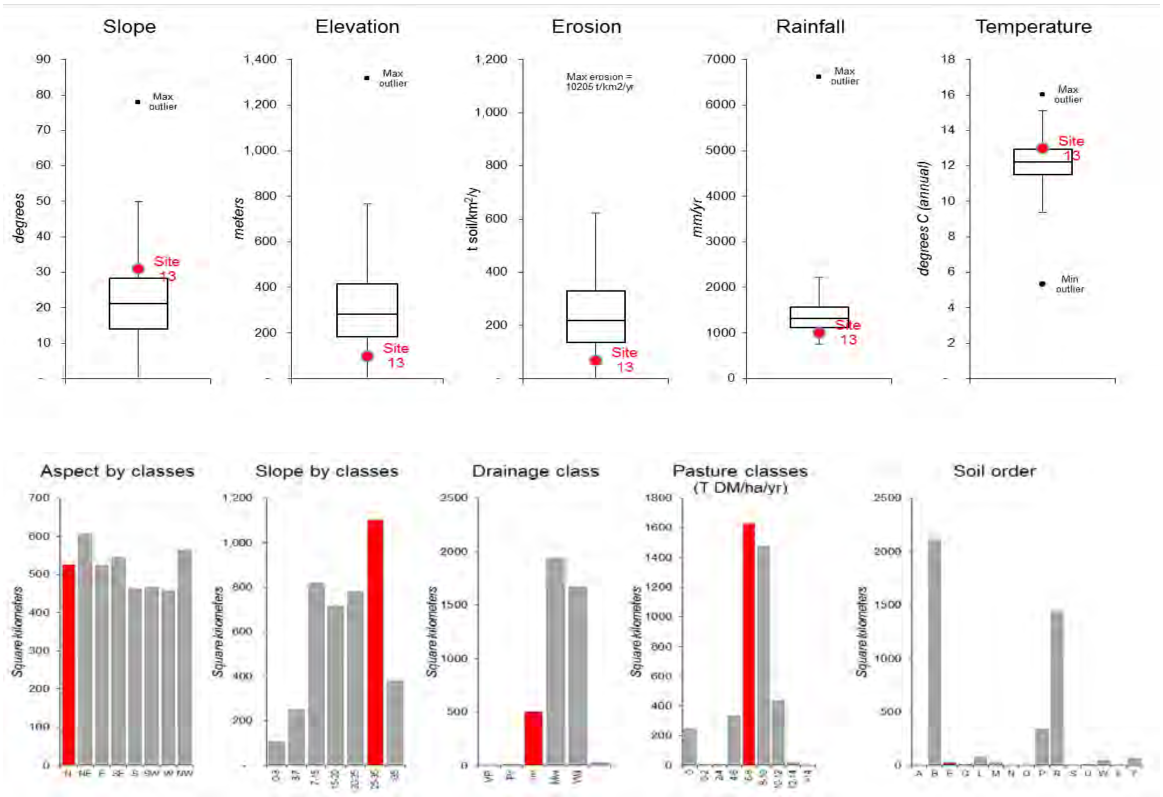


Figure 10: Representativeness of site 13 within the extent of the same soil type.



Representativeness of site 13 within Steep soft rock hill country (12).

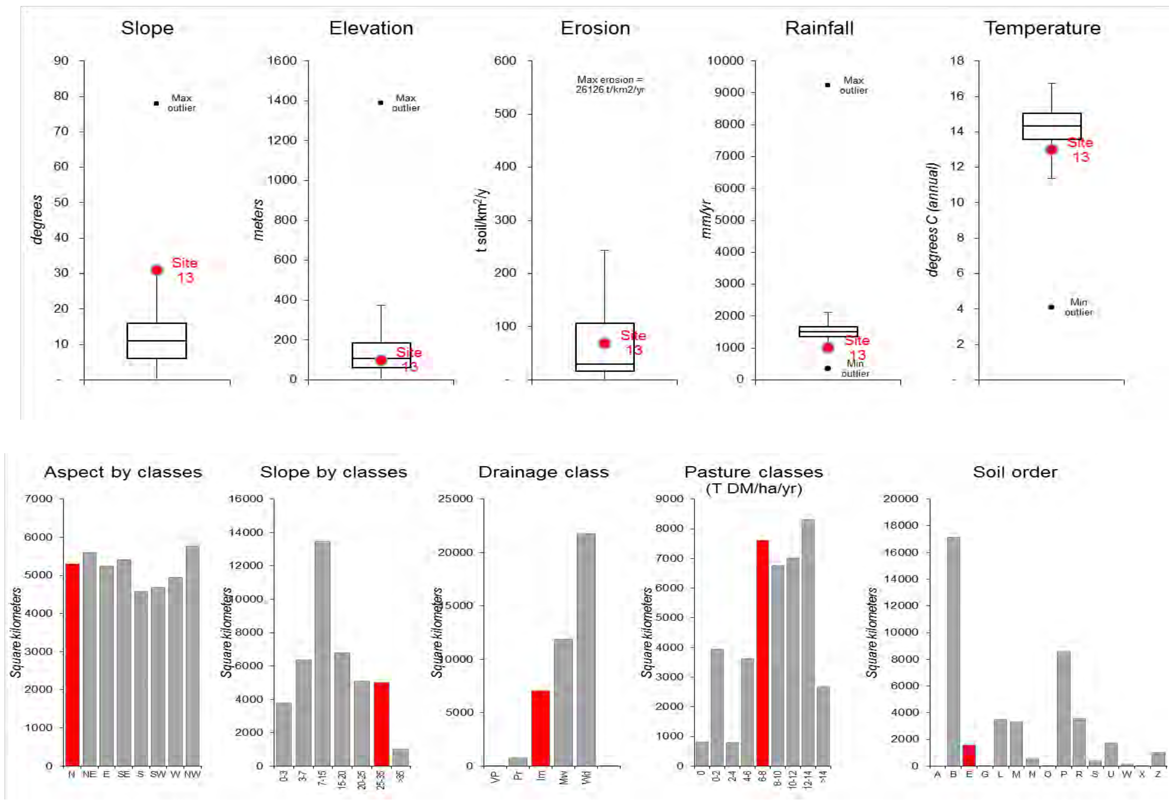


Figure 11: Representativeness of site 13 within all NZ hill country.

Table 12: Distance from the median and percent area of Site 13 characteristics according to different areas of representation

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Midslopes within 2 km²	Hill country within 2 km²	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	-	*0.004 ha*	*0.2 ha*	*244 ha*	*356 ha*	*35 ha*	*4153 km²*	*4.1 M ha*
Elevation (m)	*91*	**99**	**45**	**33**	x	**16**	**42**	**5**
Slope (degrees)	***31***	31	**25**	**15**	x	**39**	**33**	**48**
Aspect (degrees)	*270*	**6**	x	x	x	x	x	X
Erosion (t soil/km²/y)	*69.3*	x	x	x	x	**8**	**47**	**17**
Precipitation (mm)	965	**1006**	x	x	x	x	**44**	**49**
Temperature (°C)	-	**13**	x	x	x	x	**25**	**39**
Midslopes	-	x	x	x	**44%**	x	x	X
Hill country type	*12*	x	x	x	x	x	x	**10%**
Soil type	*OkS*	x	x	x	x	x	**0.5%**	**0.1%**
Soil subgroup	*EPJ*	x	x	x	x	x	x	X
Soil order	*E*	x	x	x	x	x	**1%**	**4%**
Slope group	-	25–35°	**59%**	**45%**	x	**18%**	**27%**	**12%**
Aspect group	*W*	**N**	**40%**	**20%**	x	**16%**	**13%**	**13%**
Pasture (kg DM/ha/y)	*6860*	x	x	x	x	x	**39%**	**18%**
Drainage	*I m*	x	x	x	x	x	**12%**	**17%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0–50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

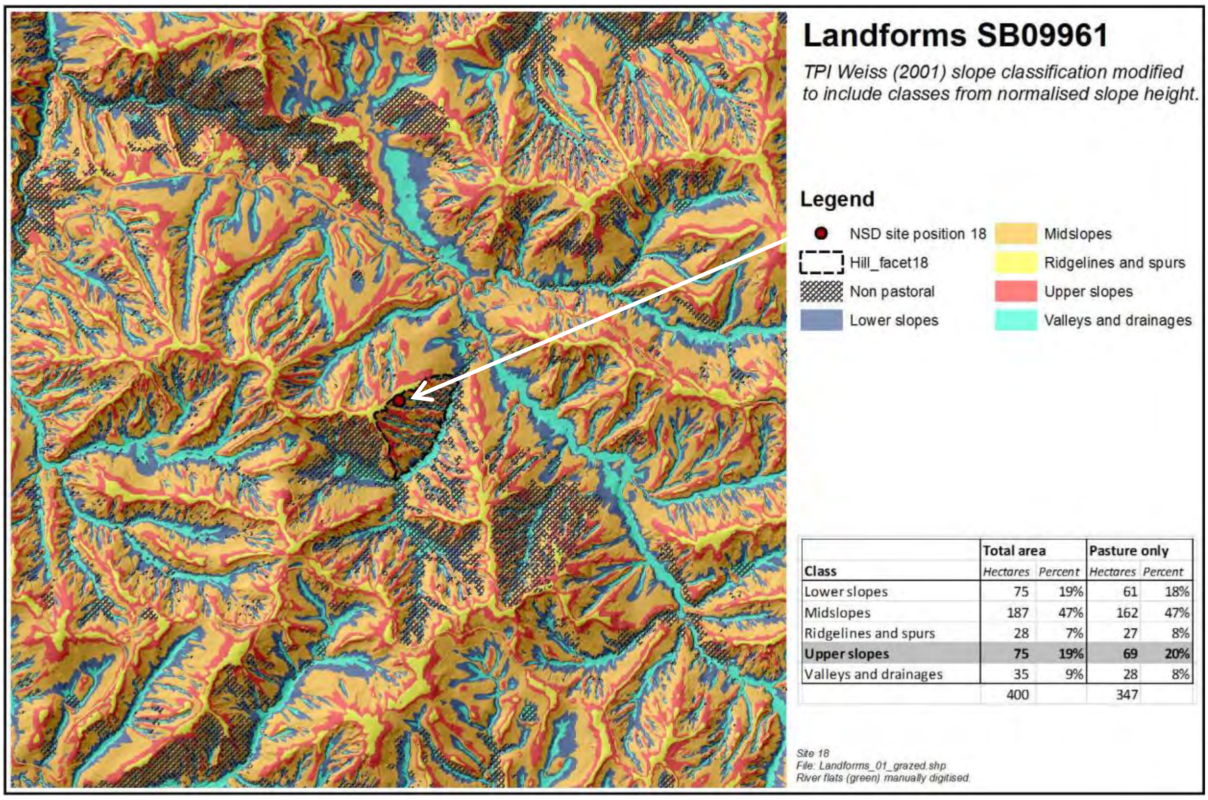
Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales).

5.6.2 Site 18 (SB09961) Te Whanga 1

Site 18 is located in Steep soft rock hill country (12) on Te Whanga Station in the Wairarapa. Soil type is Taihape steepland soil (PJM). The site location actually falls within the Loess hill country of Basher et al. (2008), but the surrounding Steep soft rock hill country is used because this is the class that Taihape steepland soils associate with. The NSD describes a midslope position but landform classification places it as an upper slope (Fig. 12).



	Total area		Pasture only	
Class	Hectares	Percent	Hectares	Percent
Lower slopes	75	19%	61	18%
Midslopes	187	47%	162	47%
Ridgelines and spurs	28	7%	27	8%
Upper slopes	**75**	**19%**	**69**	**20%**
Valleys and drainages	35	9%	28	8%
	400		347	

Figure 12: Classification of land forms for site 18 within a 2-km² grid.

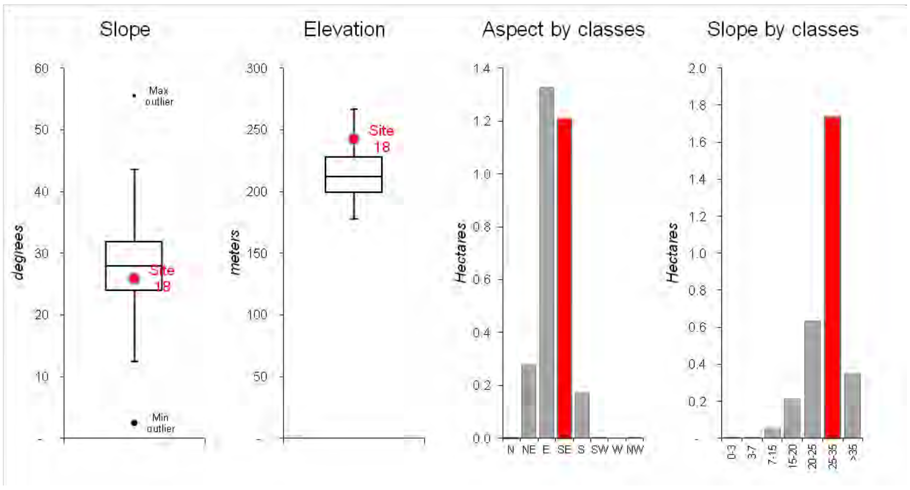


Figure 13: Representativeness of site 18 within the immediate hill facet.

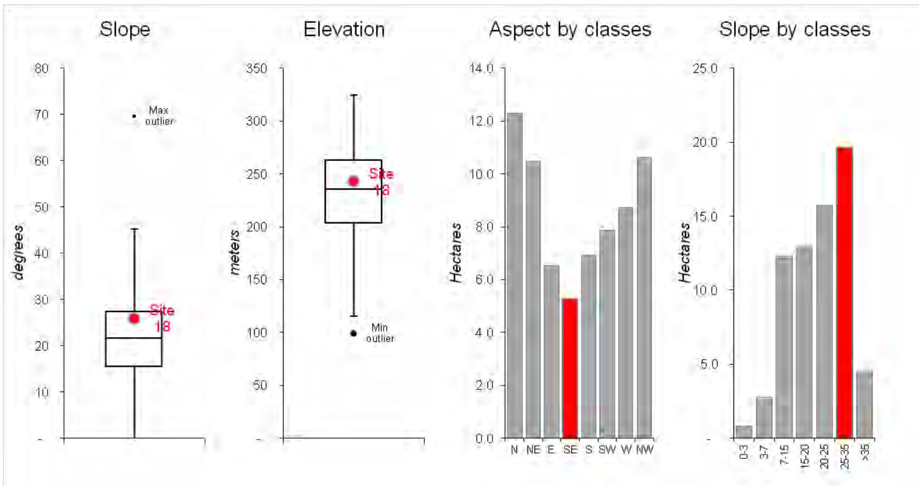


Figure 14: Representativeness of site 18 within upper slopes located within a 2-km² grid.

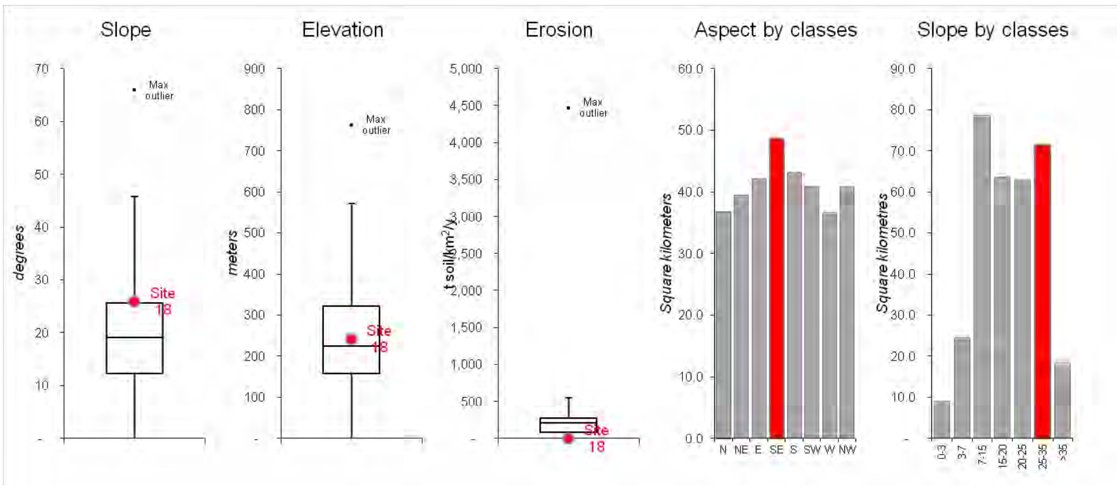
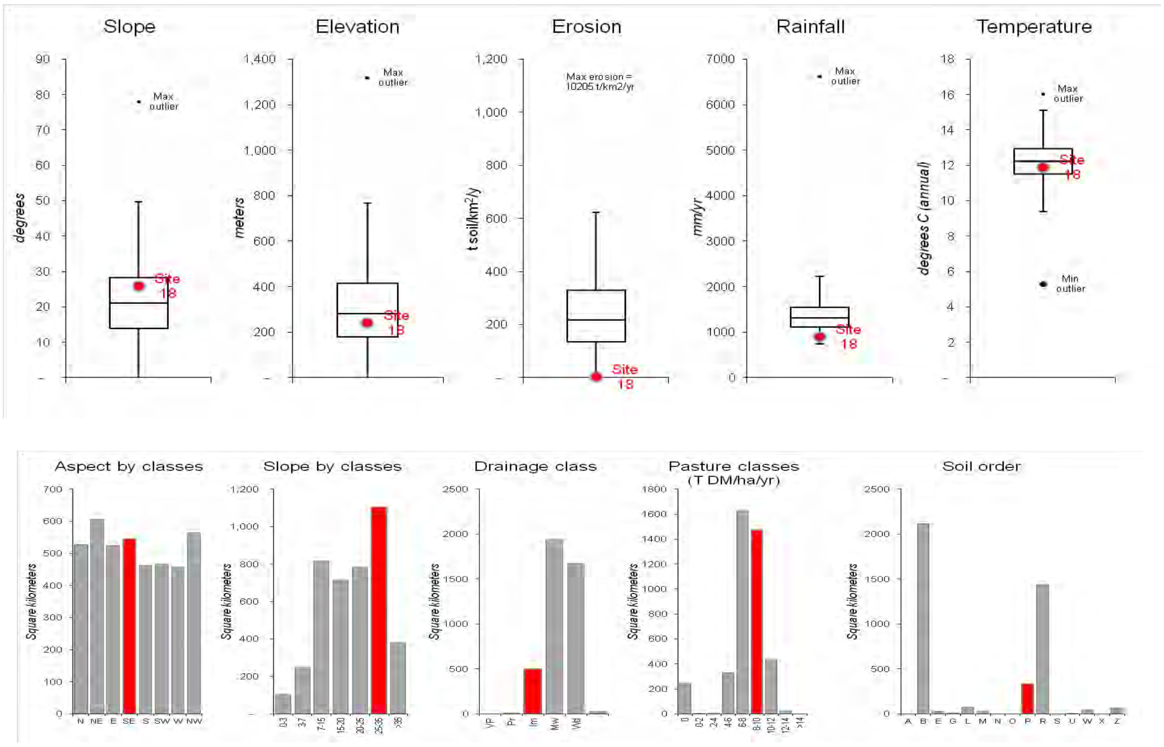


Figure 15: Representativeness of site 18 within the extent of the same soil type.



Representativeness of site 18 within Steep soft rock hill country (12).

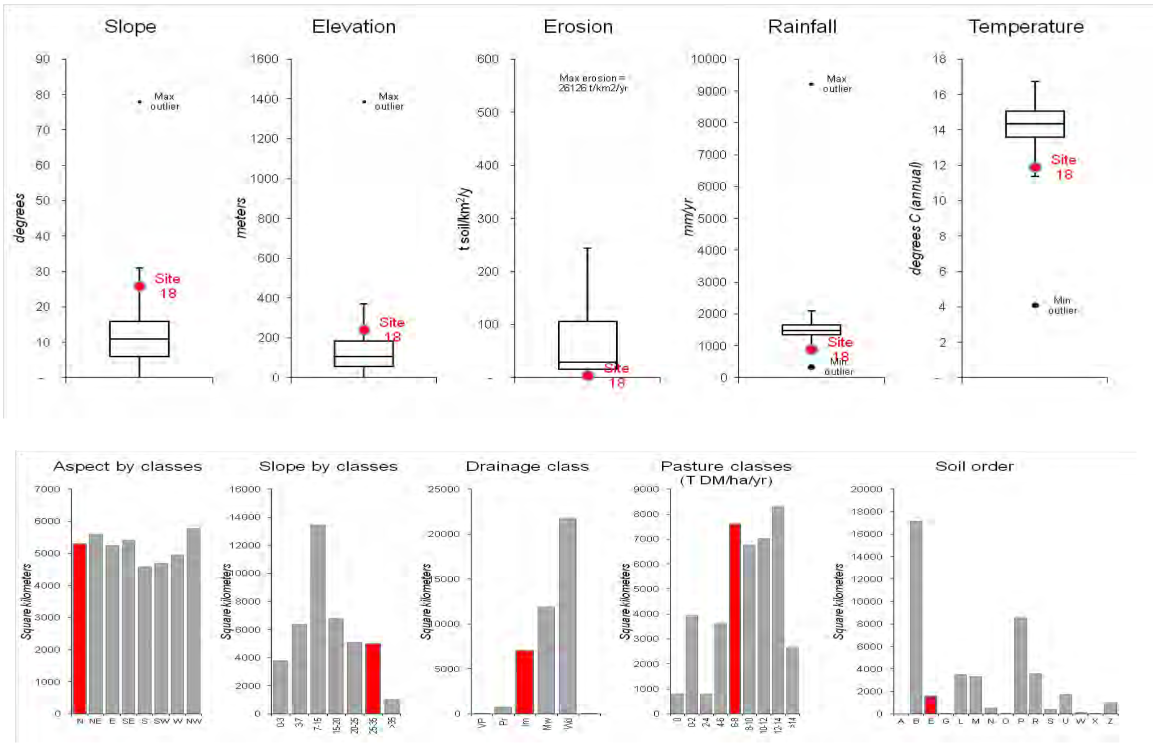


Figure 16: Representativeness of site 18 within all NZ hill country.

Table 13: Distance from the median and percent area of Site 18 characteristics according to different areas of representation

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Upper slopes within 2 km²	Hill country within 2 km²	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	-	*0.0004 ha*	*3 ha*	*69 ha*	*347 ha*	*328 ha*	*4152 km²*	*4.1 M ha*
Elevation (m)	*230*	**243**	**41**	**7**	x	**6**	**9**	**34**
Slope (degrees)	***26***	25.5	**12**	**21**	x	**25**	**18**	**45**
Aspect (degrees)	*122*	**124**	x	x	x	x	x	X
Erosion (t soil/km2/y)	*3.9*	x	x	x	x	**49**	**49**	**49**
Precipitation (mm)	1000	**898**	x	x	x	x	**48**	**49**
Temperature (°C)	11.7	**11.9**	x	x	x	x	**13**	**48**
Upper slopes	-	x	x	x	**20%**	x	x	X
Hill country type	*12*	x	x	x	x	x	x	**10%**
Soil type	*ThS*	x	x	x	x	x	**6.7%**	**0.8%**
Soil subgroup	*PJM*	x	x	x	x	x	**1%**	**2%**
Soil order	*P*	x	x	x	x	x	**8%**	**21%**
Slope group	-	25-35°	**58%**	**29%**	x	**22%**	**27%**	**12%**
Aspect group	*SE*	SE	**40%**	**8%**	x	**15%**	**13%**	**13%**
Pasture (kg DM/ha/y)	*9,430*	x	x	x	x	x	**35%**	**16%**
Drainage	*I m*	x	x	x	x	x	**12%**	**17%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0–50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

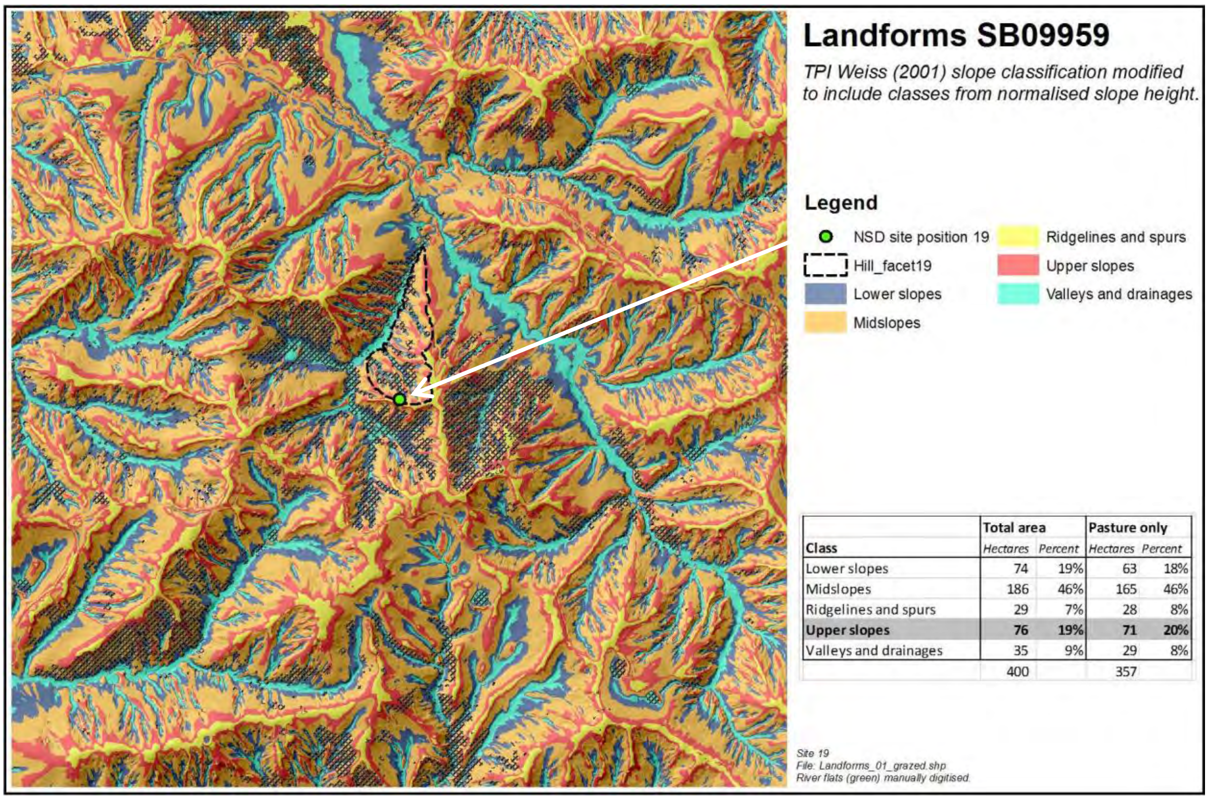
Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

5.6.3 Site 19 (SB09959) Te Whanga 2

Site 19 is located approximately 300 m to the SE of previous site 18 (Te Whanga, Wairarapa), on the opposite side of a valley. Soil type is Taihape steepland soil with a NZSC of EOJ. The NSD describes site position as being a midslope, but position is just off a spur and thus better qualifies as an upper slope. As with site 18, hill country type is assigned as nearby *Steep soft rock hill country (12)*. Both sites also share the same soil type, but somewhat unusually quite different NZ soil classifications.



	Total area		Pasture only	
Class	Hectares	Percent	Hectares	Percent
Lower slopes	74	19%	63	18%
Midslopes	186	46%	165	46%
Ridgelines and spurs	29	7%	28	8%
Upper slopes	**76**	**19%**	**71**	**20%**
Valleys and drainages	35	9%	29	8%
	400		357	

Figure 17: Classification of land forms for site 19 within a 2-km² grid.

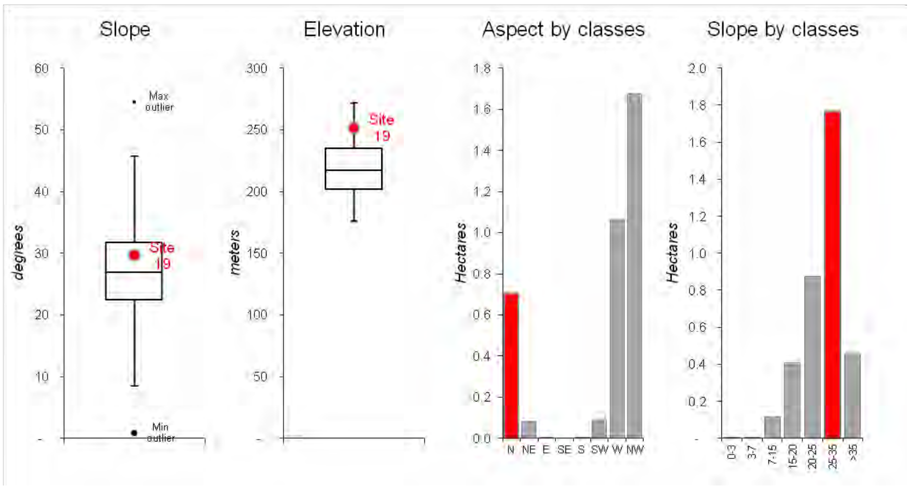


Figure 18: Representativeness of site 19 within the immediate hill facet.

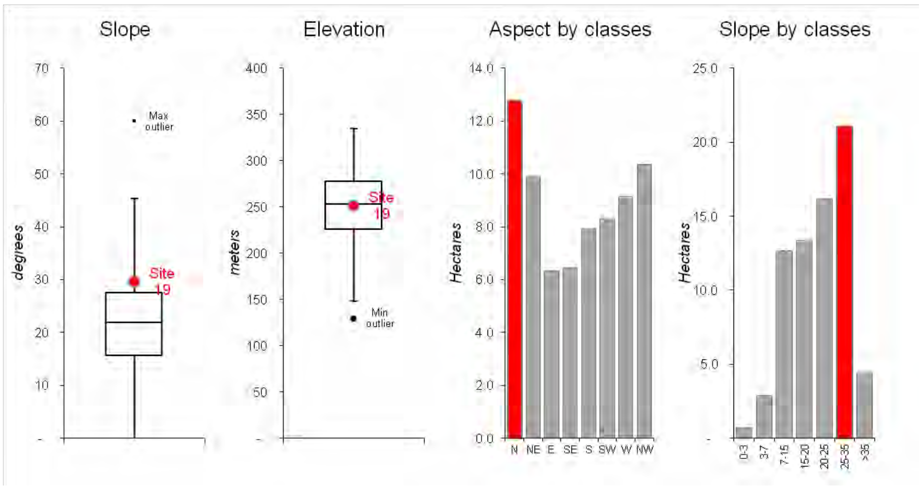


Figure 19: Representativeness of 19 within upper slopes located within a 2-km² grid.

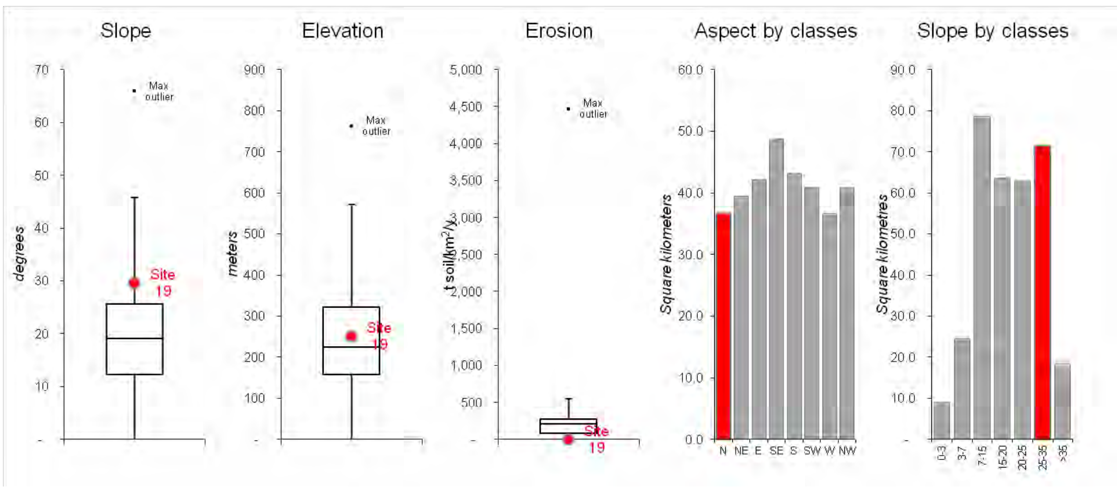
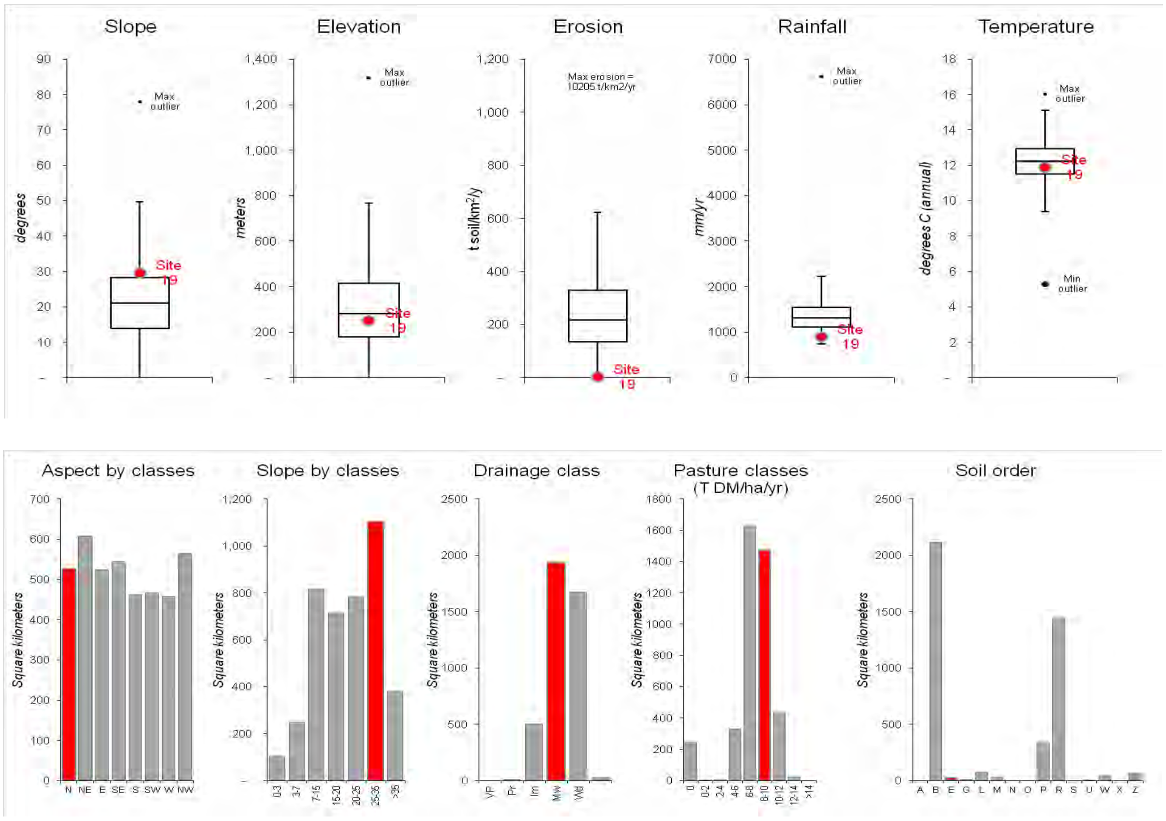


Figure 20: Representativeness of site 19 within the extent of the same soil type.



Representativeness of site 19 within Steep soft rock hill country (12).

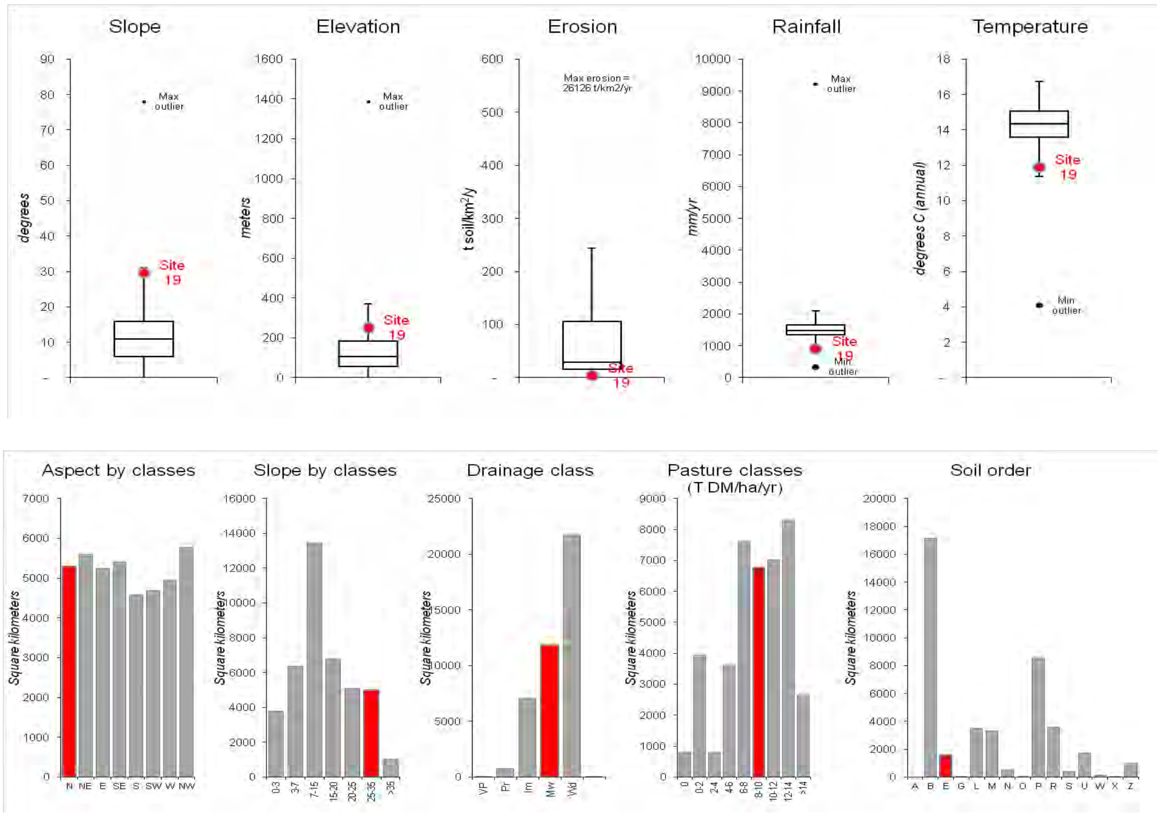


Figure 21: Representativeness of site 19 within all NZ hill country.

Table 14: Distance from the median and percent area of Site 19 characteristics according to different areas of representation

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Upper slopes within 2 km²	Hill country within 2 km²	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	*-*	*0.001 ha*	*3.6 ha*	*71 ha*	*357 ha*	*328 ha*	*4152 km²*	*4.1 M ha*
Elevation (m)	*240*	**252**	**41**	**2**	x	**8**	**7**	**34**
Slope (degrees)	***30***	29.7	**15**	**33**	x	**36**	**29**	**47**
Aspect (degrees)	*340*	**349**	x	x	x	x	x	X
Erosion (t soil/km²/y)	*4.0*	x	x	x	x	**49**	**49**	**49**
Precipitation (mm)	1000	**905**	x	x	x	x	**48**	**49**
Temperature (°C)	11.7	**11.9**	x	x	x	x	**12**	**48**
Upper slopes	-	x	x	x	**20%**	x	x	X
Hill country type	*12*	x	x	x	x	x	x	**10%**
Soil type	*ThS*	x	x	x	x	x	**6.7%**	**0.8%**
Soil subgroup	*EOJ*	x	x	x	x	x	**0%**	**1%**
Soil order	*E*	x	x	x	x	x	**1%**	**4%**
Slope group	-	25–35°	**49%**	**30%**	x	**22%**	**27%**	**12%**
Aspect group	*N*	N	**19%**	**18%**	x	**11%**	**13%**	**13%**
Pasture (kg DM/ha/y)	*9,430*	x	x	x	x	x	**35%**	**16%**
Drainage	*Mw*	x	x	x	x	x	**47%**	**29%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0–50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

6 National Soil Database (NSD) search and field campaign

6.1 Identifying NSD hill country pasture sites

A spreadsheet containing 1503 sites from the NSD database was progressively filtered to 100 pastoral sites in hill country that may be useful for further consideration with respect to characterising hill country soil carbon stocks (see Fig. 22 and Appendix 2).

The filtering was carried out in the following order with the number of sites fitting the criteria in brackets:

1. Measured slope angle (profile position) – 10° or greater and also blanks in slope field (558)
2. Measured slope angle (profile position) – 10° or greater without blanks in slope field (408)
3. Vegetation cover map classes – all classes with grasses dominant, including tussock (246)
4. Vegetation cover map classes – improved and unimproved pasture, excluding tussock (158)
5. Land use – excluded categories for rough grazing recreation, unused natural, unused reverted (130)
6. NZMG co-ordinates – excluded sites without co-ordinates (100)

Figure 22: Plotted co-ordinates of 100 hill country NSD sites.

6.2 Identifying clusters of hill country pasture NSD sites

This exercise identified where there were clusters of more than two NSD hill country pasture sites within an approximate 4-km radius. One aim of the exercise was to determine whether there were clusters of NSD sites within the same general area but on different landscape positions. If such clusters of sites existed and they were then resampled, rates of change in SOCS could have been calculated for different slope positions. There were only eight locations throughout the country (see list below) where two or more NSD sites were within 4 km of each other, and most sites at these locations were on similar landscape positions.

1. Wairarapa – Te Whanga (SB09958-64)
2. East Coast – Gisborne (SB10175-9 and SB10153)
3. Otago – Otago Peninsula (SB08503-7, SB08508)
4. Canterbury – Cashmere Spur (SB9464-6)
5. Canterbury – Port Hills (SB09467, SB09469, SB09496)
6. Whanganui – Whangaehu (SB08346, SB08347, SB08349)
7. Whanganui – Kaiiwi (SB08690, SB08613, SB08614)
8. Whanganui – Turakina (SB08251-4, SB08691-3, SB08697)

There were also up to 40 sites identified on the Ballantrae research farm, but these sites did not have coordinates recorded.

On the basis of this analysis and the overall project goals, two sites were selected to collect new information on soil carbon stocks, and the range of stocks occurring within a 2km^2 grid of the NSD site. The sites were selected using the following criteria:

- One of the 23 sites previously resampled by Schipper et al. (2010, 2013, 2014)
- Availability of a high resolution digital elevation map to enable statistical analysis of terrain attributes for stratified sampling
- Accessibility of terrains with contrasting aspects and slope classes within the 2-km^2 grid surrounding the NSD sites

The two sites selected were Okoia (Site 13, SB08318), near Wanganui, and Te Whanga Station (Site 18, SB09961, SB09959), near Masterton.

6.3 Field campaign to assess spatial variability of soil carbon stocks

6.3.1 Background

Our literature review (Section 4) explains that soil C stocks are especially variable in hill country compared with non-alluvial flat land, because soil forming processes and accompanying soil carbon accumulation are influenced by landscape position and hillslope processes. Erosion events accelerate the changes in soil carbon stocks that occur on simple non-eroded hillslopes.

This portion of the study was therefore designed to assess soil carbon stocks for two selected hill country locations by sampling all topographic units within the study area using a stratified sampling approach. We used this approach to assess how soil C stocks varied in the landscape, and whether variation could be related to differences in hillslope position.

Conventional SOCS estimation methods sample study plots, selected randomly within the area of interest (e.g. EU: Stolbovoy et al. 2005; NZ: Davis et al. 2004). Temporal change in SOCS is then estimated by sampling these study plots at a later date, which complied with Kyoto Protocol guidelines. Alternatively, a representative profile, based on pedological features, may be resampled through time to assess SOCS change for the region that it is thought to represent (Schipper et al. 2012).

These methods account for C change through time, and are economically feasible (Stolbovoy et al. 2005). However, C variability analysed using these methods, cannot be represented spatially. A method that assesses spatial variations of SOCS is desirable because it improves our understanding of topography-driven processes of soil organic C accumulation; particularly relevant in hill country.

In this study we used conditioned Latin Hypercube Sampling (cLHS) (Minasny & McBratney 2006) to stratify sampling positions, without proceeding to produce the soil carbon map (see Section 4.5.3).

The aim of this part of the study was therefore to assess the range of SOC stocks at two of the 23 sites of Schipper et al. (2012), so that the stocks within a 2-km^2 grid of the NSD sites could more accurately be assessed for the date of sampling. This study also enabled us to resample the NSD sites, and based on our observations recommend a new method for assessing change in SOC stocks with time.

Covariate datalayers obtained from a digital elevation model, were used to automate the selection of stratified sampling positions that sample the likely full range of SOCS values in the areas of interest. This aims to provide an improved estimate of mean soil carbon stocks for the hill country sites selected.

6.3.2 Method

Site selection

Two sites were selected from the 23 sites of Schipper et al. (2012) where good quality DEMs had been produced for this project (using Lidar data) to facilitate implementation of the stratified sampling method. The two selected sites were Okoia and Te Whanga.

Okoia (Site 13, SB08318) has a strong north-south aspect, enabling investigation of the effect of aspect as well as slope position on SOCS.

The site is located in steep soft rock hill country near Wanganui.

Te Whanga (Sites 18 and 19; SB09961 and SB09959) provided two SB sites, and has been the focus of a number of previous soil carbon studies, e.g. looking at recovery of soil C on erosion scars and soil quality (e.g. Sparling et al. 2003; Rosser & Ross 2011; de Rose 2013). However, these previous studies did not assess the spatial variability of SOCS, and this project provides a good opportunity to address this “knowledge gap”. Te Whanga Station is located near Masterton in the Wairarapa.

Site descriptions

Okoia (Site 13, SB08318)

This site is part of the Tweeddale property which is a summer-dry hill country property producing 7200 kg pasture DM/ha/year and running 2628 stock units (70:30 sheep: cattle ratio) across an effective area of 293 ha (9 su/ha) (LandVision Ltd, 2009). The underlying geology is a combination of massive sandstone and sandy siltstone lithologies, with high terrace flats formed from loess, with the low flats adjacent to the stream being formed from alluvium. Average annual rainfall for the Wanganui region is 920 mm, with mean annual temperature ranges from 14ºC in January to 6ºC in July.

Te Whanga (Sites 18 and 19; SB09961 and SB09959)

The study site was located on permanent pastures at Te Whanga station, Wairarapa, New Zealand (4181.9575S, 175844.530E). The terrain is steeply dissected by streams and is underlain by unconsolidated, tectonically deformed Tertiary siltstone. Soils at Te Whanga station are Taihape steepland soils (Rosser & Ross 2011). Deforestation of indigenous forest and conversion to pasture from1860 to 1890 increased the vulnerability of steeper slopes to soil slip erosion (Trustrum et al. 1990), with extensive areas of soil slipping being a feature of this landscape (Rosser and Ross, 2011). Average annual rainfall is 1075 mm; mean annual temperature ranges from 19C in January to 8C in July. The climate is described as seasonally dry, with frequent summer droughts.

Soil sampling

Stratified soil sampling strategy

The constrained Latin hypercube sampling (cLHS) method was applied to select soil sampling positions at the study sites. The analysis was conducted using the R statistical environment (R Core Team 2014). The cLHS method selects sampling sites to stratify a suite of environmental variables that represent soil-forming factors. For both sites, the environmental covariates have been produced from a high-resolution digital elevation map (DEM), derived from a Lidar survey, in a GIS environment and selected to best represent soil-forming factors at each of those two sites:

- At the Okoia site, elevation, aspect, slope, mean annual solar radiation, topographic position index (TPI), and the water accumulation pathways were selected. Additionally, a map of landform elements has also been derived from the TPI layer and used in the stratification process (Fig. 23).
- At the Te Whanga site, elevation, slope, mean annual solar radiation and SAGA wetness index (SWI) were selected (Boehner et al. 2002). At the site, the SWI was preferred to the TPI as it gives better results in flat bottom valley areas. A map of landform elements has also been used in the stratification process, along with a legacy map of parent material, sourced from previous studies at this site (Fig. 24).

Figures 23 and 24 provide boxplots to compare the population distribution of the selected sampling positions (right side) against the total population of all positions within the area of interest (left side). Frequency graphs are also provided to show the apportioning of sampling positions against the terrain units.

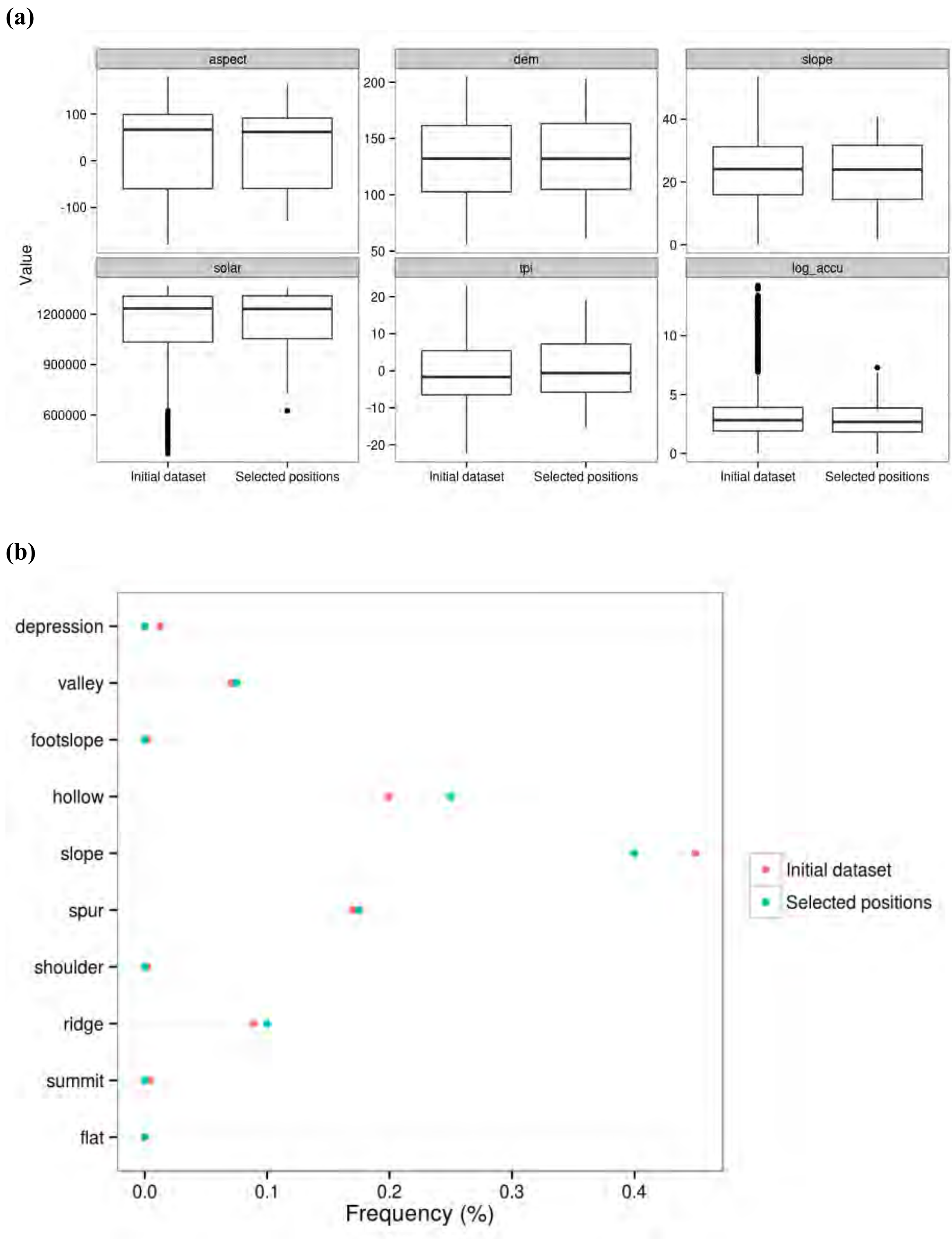
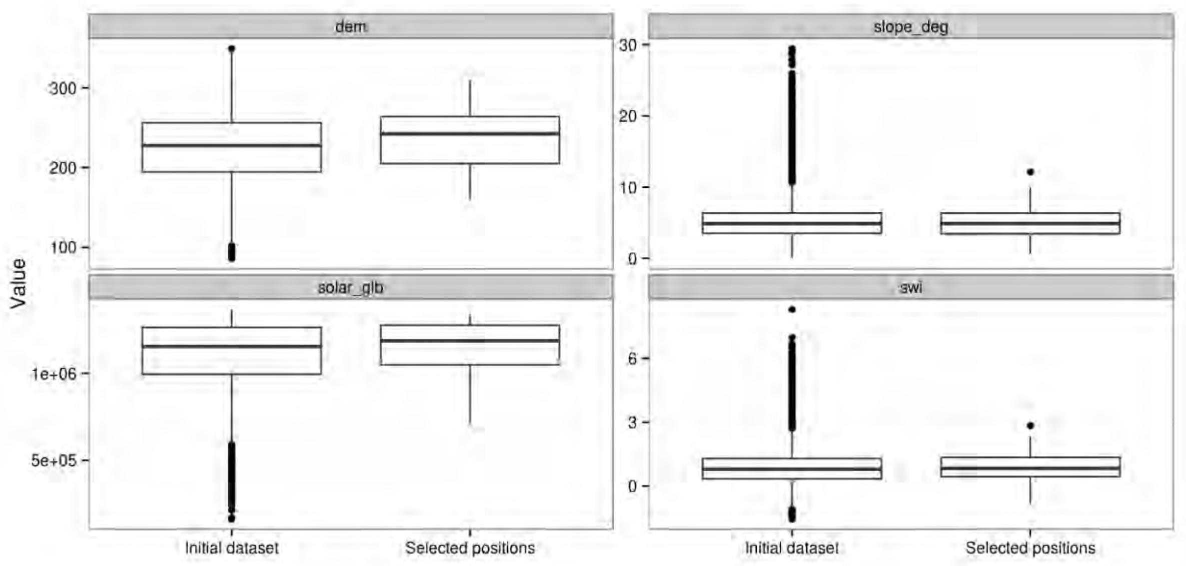


Figure 23: Boxplot (a) and frequency graph (b) to show the results of the cLHS for Okoia.

(a)



(b)

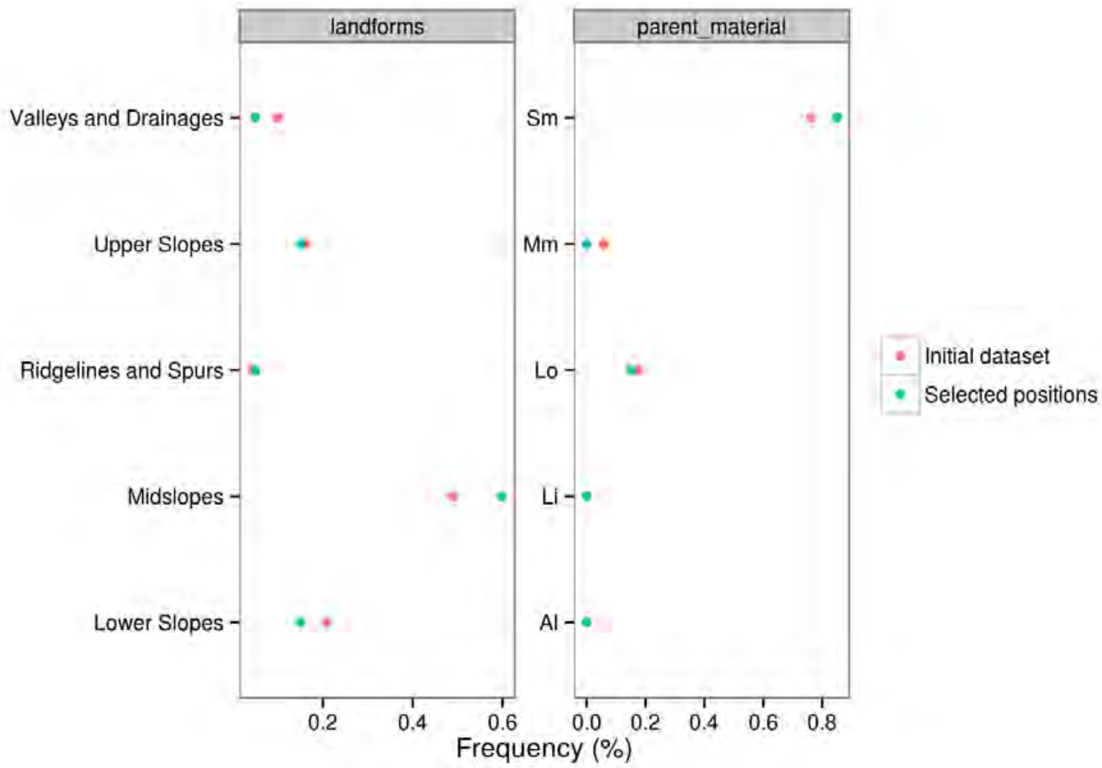


Figure 24: Boxplots (a) and frequency graph (b) to show the results of the cLHS for Te Whanga.

Figures 23 and 24 show that the statistical distributions of the sampled set, matches with the original statistical distributions of the environmental covariates; and the sampling positions are proportionally located on terrain attributes, e.g. summits, ridges, upper slopes, midslopes, lower slopes, hollows and valleys.

The sampling positions proposed by the cLHS analysis are shown in Figures 25 and 27 below.

Resampling of the NSD sites

The NSD sites at Okoia (SB08318) and Te Whanga (SB09959; SB09961) were resampled, in addition to the stratified sampling within a 2-km^2 square grid of these sites. At each NSD site, three replicated soil cores were extracted to estimate SOCS to at least 0.3 m. The three replicates were taken within 5 m of the reported NSD position, ensuring that they were within the same topographic unit and avoiding any unusual features (e.g. fence lines, large trees).

Field sampling

Field campaigns collected intact soil cores from stratified positions (Figs 25 and 27) to at least 30 cm, if possible, for lab estimation of soil organic carbon stocks.

Soil cores were collected using a portable soil corer (Fig 26), with internal diameter 45 mm. Any compaction was noted by measuring the depth of the hole and the length of the extracted soil core. If compaction was observed, the additional length was added to the deepest sampling depth. This is because the weaker structured subsoils were observed to be where the compaction occurred.

The intact soil cores were brought back to the lab inside plastic liners, for Vis-NIR scanning at 1-cm intervals (results not reported here). The cores were then subsampled at fixed lengths for bulk density and total C analysis using a Leco furnace. All C analyses were undertaken in the Landcare Research IANZ accredited ECLab, located in Palmerston North.

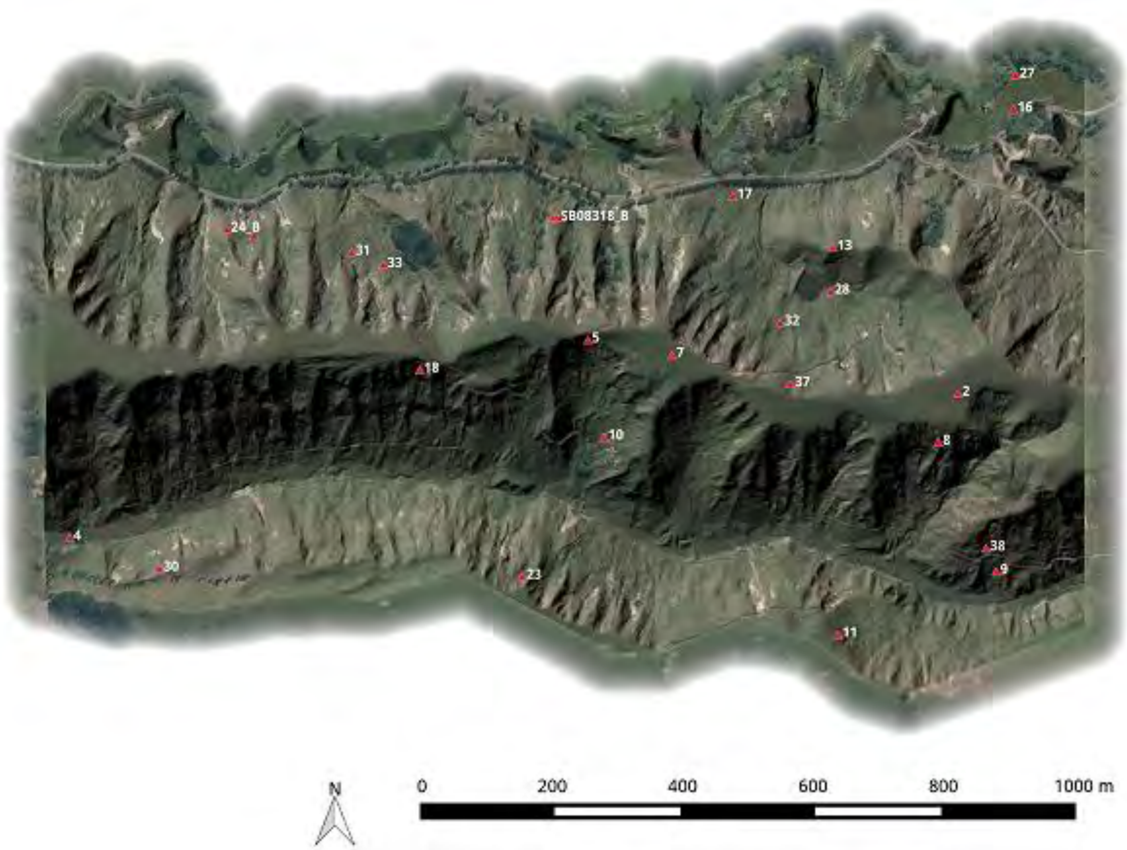


Figure 25: Stratified sampling positions, with ID numbers, in the proximity of SB08318 at Okoia.


SB08318 (lower slope, N-facing)


View from Site 30 (mid slope, N-facing)

Figure 26: Two of the soil sampling positions at Okoia (SB08318, Site 30)

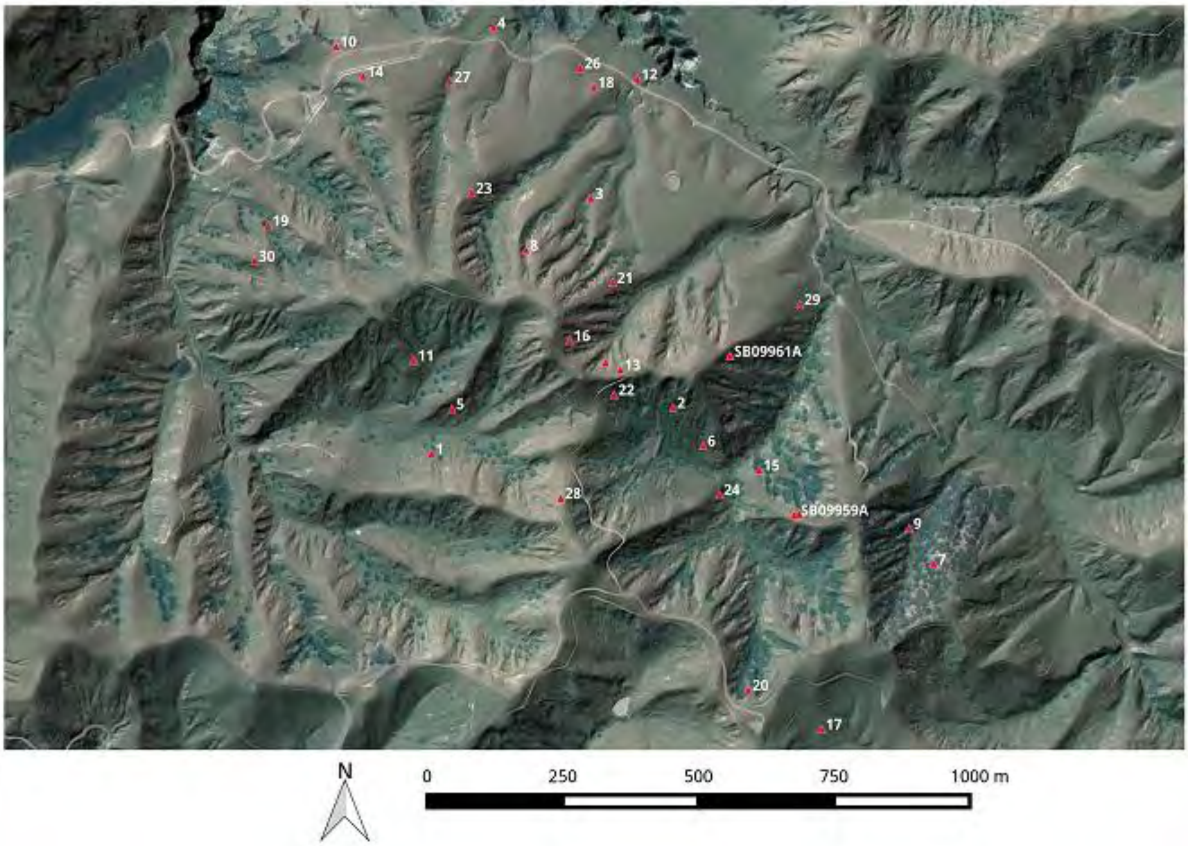


Figure 27: Stratified sampling positions, with ID numbers, in the proximity of SB09959 and SB09961 at Te Whanga.

SB09961 upper slope, S-facing (original peg was located)

Figure 28: Three of the soil sampling positions at Te Whanga (SB09961, Site 21, Site 30) – continued next page.


Site 21 upper slope, N-facing


Site 30 Flat position at top of slope, N-facing

Figure 28: Continued (Site 21, Site 30)

6.3.3 Results

Soil carbon results

The soil organic carbon stock estimates at Okoia ranged between 30.89 and 119.87 (Mg C ha^{-1} to 0.3 m). The highest value occurs on a stable spur on the N-facing side of the study area (Site 13) (Figs 25, 29, 30). The lowest value occurs at a steep midslope position on the S-facing side of the study area (Site 10) (Figs 25, 29, 30). The mean SOC stock value is 82.15±4.51 (n=26), which compares with 94.64±9.34 (n=3) measured at the SB08318 site (Table 15). SOCS were higher on the north-facing slopes (89.70±5.54) (n=13) compared with south-facing slopes (65.61±11.08) (n=6) and increased downslope from 62.54±6.2 to 94.82±5.61 (all units are Mg C ha^{-1} to 0.3 m). There was no significant difference between the SOCS measured at the SB08318 site compared with the 2007 estimate (see Table 15).

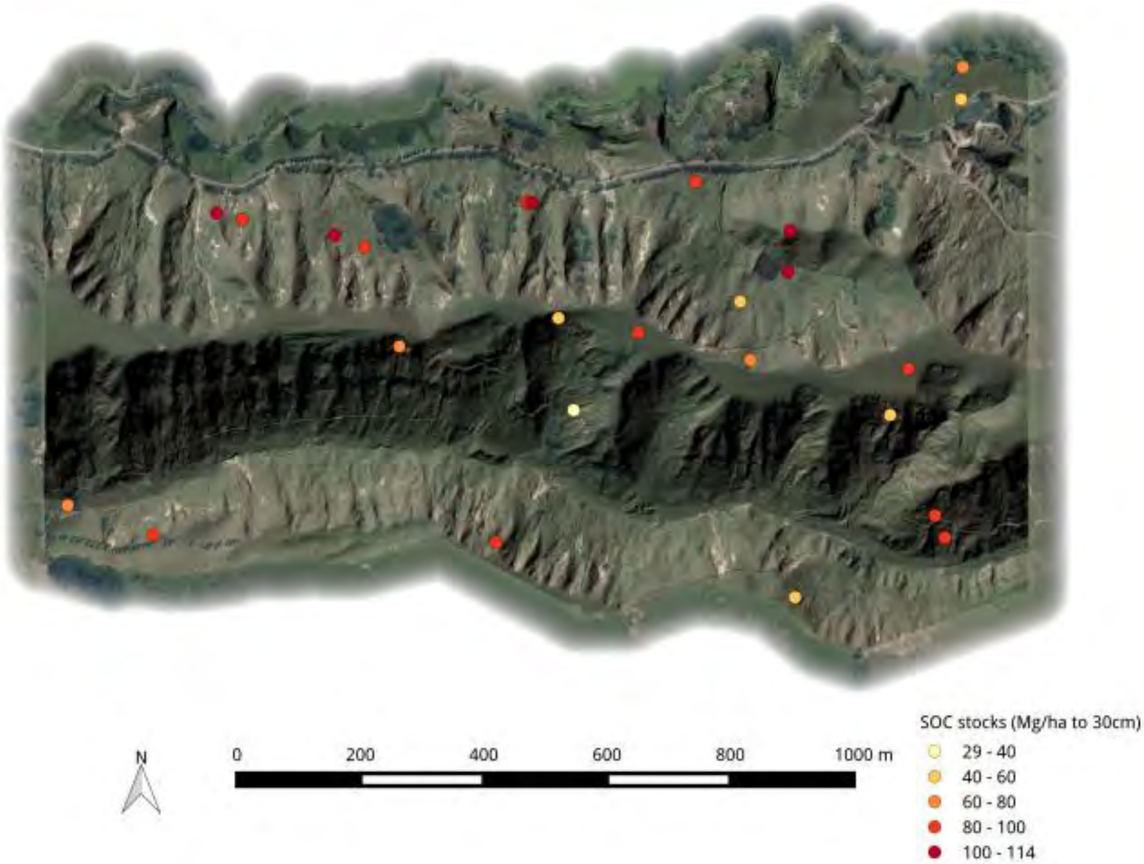


Figure 29: Diagram to show SOC variability in the landscape at Okoia

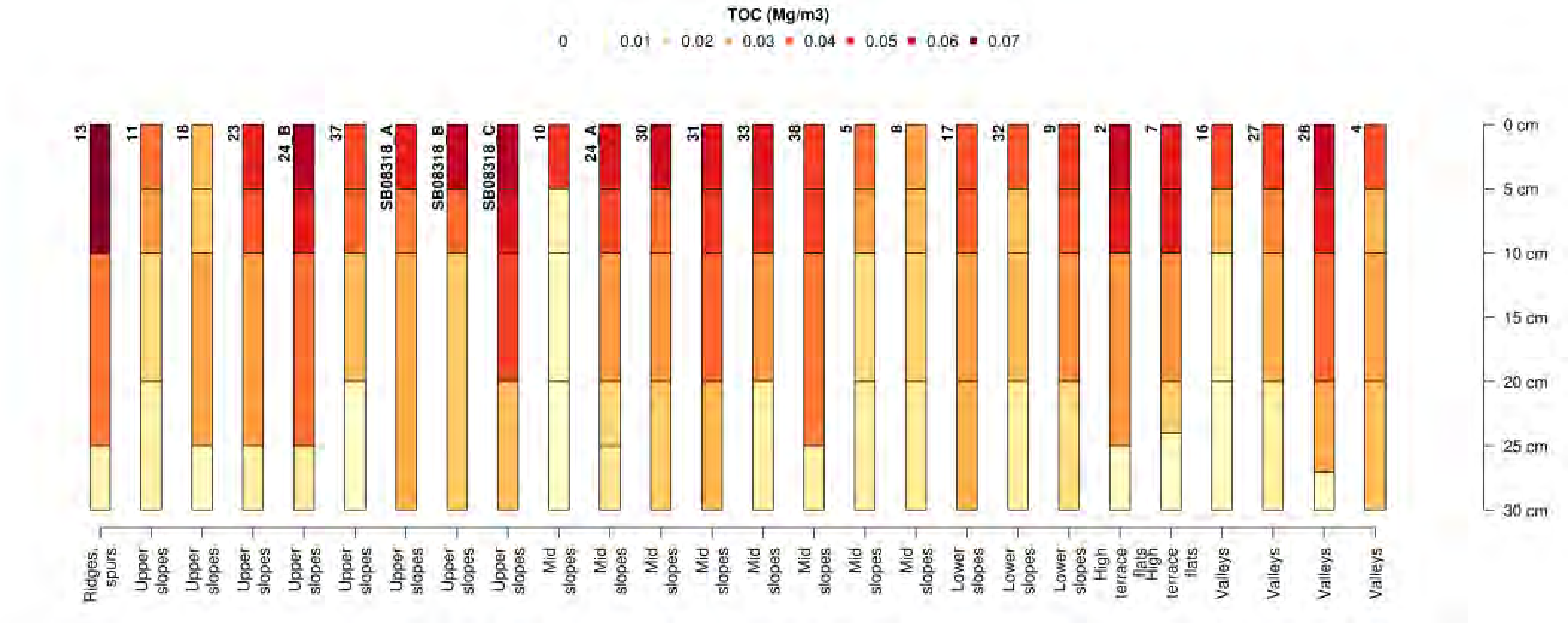


Figure 30: Diagram to show SOC variability in the soil profile at Okoia.

The SOCS estimates at Te Whanga were between 41.45 and 147.19 Mg ha^{-1} to 0.3 m (Fig. 31). The highest value was found in a gully (Site 15) where topsoil had presumably accumulated from upslope positions. The lowest value occurred at a lower slope position where the topsoil had been buried by slope deposits from above (Site 9). The mean SOC stock value was 84.08±3.44, which compares with 79.18±1.89 and 105.08±7.66 (3 reps) measured at SB09961 (south-facing) and SB09959 (north-facing) respectively.

SOCS were higher on north facing slopes (88.63±6.36) than south-facing slopes (76.67±1.98) Mg C ha^{-1} to 0.3 m. There was no significant difference between the SOCS measured at the two NSD sites compared with those previously reported in 2008 (see Table 1).

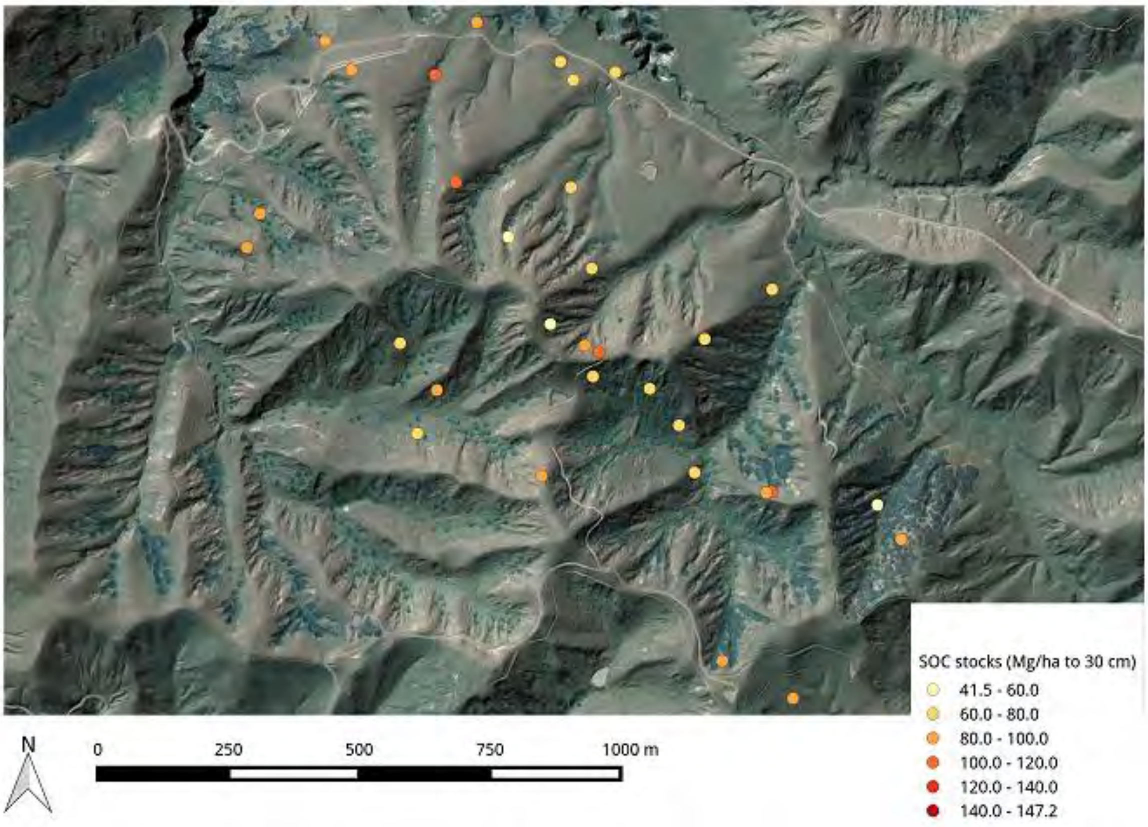


Figure 31 Diagram to show SOC variability in the landscape at Te Whanga

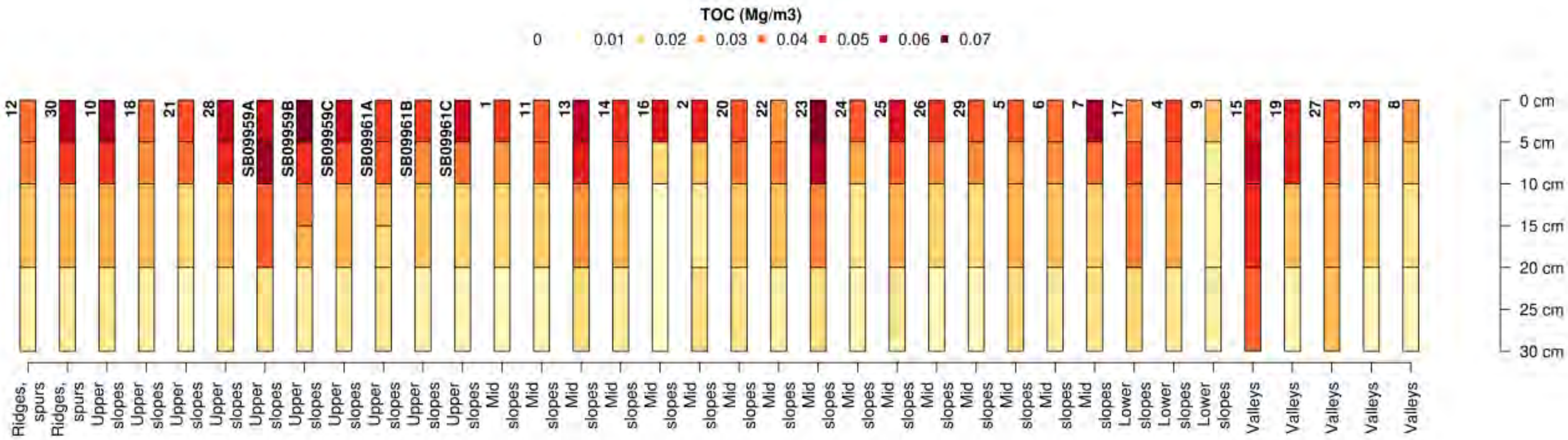


Figure 32: Diagram to show SOC variability in the soil profile at Te Whanga

Table 15: Measured SOC stock values (Mg C ha^{-1} to 0.3 m) for two selected hill country sites

Sample Position	Date of Sampling	TtlC Mg/ha (0–0.3 m)	*se*	*CV***	No. sampling positions
OKOIA					
All sites	2014	82.15	4.51	28.00	26
Time					
SB08318	1967	103.73			1
SB08318	2007	96.84			1
SB08318	2014	94.64	*9.34*	17.09	3
Aspect					
N-facing aspect	2014	89.70	*5.54*	23.10	13
S-facing aspect	2014	65.61	*11.08*	41.37	6
Slope position	*2014*				
Valley floor*	2014	77.31	*0.42*		2
Gully	2014	106.57			1
Lower slopes	2014	94.82	*5.61*		6
Mid slopes	2014	83.47	*9.97*		7
Upper slopes	2014	62.54	*6.20*		6
Ridgelines/summit	2014	100.87	*9.83*		3
All slopes^	2014	80.44	*5.25*	28.44	19
TE WHANGA					
All sites	2014	84.08	*3.44*	24.57	36
Time					
SB09959	1984	94.02			1
(N-facing)	2008	101.24			1
	2014	105.08	*7.66*	12.63	3
SB09961	1984	80.82			1
(S-facing)	2008	81.79			1
	2014	79.18	*1.89*	4.14	3
Aspect					
N-facing aspect	2014	88.63	*6.36*	28.72	16
S-facing aspect	2014	76.67	*1.98*	7.29	8
Slope position	*2014*				
Valley floor	2014	82.06	*6.49*		2
Gully	2014	100.91	*16.6*		4
Lower slopes	2014	73.73	*7.54*		7
Mid slopes	2014	77.46	*5.78*		9
Upper slopes	2014	88.47	*5.12*		13
ridgelines	2014	95.82			1
All slopes ^	2014	81.49	*3.52*	23.28	29

Note: Previous SB sampling dates and SOCS estimates of Schipper et al. (2010, 2013, 2014); the new SB sampling was within ≤5 m of recorded SB positions.

*Okoia 16 is omitted from the valley floor mean, as it is a disturbed site [anthropogenic overburden with buried soil]

** CV = coefficient of variation %; ^ All slopes = upper, middle and lower slope classes combined.

Uncertainty analysis

Reproducibility (RP), a measure of short range variability, was estimated following the procedure of Goidts et al. (2009) and Hedley et al. (2012) for the three resampled NSD sites. This provides a measure of the error associated with resampling at the same position (or within 5 m of that position) at any one time. The mean RP is estimated to be 22.02 for SOCS estimations in complex hill country terrain, assuming resampling has occurred within the same topographic feature and for the same soil type.

Table 16: Assessment of SOC short range variability using the reproducibility of estimates from three replicates sampled within 10 m distance of each other

Location	Site ID	RP (%)*	Slope class	Aspect
Okoia	SB08318	32.77	lower	North-facing
Te Whanga	SB09959	25.22	upper	North-facing
Te Whanga	SB09961	8.07	upper	South-facing

*RP = reproducibility, estimated (SOCS(max) – SOCS(min))/mean x 100

Discussion

A stratified sampling protocol was designed to assess the spatial variability of SOCS values within a 2-km^2 area around the NSD sites, using a conditioned Latin hypercube approach. These new estimates are lower than those obtained from the N-facing NSD sites at Okoia and Te Whanga, and slightly higher than that obtained for the Te Whanga S-facing SB09961 site.

Using statistics gained from this 2014 sampling, we have estimated the probability of detecting a change in C stock over time on the basis of a second, hypothetical set of samples and measurements. The calculation is based on a two-sample T test for independent samples with unequal variances. The second set's hypothetical mean is adjusted until it exceeds the first set's measured mean and the difference just exceeds the standard error of the difference, for $P < 0.05$. This is done on the basis of a one-tail T statistic for which we assume the second set of samples yields a larger soil C stock such that the C stock has increased over time. The results are presented in Table 17.

Table 17: T test results for number of samples required at a second sampling date to detect a prescribed level of change (*P*<0.05)

Site	SD as % of mean in 2014	n	Soil C stock change detection limit	Soil C stock change detection limit
	%		%	Mg C/ha
Okoia	28	26	18	14.8
Okoia	28	100	9	7.4
Te Whanga	36	36	13	10.9
Te Whanga	36	100	8	6.7

7 Project Results

7.1 Literature review

- Topographic features strongly influence the distribution of soil organic matter in pastoral hill country soils. These features include hillslope position, slope angle and aspect.
- Erosion tends to increase the proportion of labile C in downslope positions. This is likely to impact the rate of change of soil C over time, as the remaining less labile C in post-erosion upper slope positions is less easily mineralised.
- Pastoral hill country SOCS accounting methods need to account for spatial variability and one method to do this is to use a stratified sampling protocol which adequately and proportionally samples all contrasting topographic positions (that exist in the study area).
- A key finding from the literature review is that there is a lack of data on SOCS changes with time in different landscape positions.

7.2 GIS analysis of the representativeness of 23 resampled NSD sites

- A method was devised to assess whether the NSD site position fell within the entire population of relevant datasets (elevation, slope position, slope angle, aspect, erosion, climate, hill country type, pasture productivity, soil, drainage class) using a method termed "IQR representativeness" which determines a site to be representative if it falls within 50% of the population.
- Approximately a third of the 23 sites qualify as representative, over half as marginal, and approximately 10% are definitely not representative of the total number of sites required to achieve full representation of all NZ pastoral hill country, using the 'IQR representativeness' test.
- The 23 sites sample 6 of the 8 soil orders identified in New Zealand hill country. Pallic and Melanic soils are over-represented, Brown soils are under-represented, and Pumice and Podzols not represented at all, on an areal basis.
- The 23 sites sample 6 of the 16 hill country types, which is 60% of New Zealand hill country on an areal basis, as defined in this report.
- The term 'hill country' is a vague term, and the definition used in this study draws on the best data sources available. However, the definition and spatial delineation can be improved with increasing quality of data and computer processing technologies.

7.3 National Soil Database (NSD) search and field campaign

- A spreadsheet containing 1503 sites from the NSD database has been progressively filtered to 100 hill country pastoral sites that may be useful for further consideration with respect to characterising hill country soil carbon stocks.
- A stratified sampling approach was implemented at two locations using an accurate digital elevation model (derived from Lidar survey; ±0.25 m positional accuracy; ±0.15 m vertical accuracy). This proportionally sampled the full range of terrain attributes (slope, aspect, elevation and derived secondary attributes, e.g. solar radiation, wetness indices). These attributes relate to soil organic matter accumulation.
- There was a 3.6-fold difference between the lowest and highest recorded SOCS measurement at both locations (Okoia, Te Whanga) in a 2-km^2 grid square surrounding the SB sites.

- There was no significant difference between the SOCS estimates at the 3 SB sites with those recorded 6 years earlier.
- There is a weak relationship between SOCS estimates and topographic position at these two complex hillslope sites.
- SOCS were greater on north facing slopes compared with south facing slopes, at these two sites.
- There is large uncertainty (estimated by RP) associated with resampling within 5 m of one position to obtain the same estimate of SOCS in complex hill country terrains. This limitation needs to be considered when SOCS trend assessments are undertaken.

8 Project Discussion

A literature review investigated how geomorphology and management of hill country pastoral systems influences soil C storage and rates of change through time. Hillslope position and aspect are two important controlling factors to be considered when assessing SOCS. The literature shows that aspect influences soil carbon stocks, and that the effect varies in different parts of the country. The excretal return from grazing animals is not uniform in hill country terrains, tending to be greater on flatter areas and this is likely to influence soil carbon accumulation rates.

The scientific literature provides some examples, in eroded terrains, of newer (more labile) SOC on lower slopes and older (less labile) SOC on upper slopes, which is likely to affect rates of SOC change with time. Therefore both upper and lower slope positions should be investigated to account for this when assessing SOC stock changes with time.

A comprehensive assessment of IQR representativeness of the 23 resampled NSD sites (of Schipper et al. 2010, 2013) (Chapter 5) concludes that approximately one third represent pastoral New Zealand hill country on a basis of elevation, slope, erosion, rainfall and temperature. The sites do not proportionally represent aspect, drainage class, soil order, pasture productivity and hill country type. The test of representativeness was made by assessing how closely a site value fits within a target population of values, where the population size is defined by the grid-resolution of the spatial dataset. Schipper et al. (2010, 2013, 2014) sampled mostly stable mid-slope sites, but hill country terrains are heterogeneous mixes of different landform types (e.g. flats, ridges, valleys) with widely variable terrain characteristics (e.g. elevation, slope, aspect). Further sampling is therefore required to more comprehensively represent the whole of pastoral New Zealand hill country.

It is essential to establish an adequate sampling protocol that can be applied at each sampling location and time. The design must address the questions of the user of data, and provide information with accuracy and precision at the spatial and temporal scales that match the user's needs. The design must match the methods of analysis so that statistical assumptions can be justified (Arrouays et al. 2014).

If the objective is to detect a mean change over a domain, e.g. in New Zealand hill country, then random stratified sampling may be the most cost-effective, reducing the variance of predictions.

Resampling sites has the advantage of providing immediate information over longer periods. Some limits of the approach are that the locations of the sites have not necessarily been designed for SOC monitoring; that historical data from practices may be difficult to reconstruct; and that the within-site sampling of the first inventory is often a single core or a single profile (Arrouays et al., 2014). Probably one of the most cited studies on measured SOC changes by resampling a national soil inventory is that by Bellamy et al. (2005). Using repeated measurements from 1978 to 2003, they showed large losses in nearly all soils of England and Wales. Possible causes of these changes have been widely discussed (e.g. Lark et al. 2006a; Smith et al. 2007; Kirk & Bellamy 2010), but without a precise recording of management practices, they still remain difficult to interpret. Evidence from other surveys (Reynolds et al. 2013) has not corroborated the findings of Bellamy et al. (2005).

In our study we collected new data from around three of the 23 resampled NSD sites using a stratified sampling method, and this new data supports the literature that SOCS are hugely variable within a hill country catchment. The range of SOCS within a 2 km^2 region surrounding an existing NSD site was more than three-fold. SOCS were larger on more stable surfaces such as ridge-lines, summits and valley floors, compared with steep slopes. North-facing slopes had higher SOCS than south-facing slopes. SOCS increase downhill, unless disrupted by erosion events.

Our field campaign showed that SOCS do not always simply increase downslope, due to the complexity of the slope surface in e.g. eroded soft rock terrains. Erosion events move and bury topsoils, providing an erratic sequence of SOCS downslope compared to a simple more stable, non-eroded hillslope (see Fig. 33). Examples of simple slope terrain are found in North Otago, and examples of complex slope terrains are found in many of our eroded soft rock hill country landscapes, e.g. Te Whanga and Okoia.

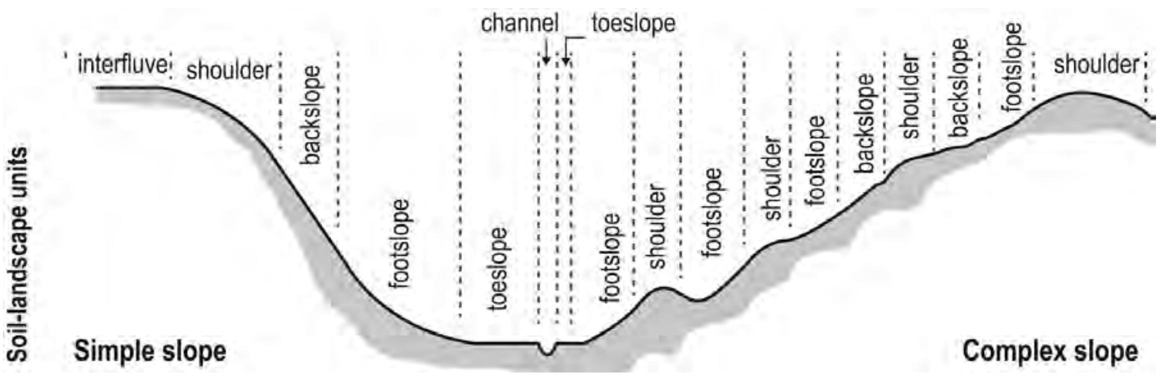


Figure 33: Illustration of a simple hillslope (topsoil depth tends to increase downslope) and a complex hillslope (complex sequence of eroded and buried topsoils). (modified from Park et al., 2001)

Previous assessments of SOCS have not adequately accounted for spatial variability although it is known to be a major (often the major) uncertainty relating to SOCS estimations. Not only does spatial variability affect estimation of the soil organic carbon store at any one time, but it is also likely to affect the change in storage through time at any one position.

New spatial modelling methods using environmental datalayers (e.g. digital elevation models) enable refined modelling of SOCS in the landscape in which they occur, accounting for spatial variability. In landscapes subject to mass movement erosion, the modelling needs to account for the proportion of erosion scars of different ages, (e.g. by including the approach of Basher et al. 2013b).

In addition, to assess change with time it is necessary to sample at sufficiently frequent intervals to track the dynamic nature of soil C stores (e.g. see Fig. 34) and physical sampling is often impractical. For example, the increasing SOCS observed at Te Whanga between 1984 and 2008 (Schipper et al., 2010, 2013, 2014) coincide with a relatively stable period when no major erosion events occurred (see Fig. 34).

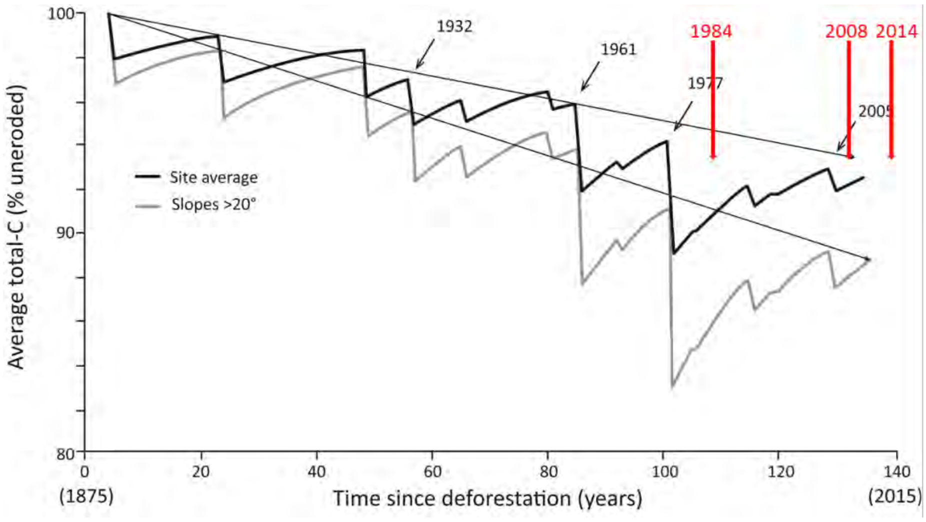


Figure 34: Graph to show long term trend of decreasing SOCS since deforestation at Te Whanga (de Rose 2013) (also see Fig. 3).
Resampling for SOCS at two Te Whanga NSD sites indicated that SOC has increased during the period 1984–2008 (red arrows), which was a period of recovery between major erosion events.

Future research should establish an adequate sampling protocol that can be applied at each sampling location and time. This method aims to reduce the variance of the estimated SOC stocks compared with other methods such as randomised, representative or grid sampling protocols. Stratification that uses topographic features is appropriate because these features affect the accumulation of soil organic matter in hill country. Examples are:

- aspect affects radiation incidence (and therefore soil temperature)
- slope angle and position affects soil wetness and topsoil depth
- elevation affects soil temperature.

Soil temperature and moisture are two major drivers of soil organic matter accumulation and decomposition, which can be modelled using process models, such as Roth-C, Century and CewW, preferably within a spatial framework.

Estimations of SOC stock changes are also addressed using process models, where parameters can be varied to investigate management effects such as grazing intensity (Parton et al. 1987), improved drainage, and land use change effects (e.g. Parshotam et al. 1995)

There is little information on the portion of native C (i.e. derived from original native vegetation) that survives in our soils. One important exception is the work of Lassey et al (1996) which showed that pre-European forest C predominates in most subsoils, including subsoils under grazed pastures, using data collected from sites throughout New Zealand. This native C provides a relatively stable pool in comparison to the rapidly utilised new C (in productive ryegrass clover pasture systems). Future research needs to investigate the proportion of old C (from native vegetation) to new C (from productive pasture swards) to improve our understanding of C turnover processes. Pyrolysis GC-MS is one method that could be used for this purpose (Suarez-Abelenda et al. 2014).

Improved understanding of how SOCS vary both in space and time will inform soil carbon sequestration efforts; and it is likely that these efforts should be targeted at specific parts of the landscape, where soil C is more likely to rapidly accumulate than other parts of the landscape.

9 Conclusions

The accumulation of soil organic carbon stocks (SOCS) in complex hill country terrains is controlled by landscape position interacting with soil type, parent material, climatic variables, land use and livestock behaviour. This study has provided some evidence for (i) higher SOCS in more stable landscape positions and gullies compared to steep hill sides, and (ii) an influence of aspect on SOCS which varies between regions of New Zealand. SOCS generally increase downslope, although this pattern is disrupted on the complex hill slopes associated with eroded landscapes, such as the soft rock hill country which comprises about one third of New Zealand's hilly landscapes.

Past studies revealed that the important farm management practices of superphosphate fertiliser application and grazing intensity did not significantly affect SOCS. However, within a given management regime, grazing animal behaviour can influence the spatial distribution of soil C, with higher C stocks reported for campsites compared to non-campsites.

The 23 NSD sites re-sampled by Schipper et al. (2014), which suggested increasing SOCS over the past three decades, represent 60 % of NZ hill country, on a basis of parent rock, but were taken from a biased sample set (modal profiles sampled for soil classification purposes). An appropriate stratified monitoring protocol is required to more accurately estimate SOCS changes for all New Zealand hill country. Further research is necessary to develop the details of an appropriate sampling method for monitoring soil carbon change in New Zealand hill country soils.

Finally, as noted by Arrounays et al. (2014), there is a need for harmonized soil carbon monitoring networks all over the world. We need appropriately designed sampling schemes in space and time, with minimal constraining prior assumptions, to address any possible future changes. Climate change is occurring – bringing more severe weather events, i.e. storms and droughts – and this increases the necessity for land managers to build resilience into their agroecosystems by promoting the retention of soil organic matter.

10 Recommendations

- To assess SOCS **at any one time**, an appropriate stratified soil sampling protocol must be designed to provide information with accuracy and precision at the spatial and temporal scales that match the user's needs.
- To assess SOCS changes **through time**, the sampling protocol established at time 1 is used at each subsequent sampling time; and 5–10 years is a likely time frame required to monitor the expected levels of SOCS changes.
- To assess SOCS changes within a shorter period of time there are two approaches:
  - Having designed an appropriate stratified sampling protocol, investigate the potential use of the remaining 100 NSD hill country sites for re-sampling, to provide a more complete representation of New Zealand hill country.
  - **Process models,** using sufficient validation data, can be used to investigate SOCS changes through time (e.g. Parton et al. 1987; Parshotam et al. 1995; Skjemstad et al. 2004; Kirschbaum et al. 2008).
- It is recommended that SOCS trend assessments be used to inform pastoral farm management to maintain or enhance soil C stores for provisioning ecosystems for food supply, for resilience to degradation, and for mitigation of climate change impacts.

11 Acknowledgements

We acknowledge the support of the Ministry for Primary Industries for providing funding for the work under contract LCR131406. Landowners and managers generously allowed access to their properties for collection of soil samples; Harley Betts derived digital elevation maps using photogrammetry; and John Dando, Craig Ross and Thilak Palmada provided field assistance. Staff of the Environmental Chemistry Laboratory at Landcare Research provided the soil analyses. Thanks to Kevin Tate, who internally reviewed this report and provided very helpful comments, Anne Austin for editing, and Cynthia Cripps for formatting.

12 References

Adhikari K, Hartemink AE, Minasny B, Kheir RB, Greve MB, Greve MH 2014. Digital mapping of soil organic carbon contents and stocks in Denmark. Open Access PLOS One August 2014 9(8), e105519. 13 p.

Aksoy H, Kavvas ML 2005. A review of hillslope and watershed scale erosion and sediment transport models. Catena 64, 247–271.

Arrouays D, Marchant BP, Saby NPA, Meersmans J, Jolivet C, Orton TG, Martin MP, Bellamy PH, Lark RM, Louis BP, Allard D, Kibblewhite M, 2014. On soil carbon monitoring networks. Chapter 6. In: Hartemink AE, McSweeney K eds Soil carbon. Heidelberg, Germany, Springer International Publishing. Pp. 59–68.

Bahn M, Lattanzi FA, Hasibeder R, Wild B, Koranda M, Danese V, Brüggemann N, Schmitt M, Siegwolf R, Richter A 2013. Responses of belowground carbon allocation dynamics to extended shading in mountain grassland. New Phytologist 198, 116–126.

Barnett AL 2012. Comparison of soil carbon and nitrogen stocks of adjacent dairy and drystock pastures. Hamilton, New Zealand, Department of Earth and Ocean Sciences. University of Waikato. 172 p.

Barnett AL, Schipper LA, Taylor A, Balks MR, Mudge PL 2014. Soil C and N contents in a paired survey of dairy and dry stock pastures in New Zealand. Agriculture Ecosystems & Environment 185, 34–40.

Basher LR, Botha N, Dodd MB, Douglas GB, Lynn I, Marden M, McIvor IR, Smith W 2008. Hill country erosion: a review of knowledge on erosion processes, mitigation options, social learning and their long-term effectiveness in the management of hill country erosion. Landcare Research Contract Report: LC0708/081. Landcare Research New Zealand Ltd. Prepared for Ministry of Agriculture and Forestry Policy (POL/INV/0708/03).

Basher L, Betts H, De Rose RC, Lynn I, Marden M, McNeill S, Sutherland A, Willoughby J, Page M, Rosser B 2011. Accounting for the effects of mass-movement erosion on soil carbon stocks in the Soil Carbon Monitoring System: a pilot project. Wellington New Zealand, Ministry for the Environment. 38 p.

Basher L, Betts H, Lynn I, Marden M, McNeill S, Page M, Rosser B 2013a. The effect of earthflow erosion on soil carbon stocks. Wellington, New Zealand, Ministry for Primary Industries Wellington. 55 p.

Basher L, McNeill S, Page M, Lynn I, Betts H, De Rose RC, Marden M, Rosser BJ 2013b. Soil carbon stocks and changes: carbon losses from erosion. Wellington New Zealand, Ministry for Primary Industries. 42 p.

Beets PN, Oliver GR, Clinton PW 2002. Soil carbon protection in podocarp/hardwood forest, and effects of conversion to pasture and exotic pine forest. Environmental Pollution 116, S63–S73.

Bellamy PH, Loveland PJ, Bradley RI, Lark RM, Kirk GJD 2005. Carbon losses from all soils across England and Wales 1978–2003. Nature 437, 245–248.

Belnap J, Welter JR, Grimm NB, Barger N, Ludwig JA 2005. Linkages between microbial and hydrologic processes in arid and semiarid watersheds. Ecology 86, 298–307.

Betteridge K, Costall D, Balladur S, Upsdell M, Umemura K 2010. Urine distribution and grazing behaviour of female sheep and cattle grazing a steep New Zealand hill pasture. Animal Production Science 50, 624–629.

Betteridge K, Ganesh S, Luo D, Kawamura K, Costall D, Yoshitoshi R 2012. A methodology for determining critical source areas of nitrogen in grazed hill pastures. In: Currie LD, Christensen CL eds Advanced nutrient management: gains from the past – goals for the future. http://flrc.massey.ac.nz/publications.html.

Blanco-Canqui H, Lal R 2004. Mechanisms of carbon sequestration in soil aggregates. Critical Reviews in Plant Sciences 23, 481–504.

Boehner J, Koethe R, Conrad O, Gross J, Ringeler A, Selige T 2002. Soil regionalisation by means of terrain analysis and process parameterisation. In: Micheli E, Nachtergaele F, Montanarella L eds Soil classification 2001. Luxembourg, European Soil Bureau, Research Report No. 7, EUR 20398 EN. Pp. 213–222.

Brackley HL, Blair NE, Trustrum NA, Carter L, Leithold EL, Canuel EA, Johnston JH, Tate KR 2010. Dispersal and transformation of organic carbon across an episodic high sediment discharge continental margin, Waipaoa Sedimentary System, New Zealand. Marine Geology 270, 202–212.

Bryan RB 2000. Soil erodibility and processes of water erosion on hillslope. Geomorphology 32, 385–415.

Bui E, Henderson B, Viergever K 2009. Using knowledge discovery with data mining from the Australian Soil Resource Information System database to inform soil carbon mapping in Australia. Global Biogeochemical Cycles 23. doi: 10.1029/2009GB003506.

Chang C-W, Laird DA 2002. Near-infrared reflectance spectroscopic analysis of soil C and N. Soil Science 167, 110–116.

Chapman DF, Macfarlane MJ 1985. Pasture growth limitations in hill country and choice of species. pp. 25-30. In: Burgess RE, Brock JL eds Using herbage cultivars. Grassland Research and Practice series No. 3. Palmerston North, New Zealand, New Zealand Grassland Association.

Clement CR, Williams TE 1967. Leys and soil organic matter: II. The accumulation of nitrogen in soils under different leys. The Journal of Agricultural Science 69, 133–138.

Conacher AJ, Dalrymple JB 1977. The nine-unit landsurface model: an approach to pedogeomorphic research. Geoderma 18: 1–153.

Conant RT, Paustian K, Elliott ET 2001. Grassland management and conversion into grassland: Effects on soil carbon. Ecological Applications 11, 343–355.

Conant RT, Ogle SM, Paul EA, Paustian K 2011. Measuring and monitoring soil organic carbon stocks in agricultural lands for climate mitigation. Frontiers in Ecology and the Environment 9, 169–173.

Condron LM, Black A, Wakelin SA 2012. Effects of long-term fertiliser inputs on the quantities of organic carbon in a soil profile under irrigated grazed pasture. New Zealand Journal of Agricultural Research 55, 161–164.

Cowley JM 1982. Taxonomic, biological, population dynamics and behavioural studies on sod webworms (Lepidoptera: Pyralidae: Crambinae and Scopariinae) of some Waitako (New Zealand) hill country pastures. Unpublished D. Phil. thesis, University of Waikato, Hamilton, New Zealand.

Davis M, Wilde H, Garrett L, Oliver G 2004 New Zealand carbon monitoring system – soil data collection manual. Prepared for the New Zealand Climate Change Office, Ministry for the Environment, PO Box 10-362, Wellington. 56 p.

Davy MC, Koen TB 2013. Variations in soil organic carbon for two soil types and six land uses in the Murray Catchment, New South Wales, Australia. Soil Research 51, 631–644.

De Baets S, Meersmans J, Vanacker V, Quine TA, Van Oost K 2013. Spatial variability and change in soil organic carbon stocks in response to recovery following land abandonment and erosion in mountainous drylands. Soil Use and Management 29, 65–76.

de Klein C, Hoogendoorn C, Manderson A, Saggar S, Giltrap DJ, Briggs C, Rowarth J 2009. Refinement of the framework for upscaling nitrous oxide emissions from hill country. MAF-POL 0809-11061 Hill Country EF3. 58 p.

De Rose RC 2013. Slope control on the frequency distribution of shallow landslides and associated soil properties, North Island, New Zealand. Earth Surface Processes and Landforms 38, 356–371.

De Rose RC, Trustrum NA, Thomson NA, Roberts AHC 1995. Effect of landslide erosion on Taranaki hill pasture production and composition. New Zealand Journal of Agricultural Research 38, 457–471.

De Reu, J, Bourgeois, J, Bats M, Zwertvaegher A, Gelorini, V, De Smedt, P, Chu W, Antrop M, De Maeyer P, Finke P, Van Meirvenne M, Verniers J, Crombé J 2013. Application of the topographic position index to heterogeneous landscapes. Geomorphology 186, 39-49.

Douglas GB, Trustrum NA, Brown IC 1986. Effect of soil slip erosion on Wairoa hill pasture production and composition. New Zealand Journal of Agricultural Research 29, 183–192.

Dlugoss V, Fiener P, Schneider K 2010. Layer-specific analysis and spatial prediction of soil organic carbon using terrain attributes and erosion modelling. Soil Science Society of America Journal 74 (3), 922–935.

During C, Radcliffe JE 1962. Observations on the effect of grazing animals on steepland soils. Transactions of joint meeting of Commissions 4 & 5, International Society of Soil Science. Pp. 685–690.

Dymond JR 2010. Soil erosion in New Zealand is a net sink of CO2. Earth Surface Processes and Landforms 35, 1763–1772.

Dymond JR, Ausseil AG, Shepherd JD, Buettner L 2006. Validation of a region-wide model of landslide susceptibility in the Manawatu-Wanganui region of New Zealand. Geomorphology 74, 70–79.

Fornara DA, Tilman D 2012. Soil carbon sequestration in prairie grasslands increased by chronic nitrogen addition. Ecology 93, 2030–2036.

Frogbrook ZL, Bell J, Bradley RI, Evans C, Lark RM, Reynolds B, Smith P, Towers W 2009. Quantifying terrestrial carbon stocks: examining the spatial variation in two upland areas in the UK and a comparison to mapped estimates of soil carbon. Soil Use and Management 25: 320–332.

Gehl RJ, Rice CW 2007. Emerging technologies for in situ measurement of soil carbon. Climatic Change 80, 43–54.

Ghani A, Dexter M, Perrott KW 2003. Hot-water extractable carbon in soils: a sensitive measurement for determining impacts of fertilisation, grazing and cultivation. Soil Biol. Biochem. 35, 1231–1243.

Gillingham AG 1974 Influence of physical factors on pasture growth on hill country. In Proceedings of the New Zealand Grassland Association 35, 77–85.

Gillingham AG 1980 Phosphorus uptake and return in grazed, steep hill pastures. 1. Pasture production and dung and litter accumulation. New Zealand Journal of Agricultural Research 23(3), 313–321.

Gillingham AG, Syers, JK, Gregg PEH 1980 Phosphorus uptake and return in grazed, steep hill pastures. 2. Above-ground components of the phosphorus cycle. New Zealand Journal of Agricultural Research 23(3), 323–330.

Goidts E, Van Wesemael B, Crucifix M 2009. Magnitude and sources of uncertainties in soil organic carbon (SOC) stock assessments at various scales. European Journal of Soil Science 60, 723–739.

Grant DA, Rumball PJ, Suckling FET 1973. Pasture improvement and potential productivity in southern North Island hill country. Proceedings of the NZ Grassland Association 34: 185–194.

Guo LB, Gifford RM 2002. Soil carbon stocks and land use change: A meta analysis. Global Change Biology 8, 345–360.

Hao Y, Lal R, Owens LB, Izaurralde RC, Post WM, Hothem DL 2002. Effect of cropland management and slope position on soil organic carbon pool at the North Appalachian Experimental Watersheds. Soil and Tillage Research 68, 133–142.

Hancox GT, Wright K 2005. Analysis of landsliding caused by the 15–17 February 2004 rainstorm in the Wanganui-Manawatu hill country, southern North Island, New Zealand. Institute of Geological & Nuclear Sciences. 64 p.

Hassink J 1994. Effects of soil texture and grassland management on soil organic C and N and rates of C and N mineralization. Soil Biology & Biochemistry 26, 1221–1231.

Hassink J, Neeteson JJ 1991. Effect of grassland management on the amounts of soil organic-N and C. Netherlands Journal of Agricultural Science 39, 225–236.

Haynes RJ, Williams PH 1999. Influence of stock camping behaviour on the soil microbiological and biochemical properties of grazed pastoral soils. Biology and Fertility of Soils 28, 253–258.

Hedley CB, Kusumo BH, Hedley MJ, Tuohy MP, Hawke M 2009. Soil C and N sequestration and fertility development under land recently converted from plantation forest to pastoral farming. New Zealand Journal of Agricultural Research 52, 443–453.

Hedley CB, Payton IJ, Lynn IH, Carrick ST, Webb TH, McNeill S 2012. Random sampling of stony and non-stony soils for testing a national soil carbon monitoring system. Soil Research 50, 18–29.

Hedley CB, Roudier P, Ekanayake J 2013. Hill Country Irrigation Project – knowledge into practice. Landcare Research Report No. LC1584, prepared for Irrigation New Zealand. 20 p.

Hedley CB, Roudier P, Maddi L 2014a Visible near infrared soil spectroscopy for field soil analysis. Communications in Soil Science and Plant Analysis. In Press. doi: 10.1080/00103624.2014.988582.

Hedley C, Roudier P, Valette L 2014b Digital elevation maps for spatial modelling of soil services. In: Currie LD, Christensen CL eds Nutrient management for the farm, catchment and community .http://flrc.massey.ac.nz/publications.html. Occasional Report No. 27. Palmerston North, New Zealand, Fertilizer and Lime Research Centre, Massey University.

Hewitt A, Forrester G, Fraser S, Hedley C, Lynn I, Payton I 2012. Afforestation effects on soil carbon stocks of low productivity grassland in New Zealand. Soil Use and Management 28, 508–516.

Hoogendoorn CJ, Bowatte S, Tillman RW 2011. Simple models of carbon and nitrogen cycling in New Zealand hill country pastures: exploring impacts of intensification on soil C and N pools. New Zealand Journal of Agricultural Research 54, 221–249.

Jackman RH 1964. Accumulation of organic matter in some New Zealand soils under permanent pasture. II. Rates of mineralisation of organic matter and the supply of available nutrients. New Zealand Journal of Agricultural Research 7, 472–479.

Jansen B, Kalbitz K, McDowell WH 2014 Dissolved organic matter: linking soils and aquatic systems. Vadose Zone Journal, open access, received 12 May 2014. doi:10.2136/vzj2014.05.0051.

Jenny H 1941. Factors of soil formation: a system of quantitative pedology. Originally published New York, McGraw-Hill; New York Dover Publications. 191 p.

Johnston AE, Poulton PR, Coleman K 2009. Soil organic matter: its importance in sustainable agriculture and carbon dioxide fluxes. In: Sparks DL ed. Advances in agronomy, Vol 101. Burlington, Academic Press. Pp.1–57.

Jones H, Clough P, Hock B, Phillips C 2008. Economic costs of hill country erosion and benefits of mitigation in New Zealand: Review and recommendation of approach. Scion client report to Ministry of Agriculture and Forestry.

Kirk GJD, Bellamy PB 2010. Analysis of changes in organic carbon in mineral soils across England and Wales using a simple single-pool model. European Journal of Soil Science 61, 401–411.

Kirschbaum MUF, Guo LB, Gifford RM 2008. Why does rainfall affect the trend in soil carbon after converting pastures to forests? A possible explanation based on nitrogen dynamics. Forest Ecology and Management 255, 2990–3000.

Kriszan M, Amelung W, Schellberg J, Gebbing T, Kuhbauch W 2009. Long-term changes of the δ15N natural abundance of plants and soil in a temperate grassland. Plant and Soil 325, 157–169.

Kool DM, Chung H, Tate KR, Ross DJ, Newton PCD, Six J 2007 Hierarchical saturation of soil carbon pools near a paturam CO2 spring. Global Change Biology 13, 1282–1293.

Lagacherie P, McBratney AB, Voltz M eds 2006. Digital soil mapping: an introductory perspective. Amsterdam, Elsevier. 600 p. ISBN 978-0-444-52958-9.

Lal R 2014 Societal value of soil carbon. Journal of Soil and Water Conservation 69(60), 186–192.

Lambert MG, Roberts E 1978. Aspect differences in an unimproved hill country pasture. II. Edaphic and biotic differences. New Zealand Journal of Agricultural Research 21, 255–260.

Lambert MG, Clark DA, Grant DA, Costall DA 1983. Influence of fertiliser and grazing management on North Island moist hill country. 1. Herbage accumulation. New Zealand Journal of Agricultural Research 26, 95–108.

Lambert MG, Trustrum NA, Costall DA 1984. Effect of soil slip erosion on seasonally dry Wairarapa hill pastures. New Zealand Journal of Agricultural Research 27, 57–64.

Lambert MG, Clark DA, Mackay AD, Costall DA 2000. Effects of fertiliser application on nutrient status and organic matter content of hill soils. New Zealand Journal of Agricultural Research 43, 127–138.

Lambie SM, Schipper LA, Balks MR Baisden WT 2012. Carbon leaching from undisturbed soil cores treated with dairy cow urine. Soil Research 50, 320–327.

Lambie SM, Schipper LA, Balks MR, Baisden WT 2013. Priming of soil decomposition leads to losses of carbon in soil treated with cow urine. Soil Research 51, 513–520.

LandVision Ltd 2009 Tweeddale Family Trust 745 Kaukatea Valley Road, Wanganui, Whole Farm Plan, November 2009. Managing our environment. Horizons Regional Council Report No: 2009/INT/770. 64 p.

Lassey KR, Tate KR, Sparks RJ, Claydon JJ 1996. Historic measurements of radiocarbon in New Zealand soils. Radiocarbon 38, 253–270.

Lorenz K, Lal R 2005. The depth distribution OF soil organic carbon in relation to land use and management and the potential of carbon sequestration in subsoil horizons. Advances in Agronomy 88, 35–66.

Lynn IH, Manderson AK, Page, MJ, Harmsworth GR, Eyles GO, Douglas GB, Mackay AD, Newsome PJF 2009 Land use capability survey handbook – a New Zealand handbook for the classification of land, 3rd edn. Hamilton, AgResearch; Lincoln, Landcare Research; Lower Hutt, GNS Science. 163 p.

Marchetti A, Piccini R, Francaviglia R, Santucci S., Chiuchiarelli I 2010. Estimating soil organic matter content by regression kriging. Progress in Soil Science 2. In: Boettinger JL, Howell DW, Moore AC, Hartemink AE, Kienast-Brown S eds Digital soil mapping. Bridging research, environmental application, and operation. Heidelberg, Springer. Pp. 241–254.

McBratney AB, Mendonca Santos ML, Minasny B 2003. On digital soil mapping. Geoderma 117, 3–52.

McDowell RW, Cosgrove GP, Orchiston T, Chrystal J 2014. A cost-effective management practice to decrease phosphorus loss from dairy farms. Journal of Environmental Quality 43: 2044–2052.

McDowell, R.W., Wilcock, R.J., 2008. Water quality and the effects of different pastoral animals. New Zealand Veterinary Journal 56, 289–296.

McIntosh PD, Allen RB, Scott N 1997. Effects of exclosure and management on biomass and soil nutrient pools in seasonally dry high country, New Zealand. Journal of Environmental Management 51, 169–186.

McIntosh PD, Gibson RS, Saggar S, Yeates GW, McGimpsey P 1999. Effect of contrasting farm management on vegetation and biochemical, chemical, and biological condition of moist steepland soils of the South Island high country, New Zealand. Australian Journal of Soil Research 37, 847–865.

McKay MD, Beckman RJ, Conover WJ 1979. A comparison of three methods for selecting values of input variables in the analysis of output from a computer code. Technometrics 21, 239–245.

Mendonça-Santos ML, McBratney AB, Minasny B 2006. Soil prediction with spatially decomposed environmental factors. In: Lagacherie P, McBratney AB, Voltz M eds Developments in soil science. Amsterdam, Elsevier. Pp. 269–278.

Milne JDG, Clayden B, Singleton PL, Wilson AD 1995. Soil description handbook. Lincoln, New Zealand, Manaaki Whenua Press. 157 p.

Minasny B, McBratney AB 2006. A conditioned Latin hypercube method for sampling in the presence of ancillary information. Computers and Geosciences 32, 1378–1388.

Minasny B, McBratney AB, Malone BP, Wheeler I 2013. Digital mapping of soil carbon. Advances in Agronomy 118, 1–47.

MfE (Ministry for the Environment) 2007. Hill country erosion [Web page]. Available: http://www.mfe.govt.nz/issues/land/soil/erosion.html Last updated: 17 September 2007 (accessed: 2 February 2013).

Molloy L 1998. Soils of the New Zealand Landscape – the living mantle, 2nd edn. Lincoln, New Zealand Society of Soil Science, 253 p.

Morton JD, Baird DB, Manning MJ 2000. A soil sampling protocol to minimise the spatial variability in soil test values in New Zealand hill country. New Zealand Journal of Agricultural Research 43, 367–375.

Murty D, Kirschbaum MUF, Mcmurtrie RE, Mcgilvray H 2002. Does conversion of forest to agricultural land change soil carbon and nitrogen? A review of the literature. Global Change Biology 8, 105–123.

Mudge PL 2012. Changes in δ15N in pastoral soils under varying management intensity. Earth and Ocean Sciences. Hamilton, New Zealand, University of Waikato. 192 p.

Nguyen ML, Goh KM 1990. Accumulation of soil sulphur fractions in grazed pastures receiving long-term superphosphate applications. New Zealand Journal of Agricultural Research 33, 111–128.

Nguyen ML, Goh KM 1992. Status and distribution of soil sulphur fractions, total nitrogen and organic carbon in camp and non-camp soils of grazed pastures supplied with long-term superphosphate. Biology and Fertility of Soils 14, 181–190.

Nguyen ML, Sheath GW, Smith CM, Cooper AB 1998. Impact of cattle treading on hill land 2. Soil physical properties and contaminant runoff. New Zealand Journal of Agricultural Research 41, 279–290.

OECD 2001. OECD Guideline for testing of chemicals 423. Acute oral toxicity – acute toxic class method. Paris, Organisation for Economic Cooperation and Development.

Oliver GR, Beets PN, Garrett LG, Pearce SH, Kimberly MO, Ford-Robertson JB, Robertson KA 2004. Variation in soil carbon in pine plantations and implications for monitoring soil carbon stocks in relation to land-use change and forest site management in New Zealand. Forest Ecology and Management 203, 283–295.

Page M, Trustrum N, Brackley H, Baisden T, 2004. Erosion-related soil carbon fluxes in a pastoral steepland catchment, New Zealand. Agriculture, Ecosystems & Environment 103, 561–579.

Parfitt RL, Scott NA, Ross DJ, Salt GJ, Tate KR 2003. Land-use change effects on soil C and N transformations in soils of high N status: Comparisons under indigenous forest, pasture and pine plantation. Biogeochemistry 66, 203–221.

Parfitt RL, Yeates GW, Ross DJ, Schon NL, Mackay AD, Wardle DA 2010. Effect of fertilizer, herbicide and grazing management of pastures on plant and soil communities. Applied Soil Ecology 45, 175–186.

Parfitt RL, Couper J, Parkinson R, Schon NL, Stevenson BA 2012. Effect of nitrogen fertiliser on soil communities under grazed pastures. New Zealand Journal of Agricultural Research, 217–233.

Parfitt RL, Baisden WT, Ross CW, Rosser BJ, Schipper LA, Barry B 2013. Influence of erosion and deposition on carbon and nitrogen accumulation in resampled steepland soils under pasture in New Zealand. Geoderma 192, 154–159.

Parfitt RL, Stevenson BA, Ross C, Fraser S 2014. Changes in pH, bicarbonate-extractable-P, carbon and nitrogen in soils under pasture over 7 to 27 years. New Zealand Journal of Agricultural Research 57, 216–227.

Park SJ, McSweeney K, Lowery B 2001. Identification of the spatial distribution of soil using a process-based terrain characterization. Geoderma 103, 249–272.

Parshotam A, Tate KR, Giltrap DJ 1995. Potential effects of climate and land use change on soil C and CO2 emissions from New Zealand's indigenous forests and unimproved grasslands. Weather and Climate 15(2), 47–56.

Parton WJ, Schimel DS, Cole CV, Ojima DS 1987. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. Soil Science Society of America Journal 51: 1173–1179.

Poeplau C, Don A, Vesterdal L, Leifeld J, Van Wesemael B, Schumacher J, Gensior A 2011. Temporal dynamics of soil organic carbon after land-use change in the temperate zone - carbon response functions as a model approach. Global Change Biology 17, 2415–2427.

Powers JS, Corre MD, Twine TE, Veldkamp E 2011. Geographic bias of field observations of soil carbon stocks with tropical land-use changes precludes spatial extrapolation. Proceedings of the National Academy of Science of the United States of America 108, 6318–6322.

R Core Team. 2014. R: a language and environment for statistical computing. Vienna, Austria, R Foundation for Statistical Computing.

Radcliffe JE 1974. Seasonal distribution of pasture production in New Zealand. New Zealand Journal of Experimental Agriculture 2, 341–348.

Radcliffe J, Dale W, Viggers E 1968. Pasture production measurements on hill country, New Zealand Journal of Agricultural Research 11(3), 685–700.

Radcliffe JE, Young SR, Clarke DG 1976. Effects of sunny and shady aspects on pasture yield, digestibility and sheep performance in Canterbury. Proceedings of the N.Z. Grasslands Association 38(1), 66–77.

Ross DJ, Tate KR, Scott NA, Feltham CW 1999. Land-use change: Effects on soil carbon, nitrogen and phosphorus pools and fluxes in three adjacent ecosystems. Soil Biology and Biochemistry 31, 803–813.

Rasse DP, Rumpel C, Dignac MF 2005. Is soil carbon mostly root carbon? Mechanisms for a specific stabilisation. Plant and Soil 269, 341–356.

Reynolds B, Chamberlain PM, Poskitt J, Woods C, Scott WA, Rowe EC, Robinson DA, Frogbrook ZL, Keith AM, Henrys PA, Black HIJ, Emmett BA 2013. Countryside survey: national “soil change” 1978–2007 for topsoils in Great Britain—acidity, carbon, and total nitrogen status. Vadose Zone J 12: vzj2012.0114. doi: 10.2136/vzj2012.0114

Rosser BJ, Ross CW 2011. Recovery of pasture production and soil properties on soil slip scars in erodible siltstone hill country, Wairarapa, New Zealand. New Zealand Journal of Agricultural Research 54, 23–44.

Rowarth JS, Tillman RW, Gillingham AG, Gregg PEH 1992. Phosphorus balances in grazed, hill-country pastures: the effect of slope and fertiliser input. New Zealand Journal of Agricultural Research 35, 337–342.

Roudier P, Hewitt AE, Beaudette DE 2012. A conditioned Latin hypercube sampling algorithm incorporating operational constraints. In: Minasny B, Malone BP, McBratney AB eds, Digital soil assessments and beyond. Proceedings of the 5th Global Workshop on Digital Soil Mapping 2012, Sydney, Australia. Pp. 227–231.

Saggar S, Mackay AD, Hedley MJ, Lambert MG, Clark DA 1990. A nutrient-transfer model to explain the fate of phosphorus and sulfur in a grazed hill-country pasture. Agriculture, Ecosystems & Environment 30, 295–315.

Saggar S, Hedley, C.B., Mackay, A.D., 1997. Partitioning and translocation of photosynthetically fixed 14C in grazed hill pastures. Biology and Fertility of Soils. 25: 152–158.

Saggar S, Mackay AD, Hedley CB 1999. Hill slope effects on the vertical fluxes of photosynthetically fixed 14C in a grazed pasture. Australian Journal of Soil Research 37, 655–666.

Schipper LA, Sparling GP 2011. Accumulation of soil organic C and change in C:N ratio after establishment of pastures on reverted scrubland in New Zealand. Biogeochemistry 104, 49–58.

Schipper LA, Parfitt RL, Ross C, Baisden WT, Claydon JJ, Fraser S 2010. Gains and losses in C and N stocks of New Zealand pasture soils depend on land use. Agriculture, Ecosystems & Environment 139, 611–617.

Schipper LA, Dodd MB, Fisk LM, Power IL, Parenzee J, Arnold G 2011. Trends in soil carbon and nutrients of hill-country pastures receiving different phosphorus fertilizer loadings for 20 years. Biogeochemistry 104, 35–48.

Schipper LA, Littler R, Parfitt R, Fraser S, Ross C, Baisden T 2013. Soil order and landuse effects on changes in soil C and N under different grazing management practices, New Zealand. Ministry for Primary Industries Technical Paper No: 2013/?? FRST Contract ID CONT-21616-SLMACC-LCR. 19 p.

Schipper LA, Dodd MB, Pronger J, Mudge PL, Upsdell MP, Moss RA 2013a. Decadal changes in total surface soil C and N in pastures under differing irrigation frequencies and superphosphate fertilizer application rates. Soil Science Society of America Journal 77, 246–256.

Schipper LA, Parfitt RL, Fraser S, Littler RA, Baisden WT, Ross C 2014. Soil order and grazing management effects on changes in soil C and N in New Zealand pastures. Agriculture, Ecosystems & Environment 184, 67–75.

Schmitt A, Pausch J, Kuzyakov Y 2013. Effect of clipping and shading on C allocation and fluxes in soil under ryegrass and alfalfa estimated by 14C labelling. Applied Soil Ecology 64, 228–236.

Schulp CJE, Verburg PH 2009 Effect of land use history and site factors on spatial variation of the soil organic carbon across a physiographic region. Agriculture, Ecosystems & Environment 133, 86–97.

Schwanghart W, Jarmer T 2011. Linking spatial patterns of soil organic carbon to topography – a case study from south-eastern Spain. Geomorphology 126, 252–263.

Scott DT, Baisden WT, Davies-Colley R, Gomez B, Hicks DM, Page MJ, Preston NJ, Trustrum NA, Tate KR, Woods RA 2006. Localized erosion affects national carbon budget. Geophysical Research Letters 33.

Scott JT, Stewart DPC, Metherell AK 2012. Alteration of pasture root carbon turnover in response to superphosphate and irrigation at Winchmore New Zealand. New Zealand Journal of Agricultural Research 55, 147–159.

Senthilkumar S, Kravchenko AN, Robertson GP 2009. Topography influences management system effects on total soil carbon and nitrogen. Soil Science Society of America Journal 73, 2059–2067.

Sigua GC, Coleman SW 2010. Spatial distribution of soil carbon in pastures with cow-calf operation: Effects of slope aspect and slope position. Journal of Soils and Sediments 10, 240–247.

Singh K, Murphy BW, Marchant BP 2012. Towards cost-effective estimation of soil carbon stocks at the field scale. Soil Research 50, 672–684.

Skjemstad JO, Spouncer LR, Cowie B, Swift RS 2004. Calibration of the Rothamsted organic carbon turnover model (RothC ver. 26.3), using measurable soil organic carbon pools. Australian Journal of Soil Research 42, 79–88.

Sparling G, Ross D, Trustrum N, Arnold G, West A, Speir T, Schipper L 2003. Recovery of topsoil characteristics after landslip erosion in dry hill country of New Zealand, and a test of the space-for-time hypothesis. Soil Biology and Biochemistry 35, 1575–1586.

Sparling GP, Lewis R, Schipper LA, Mudge P, Balks M 2014. Changes in soil total C and N contents at three chronosequences after conversion from plantation pine forest to dairy pasture on a New Zealand Pumice soil. Soil Research 52, 38–45.

Soriano-Disla JM, Janik LJ, Viscarra Rossel RA, MacDonald LM, McLaughlin MJ 2014. The performance of visible, near-, and mid-infrared reflectance spectroscopy for prediction of soil physical, chemical, and biological properties. Applied Spectroscopy Reviews 49(2), 139–186.

Statistics New Zealand 2012. Agricultural production census (Final Results), June 2012. Wellington, Statistics New Zealand.

Stenberg B, Viscarra Rossel RA, Mouazen A, Wetterlind J 2010. Visible and near infrared spectroscopy in soil science. Advances in Agronomy 107, 163–215.

Stevens A, Udelhoven T, Denis A, Tychon B, Lioy R, Hoffmann L, van Wesemael B 2010. Measuring soil organic carbon in croplands at regional scale using airborne imaging spectroscopy. Geoderma 158, 32–45.

Stewart DPC, Metherell AK 1999. Carbon (13C) uptake and allocation in pasture plants following field pulse-labelling. Plant and Soil 210, 61–73.

Stolbovoy V, Montanarella L, Filippi N, Jones A, Gallego J, Grassi G 2007. Soil sampling protocol to certify the changes of organic carbon stock in mineral soil of the European Union. Version 2. EUR 21576 EN/2. Luxembourg, Office for Official Publications of the European Communities. 56 p. ISBN: 978-92-79-05379-5

Suarez-Abelenda M, Kaal J, Camps-Arbestain M, Knicker H, Macias F 2014 Molecular characteristics of permanganate and dichromate oxidation-resistant soil organic matter from a black-C-rich colluvial soil. Soil Research 52, 164–179.

Suckling FET 1960. Pasture management trials on unploughable hill country at Te Awa. New Zealand Journal of Experimental Agriculture 3, 351–436

Tate KR 1992. Assessment based on a climosequence of soils in tussock grasslands, of soil carbon storage and release in response to global warming. Journal of Soil Science 43, 697–707.

Tate KR, Scott NA, Ross, DJ, Parshotam A, Claydon JJ 2000. Plant effects on soil carbon storage and turnover in a montane beech (Nothofagus) forest and adjacent tussock grassland in New Zealand. Australian Journal of Soil Research 38, 685–698.

Tate KR, Wilde RH, Giltrap DJ, Baisden WT, Saggar S, Trustum NA, Scott NA, Barton JP, 2005. Soil organic carbon stocks and flows in New Zealand: system development, measurement and modelling. Canadian Journal of Soil Science 85, 481–489.

Trustrum NA, De Rose RC 1988. Soil depth-age relationship of landslides on deforested hillslopes, Taranaki, New Zealand. Geomorphology 1, 143–160.

Trustrum NA, Blaschke PM, De Rose RC, West AW 1990. Regolith changes and pastoral productivity declines following deforestation in steeplands of north Island, New Zealand. Transactions of 14th international soil science congress. International Soil Science Society, Kyoto, Japan, August 1990. Section I. Pp. 125–130.

Valette L 2013. Farm-scale mapping of soil organic carbon on a hill country farm using visible near infrared spectroscopy. Thesis submitted in partial fulfilment of M.Sc. specialising in Agro-technology, Supagro, Montpellier, France, and Massey University, New Zealand, September 2013, hosted and supervised by Landcare Research NZ. 60 p.

Vanden Bygaart AJ, Angers DA 2006. Towards accurate measurements of soil organic carbon stock change in agroecosystems. Canadian Journal of Soil Science 86, 465–471.

Vitharana UWA, Van Meirvenne M, Simpson D, Cockx L, De Baerdemaeker J 2008. Key soil and topographic properties to delineate potential management classes for precision agriculture in the European loess area. Geoderma 143, 206–215.

Wan S, Luo Y 2003. Substrate regulation of soil respiration in a tallgrass prairie: Results of a clipping and shading experiment. Global Biogeochemical Cycles 17, 1054.

Whitehead D, Baisden T, Beare M, Campbell D, Curtin D, Davis M, Hedley C, Hedley M, Jones H, Kelliher F, Saggar S, Schipper L 2012. Review of soil carbon measurement methodologies and technologies, including nature and intensity of sampling, their uncertainties and costs. Ministry for Primary Industries Technical Paper No: 2012/36.

Walker TW, Thapa BK, Adams AFR 1959. Studies on soil organic matter: 3. Accumulation of carbon, nitrogen, sulphur, organic and total phosphorus in improved grassland soils. Soil Science 87, 135–140.

Watson CJ, Jordan C, Kilpatrick D, McCarney B, Stewart R 2007. Impact of grazed grassland management on total N accumulation in soil receiving different levels of N inputs. Soil Use and Management 23, 121–128.

Watzka M, Buchgraber K, Wanek W 2006. Natural 15N abundance of plants and soils under different management practices in a montane grassland. Soil Biology & Biochemistry 38, 1564–1576.

Webster R Oliver M 2007. Geostatistics for environmental scientists. 2nd Edn. Hoboken, NJ, Wiley Publishers. 315 p.

Wiaux F, Cornelis JT, Cao W, Vanclooster M, Van Oost K 2014 Combined effect of geomorphic and pedogenic processes on the distribution of soil organic carbon quality along an eroding hillslope on loess soil. Geoderma 216, 36–47.

Yanai RD, Stehman SV, Arthur MA, Prescott CE, Friedland AJ, Siccama TG, Binkley D 2003. Detecting change in forest floor carbon. Soil Science Society of America Journal 67, 1583–1593.

Appendix 1 – Selected non-resampled hill country NSD sites

100 selected NSD sites where there is potentially useful data for future studies of SOCS in pastoral hill country.

Table A1 - 1: Hill Country NSD sites, with measured slope angle ≥10°, improved and unimproved pasture, excluding rough grazing recreation, unused natural, unused reverted, and sites without coordinates (reported coordinates are in NZMG)

site_id	Series name	NZ Revised subgroup	East	North
SB09626	ARAPAWA	GOA	2607611	5985646
SB07643	ARAPOHUE	Na	2596800	6580000
SB09956	CASTLECLIFF	RST	2617800	6245750
SB09465	CLIFTON	PIT	2483238	5735958
SB08237	CLUDEN	PLT	2219935	5527909
SB09265	DUNMORE	LOT	2684481	6392460
SB10027	FOXTON	BST	2687700	6043300
SB09470	GODLEY	PXJN	2492215	5735114
SB09441	GRAMPIANS VARIANT	PIT	2265378	5625888
SB09847	HALCOMBE	PJM	2735637	6099440
SB07950	HALCOMBE	PPT	2736700	6089400
SB08734	HIGHCLIFF	EMT	2320558	5477722
SB08562	HUIHUI	EOC	2483060	5796764
SB08636	KAIRUA	ZXQ	2804405	6380192
SB08261	KAPU	BOT	2677680	6436646
SB08473	KARITANE	ERT	2312732	5475483
SB09466	KIWI	PID	2483238	5735958
SB08614	KUMEROA	PJT	2681920	6146786
SB08744	MACANDREW	EMT	2325004	5479811
SB10013	MAHINAPUA	BST	2406300	5945100
SB07812	MAHOENUI	BOM	2743300	6040100
SB08306	MAKARETU	LIT	2730431	6048181
SB10177	MAKORORI	ROW	2961600	6284500
SB08317	MAKOTUKU	PIT	2749859	6107452
SB09642	MARAMARUA	UYT	2719200	6433500
SB09560	MATAMAU	PIM	2745762	6082323
SB08537	MOTUHORA	Na	2860469	6364149
SB07683	NAIKE	Na	2698000	6397200
SB09734	NGAKURU	LOT	2758431	6294062
SB08370	NGAMOKA	PID	2749000	6195000
SB08318	OKOIA	EPJ	2697869	6141578
SB08476	OPOHO	BFT	2311098	5474815
SB09313	OPUA	LIT	2585965	6200902
SB09558	OPUA	LIT	2585965	6200902
SB10152	ORMOND	PPT	2945500	6274700
SB09467	OTAHUNA	PIM	2481230	5735739
SB08705	OTOKIA	PPX	2298943	5474330
SB10178	OTOKO	BOT	2961400	6284800

site_id	Series name	NZ Revised subgroup	East	North
SB09111	OTOROHANGA	LOT	2721426	6334070
SB09766	OWHAI	EMT	2576515	6039948
SB08723	PAPAKAIO	PIT	2346700	5577681
SB09536	PAPAKAURI	LOT	2587429	6649283
SB07657	PAPAKAURI	Na	2624800	6613200
SB08228	POHANGINA	PIM	2755234	6116355
SB07515	PORIRUA	Na	2667800	6014100
SB08586	PORIRUA	BOP	2667808	6014111
SB08513	PORIRUA	Na	2667808	6014111
SB08464	PORTEOUS	BFA	2320098	5483201
SB08506	PORTOBELLO	PJT	2328429	5482706
SB08504	PORTOBELLO	EMT	2329608	5483275
SB08507	PORTOBELLO	EMT	2328793	5482804
SB08505	PORTOBELLO	BMA	2328979	5482624
SB08508	PORTOBELLO	BAT	2328618	5482343
SB10146	POUAWA	ROW	2901430	6309420
SB07652	PUHOI	Na	2661300	6517500
SB09110	PUKERATA	BOA	2724337	6333530
SB08010	RAUMAI	PIT	2736500	6084800
SB08589	RUAHINE	BOT	2751758	6103465
SB10149	TAHIKI	ROW	2903000	6300670
SB08321	TAIHAPE	BOM	2700195	6155871
SB09958	TAIHAPE	PPT	2740586	6015653
SB09960	TAIHAPE	PPT	2740430	6015832
SB09964	TAIHAPE	PPT	2740563	6015532
SB09961	TAIHAPE	PJM	2740419	6015827
SB09962	TAIHAPE	PIM	2740358	6015754
SB09959	TAIHAPE	EOJ	2740541	6015535
SB08719	TAIKO	PIT	2332986	5582651
SB10179	TAITEATEA	RTT	2961800	6284900
SB09469	TAKAHE	PXM	2481227	5735922
SB09805	TAUHEI	UYM	2716700	6432100
SB07641	TE KIE	Na	2576600	6625800
SB09319	TE KIRI	LOV	2589650	6203625
SB08510	TE MATA	ERT	2711634	5985689
SB10150	TE RANUI	BOM	2944100	6290600
SB09843	TEKOA	BOT	2539961	5944339
SB08538	TIMPENDEAN	PJT	2486776	5803689
SB08692	TURAKINA	PID	2711820	6172371
SB08693	TURAKINA	BOP	2711462	6172655
SB08697	TURAKINA	BOP	2714719	6171374
SB08254	TURAKINA	PIM	2712332	6171075
SB08251	TURAKINA	BOP	2714917	6171917
SB08253	TURAKINA	BOP	2714719	6171374
SB07642	TUTAMOE	Na	2545500	6618500

site_id	Series name	NZ Revised subgroup	East	North
SB09865	TUTURAU	BOA	2200400	5440500
SB08404	UMUTOI	LOT	2762626	6135171
SB08249	UPOKONUI	BOP	2703450	6160992
SB09105	WAENGA	SJT	2217331	5561776
SB08669	WAIKARE	UEM	2649403	6543273
SB10176	WAIMOKO	ROT	2961400	6284600
SB09315	WAREA	LOT	2580773	6208090
SB10153	WEBER	BOM	2964400	6283600
SB08613	WESTMERE	EMT	2681912	6146512
SB08346	WHANGAEHU	PIM	2700800	6135276
SB08362	WHETUKURA	BOM	2750561	6096730
SB08363	WHETUKURA	BOM	2750467	6096642
SB08618	WILFORD	EOM	2696195	6143821
SB08390	WILFORD	PJT	2751619	6095328
SB08391	WILFORD	PJM	2751617	6095237
SB09987	WINGATE	PPJX	2674700	6001050
SB09986	WINGATE	BOM	2674700	6001050

Appendix 2 – Total organic C and N stocks for Okoia and Te Whanga Station

Table A2 - 1: Total organic carbon and nitrogen analyses for different hillslope positions within a 2-km^2 grid perimeter of the SB08318 site, Okoia, Wanganui, North Island, New Zealand

Site ID	easting	northing	Slope class	Aspect	TtlC0_30C30	TtlN0_30	C:N
2	1788443	5579450	summit	flat	95.81	9.45	10
4	1787079	5579229	floor	flat	77.73	8.12	10
5	1787875	5579532	upper	south	52.60	4.87	11
7	1788004	5579509	summit	flat	86.95	7.91	11
8	1788413	5579375	upper	south	51.31	4.99	10
9	1788501	5579177	mid	south	90.70	8.01	11
10	1787900	5579383	mid	south	30.89	2.92	11
11	1788259	5579080	upper	north	53.51	4.78	11
13	1788251	5579673	ridge/spur	north	119.87	11.79	10
16*	1788528	5579885	floor	flat	43.70	5.04	9
17	1788098	5579753	lower	flat	88.54	7.58	12
18	1787617	5579486	upper	south	64.17	6.07	11
23	1787774	5579169	upper	north	90.18	8.56	11
27	1788531	5579938	floor	flat	76.90	8.80	9
28	1788247	5579606	gully	flat	106.57	10.15	10
30	1787217	5579181	mid	north	90.19	7.83	12
31	1787512	5579666	mid	north	107.64	10.27	10
32	1788170	5579558	mid	north	68.36	7.23	9
33	1787561	5579647	mid	north	92.50	8.65	11
37	1788186	5579464	upper	north	63.47	5.91	11
38	1788486	5579212	mid	south	103.98	9.96	10
24a	1787363	5579691	lower	north	84.88	8.60	10
24b	1787321	5579701	lower	north	111.61	10.28	11
SB08318_A	1787822	5579720	lower	north	89.33	7.69	12
SB08318_B	1787827	5579718	lower	north	81.79	7.01	12
SB08318_C	1787832	5579719	lower	north	112.80	7.24	16

*16 – outlier for valley floor with overburden and buried topsoil

Table A2 - 2: Total organic carbon and nitrogen analyses for different hillslope positions within a 2-km^2 grid perimeter of the SB09959 and SB09961 sites, Te Whanga, Wairarapa, North Island, New Zealand

Site ID			Slope class	Aspect	**TtlC0_30**	**TtlN0_30**	C:N
1	1829849	5453922	mid	north	68.93	6.55	11
2	1830293	5454008	mid	south	68.83	6.60	10
3	1830143	5454393	gully	north	70.19	7.03	10
4	1829963	5454708	floor	flat	88.55	8.92	10
5	1829886	5454005	lower	south	85.78	7.27	12
6	1830349	5453938	mid	south	76.08	7.15	11
7	1830774	5453720	mid	north	89.20	8.18	11
8	1830023	5454298	lower	north	53.77	5.71	9
9	1830729	5453785	lower	west	41.45	4.58	9
10	1829673	5454673	upper	east	99.92	10.26	10
11	1829816	5454095	mid	south	72.78	7.95	9
12	1830228	5454613	floor	flat	75.56	7.00	11
13	1830196	5454077	upper	flat	108.63	11.07	10
14	1829723	5454618	lower	north	86.92	10.13	9
15	1830452	5453892	gully	north	147.19	11.35	13
16	1830103	5454131	upper	north	48.07	4.75	10
17	1830568	5453416	lower	north	98.41	9.18	11
18	1830148	5454598	lower	north	77.56	7.10	11
19	1829548	5454343	gully	flat	85.99	8.31	10
20	1830432	5453487	upper	north	81.62	7.50	11
21	1830183	5454238	upper	north	70.57	6.51	11
22	1830185	5454031	mid	south	72.37	6.51	11
23	1829923	5454403	mid	north	119.13	10.13	12
24	1830379	5453847	mid	flat	61.78	5.97	10
25	1830169	5454090	upper	north	91.21	7.88	12
26	1830123	5454633	lower	flat	72.19	6.75	11
27	1829883	5454608	gully	flat	100.28	9.27	11
28	1830087	5453841	upper	west	97.31	9.23	11
29	1830528	5454198	mid	east	68.07	6.64	10
30	1829523	5454278	ridgeline	flat	95.82	8.90	11
SB09959A	1830521	5453810	upper	north	118.75	11.05	11
SB09959B	1830526	5453811	upper	north	104.24	9.12	11
SB09959C	1830516	5453809	upper	north	92.25	8.31	11
SB09961A	1830399	5454102	upper	south	82.80	7.81	11
SB09961B	1830399	5454102	upper	south	76.41	7.40	10
SB09961C	1830399	5454102	upper	south	78.32	6.94	11

Appendix 3 – Site details and estimated SOCS changes for the 23 NSD sites

Table A3 - 1: Environmental parameters for the 23 sites selected by Schipper et al. (2010, 2013, 2014) to resample NSD sites to assess soil carbon stocks (land use: drystock, topography: hill)

Soil ID	Soil Name	Easting	Northing	Soil Order	IPCC class	Rain (mm)	Elevation (m)	Slope (°)	MAT (°C)
SB08249	Upokonui steepland soil	2703291	6160961	Brown	LAC	1520	488	33	106
SB08253	Turakina steepland soil	2714638	6171412	Brown	LAC	1270	432	33	103
SB08317	Makotuku	2749819	6107331	Pallic	LAC	1143	229	22	117
SB08318	Okoia steepland soil	2697849	6141428	Melanic	HAC	965	91	31	128
SB08347	Whangaehu	2700798	6135402	Pallic	HAC	914	73	35	126
SB08404	Umutoi	2762670	6135107	Allophanic	Andisol	1500	640	28	96
SB08613	Westmere hill soil	2681961	6146492	Melanic	HAC	762	107	23	126
SB08614	Kumeroa hill soil	2682014	6146780	Pallic	LAC	826	107	25	128
SB09268	Kinohaku	2680914	6347231	Allophanic	Andisol	1400	90		135
SB09464	Scarborough hill	2481363	5736094	Pallic	HAC	693	120	26	116
SB09467	Otahuna hill	2481395	5735867	Pallic	HAC	693	230	24	115
SB09470	Godley silt loam	2492261	5735171	Pallic	HAC	563	175	13	116
SB09555	Tahora	2665039	6236723	Brown	LAC	2400	300	31	120
SB09560	Matamau	2745634	6082395	Pallic	LAC	1400	150	25	122
SB09642	Maramarua	2719203	6433465	Ultic	LAC	1300	30	13	140
SB09734	Ngakuru	2758452	6293910	Allophanic	Andisol	1600	475	20	115
SB09959	Taihape N	2740540	6015531	Melanic	HAC	1000	240	30	115
SB09961	Taihape S	2740413	6015826	Pallic	HAC	1000	230	26	115
SB09997	Pawson sillt loam	2502741	5715347	Pallic	HAC	980	90	9	119
SB10149	Tahiki	2929731	6306268	Recent	HAC	1400	220	32	126
SB10150	Te Ranui	2943937	6290692	Brown	HAC	1600	200	27	130
SB10153	Weber	2963834	6284129	Brown	HAC	1400	160	24	134
SB10179	Taiteatea	2961671	6284608	Recent	Sandy	1600	140	19	135

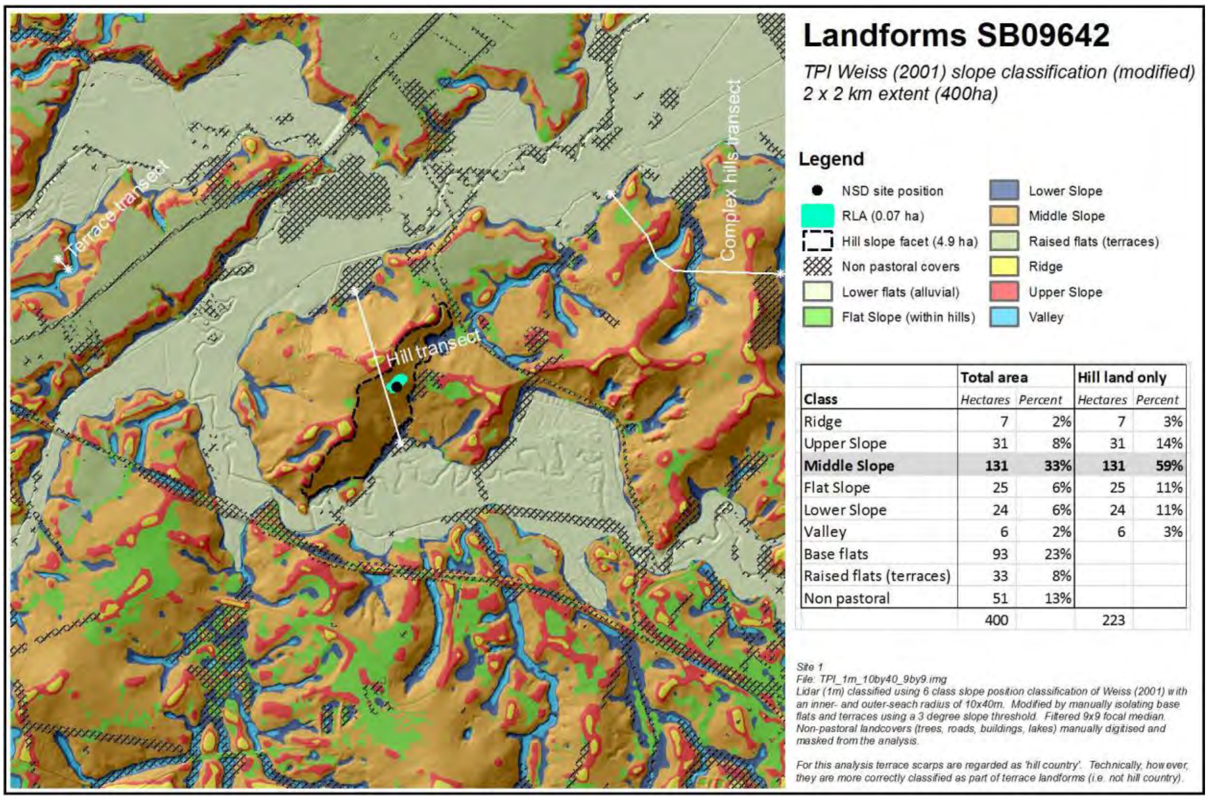
Table A3 - 2: Estimated soil carbon stocks for 23 NSD sites at two sampling dates (land use: drystock, topography: hill) (Schipper et al. 2010, 2013, 2014)

Soil ID	Soil Name	First year of sampling	Second year of sampling	First sampling *Carbon (Mg/ha to 0.3 m)*	Second sampling *Carbon (Mg/ha to 0.3 m)*	First sampling *Nitrogen (Mg/ha to 0.3 m)*	Second sampling *Nitrogen (Mg/ha to 0.3 m)*	Change in C *Carbon (Mg/ha to 0.3 m)*	Change in N *Nitrogen (Mg/ha to 0.3 m)*
SB08249	Upokonui steepland soil	1967	2007	109.94	98.99	6.47	8.39	-11.0	1.92
SB08253	Turakina steepland soil	1967	2007	126.12	164.17	11.63	14.58	38.0	2.95
SB08317	Makotuku	1968	2008	93.42	97.14	5.82	5.48	3.7	-0.34
SB08318	Okoia steepland soil	1968	2007	103.73	96.84	7.48	7.73	-6.9	0.25
SB08347	Whangaehu	1968	2010	84.28	82.20	6.19	6.34	-2.1	0.16
SB08404	Umutoi	1968	2008	193.68	177.72	14.92	13.31	-16.0	-1.61
SB08613	Westmere hill soil	1970	2007	121.86	119.33	9.93	10.15	-2.5	0.22
SB08614	Kumeroa hill soil	1970	2007	91.95	126.30	6.70	9.68	34.4	2.98
SB09268	Kinohaku	1976	2011	218.25	174.90	17.10	15.47	-43.4	-1.63
SB09464	Scarborough hill	1978	2010	94.15	128.65	8.17	10.55	34.5	2.38
SB09467	Otahuna hill	1978	2010	77.49	104.40	6.54	8.64	26.9	2.10
SB09470	Godley silt loam	1978	2010	76.24	118.10	6.49	10.82	41.9	4.33
SB09555	Tahora	1980	2011	78.18	106.74	5.89	9.56	28.6	3.67
SB09560	Matamau	1977	2008	64.09	106.61	4.60	8.89	42.5	4.29
SB09642	Maramarua	1980	2004	75.74	88.90	5.25	6.00	13.2	0.75
SB09734	Ngakuru	1981	2011	115.52	136.51	7.30	9.68	21.0	2.38
SB09959	Taihape N	1984	2008	94.02	101.24	7.20	8.03	7.2	0.82
SB09961	Taihape S	1984	2008	80.82	81.79	6.91	7.35	1.0	0.45
SB09997	Pawson sillt loam	1985	2010	89.48	126.56	7.69	10.70	37.1	3.01
SB10149	Tahiki	1990	2005	77.38	99.74	6.02	8.05	22.4	2.04
SB10150	Te Ranui	1990	2005	89.28	91.63	6.80	8.74	2.4	1.94
SB10153	Weber	1990	2005	79.49	93.05	6.58	8.53	13.6	1.95
SB10179	Taiteatea	1992	2005	95.36	120.00	8.21	10.83	24.6	2.62

Appendix 4 – Site representativeness results for 23 sites

Site 1 (SB09642)

Site 1 is located is within the margins of hill country between the Hapuakohe Ranges and the Hauraki Plains near Mangatarata (Waikato). A sizeable area of the 2km^2 grid contains large areas of flat landforms that associate more closely with the Hauraki plains (classed as lower flats and raised flats). Hill country type is *Deeply Weathered Hill Country* (2).



	Total area		Hill land only	
Class	Hectares	Percent	Hectares	Percent
Ridge	7	2%	7	3%
Upper Slope	31	8%	31	14%
Middle Slope	**131**	**33%**	**131**	**59%**
Flat Slope	25	6%	25	11%
Lower Slope	24	6%	24	11%
Valley	6	2%	6	3%
Base flats	93	23%		
Raised flats (terraces)	33	8%		
Non pastoral	51	13%		
	400		223	

Figure A4 - 1: Classification of land forms for site SB09642 within a 2km^2 grid.

Results for Site 1 are presented as Figures 2 through 6, and summarised in Table 1. Note that aspect becomes less meaningful as the area being assessed increases in size (all aspect classes tend to be included at similar percentages).

The site is marginally representative at the **hill facet scale** (Figure 2). Only aspect exhibits a strong match. The site exhibits good representation of **midslopes** found within the 2km^2 grid for all characteristics other than elevation (Figure 3), and the midslope land element accounts for 59% of the hill land found within the 2km^2 extent (Figure 1). Overall representation within the same **soil type** is marginal (Figure 4), especially in terms of erosion. However, slope is very strongly represented (distance from median = 1). Representation within '**Deeply Weathered Hill Country**' is good for slope, pasture and soil order, but only marginal for elevation, erosion, rainfall, temperature and drainage (Figure 5). Similarly, the site represents NZ hill country at the better end of marginal, with three of eight characteristics qualifying as representative (Figure 6).

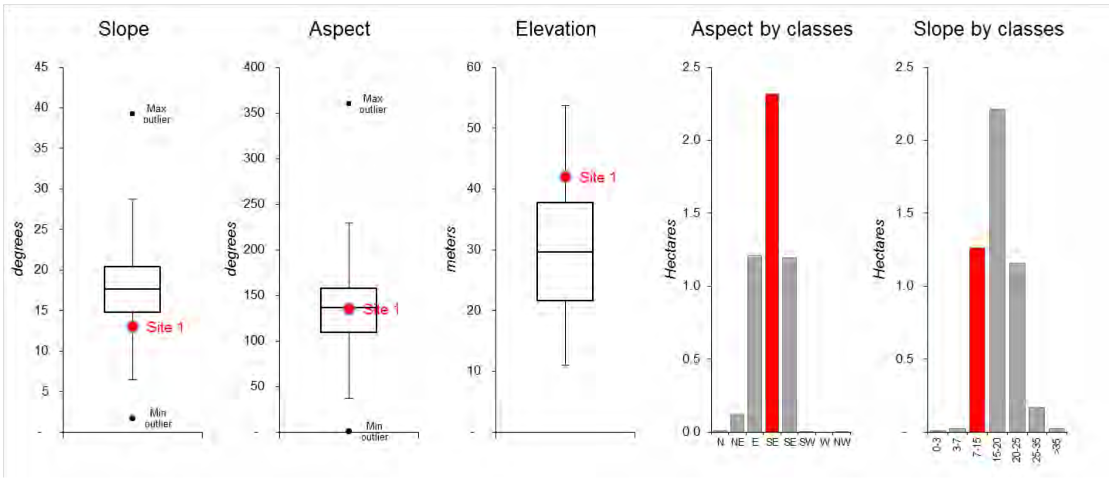


Figure A4 - 2: Representativeness of site 1 within a hill facet. Red indicates the position or class that the site value occurs within.

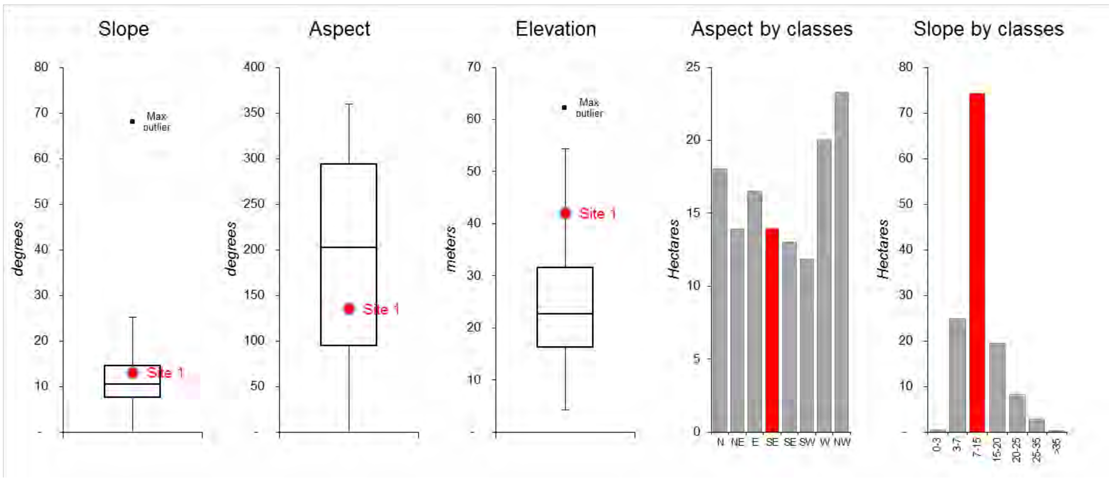


Figure A4 - 3: Representativeness of site 1 within midslopes located within a 2km² grid.

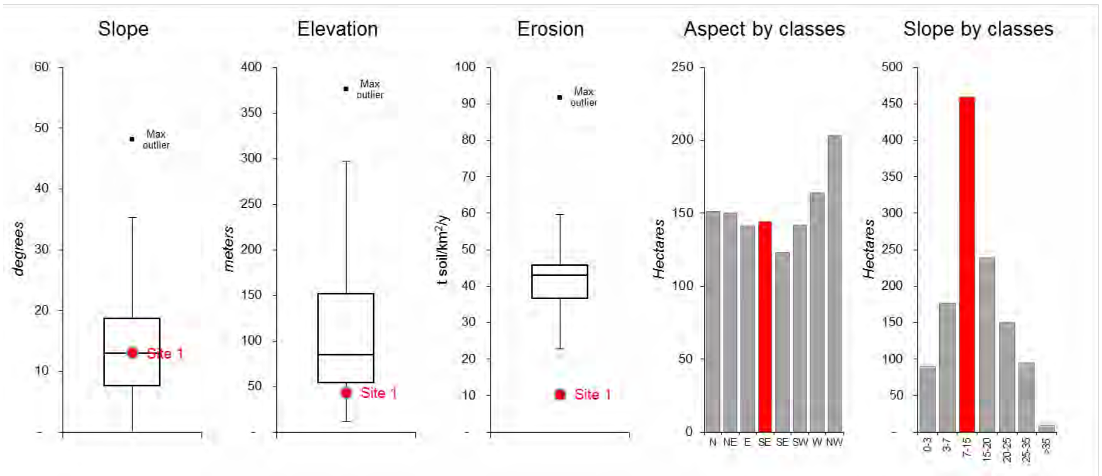


Figure A4 - 4: Representativeness of site 1 within the same soil type (Maramarua silt loam, hill phase).

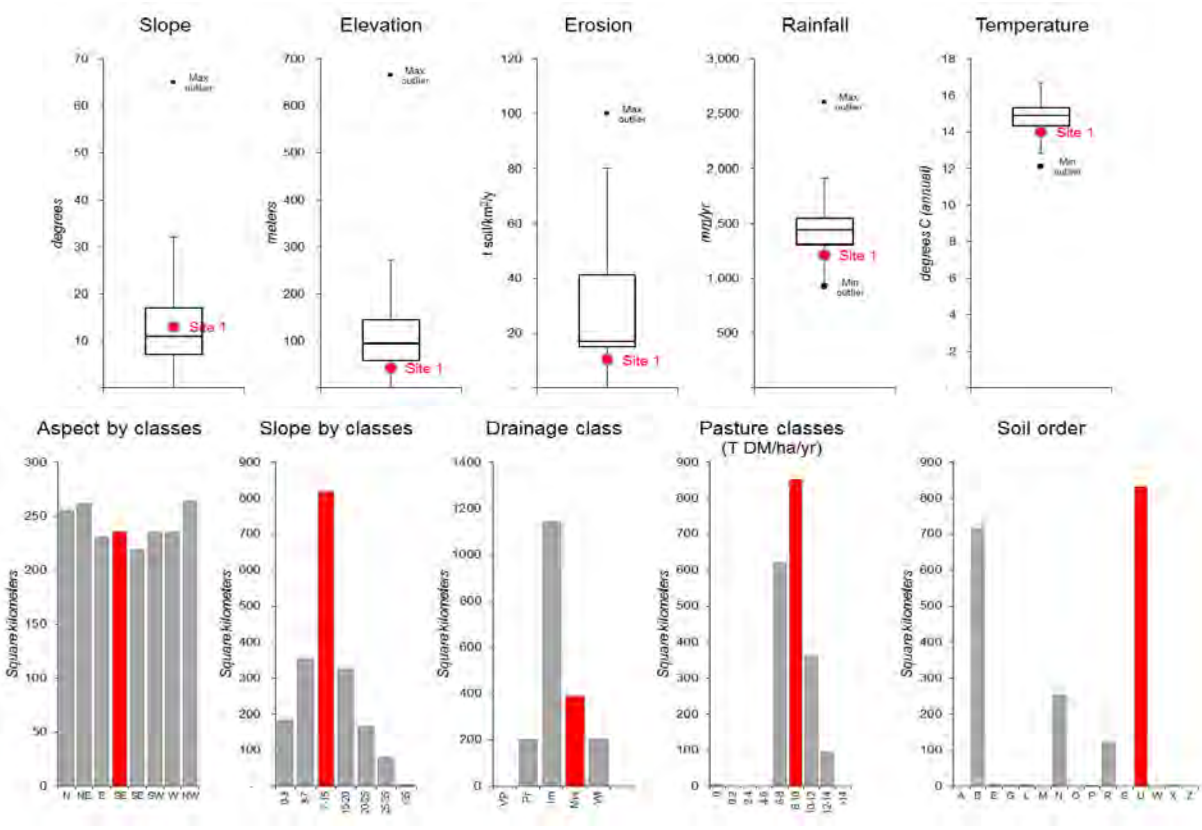


Figure A4 - 5: Representativeness of site 1 within "Deeply Weathered Hill Country" hill country type.

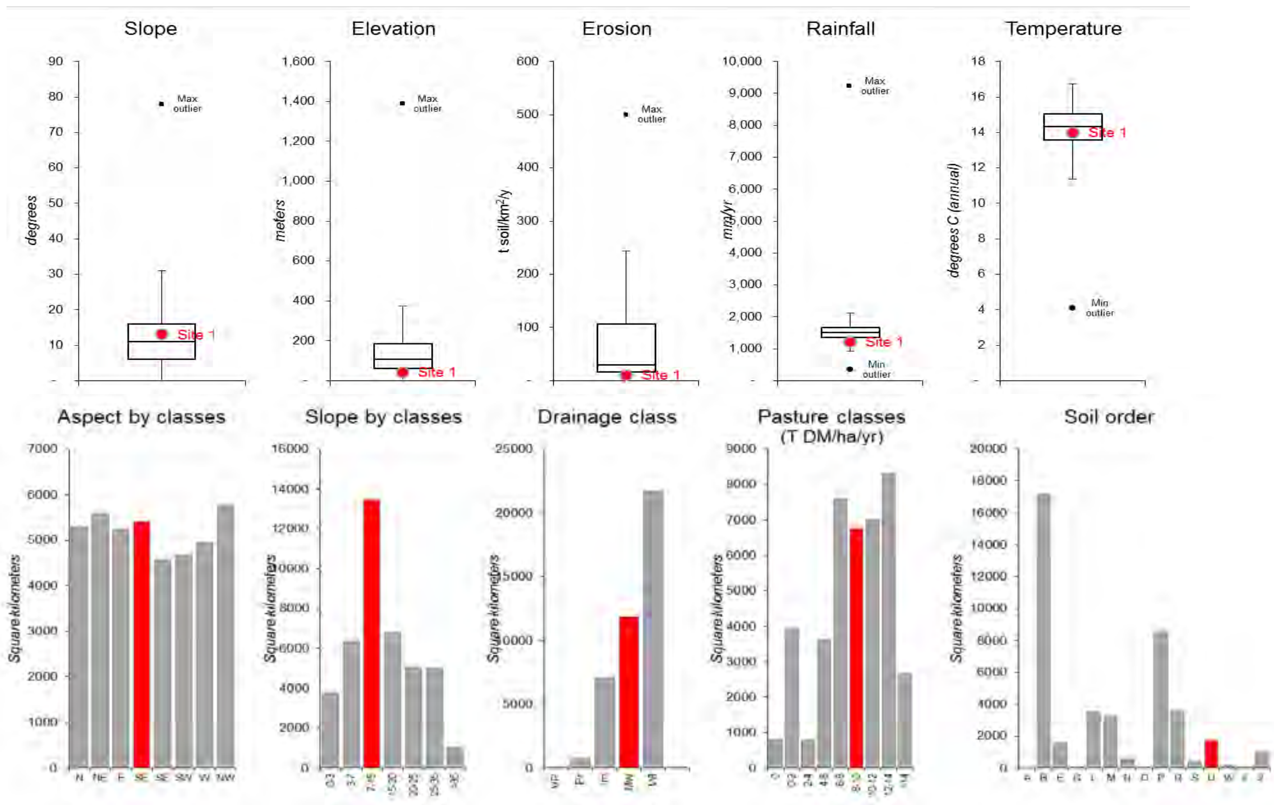


Figure A4 - 6: Representativeness of site 1 within all NZ hill country.

Table A4 - 1: Distance from the median and percent area of Site 1 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Midslopes within 2km²	Hill country within 2km²	Hill soil type	Hill country type	Hill country all
Eligible total area	-	*0.007 ha*	*4.9 ha*	*131 ha*	*223 ha*	*1218 ha*	*1938 km²*	*4.1 M ha*
Elevation (m)	*30*	**43**	**37**	**41**	x	**33**	**33**	**35**
Slope (degrees)	***13***	13	**36**	**17**	x	**1**	**8**	**12**
Aspect (degrees)	***135***	138	**2**	x	x	x	x	x
Erosion (t soil/km²/y)	***10.3***	x	x	x	x	**+50**	**46**	**46**
Precipitation (mm)	1300	**1210**	x	x	x	x	**38**	**43**
Temperature (°C)	-	14	x	x	x	x	**33**	**11**
Midslopes	-	x	x	x	**69%**	x	x	x
Hill country type	***2***	x	x	x	x	x	x	**5%**
Soil type	***MmH***	x	x	x	x	x	**1%**	**<0.1%**
Soil subgroup	***UYT***	x	x	x	x	x	**10%**	**1%**
Soil order	***U***	x	x	x	x	x	**43%**	**4%**
Slope group	*x*	***7-15°***	**26%**	**57%**	x	**38%**	**42%**	**32%**
Aspect group	*x*	***SE***	**48%**	**11%**	x	**12%**	**12%**	**13%**
Pasture (kg DM/ha/y)	***8500***	x	x	x	x	x	**44%**	**16%**
Drainage	***Mw***	x	x	x	x	x	**20%**	**29%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 2 (SB09268)

Site 2 is located within hill country (Waikato west coast near Kawhia Harbour), but within an area of gently rolling land where the site itself appears to be flat (<2°). No slope is recorded in the NSD, but some inference is obtained from the soil type in that it was not recorded as either a rolling or hill phase (there is a hill phase recorded for this soil elsewhere). Hence, the phase is assumed to be for flat land. Likewise, median slope within a 10m radius of the site is a similar 2.4° (Q1=1.5°, Q2=2.4°, Q3=3.2°). Even if the search was extended to 20m, the highest clustering of local slopes would only fall within the rolling rather than hill slope categories.

In being flat, Site 2 does not qualify as hill country according to the Basher et al. (2008) definition (and thus falls outside this study's area of analysis) nor does it qualify for inclusion in Schipper et al.'s (2010) description of their hill country group - *drystock grazing on hill country (>15°) in the North Island* (p. 612).

As a workaround, the site is assigned to the neighbouring *Tephric (ash) hill country type (16)* on the basis that the site's soil (Kinohaku silt loam) occurs in this hill country type. Likewise, we use the full area of the soil type irrespective of whether or not it occurs within the Basher et al. (2008) definition. Missing NSD values are populated from the RLA (Table 2). For this site there is no hill facet (hence, not assessed) and the landform element being represented is *Flat slopes (within hills)* rather than midslopes (Figure 7).

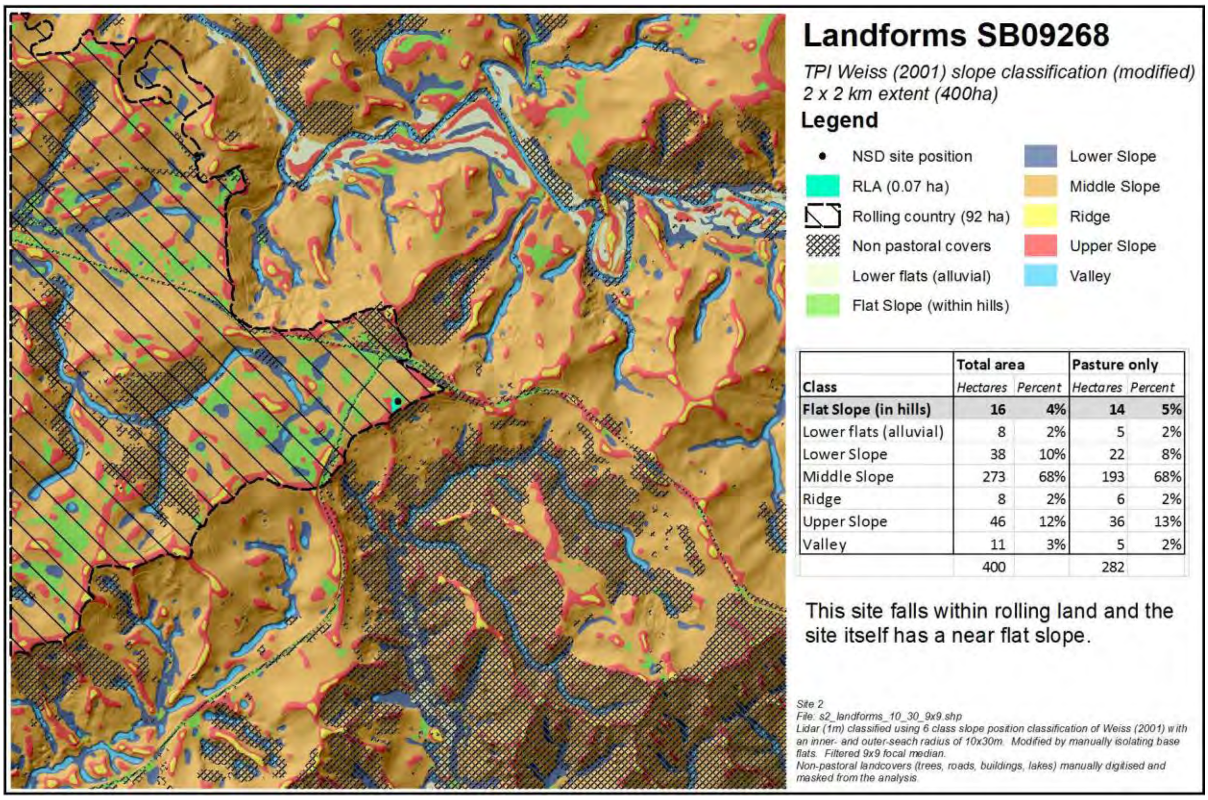


Figure A4 - 7: Classification of land forms for site SB09268 within a $2km^2$ grid.

Based on the information we have, Site 2 is representative of flat land within hill country. This would make Site 2 marginally representative of other **flat hill slopes** found within 2km^2 (Figure 8), and reasonably representative of of the Kinohaku silt loam **soil type** (Figure 9), especially if slope was to fall into the undulating and rolling categories. Similarly, the site is reasonably representative for both the "Tephric (ash) hill country" (Figure 10) and all NZ hill country (Figure 11) scales of analysis, which again would be further improved if the Site's slope fell within the rolling category.

For soil type (Figure 9) the spread of slope values (5-17°) would suggest that this particular soil type most closely associates with undulating and rolling landscapes, although not described as such (i.e. not indicated by the phase). This site could therefore perhaps be re-evaluated as having a higher slope which is likely to improve representativeness.

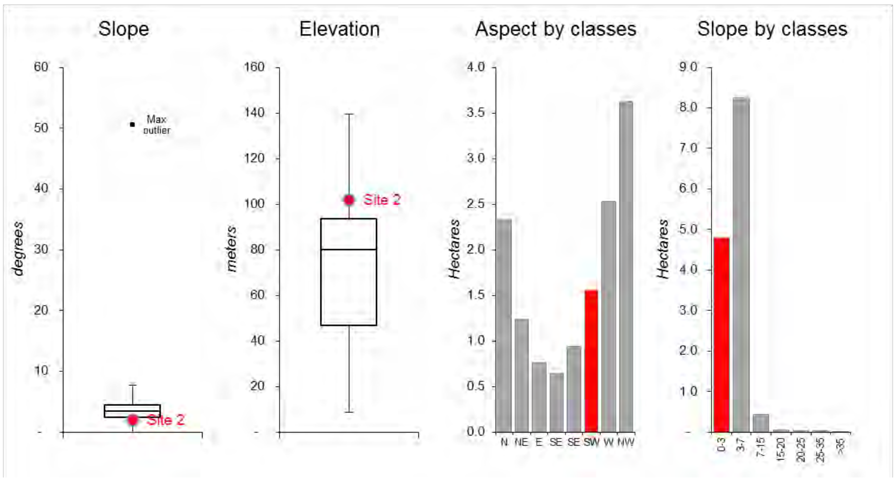


Figure A4 - 8: Representativeness of site 2 within 'hill flat slopes' located within a 2km^2 grid.

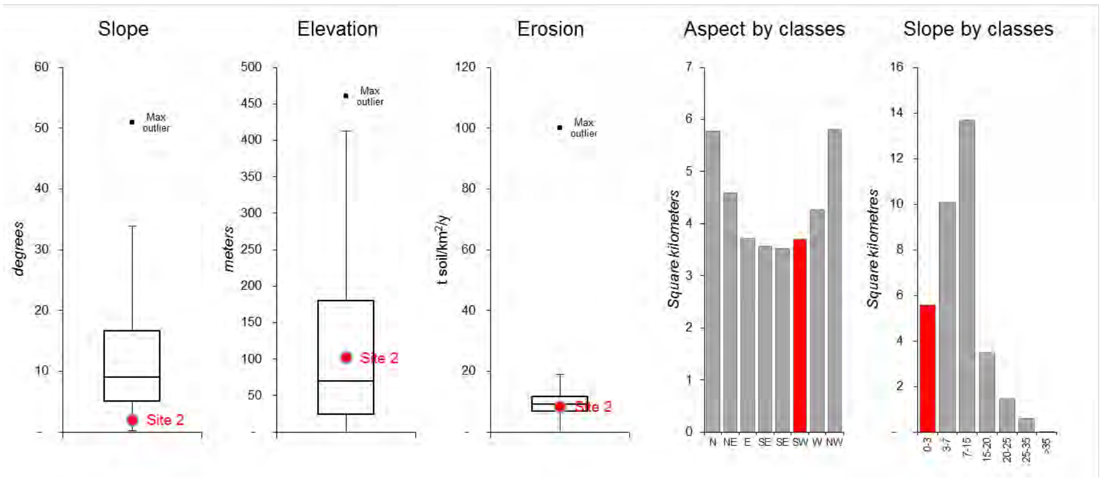


Figure A4 - 9: Representativeness of site 2 within the same soil type (Kinohaku silt loam).

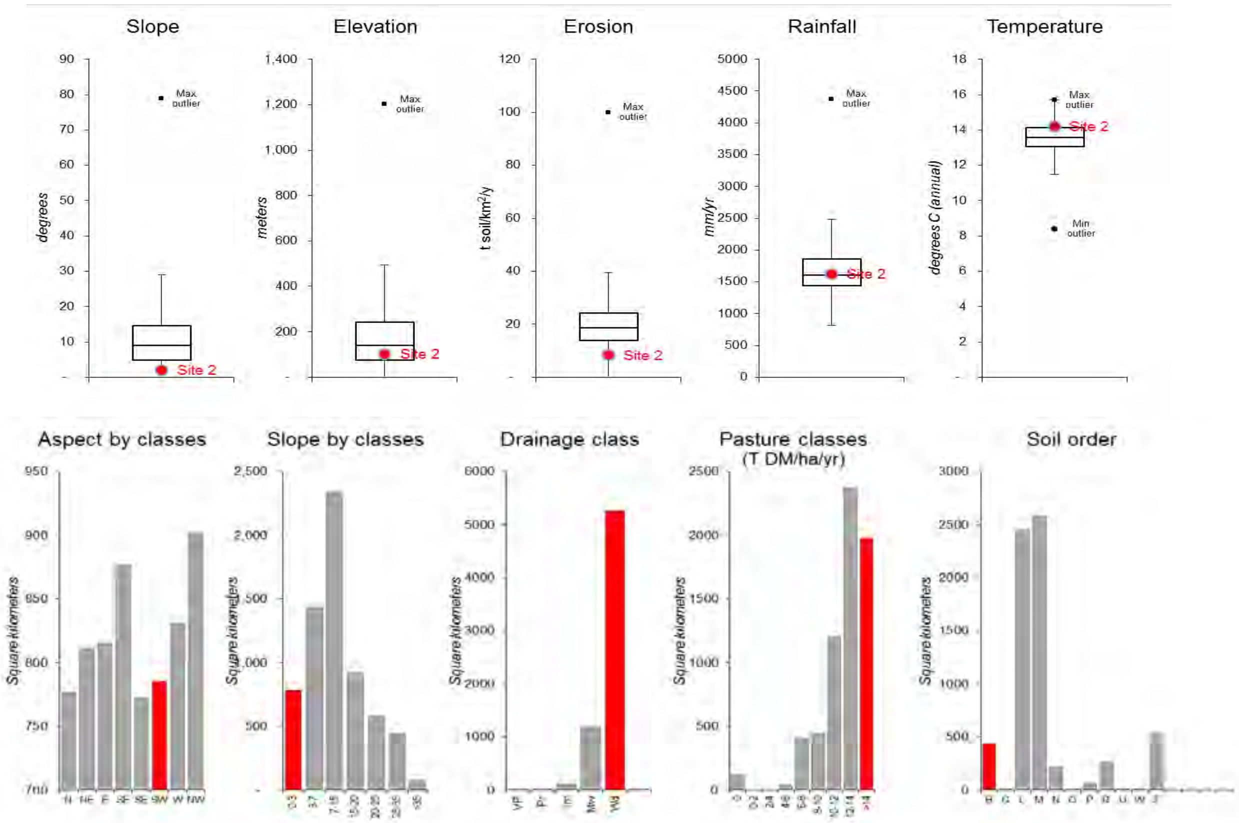


Figure A4 - 10: Representativeness of site 2 within “Tephric (ash) hill country” hill country type.

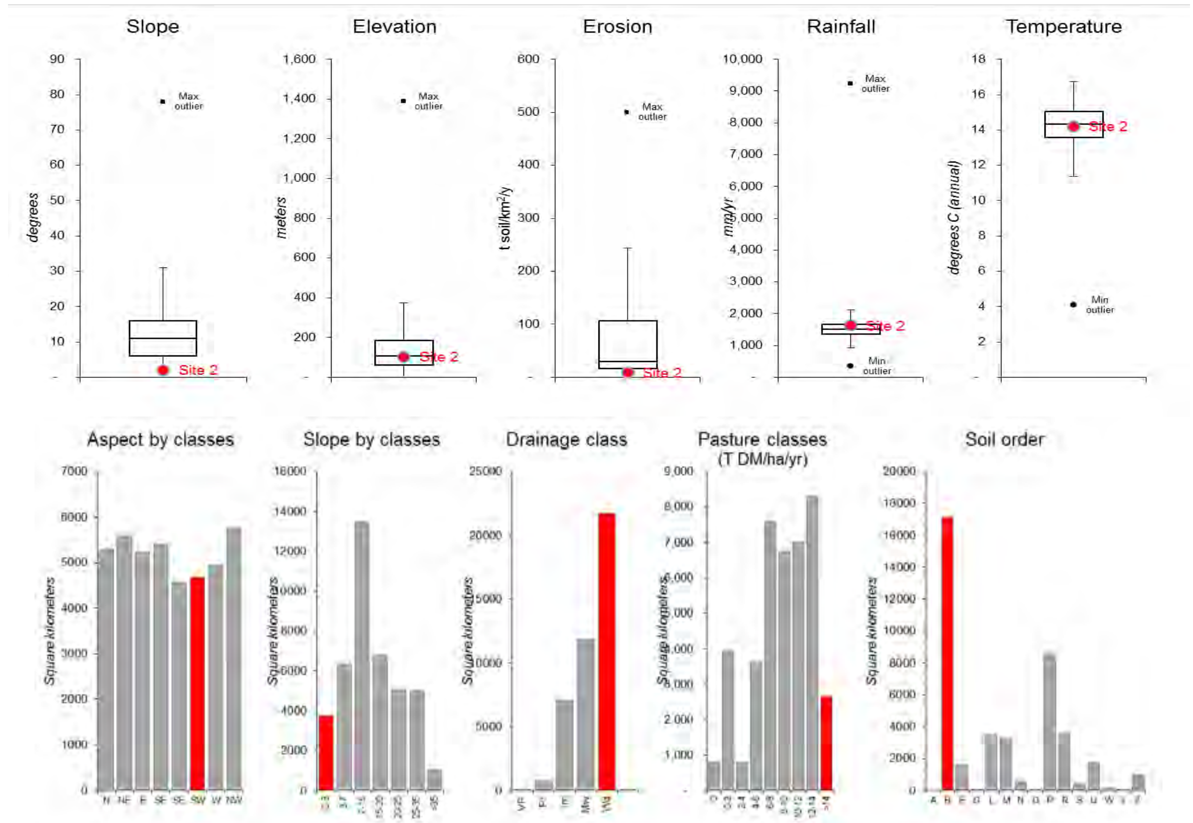


Figure A4 - 11: Representativeness of site 2 within all NZ hill country.

Table A4 - 2: Distance from the median and percent area of Site 2 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Hill flats within $2km^2$	Hill country within $2km^2$	Soil type (all NZ)	Hill country type	Hill country all
Eligible total area	-	*0.04 ha*	-	*13.6 ha*	*282 ha*	*35 km^2*	*6571 km^2*	*4.1 M ha*
Elevation (m)	*90*	**102**	x	**45**	x	**10**	**14**	**3**
Slope (degrees)	-	**2**	x	**35**	x	**45**	**42**	**43**
Aspect (degrees)	-	**229**	x	x	x	x	x	x
Erosion (t soil/km^2/y)	***8.4***	x	x	x	x	**7**	**49**	**48**
Precipitation (mm)	-	**1625**	x	x	x	x	**2**	**21**
Temperature (°C)	-	**14.2**	x	x	x	x	**28**	**4**
Flat slopes	-	x	x	x	**5%**	x	x	x
Hill country type	***16***	x	x	x	x	x	x	**16%**
Soil type	***62a***	x	x	x	x	x	**0.1%**	**<0.1%**
Soil subgroup	***BLA***	x	x	x	x	x	**0%**	**1%**
Soil order	***B***	x	x	x	x	x	**7%**	**41%**
Slope group	-	**0-3°**	x	**35%**	x	**16%**	**12%**	**9%**
Aspect group	-	**SW**	x	**11%**	x	**11%**	**12%**	**11%**
Pasture (kg DM/ha/y)	***15430***	x	x	x	x	x	**30%**	**6%**
Drainage	***Wd***	x	x	x	x	x	**80%**	**52%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

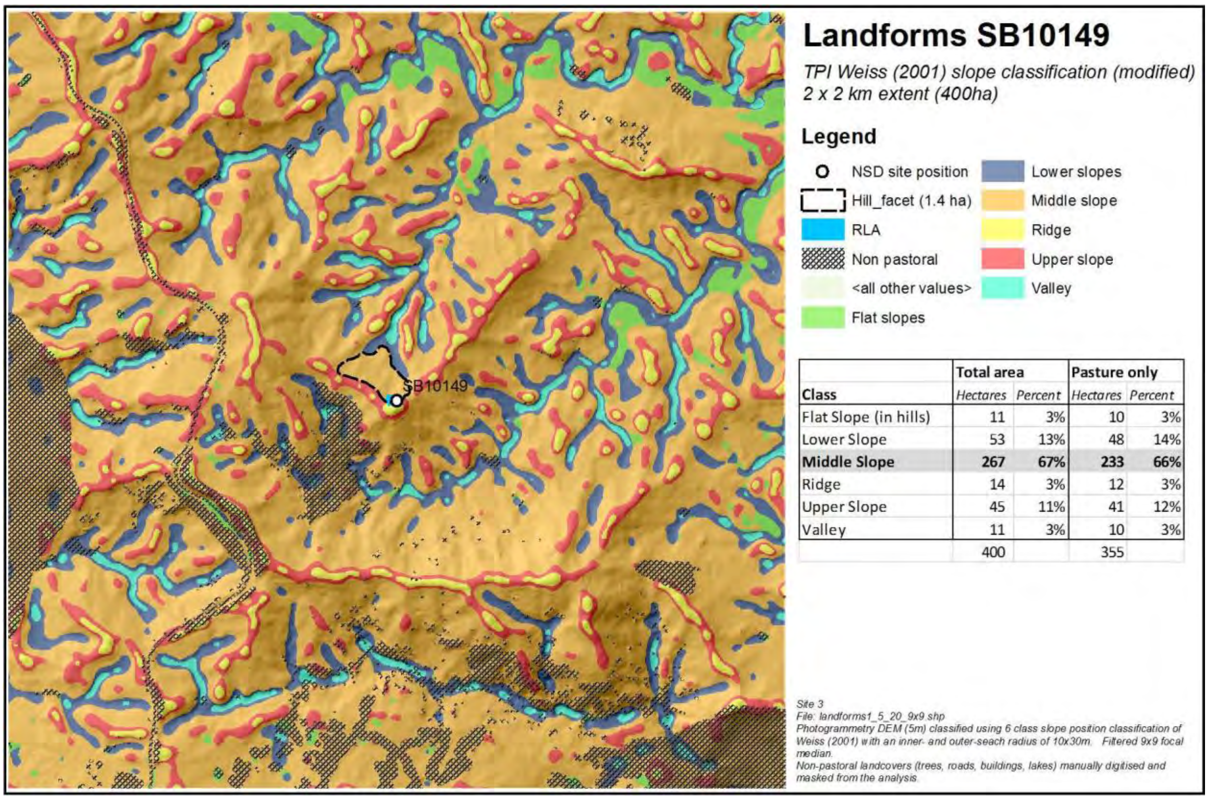
Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 3 (SB10149)

Site 3 is located within Gisborne hill country (inland, near Whatatutu) very near the apex of a hill slope, and on the border of the upslope vs. midslope classficiation boundary (Figure 12). The NSD describes the site as having convex rather than concave curvature, so the site is assigned to the midslope category. The soil type - Tahiki steepland soils – is not recognised in the FSL database so representativeness within the same soil type is not assessed. Hill country type is *Tephric (ash) hill country (16)*.



	Total area		Pasture only	
Class	Hectares	Percent	Hectares	Percent
Flat Slope (in hills)	11	3%	10	3%
Lower Slope	53	13%	48	14%
Middle Slope	**267**	**67%**	**233**	**66%**
Ridge	14	3%	12	3%
Upper Slope	45	11%	41	12%
Valley	11	3%	10	3%
	400		355	

Figure A4 - 12: Classification of land forms for site SB10149 within a 2km² grid.

In being located on a midslope, Site 3 is strongly representative of landforms within the 2 km² grid, accounting for 66% of grazed area (Figure 14). If the site had been assigned to the upper slope category then representation would have been far less at 12%.

At other scales the site is only marginally representative (Table 3). For the immediate **hill facet**, site slope and elevation is at the upper end of marginal (Figure 13), although aspect is strongly represented. Similarly, the site exhibits marginal representativeness of all **midslope** characteristics found within the 2km² grid (Figure 14). **Hill country type** is marginal to poorly represented in all characteristics other than estimated pasture yield (Figure 15). Slope representation is particularly poor. This carries through to results for all **NZ hill country** (Figure 16), although better representation is achieved for erosion, rainfall and pasture yield estimates.

Overally, Site 3 is interpreted as being marginally representative.

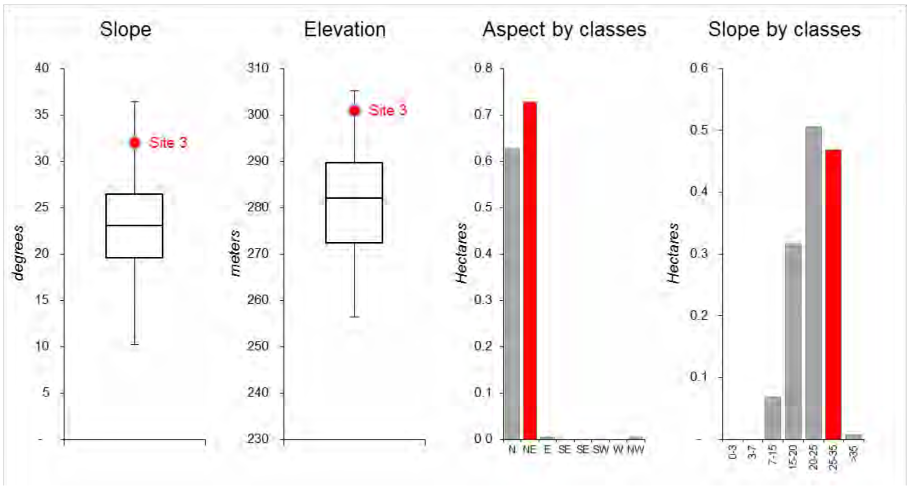


Figure A4 - 13: Representativeness of site 3 within the immediate hill facet.

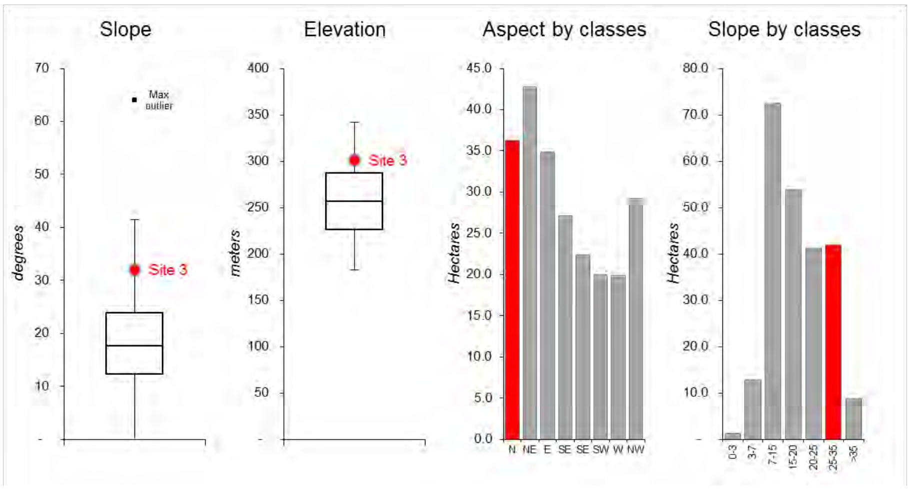


Figure A4 - 14: Representativeness of site 3 within midslopes located within a 2km² grid.

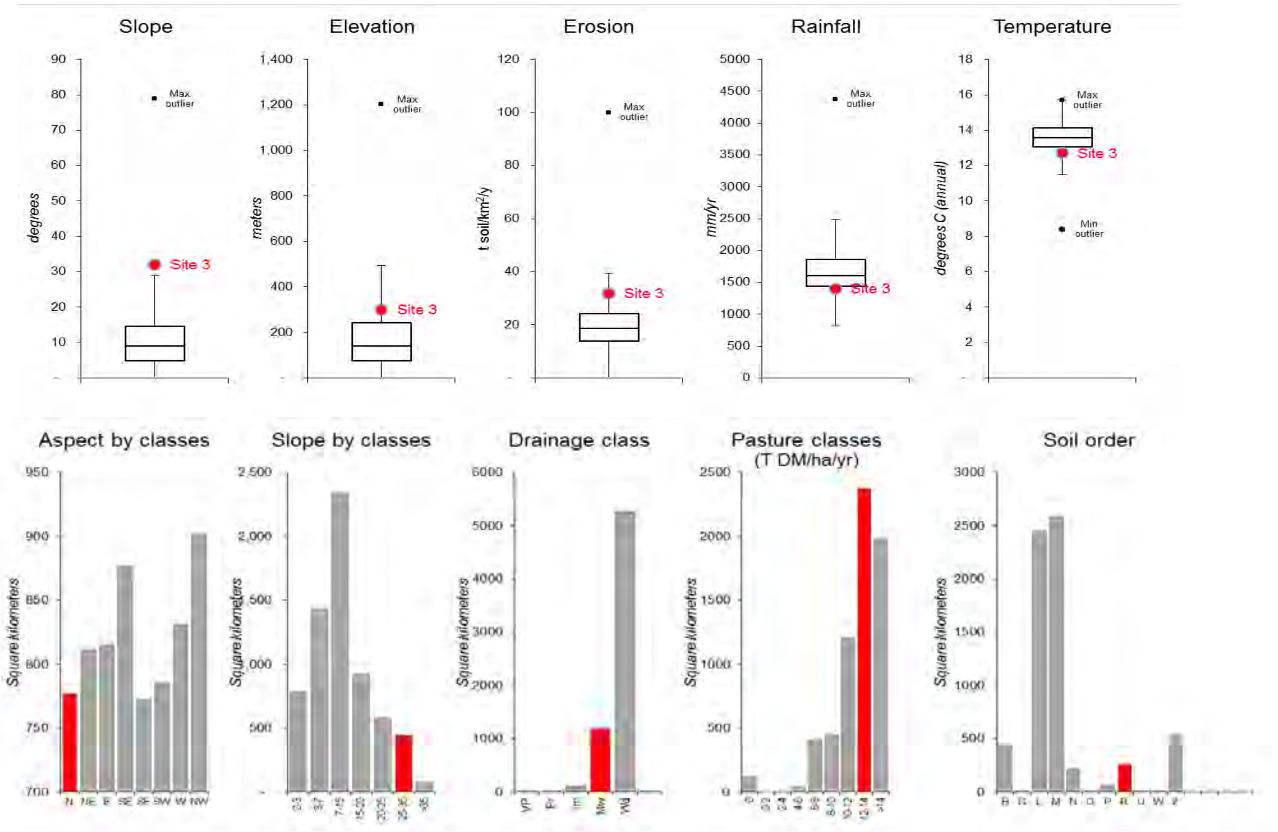


Figure A4 - 15: Representativeness of site 3 within “Tephric (ash) hill country” hill country type.

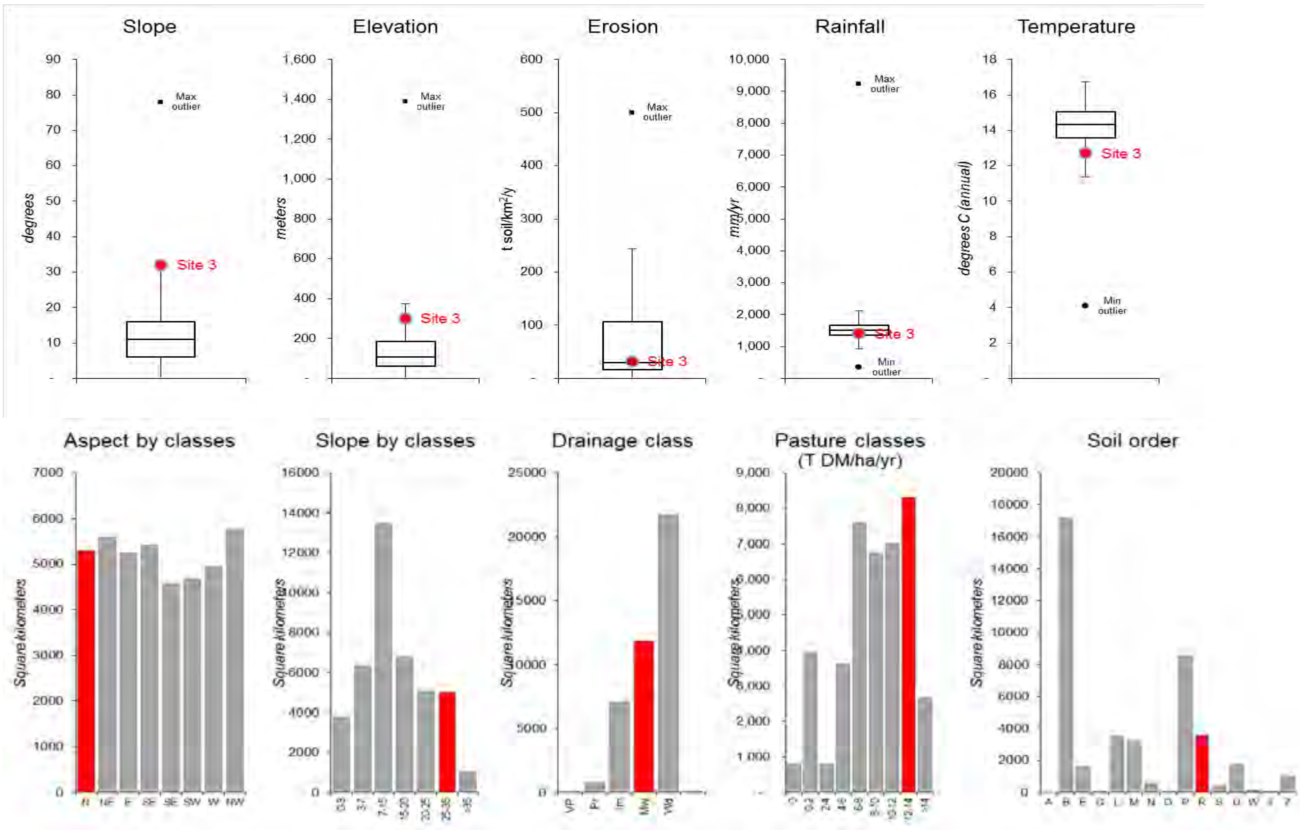


Figure A4 - 16: Representativeness of site 3 within all NZ hill country.

Table A4 - 3: Distance from the median and percent area of Site 4 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Midslopes within $2km^2$	Hill country within $2km^2$	Soil type (all NZ)	Hill country type	Hill country all
Eligible total area	-	*0.1 ha*	*1.4 ha*	*233 ha*	*355 ha*	x	*6571 km²*	*4.1 M ha*
Elevation (m)	*220*	**301**	**48**	**36**	x	x	**32**	**39**
Slope (degrees)	***32***	33	**45**	**43**	x	x	**50**	**50**
Aspect (degrees)	*0*	**347**	x	x	x	x	x	x
Erosion (t soil/km²/y)	*31.8*	x	x	x	x	x	**48**	**1**
Precipitation (mm)	**1400**	1260	x	x	x	x	**28**	**19**
Temperature (°C)	-	**12.7**	x	x	x	x	**34**	**42**
Midslopes	-	x	x	x	**66%**	x	x	x
Hill country type	***16***	x	x	x	x	x	x	**16%**
Soil type		x	x	x	x	x	**x**	**x**
Soil subgroup	***ROW***	x	x	x	x	x	**1%**	**4%**
Soil order	***R***	x	x	x	x	x	**4%**	**9%**
Slope group	-	**25-35°**	**34%**	**18%**	x	x	**7%**	**12%**
Aspect group	*N*	**N**	**53%**	**16%**	x	x	**12%**	**13%**
Pasture (kg DM/ha/y)	*12860*	x	x	x	x	x	**36%**	**20%**
Drainage	*Mw*	x	x	x	x	x	**18%**	**29%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

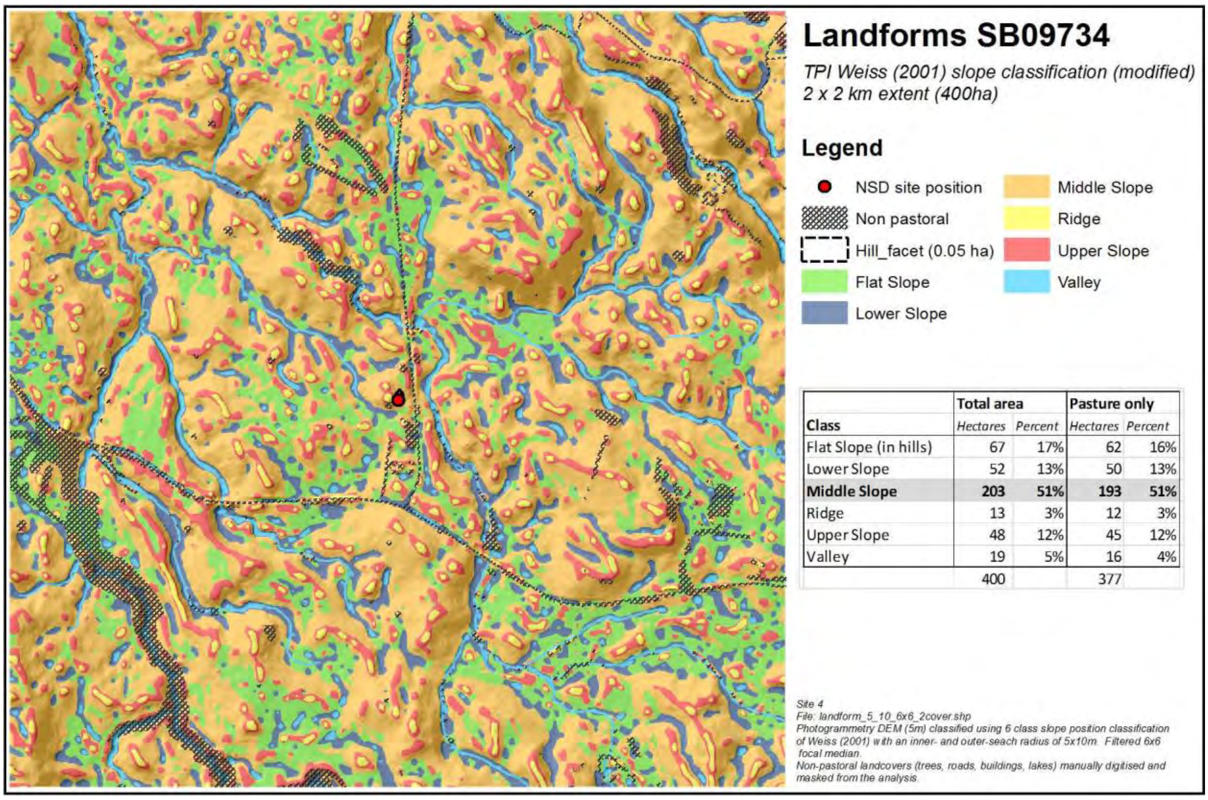
Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 4 (SB09734)

Site 4 is located in a complex rolling and hilly landscape (Figure 17) 15km due north of Lake Taupo, with the site itself being located on the eastern face of a small hill. Because of the small landform size, both the RLA (0.005 ha) and hill facet (0.05 ha) are too small to display on the map. Slope is 20° which is borderline for the NZLRI strongly rolling and moderately steep categories; we select the steeper category because it better aligns with the hill facet (and thus the overall character of the site). Soil type is Ngakuru fine sandy loam (hill soil), a well drained typic allophanic soil, while hill country type is *Tephric (ash) hill country (16)*. In being positioned on a lone hill, the closest NZLRI polygon that best describes the site and its soils is located approximately 500m to the NE.



Class	Total area		Pasture only	
	Hectares	Percent	Hectares	Percent
Flat Slope (in hills)	67	17%	62	16%
Lower Slope	52	13%	50	13%
Middle Slope	**203**	**51%**	**193**	**51%**
Ridge	13	3%	12	3%
Upper Slope	48	12%	45	12%
Valley	19	5%	16	4%
	400		377	

Figure A4 - 17: Classification of land forms for site SB09734 within a 2km^2 grid.

The site is strongly representative of elevation and slope found within the immediate **hill facet** (Figure 18). Likewise, strong representation of elevation is evident within all local **midslopes**, but slope falls just within marginal representation (i.e. slightly steeper than most local slopes) (Figure 19). Midslopes account for 51% of the grazed land within the local area (2km^2 grid).

The site offers marginal representation of variables within the Ngakuru fine sandy loam **soil type** (Figure 20), especially with slope which nearly qualifies as an outlier. Similarly, the site appears to offer marginal representation overall within the **hill country type** (Figure 21), although drainage, pasture and soil order are interpreted as being representative. Site representativeness of all **NZ hill country** is also variable, being notably low for elevation and temperature, high for erosion, rainfall, drainage and perhaps pasture, and generally modest for other variables.

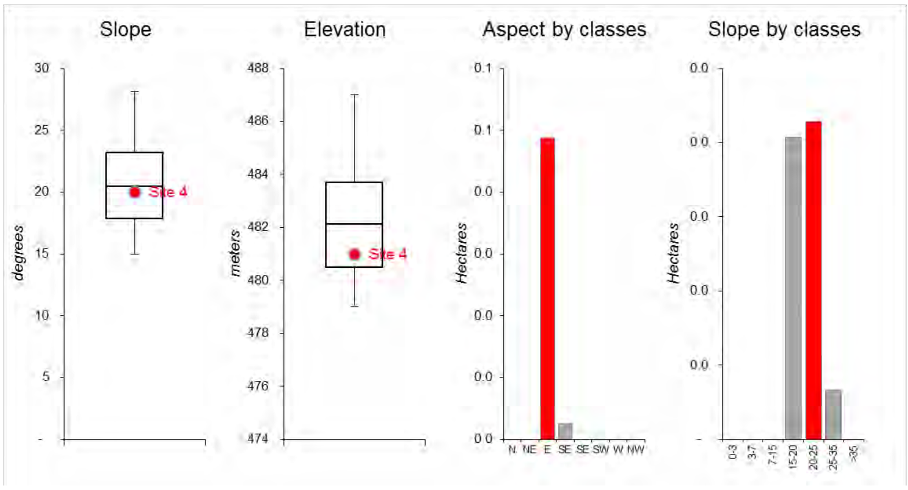


Figure A4 - 18: Representativeness of site 4 within the immediate hill facet.

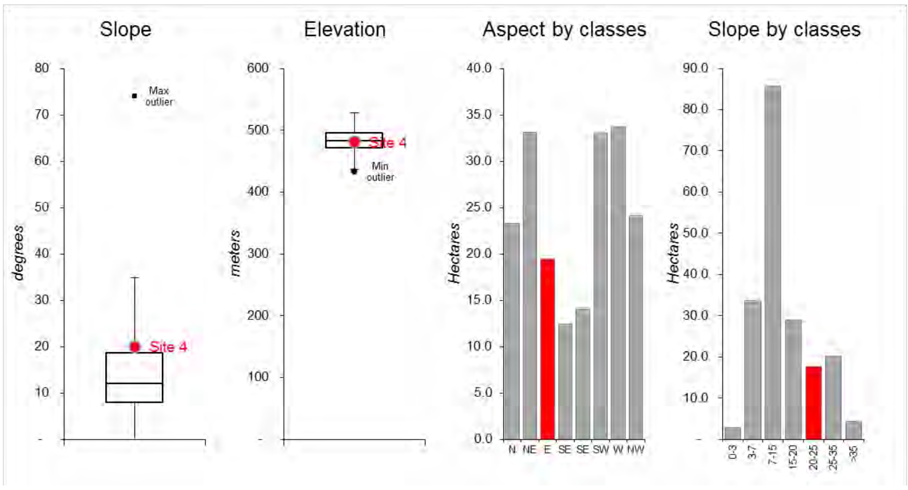


Figure A4 - 19: Representativeness of site 4 within midslopes located within a $2km^2$ grid.

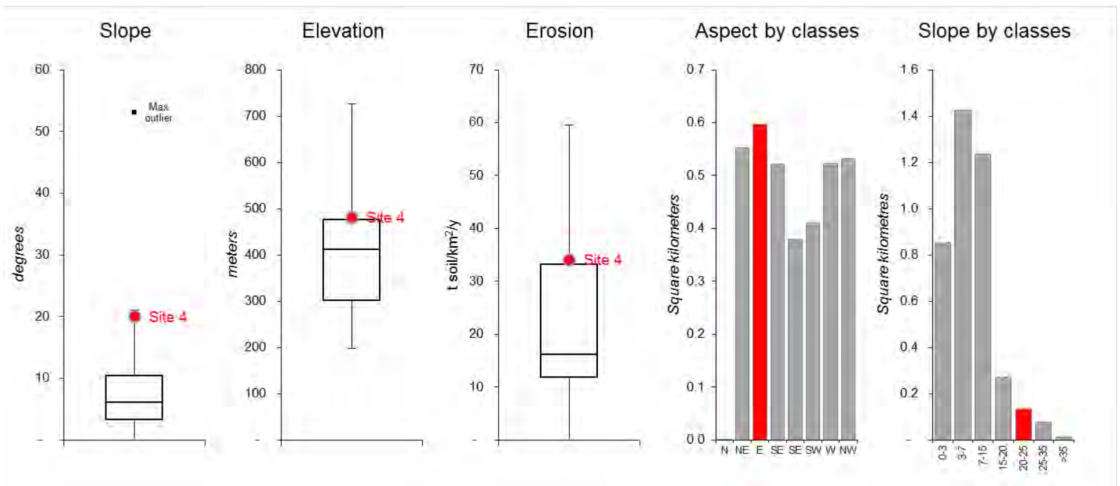


Figure A4 - 20: Representativeness of site 4 within the extent of the same soil type.

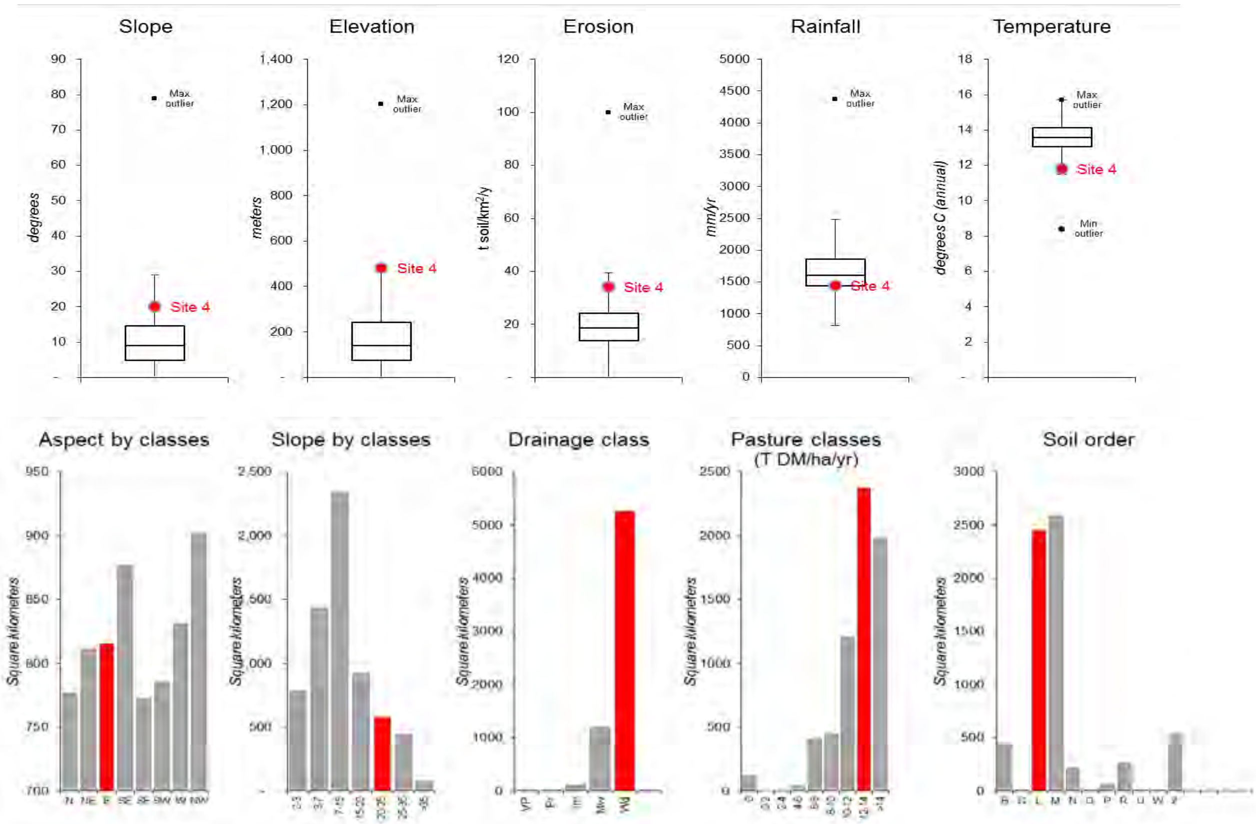


Figure A4 - 21: Representativeness of site 4 within "Tephric (ash) hill country" hill country type.

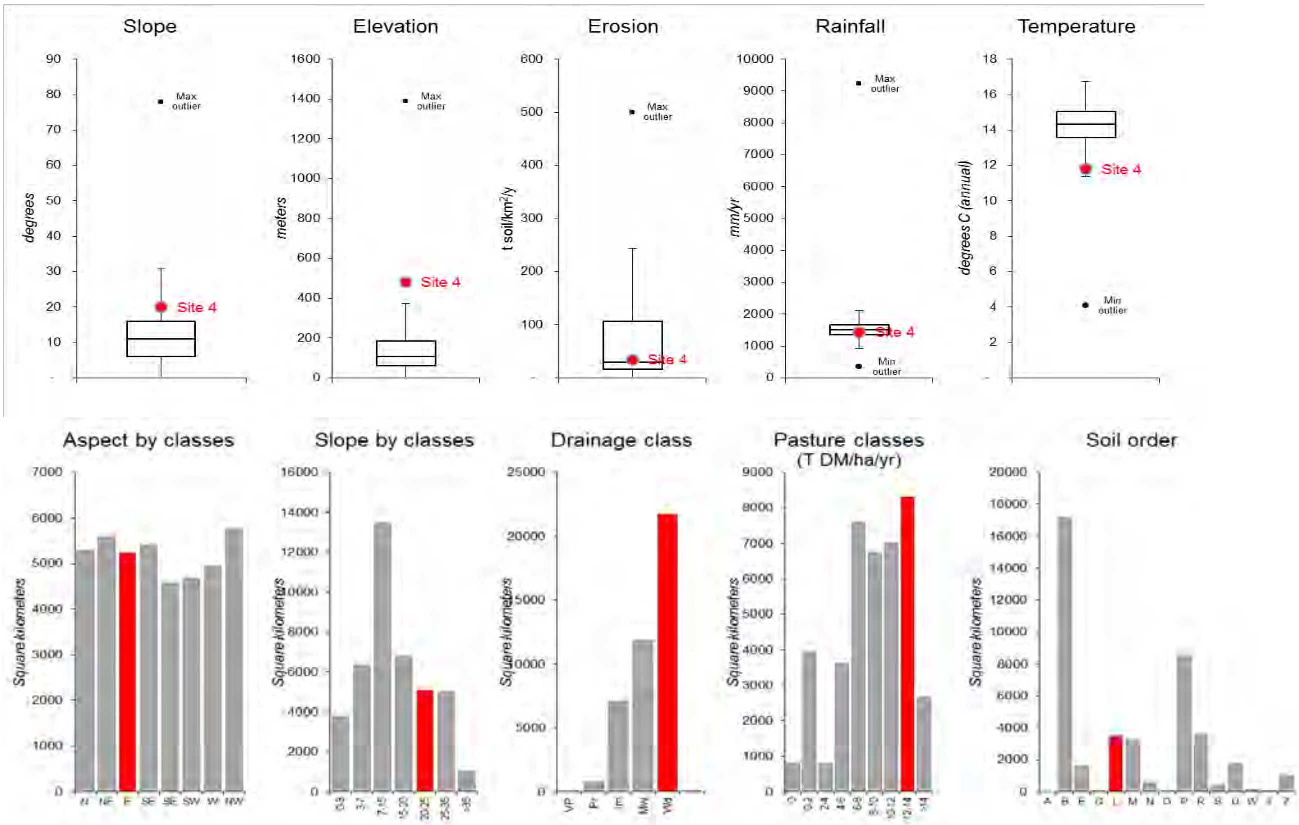


Figure A4 - 22: Representativeness of site 4 within all NZ hill country.

Table A4 - 4: Distance from the median and percent area of Site 4 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Midslopes within 2km²	Hill country within 2km²	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	-	*0.005 ha*	*0.05 ha*	*193 ha*	*377 ha*	351 ha	*6571 km2*	*4.1 M ha*
Elevation (m)	*475*	**481**	**14**	**5**	x	**28**	**46**	**50**
Slope (degrees)	***20***	20	**7**	**28**	x	**44**	**39**	**35**
Aspect (degrees)	*90*	**88**	x	x	x	x	x	x
Erosion (t soil/km²/y)	*34.1*	x	x	x	x	**33**	**45**	**2**
Precipitation (mm)	1600	**1440**	x	x	x	x	**25**	**13**
Temperature (°C)	-	**11.8**	x	x	x	x	**47**	**48**
Midslopes	-	x	x	x	**51%**	x	x	x
Hill country type	*16*	x	x	x	x	x	x	**16%**
Soil type	*NaH*	x	x	x	x	x	**2.2%**	**0.3%**
Soil subgroup	*LOT*	x	x	x	x	x	**36%**	**8%**
Soil order	*L*	x	x	x	x	x	**37%**	**8%**
Slope group	-	20-25°	**42%**	**9%**	x	x	**9%**	**12%**
Aspect group	*E*	E	**95%**	**10%**	x	**17%**	**12%**	**13%**
Pasture (kg DM/ha/y)	*12,000*	x	x	x	x	**3%**	**36%**	**20%**
Drainage	*Wd*	x	x	x	x	x	**80%**	**52%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

Red values indicate outliers that would definitely not be representative.

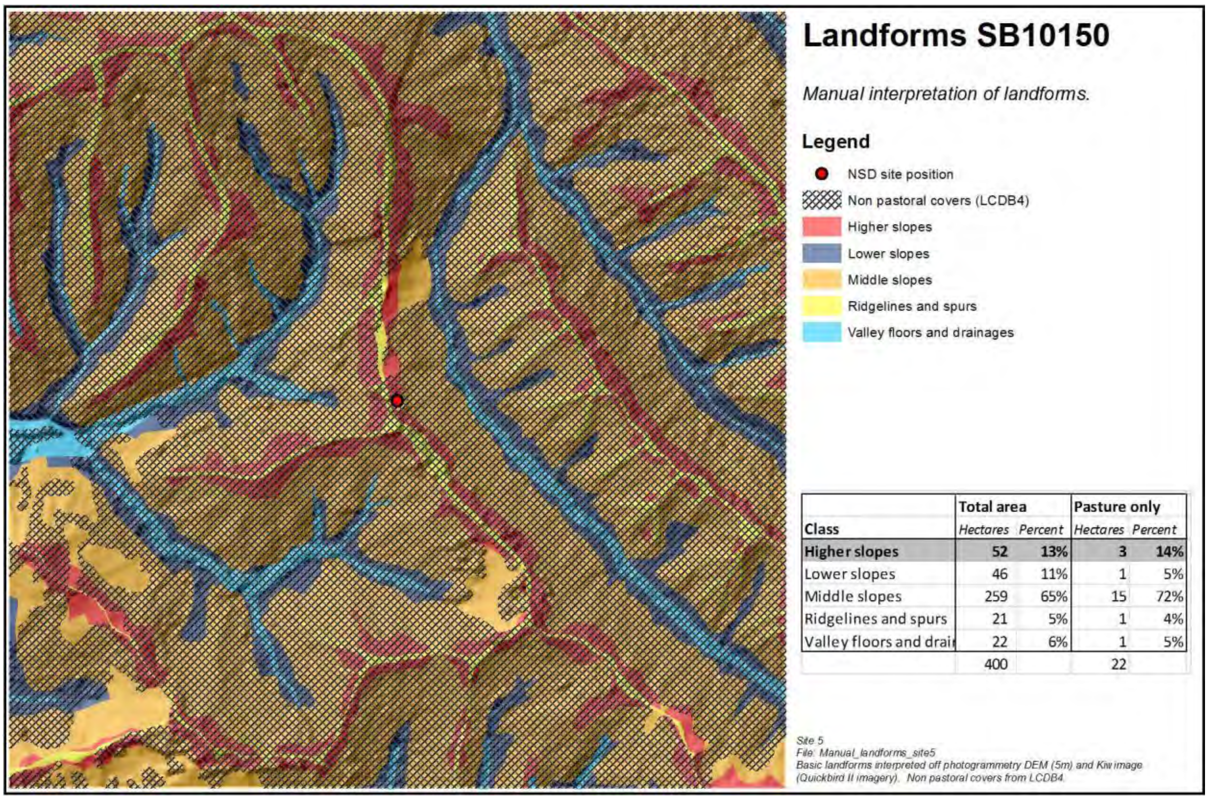
Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 5 (SB10150)

Site 5 is located in Gisborne hill country (Figure 23) near Te Karaka (Kia Ora Station). The area is dominanted by scrub and forestry, with only 5% open pasture (based on LCDB4, although there is likely considerably more pasture within the 'Gorse and/or broom' classification). Because of this the 5m photogrammetry DEM was unuseable for landform classification. As an alternative, ridgelines and valleys were manually interpreted from aerial photography and the hill-shaded DEM, while slope position was estimated from normalised slope heights using 15% and 85% thresholds for lower and upper slopes respectively (which is within the maximum 20% limit specified by Milne et al., 1995). Landcare's national 15m DEM re-interpolated to include manually digitised drainage pathways was used to calculate normalised slope heights. Site position is on an upper slope (Figure 23). A small RLA was constructed by digitising pasture-only areas. Interpretation of results relating to upper slopes within the 2km^2 extent should therefore be tempered with a recognition that results may only be broadly indicative. Upper slope analysis is undertaken for all hill slopes (including non-pastoral) within the 2km^2 extent. The hill facet scale was not analysed.

Soil type is Te Ranui steepland soil (ridge variant) and hill country type is "Steep soft rock hill country (12)". The soil type is not recognised in the second edition NZLRI or FSL databases so analysis can be undertaken within the extent of 'soil type'.



	Total area		Pasture only	
Class	*Hectares*	*Percent*	*Hectares*	*Percent*
Higher slopes	**52**	**13%**	**3**	**14%**
Lower slopes	46	11%	1	5%
Middle slopes	259	65%	15	72%
Ridgelines and spurs	21	5%	1	4%
Valley floors and drai	22	6%	1	5%
	400		22	

Figure A4 - 23: Classification of land forms for site 5 within a 2km^2 grid.

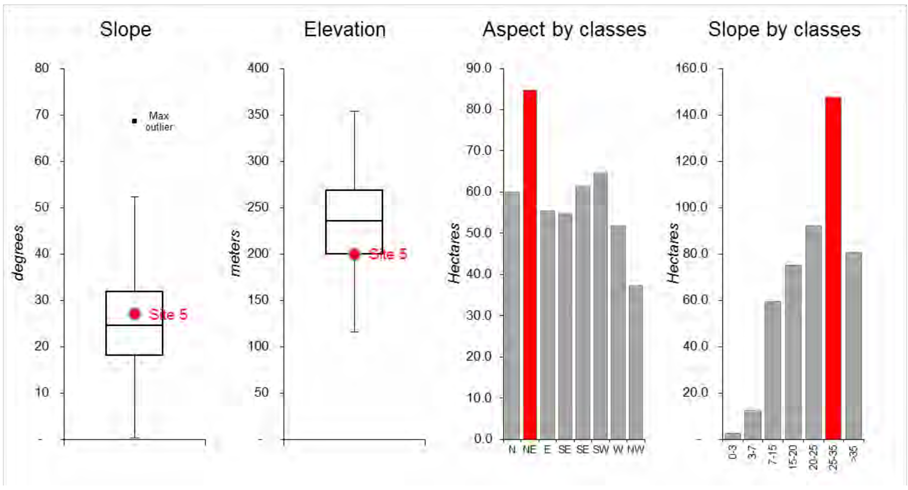


Figure A4 - 24: Representativeness of site 5 within upper slopes located within a 2km² grid.

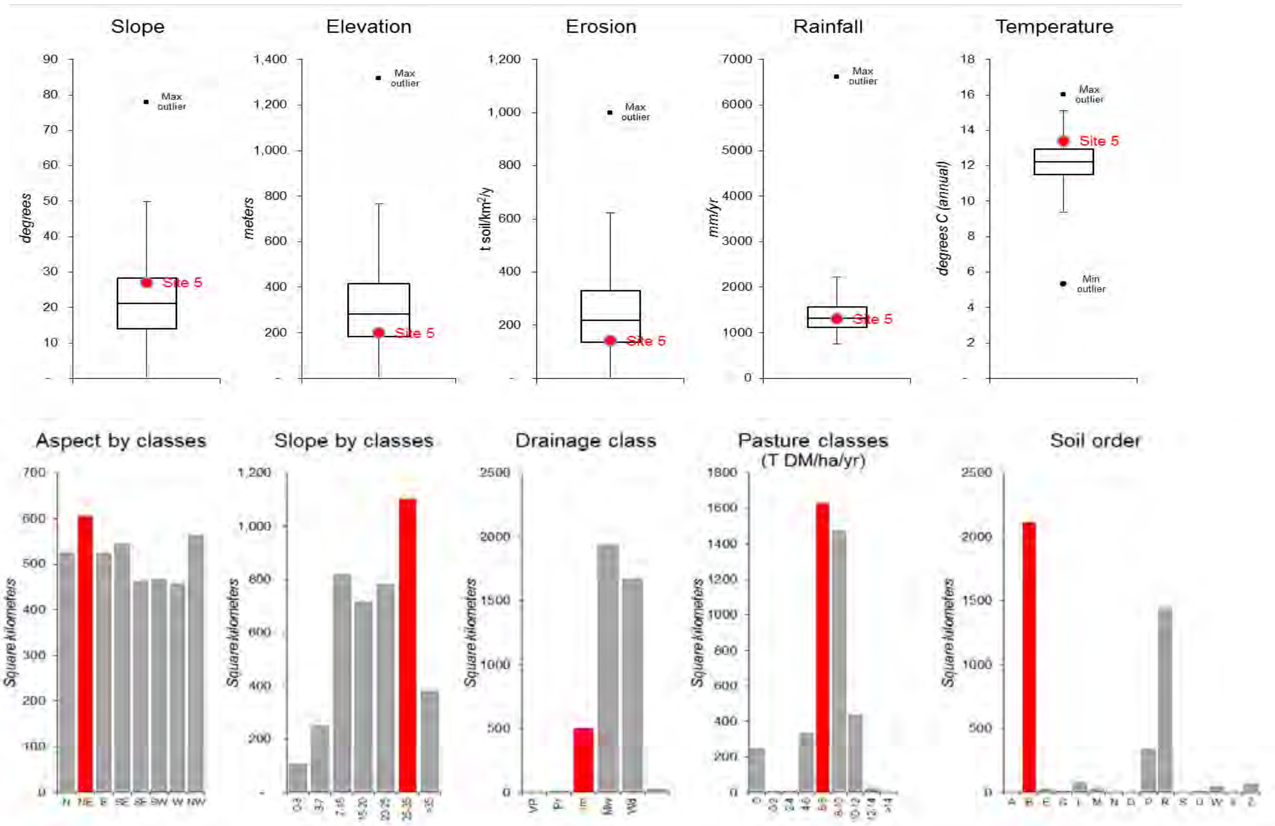


Figure A4 - 25: Representativeness of site 5 within *Steep soft rock hill country*.

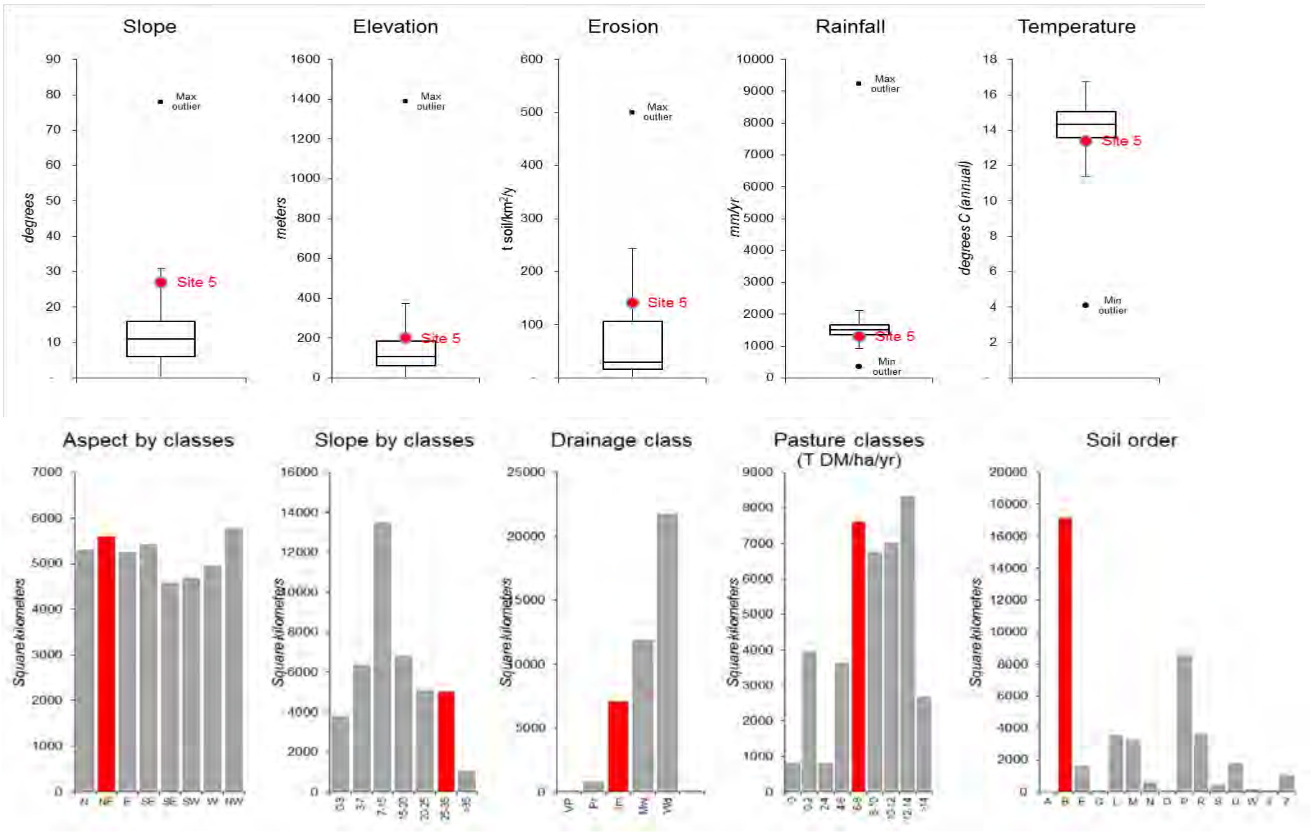


Figure A4 - 26: Representativeness of site 5 within all NZ hill country.

Table A4 - 5: Distance from the median and percent area of Site 5 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Top slopes within 2km²	Within 2km² (grazed)	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	-	*0.005 ha*	*x*	*470 ha*	*3 ha*	x	*4152 km²*	*4.1 M ha*
Elevation (m)	***200***	*209*	*x*	**25**	*x*	x	**21**	**28**
Slope (degrees)	***27***	*27*	*x*	**11**	*x*	x	**22**	**46**
Aspect (degrees)	***45***	*72*	*x*	*x*	*x*	x	*x*	*x*
Erosion (t soil /km²/y)	-	***141.7***	*x*	*x*	*x*	x	**24**	**26**
Precipitation (mm)	1600	**1305**	*x*	*x*	*x*	x	**2**	**33**
Temperature (°C)	-	**13.4**	*x*	*x*	*x*	x	**37**	**31**
Top slopes	-	*x*	*x*	*x*	**14%**	x	*x*	x
Hill country type	***16***	*x*	*x*	*x*	*x*	x	*x*	**10%**
Soil type	-	*x*	*x*	*x*	*x*	x	-	-
Soil subgroup	***BOM***	*x*	*x*	*x*	*x*	x	**4%**	**2.4%**
Soil order	***B***	*x*	*x*	*x*	*x*	x	**51%**	**41%**
Slope group	**25-35°**	*20-25°*	*x*	**31%**	*x*	x	**27%**	**12%**
Aspect group	***NE***	*E*	*x*	**18%**	*x*	x	**15%**	**13%**
Pasture (kg DM/ha/y)	*x*	***7700***	*x*	*x*	*x*	x	**39%**	**18%**
Drainage	***Im***	*x*	*x*	*x*	*x*	x	**12%**	**17%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

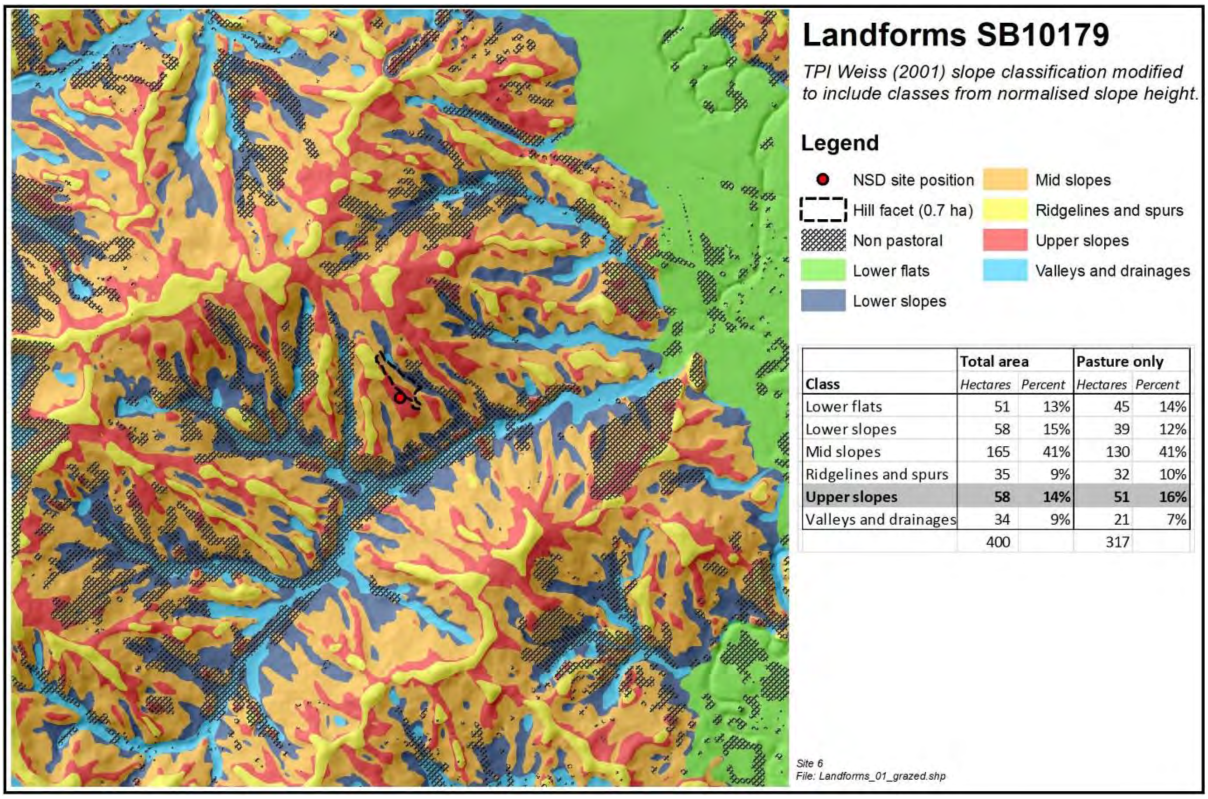
Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 6 (SB10179)

Site 6 is located in Gisborne hill country near Whangara. Hill country type is Soft rock hill country (including soft Limestone) (7). The soil – Taiteatea hill soil - is not recognised in either the FSL or NZLRI database, so soil type extent is not analysed. Site location appears to be just off an easy spur which qualifies it as an upper slope position (relative to the spur line) (Figure 27).



	Total area		Pasture only	
Class	Hectares	Percent	Hectares	Percent
Lower flats	51	13%	45	14%
Lower slopes	58	15%	39	12%
Mid slopes	165	41%	130	41%
Ridgelines and spurs	35	9%	32	10%
Upper slopes	**58**	**14%**	**51**	**16%**
Valleys and drainages	34	9%	21	7%
	400		317	

Figure A4 - 27: Classification of land forms for site 6 within a 2km² grid.

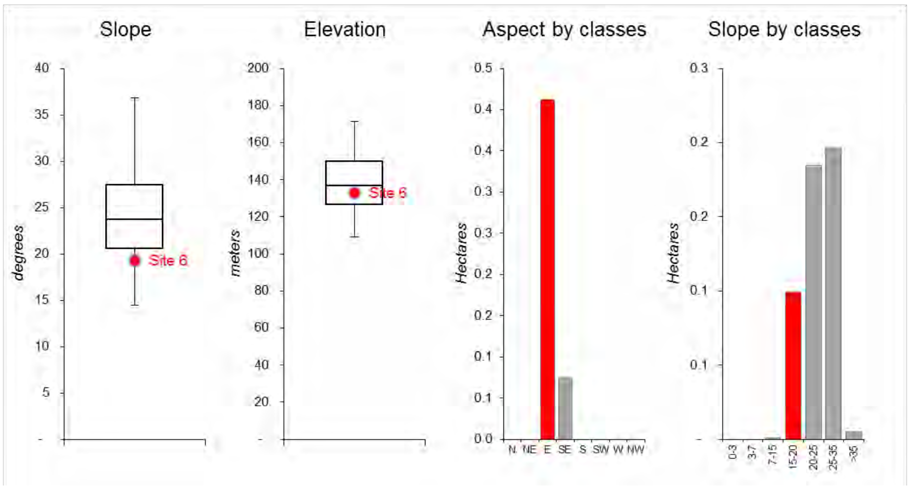


Figure A4 - 28: Representativeness of site 6 within the immediate hill facet.

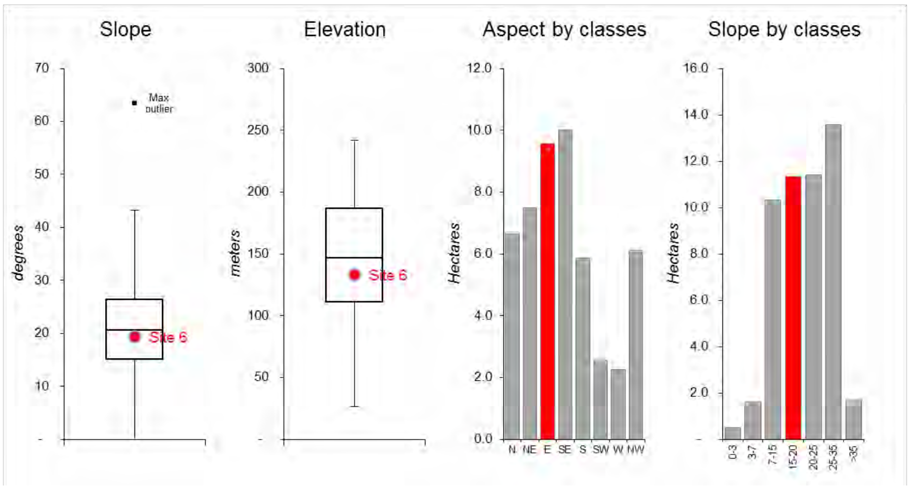


Figure A4 - 29: Representativeness of site 6 within upper slopes located within a 2km² grid.

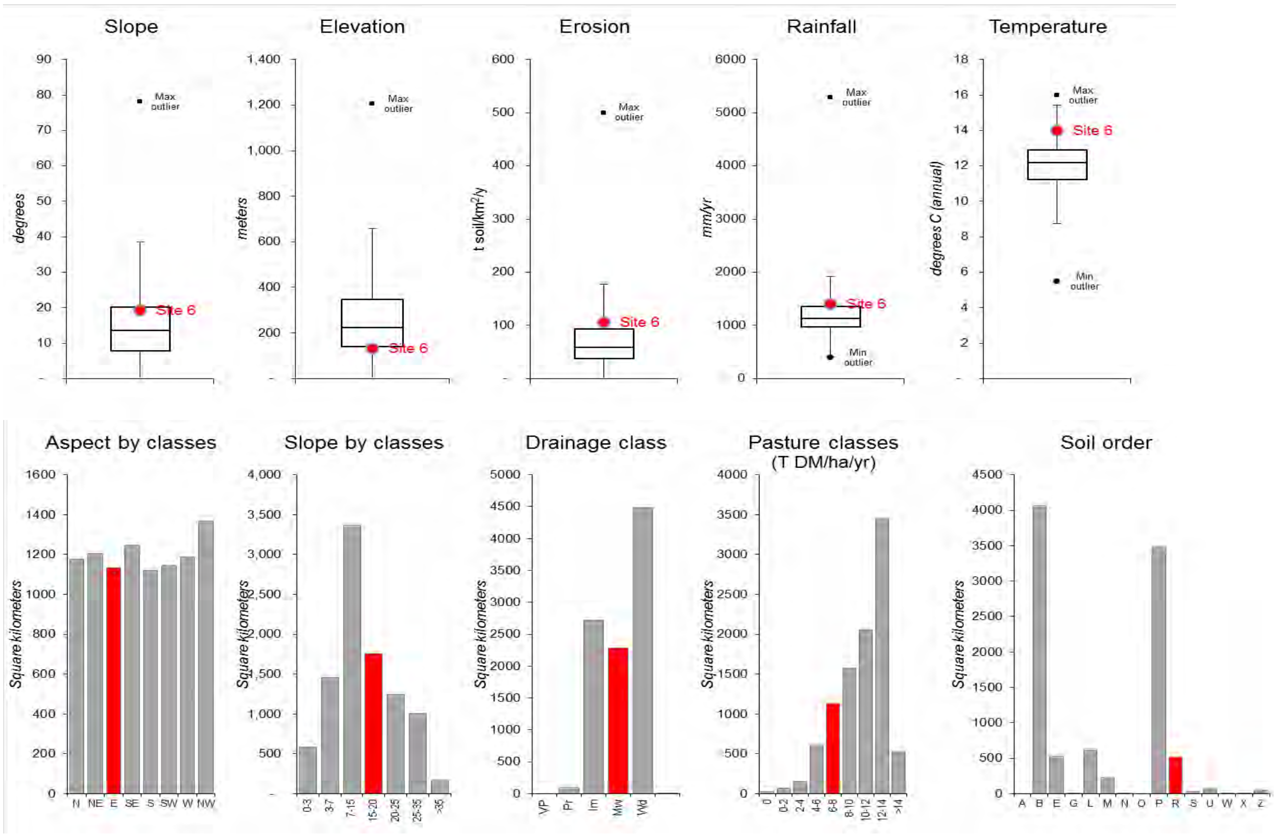


Figure A4 - 30: Representativeness of site 6 within *Soft rock hill country (including soft Limestone)* (7).

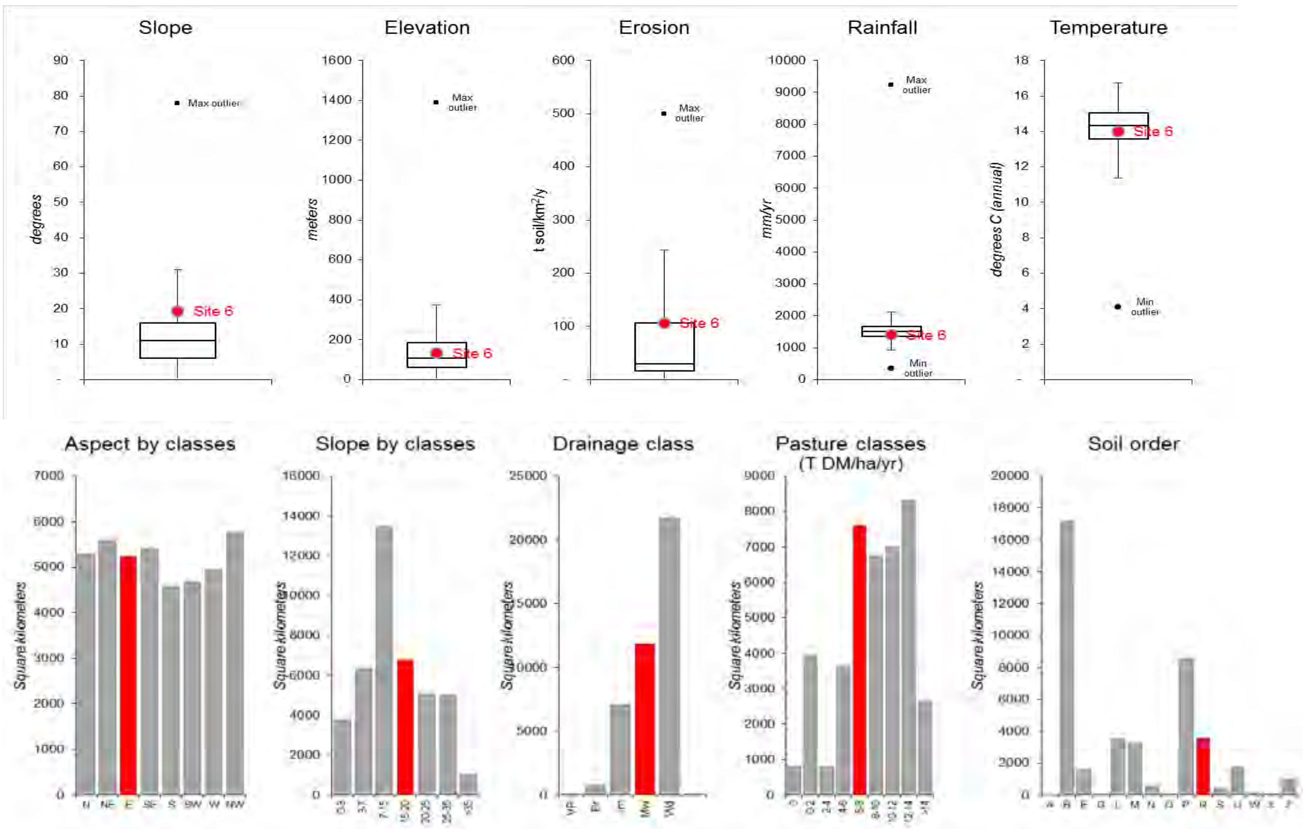


Figure A4 - 31: Representativeness of site 6 within all NZ hill country.

Table A4 - 6: Distance from the median and percent area of Site 6 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Upper slopes within 2km²	Within 2km² (grazed)	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	-	*0.04 ha*	*0.5 ha*	*50.5 ha*	*317 ha*	x	*9583 km²*	*4.1 M ha*
Elevation (m)	*140*	**133**	**9**	**11**	x	x	**27**	**10**
Slope (degrees)	***19***	19.3	**35**	**6**	x	x	**23**	**33**
Aspect (degrees)	*90*	**110**	x	x	x	x	x	x
Erosion (t soil/km²/y)	-	**105.7**	x	x	x	x	**30**	**25**
Precipitation (mm)	*1400*	**1404**	x	x	x	x	**28**	**19**
Temperature (°C)	-	**13.99**	x	x	x	x	**43**	**12**
Upper slopes	-	x	x	x	**16%**	x	x	*x*
Hill country type	*7*	x	x	x	x	x	x	**23%**
Soil type	-	x	x	x	x	x	x	*x*
Soil subgroup	*RTT*	x	x	x	x	x	**0.04%**	**0.2%**
Soil order	*R*	x	x	x	x	x	**5%**	**9%**
Slope group	-	15-20°	**20%**	**22%**	x	x	**18%**	**12%**
Aspect group	*E*	E	**85%**	**19%**	x	x	**12%**	**11%**
Pasture (kg DM/ha/y)	*7,700*	x	x	x	x	x	**12%**	**18%**
Drainage	*Mw*	x	x	x	x	x	**24%**	**29%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

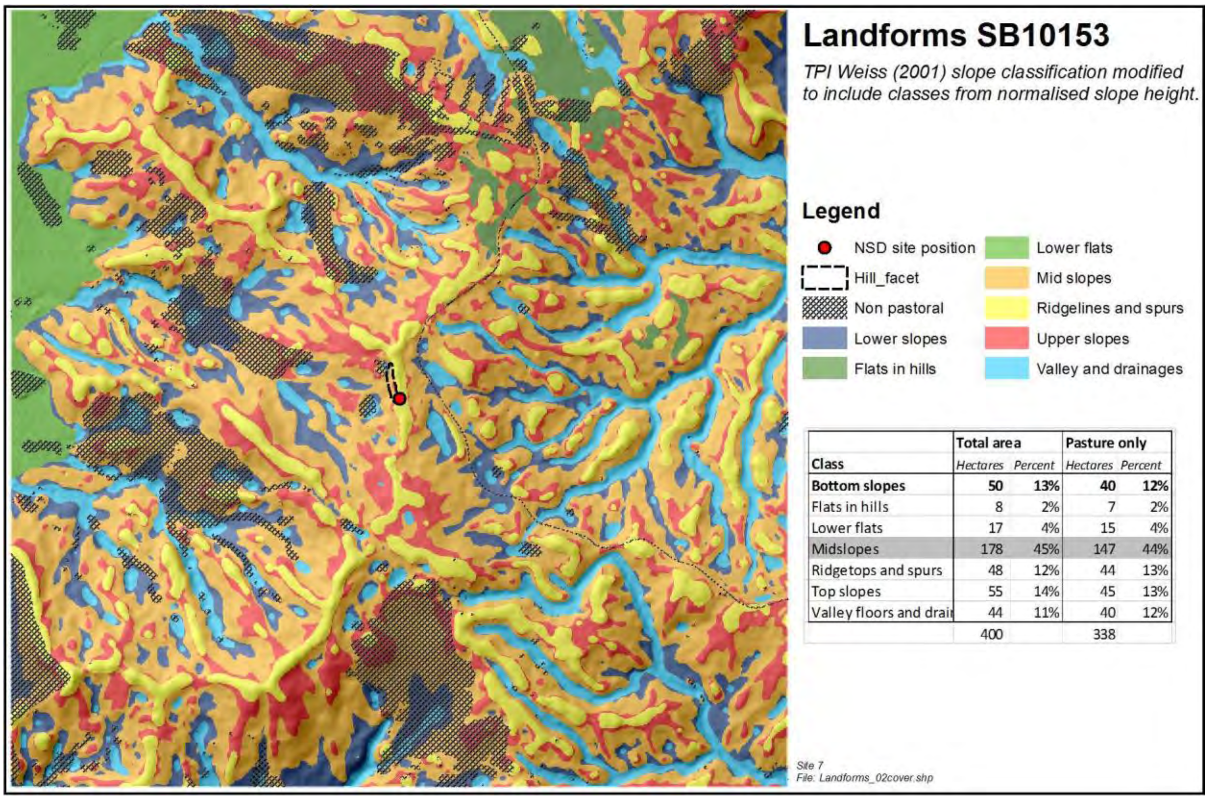
Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 7 (SB10153)

Site 7 is located within rolling and undulating hill country near Whangara in the Gisborne area. The NZLRI classifies the immediately surrounding land as rolling and undulating country assigned an LUC class of 4. As such it falls outside the hill country classification of Basher et al. (2008). The closest (<70m away) and most appropriate hill country type is "Crushed soft rock hill country with moderate to severe erosion" (1). Soils are classed as Weber hill soils which are not recognised in the NSD or FSL, so no soil type extent analysis is undertaken. The NSD describes the site as being a south-facing convex-shaped 24° midslope. However, landscape position appears to be on a spurline with slopes considerable less than 24° (Figure 32). Because the spurline runs in a north-south direction, the only location that can have a southern aspect is on the spurline itself. The only place that has a slope of 24° is off the spur-line. For this analysis we ignore recorded aspect and place the RLA off the ridgeline in a midslope position that qualifies as a hill slope.



	Total area		Pasture only	
Class	Hectares	Percent	Hectares	Percent
Bottom slopes	**50**	**13%**	**40**	**12%**
Flats in hills	8	2%	7	2%
Lower flats	17	4%	15	4%
Midslopes	178	45%	147	44%
Ridgetops and spurs	48	12%	44	13%
Top slopes	55	14%	45	13%
Valley floors and drai	44	11%	40	12%
	400		338	

Figure A4 - 32: Classification of land forms for site 7 within a 2km^2 grid.

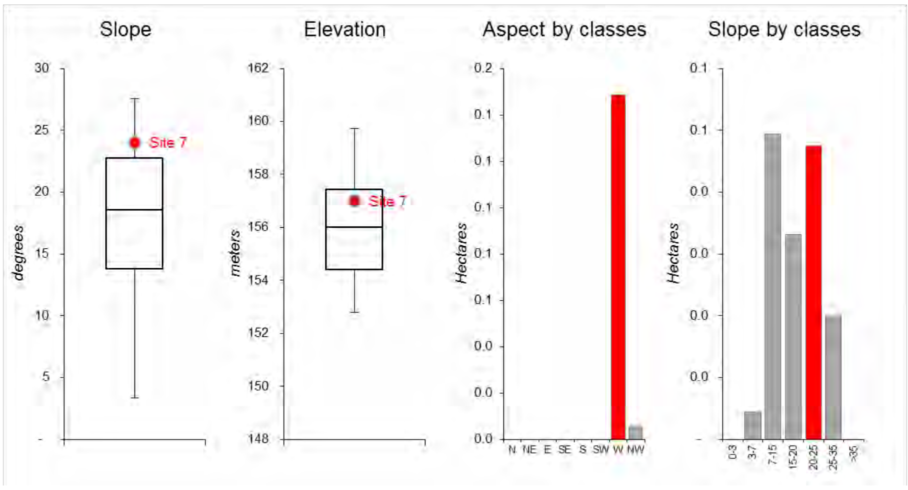


Figure A4 - 33: Representativeness of site 7 within the immediate hill facet.

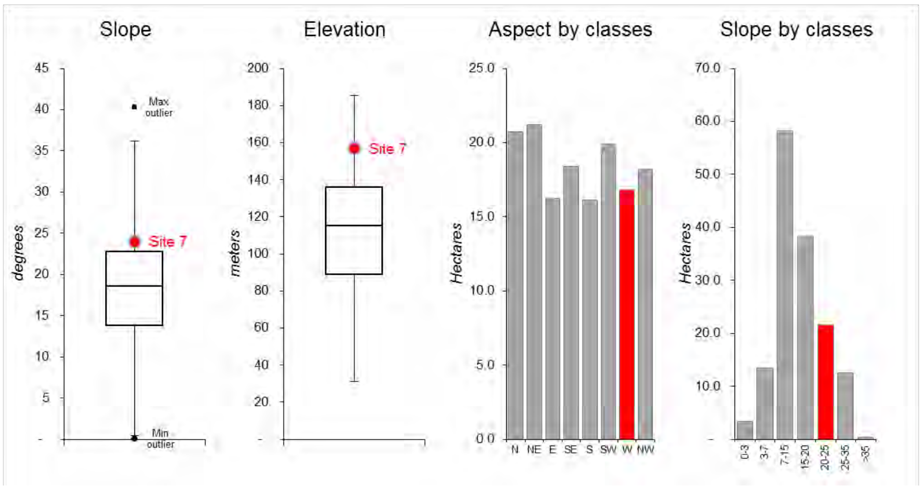


Figure A4 - 34: Representativeness of site 7 within midslopes located within a 2km² grid.

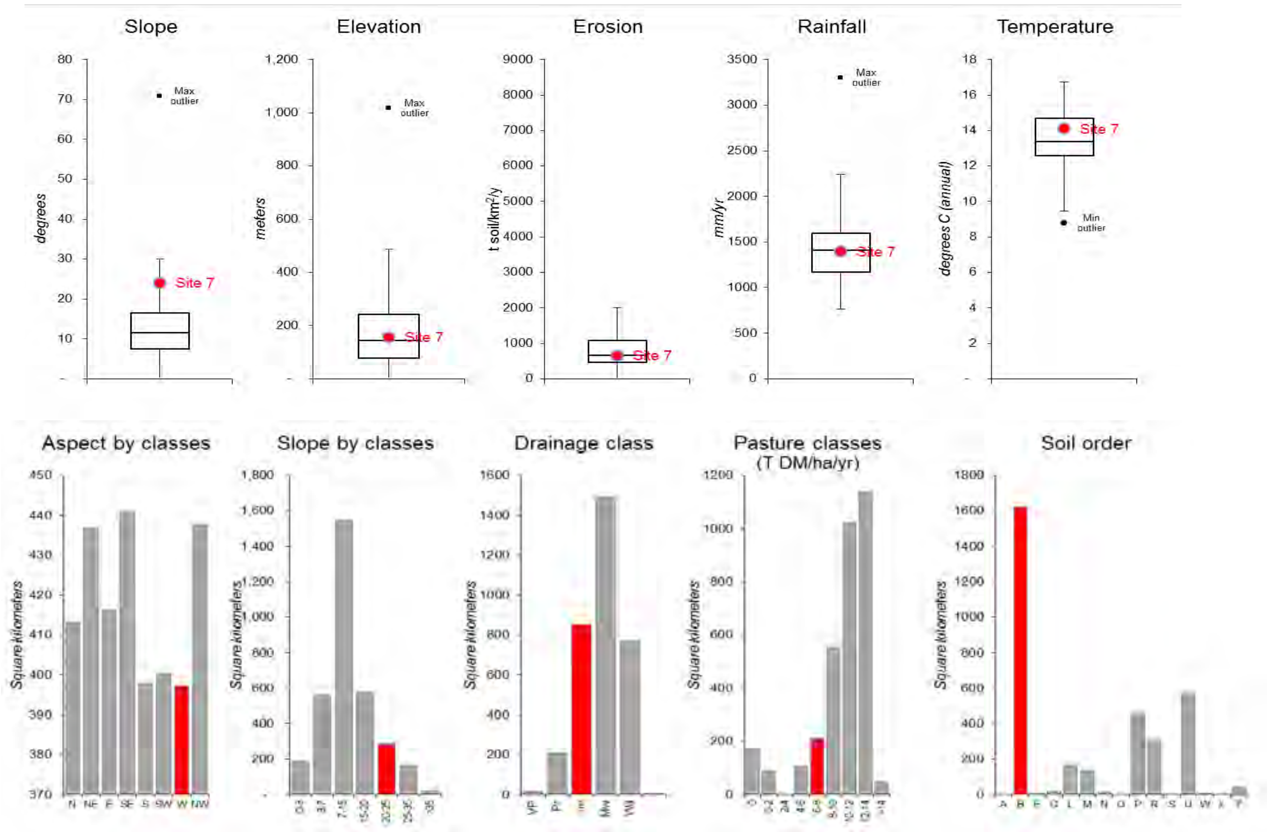


Figure A4 - 35: Representativeness of site 7 within Crushed soft rock hill country.

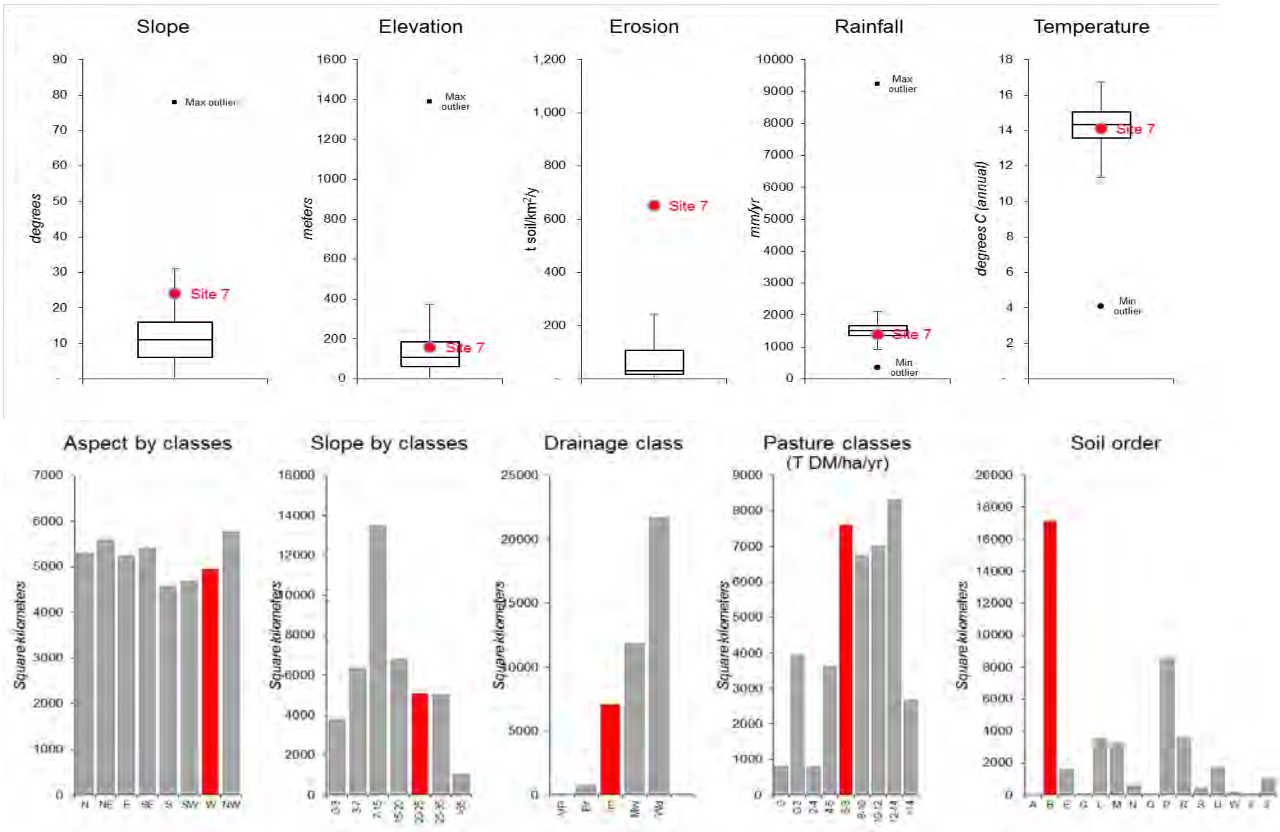


Figure A4 - 36: Representativeness of site 7 within all NZ hill country.

Table A4 - 7: Distance from the median and percent area of Site 7 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Midslopes within 2km²	Hill country within 2km²	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	-	*0.01 ha*	*0.15ha*	*148 ha*	*338 ha*	-	*3341 km²*	*4.1 M ha*
Elevation (m)	*160*	**157**	**25**	**42**	x	x	**4**	**18**
Slope (degrees)	***24***	24.0	**33**	**33**	x	x	**44**	**43**
Aspect (degrees)	*180*	**258**	x	x	x	x	x	x
Erosion (t soil/km²/y)	-	**650.9**	x	x	x	x	**2**	**50**
Precipitation (mm)	1400	**1396**	x	x	x	x	**2**	**20**
Temperature (°C)	-	**14.1**	x	x	x	x	**16**	**7**
Midslopes	-	x	x	x	**44%**	x	x	x
Hill country type	*1*	x	x	x	x	x	x	**8%**
Soil type	-	x	x	x	x	x	x	x
Soil subgroup	*BOM*	x	x	x	x	x	**2%**	**2.4%**
Soil order	*B*	x	x	x	x	x	**49%**	**41%**
Slope group	-	20-25°	**31%**	**15%**	x	x	**9%**	**12%**
Aspect group	*S*	W	**96%**	**11%**	x	x	**12%**	**12%**
Pasture (kg DM/ha/y)	*7,700*	x	x	x	x	x	**6%**	**18%**
Drainage	*Im*	x	x	x	x	x	**25%**	**17%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

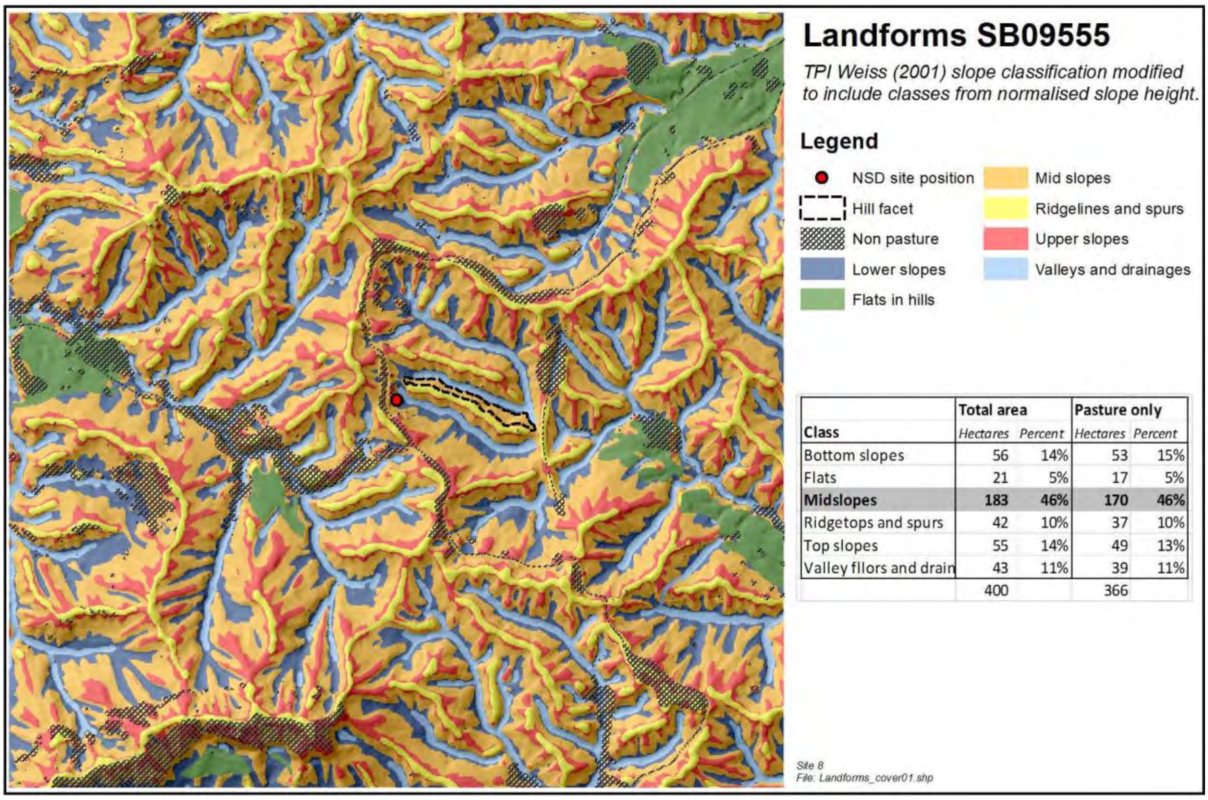
Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 8 (SB09555)

Site 8 is located within steepland on the boundary of Taranaki and Manawatu-Wanganui Regions (near Tahora Saddle). Soil type is Tahora silt loam steepland soil. Hill country type is *Soft rock hill country (including soft Limestone) (7)*. The site itself is placed on a small eastern-facing slope near the road. Because of the small area and the presence of trees (which lessen the quality of the 5m DEM), a larger less-obstructed slope is used as the hill facet (Figure 37) with a recognition that aspect will no longer be representative. The extent of the soil type within grazed hill country is assessed at the series level because the FSL database NZSC is in conflict with the site's designated NZSC.



Class	Total area		Pasture only	
	Hectares	Percent	Hectares	Percent
Bottom slopes	56	14%	53	15%
Flats	21	5%	17	5%
Midslopes	**183**	**46%**	**170**	**46%**
Ridgetops and spurs	42	10%	37	10%
Top slopes	55	14%	49	13%
Valley fllors and drain	43	11%	39	11%
	400		366	

Figure A4 - 37: Classification of land forms for site 8 within a 2km² grid.

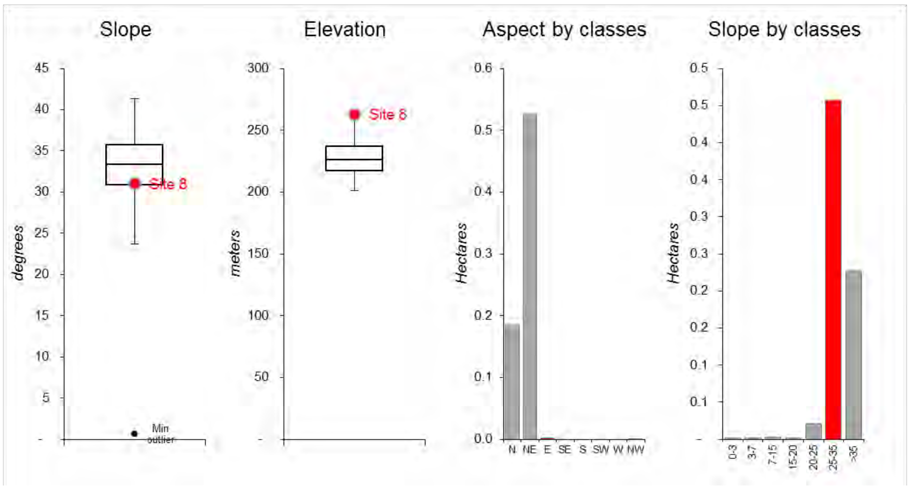


Figure A4 - 38: Representativeness of site 8 within the immediate hill facet.

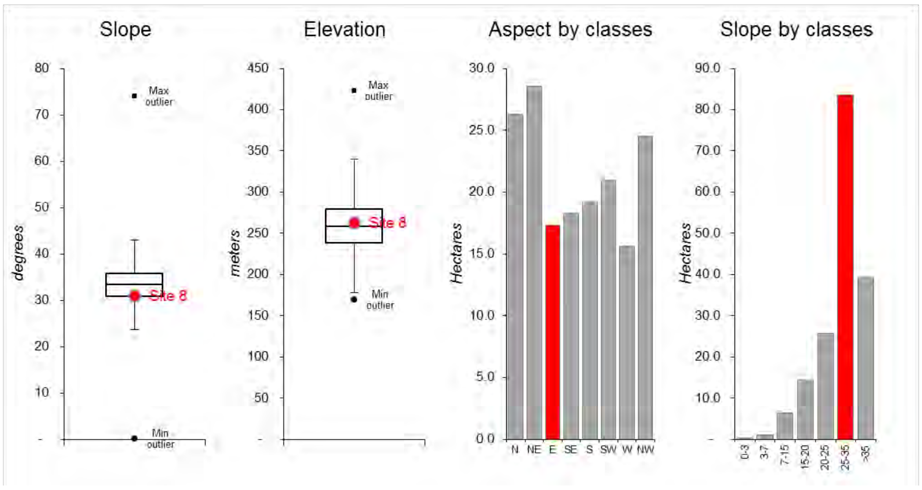


Figure A4 - 39: Representativeness of site 8 within midslopes located within a 2km² grid.

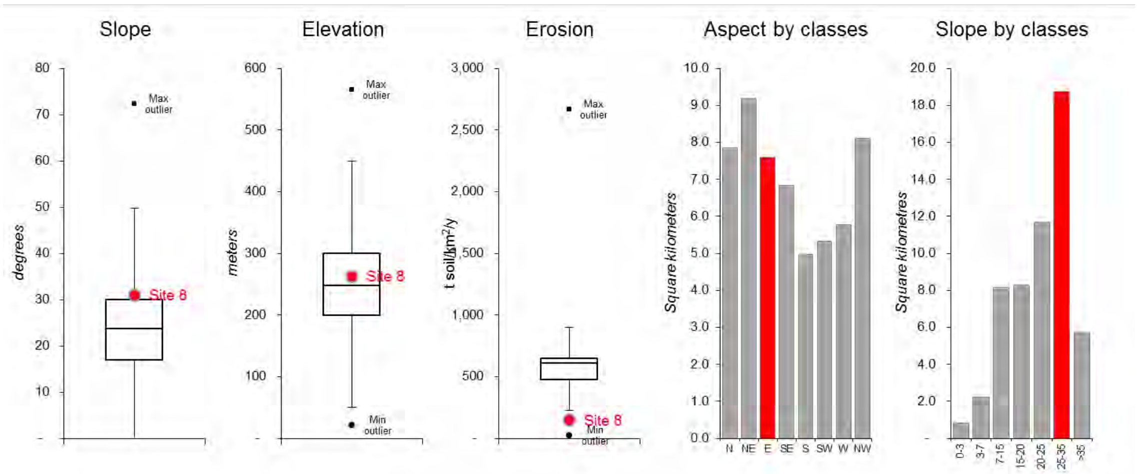


Figure A4 - 40: Representativeness of site 8 within the extent of the same soil series.

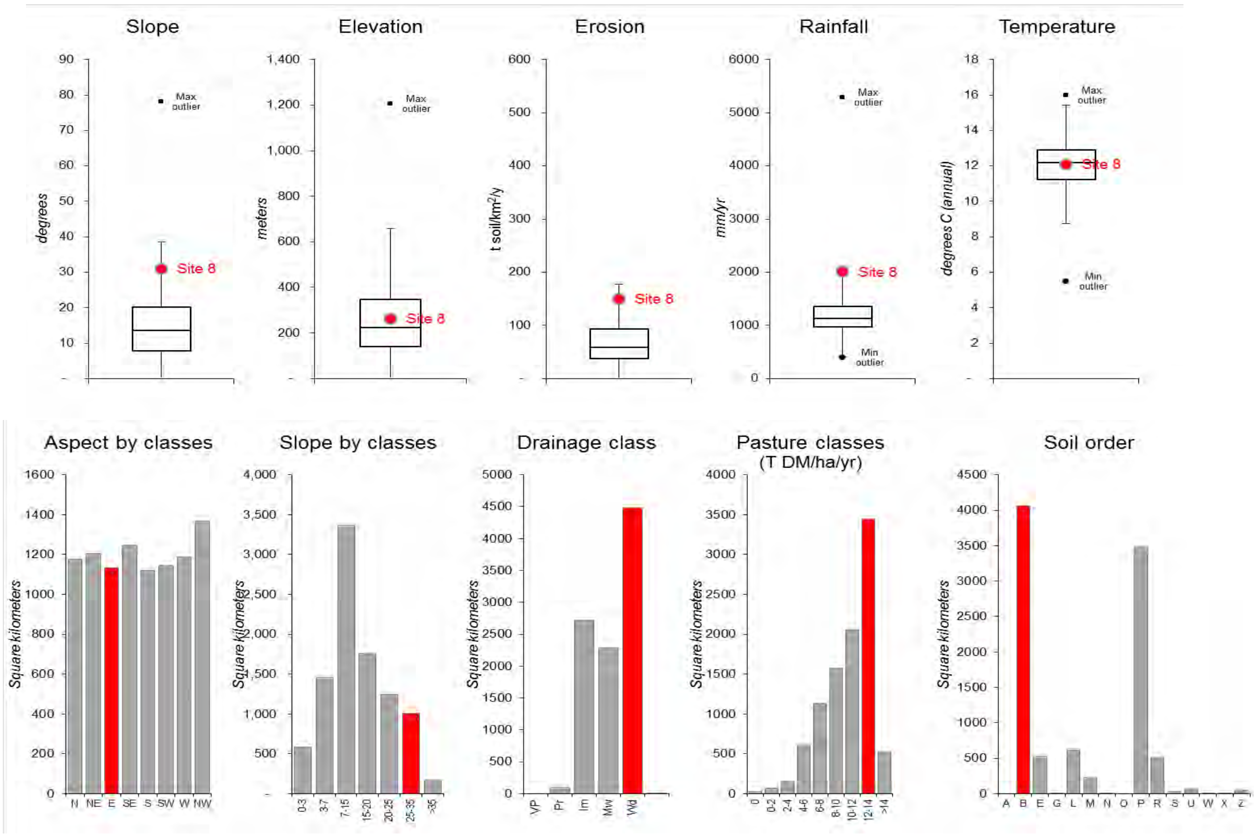


Figure A4 - 41: Representativeness of site 8 within Soft rock hill country (including soft Limestone).

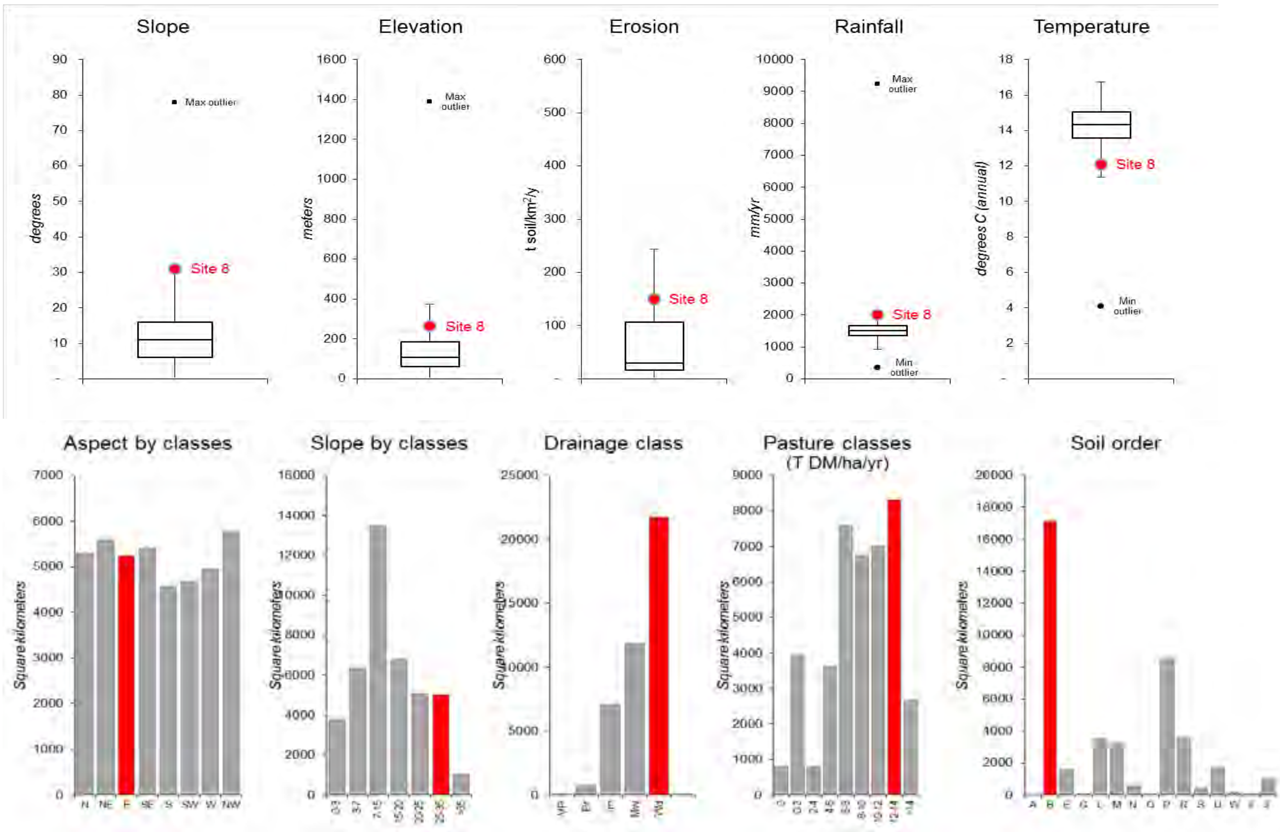


Figure A4 - 42: Representativeness of site 8 within all NZ hill country.

Table A4 - 8: Distance from the median and percent area of Site 8 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Midslopes within 2km^2	Hill country within 2km^2	Soil series (within all hill country)	Hill country type	Hill country all
Eligible total area	-	*0.0025 ha*	*0.7 ha*	*171 ha*	*366 ha*	5565 ha	*9582 km^2*	*4.1 M ha*
Elevation (m)	*300*	**263**	**49**	**7**	x	**9**	**10**	**36**
Slope (degrees)	***31***	29.4	**24**	**24**	x	**26**	**45**	**49**
Aspect (degrees)	***90***	90.5	x	x	x	x	x	x
Erosion (t soil/km^2/y)	*149.6*	x	x	x	x	**50**	**42**	**27**
Precipitation (mm)	2400	**2011**	x	x	x	x	**50**	**48**
Temperature (°C)	-	**12.1**	x	x	x	x	**3**	**46**
Midslopes	-	x	x	x	**46%**	x	x	x
Hill country type	*7*	x	x	x	x	x	x	**23%**
Soil type	*TorS*	x	x	x	x	x	**0.03%**	**0.1%**
Soil subgroup	*BOA*	x	x	x	x	x	**5.6%**	**9.3%**
Soil order	*B*	x	x	x	x	x	**42%**	**41%**
Slope group	-	25-35°	**64%**	**49%**	x	**34%**	**10%**	**12%**
Aspect group	*E*	E	**0%**	**10%**	x	**14%**	**12%**	**13%**
Pasture (kg DM/ha/y)	*12,860*	x	x	x	x	x	**36%**	**20%**
Drainage	*Wd*	x	x	x	x	x	**47%**	**52%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

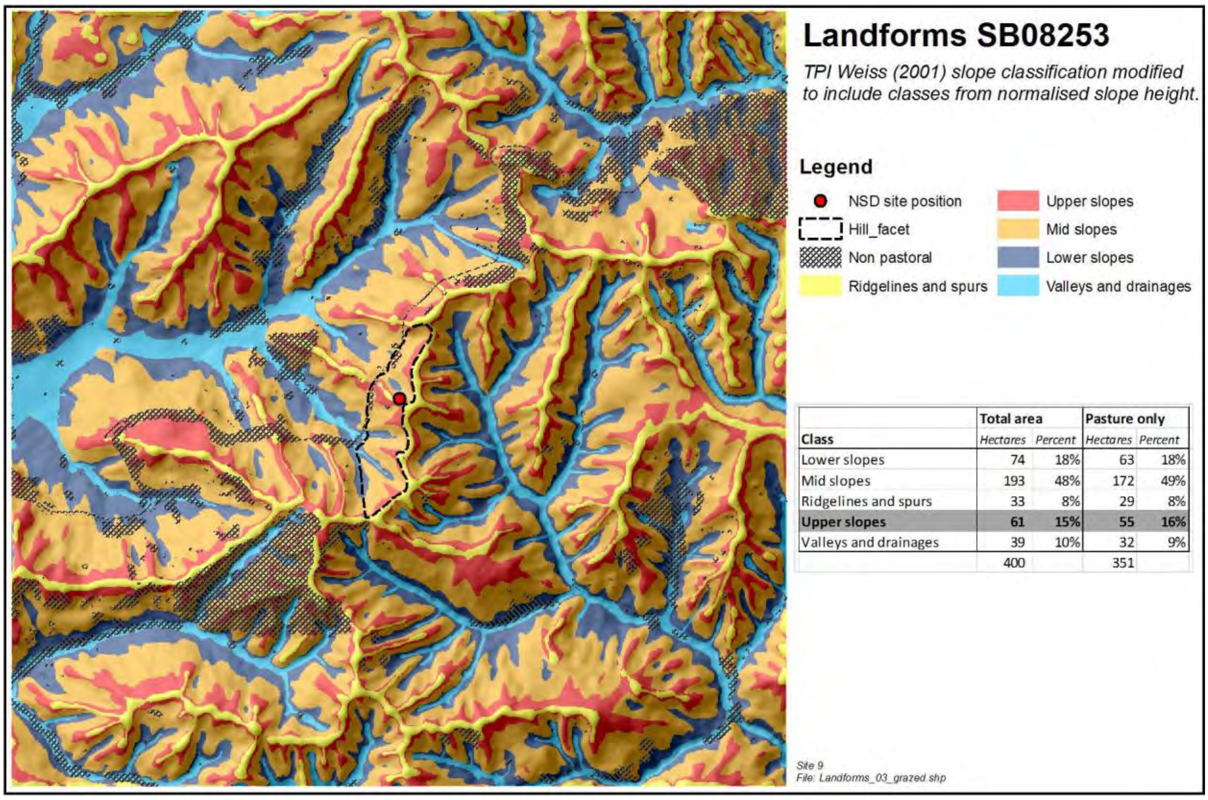
Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 9 (SB08253)

Site 9 is located within Wanganui steep hill country near Kakatahi and the Whangaehu River. Soil type is Turakina steepland soil (normal steep slope variant). The soil is classified as BOT in the NSD, but as BOP by Schipper et al. (2008). We used the BOP classification on the assumption that Schipper et al. (2008) re-evaluated the site's soil classification according to the most recent criteria and standards. Site position is just off a steep spur (Figure 43) which qualifies as an upper slope position. If spurs were ignored (i.e. if position was evaluated at a larger landform scale), then the site could be interpreted as being on a midslope.



	Total area		Pasture only	
Class	*Hectares*	*Percent*	*Hectares*	*Percent*
Lower slopes	74	18%	63	18%
Mid slopes	193	48%	172	49%
Ridgelines and spurs	33	8%	29	8%
Upper slopes	**61**	**15%**	**55**	**16%**
Valleys and drainages	39	10%	32	9%
	400		351	

Figure A4 - 43: Classification of land forms for site 9 within a 2 km² grid.

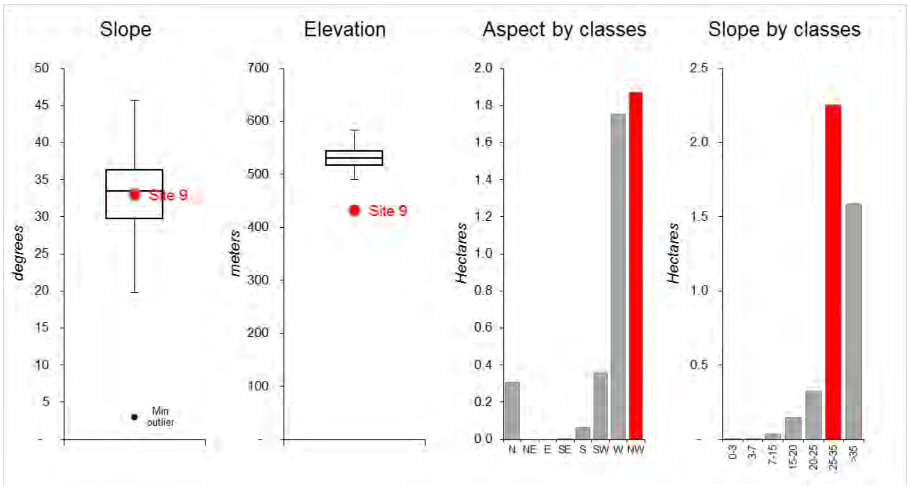


Figure A4 - 44: Representativeness of site 9 within the immediate hill facet.

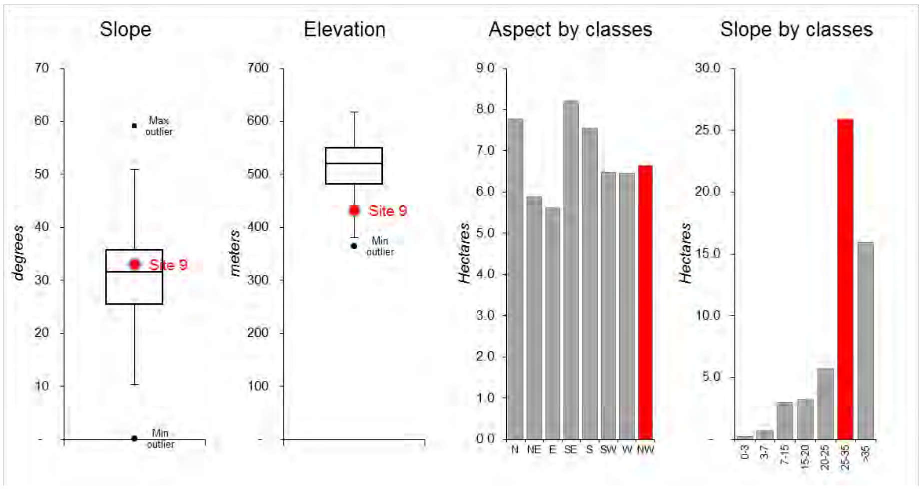


Figure A4 - 45: Representativeness of site 9 within upper slopes located within a 2km² grid.

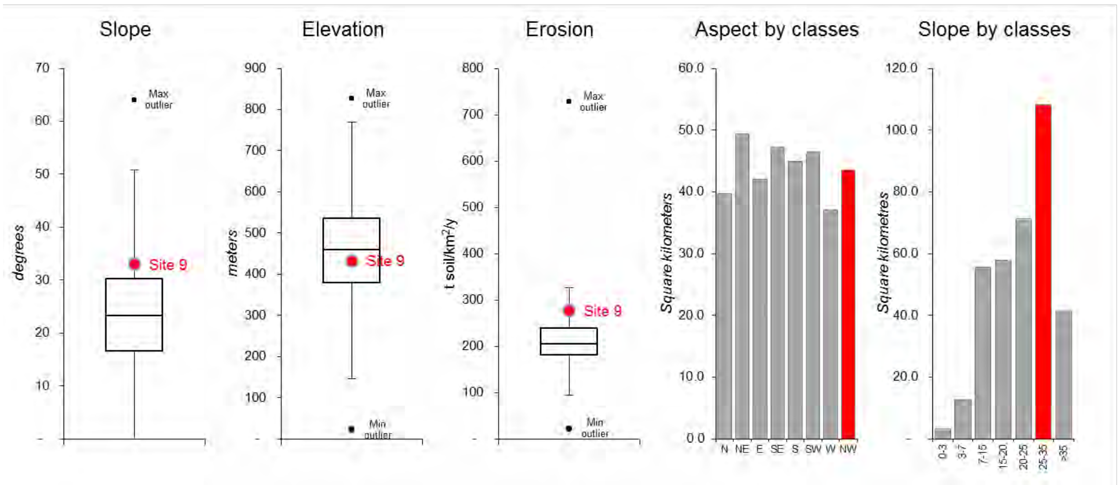


Figure A4 - 46: Representativeness of site 9 within the extent of the same soil type.

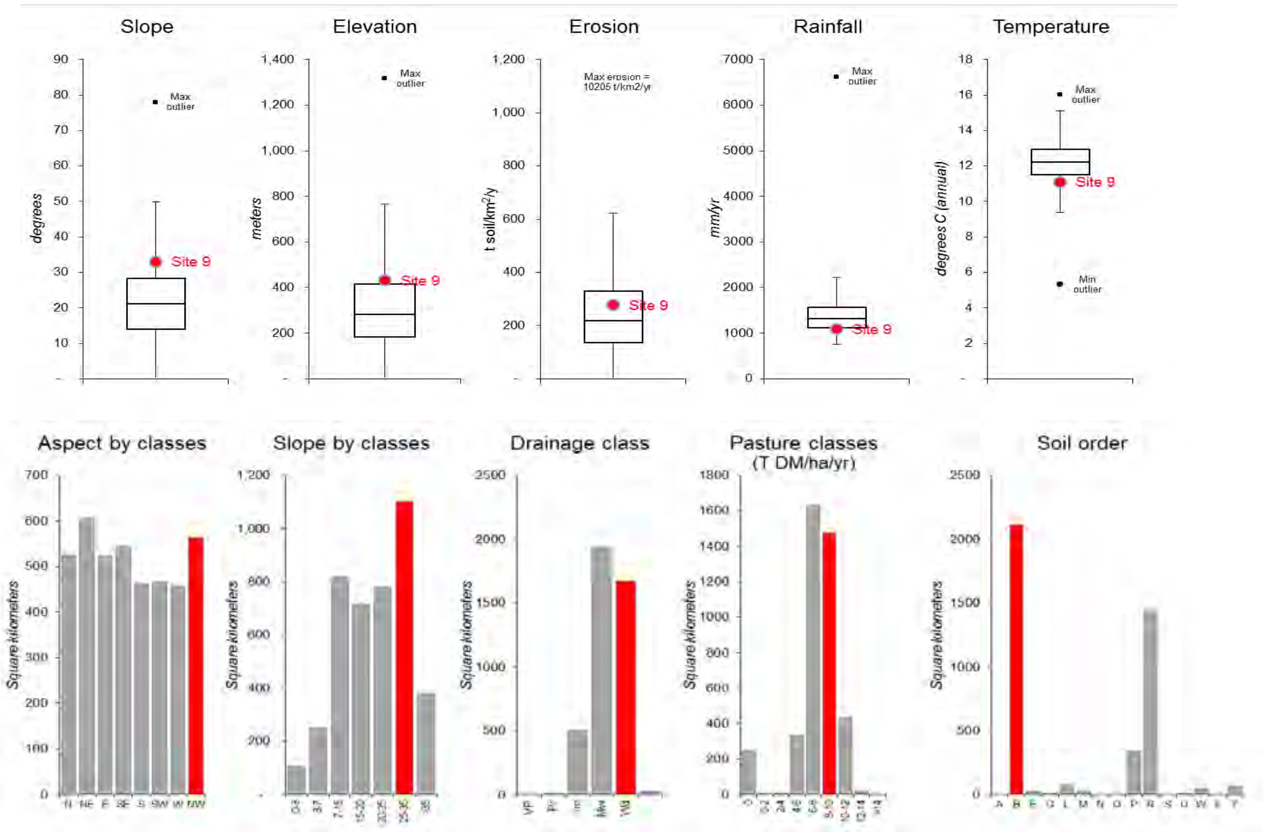


Figure A4 - 47: Representativeness of site 9 within Steep soft rock hill country (12).

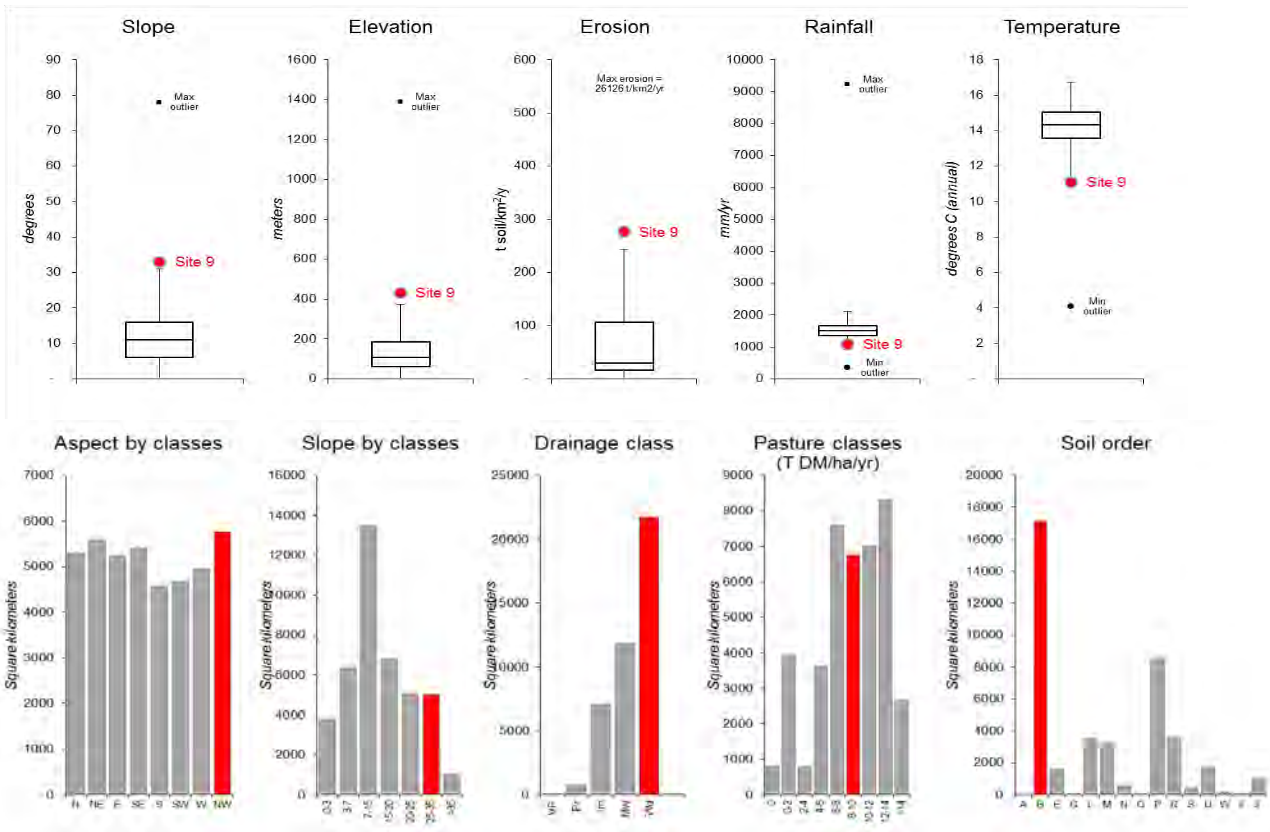


Figure A4 - 48: Representativeness of site 9 within all NZ hill country.

Table A4 - 9: Distance from the median and percent area of Site 9 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only): Hill slope facet	Upper slopes within 2km^2	Hill country within 2km^2	Soil type (within all hill country)	Hill country type	Hill country all
Eligible total area	-	*0.01 ha*	*4.4 ha*	*55 ha*	*351 ha*	350 ha	*4152 km^2*	*4.1 M ha*
Elevation (m)	***432***	554	**50**	**42**	x	**9**	**27**	**50**
Slope (degrees)	***33***	33	**3**	**10**	x	**34**	**37**	**50**
Aspect (degrees)	*315*	**319**	x	x	x	x	x	x
Erosion (t soil/km^2/y)	*277*	x	x	x	x	**39**	**16**	**50**
Precipitation (mm)	1270	**1088**	x	x	x	x	**30**	**49**
Temperature (°C)	-	**11.1**	x	x	x	x	**34**	**49**
Midslopes	-	x	x	x	**8%**	x	x	x
Hill country type	*12*	x	x	x	x	x	x	**10%**
Soil type	*TkS*	x	x	x	x	x	**7.9%**	**0.8%**
Soil subgroup	*BOP*	x	x	x	x	x	**24%**	**8%**
Soil order	*B*	x	x	x	x	x	**51%**	**41%**
Slope group	-	25-35°	**52%**	**47%**	x	x	**27%**	**12%**
Aspect group	*NW*	NW	**43%**	**12%**	x	**12%**	**14%**	**14%**
Pasture (kg DM/ha/y)	*8570*	x	x	x	x	**31%**	**35%**	**16%**
Drainage	*Wd*	x	x	x	x	x	**40%**	**52%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

Red values indicate outliers that would definitely not be representative.

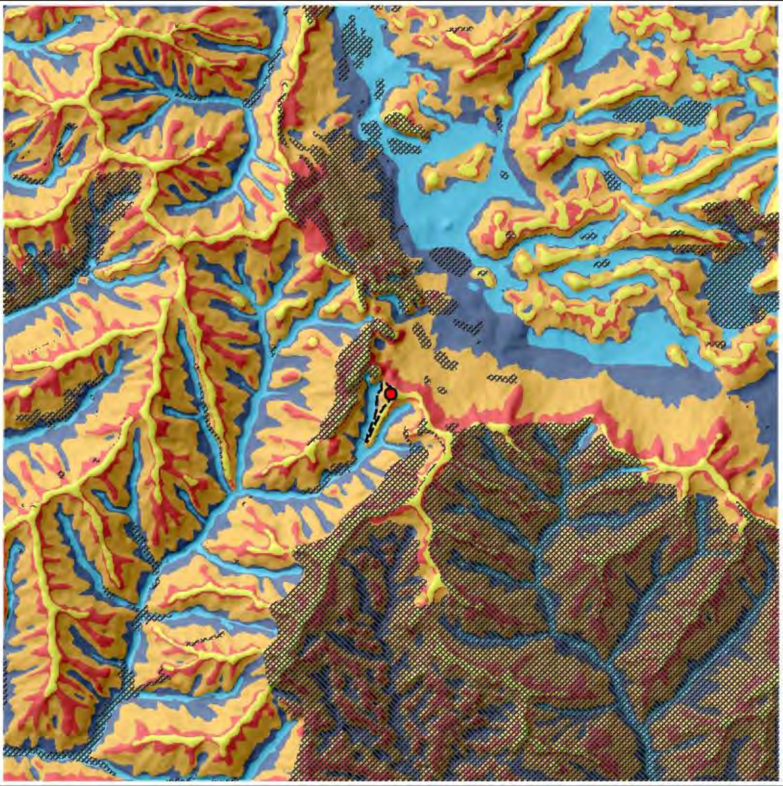
Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Elevation is not particularly well represented at the hill facet scale (50 = an outlier) because we used the NSD value (432m asl) on the assumption that the recorded precision was suggestive of a measurement rather than inference. If the RLA value of 554m had been used, distance from the median would be 37 units.

Site 10 (SB08249)

Site 10 is located within steep Wanganui hill country (Parihauhau Road), on a steep slope at the head of a shallow gully just below a ridge. This qualifies the postion as an upper slope. Approximately 25% of the $2km^2$ area is rolling rather than steepland hill country (Figure 49). Soil type is Upokonui steepland soil (UpS) classified as BOT in the NSD but reclassified to BOP by Schipper et al. (2010). Hill country type is *Steep soft rock hill country (12)*.



Class	Total area Hectares	Total area Percent	Pasture only Hectares	Pasture only Percent
Flat areas	18	5%	13	5%
Lower slopes	73	18%	50	18%
Mid slopes	182	46%	123	46%
Ridgelines and spurs	37	9%	26	10%
Upper slopes	60	15%	38	14%
Valleys and drainages	29	7%	20	7%
	400		269	

Figure A4 - 49: Classification of land forms for site 10 within a $2km^2$ grid.

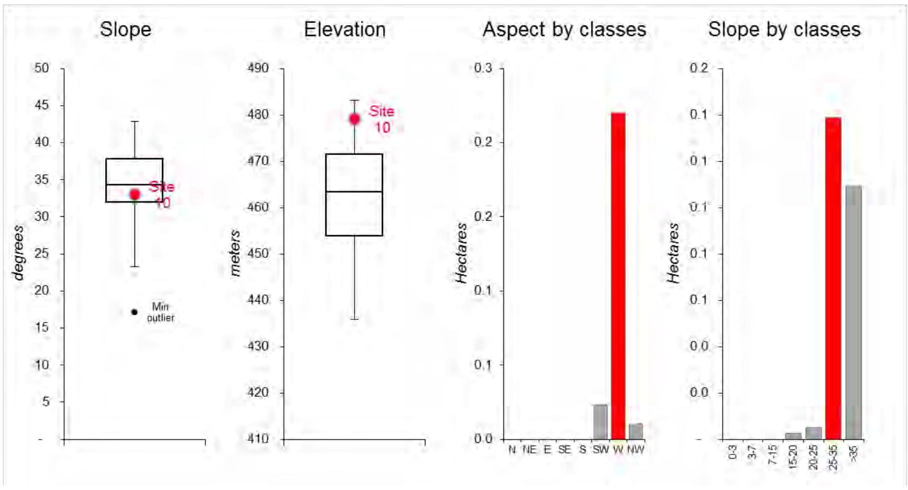


Figure A4 - 50: Representativeness of site 10 within the immediate hill facet.

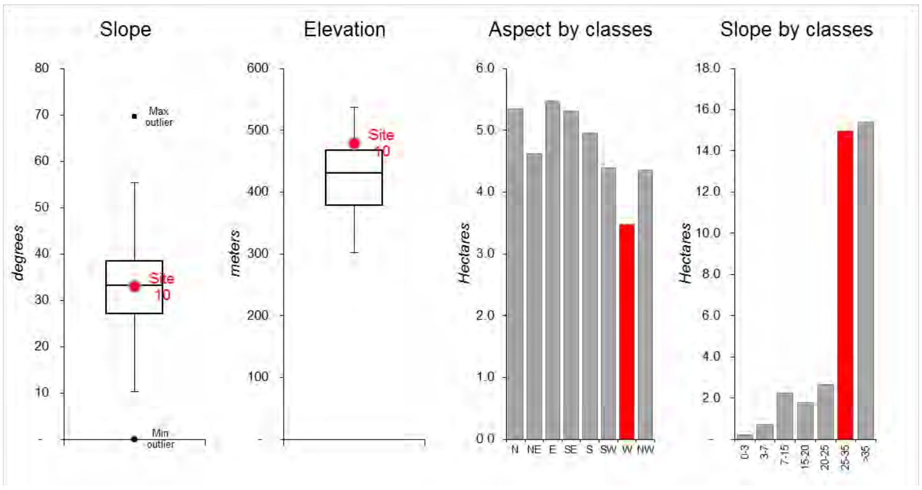


Figure A4 - 51: Representativeness of 10 within upper slopes located within a 2km² grid.

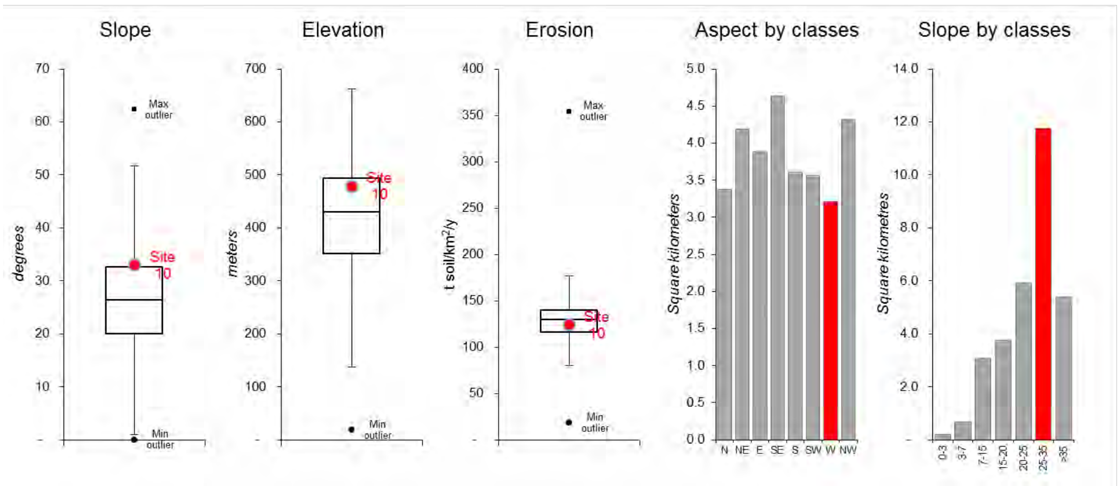


Figure A4 - 52: Representativeness of site 10 within the extent of the same soil type.

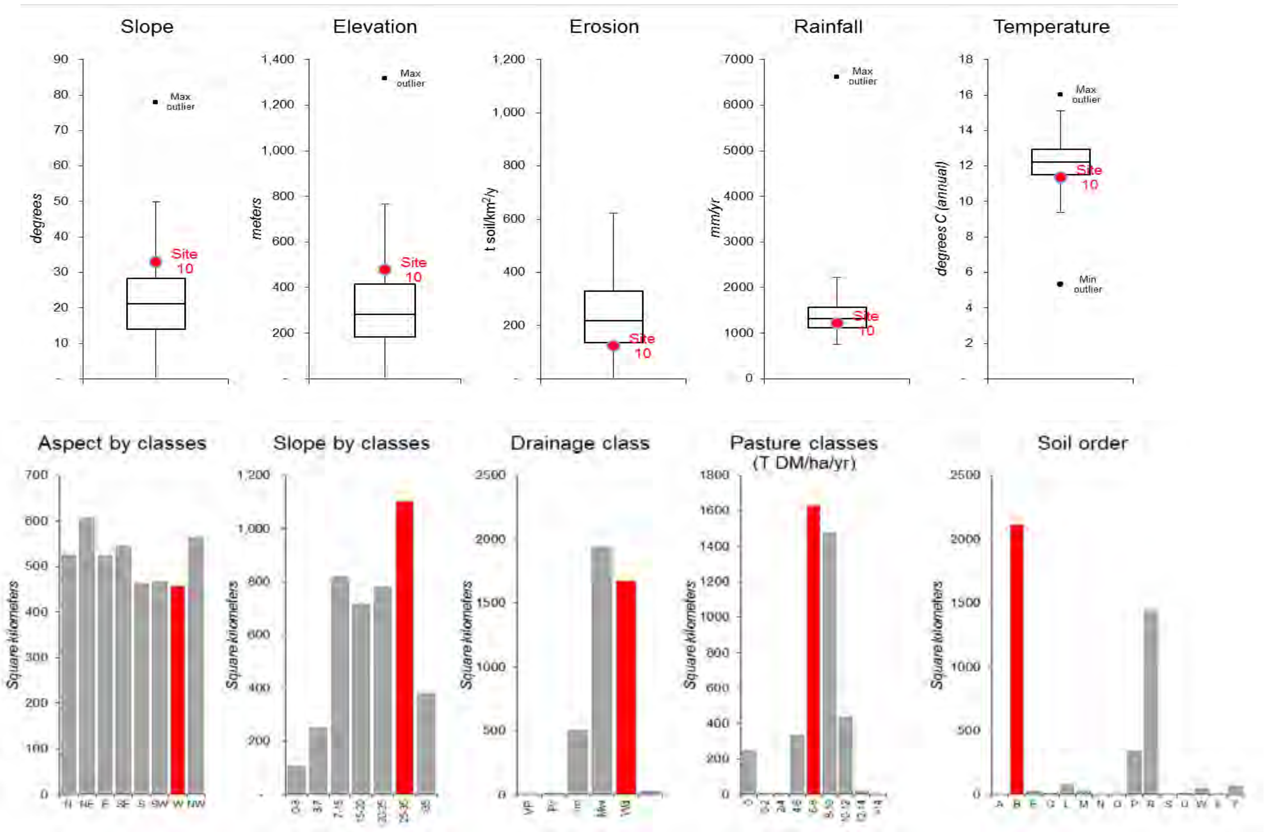


Figure A4 - 53: Representativeness of site 10 within Steep soft rock hill country (12).

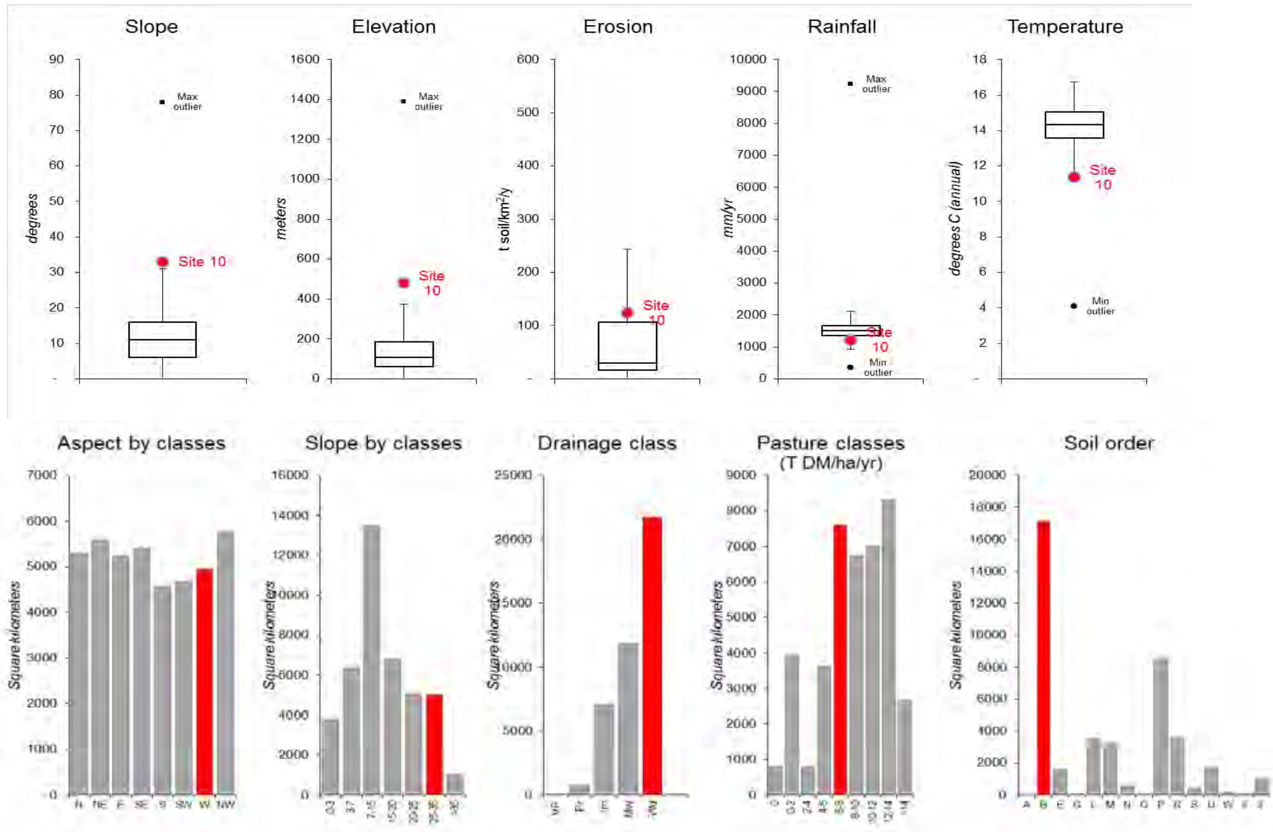


Figure A4 - 54: Representativeness of site 10 within all NZ hill country.

Table A4 - 10: Distance from the median and percent area of Site 10 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Upper slopes within 2km²	Hill country within 2km²	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	-	*0.01 ha*	*0.3 ha*	*38 ha*	*269 ha*	3077 ha	*4152 km²*	*4.1 M ha*
Elevation (m)	*488*	**479**	**43**	**32**	x	**19**	**33**	**47**
Slope (degrees)	***33***	33	**19**	**0**	x	**26**	**37**	**49**
Aspect (degrees)	*225*	**270**	x	x	x	x	x	x
Erosion (t soil/km²/y)	*11.4*	x	x	x	x	**11**	**29**	**25**
Precipitation (mm)	1520	**1217**	x	x	x	x	**11**	**42**
Temperature (°C)	-	**11.8**	x	x	x	x	**29**	**49**
Midslopes	-	x	x	x	**14%**	x	x	x
Hill country type	*16*	x	x	x	x	x	x	**10%**
Soil type	*UpS*	x	x	x	x	x	**0.7%**	**0.1%**
Soil subgroup	*BOP*	x	x	x	x	x	**24%**	**8%**
Soil order	*B*	x	x	x	x	x	**51%**	**41%**
Slope group	-	25-35°	**54%**	**39%**	x	**38%**	**27%**	**12%**
Aspect group	*SW*	**W**	**86%**	**9%**	x	**10%**	**11%**	**12%**
Pasture (kg DM/ha/y)	*6000*	x	x	x	x	x	**39%**	**18%**
Drainage	*Mw*	x	x	x	x	x	**40%**	**52%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

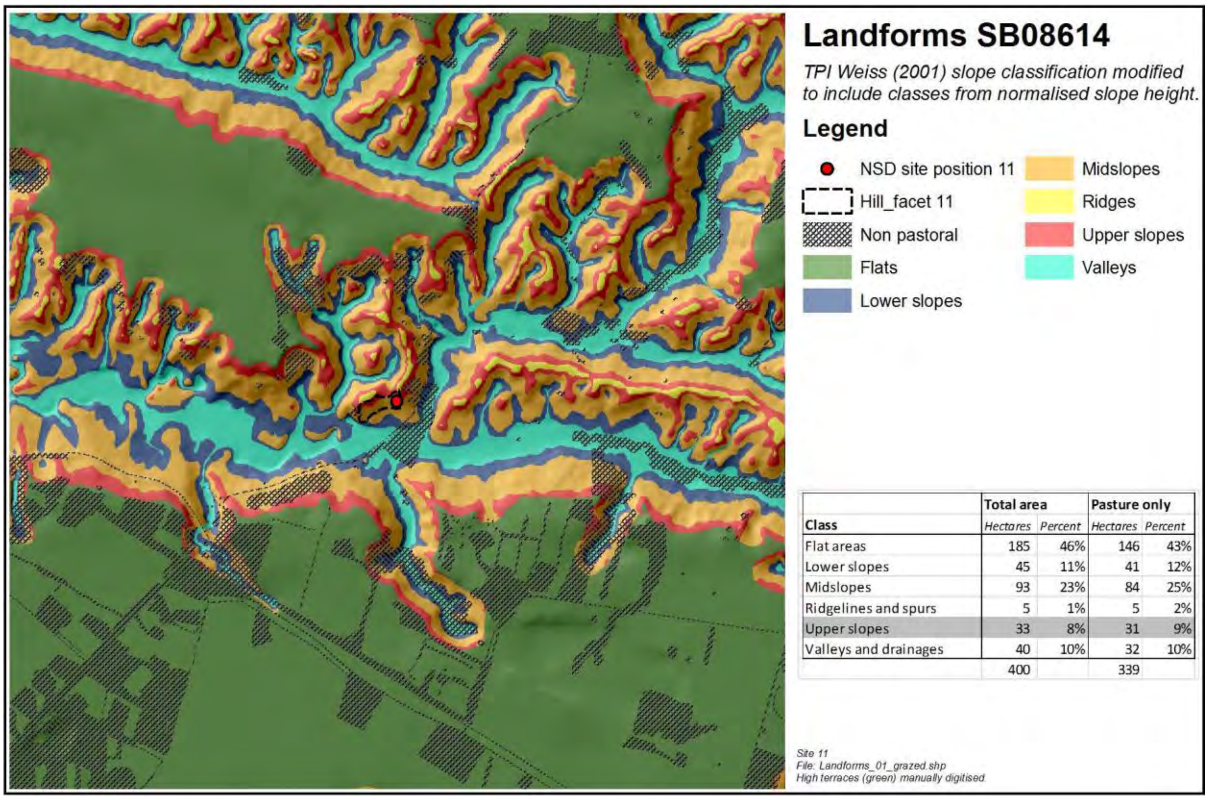
Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 11 (SB08614)

Sites 11 and 12 are from the same locality (Wanganui dissected terrace land) and represent the same dissected gully landform, with Site 11 being positioned on the northern side and Site 12 on the southern side. The area is dominated by high terrace flats (Figure 55). The site's slope (25°) is at the boundary of two slope classes; the 20-25° class is selected on the basis that surrounding slopes fall into this category (see RLA, Table 11). The site is located in an upper slope position. Soil type is Kumeroa hill soil (PJT), while hill country type is Soft rock hill country (including soft Limestone) (7).



	Total area		Pasture only	
Class	*Hectares*	*Percent*	*Hectares*	*Percent*
Flat areas	185	46%	146	43%
Lower slopes	45	11%	41	12%
Midslopes	93	23%	84	25%
Ridgelines and spurs	5	1%	5	2%
Upper slopes	33	8%	31	9%
Valleys and drainages	40	10%	32	10%
	400		339	

Figure A4 - 55: Classification of land forms for site 11 within a 2km² grid.

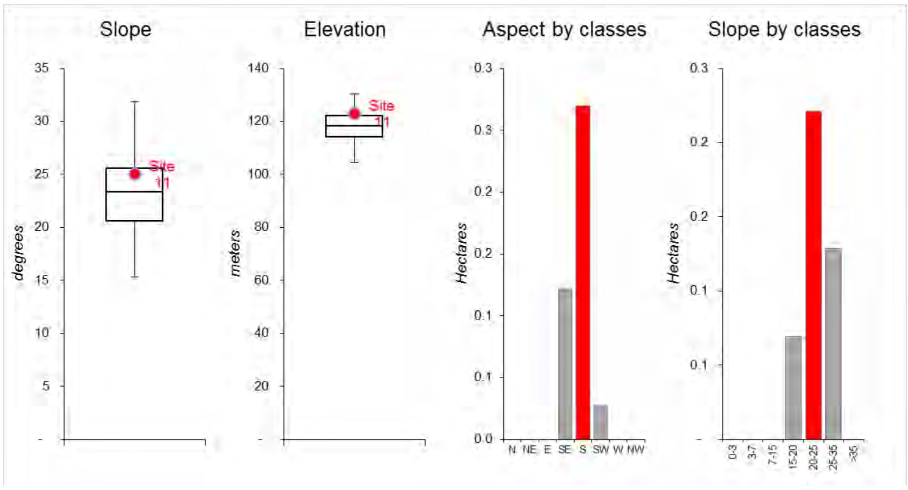


Figure A4 - 56: Representativeness of site 11 within the immediate hill facet.

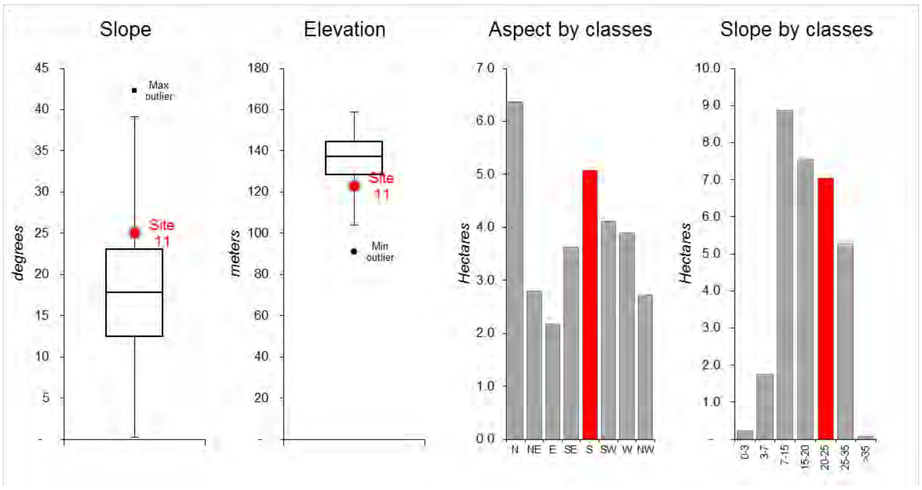


Figure A4 - 57: Representativeness of 11 within upper slopes located within a 2km² grid.

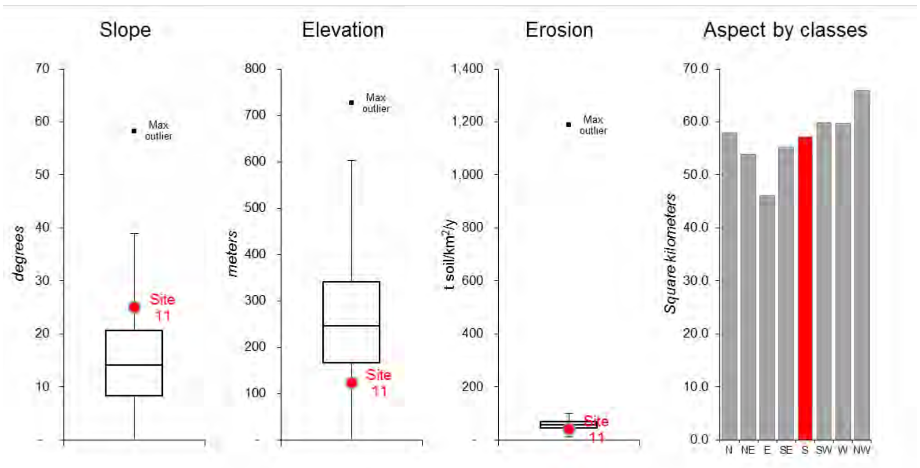


Figure A4 - 58: Representativeness of site 11 within the extent of the same soil type.

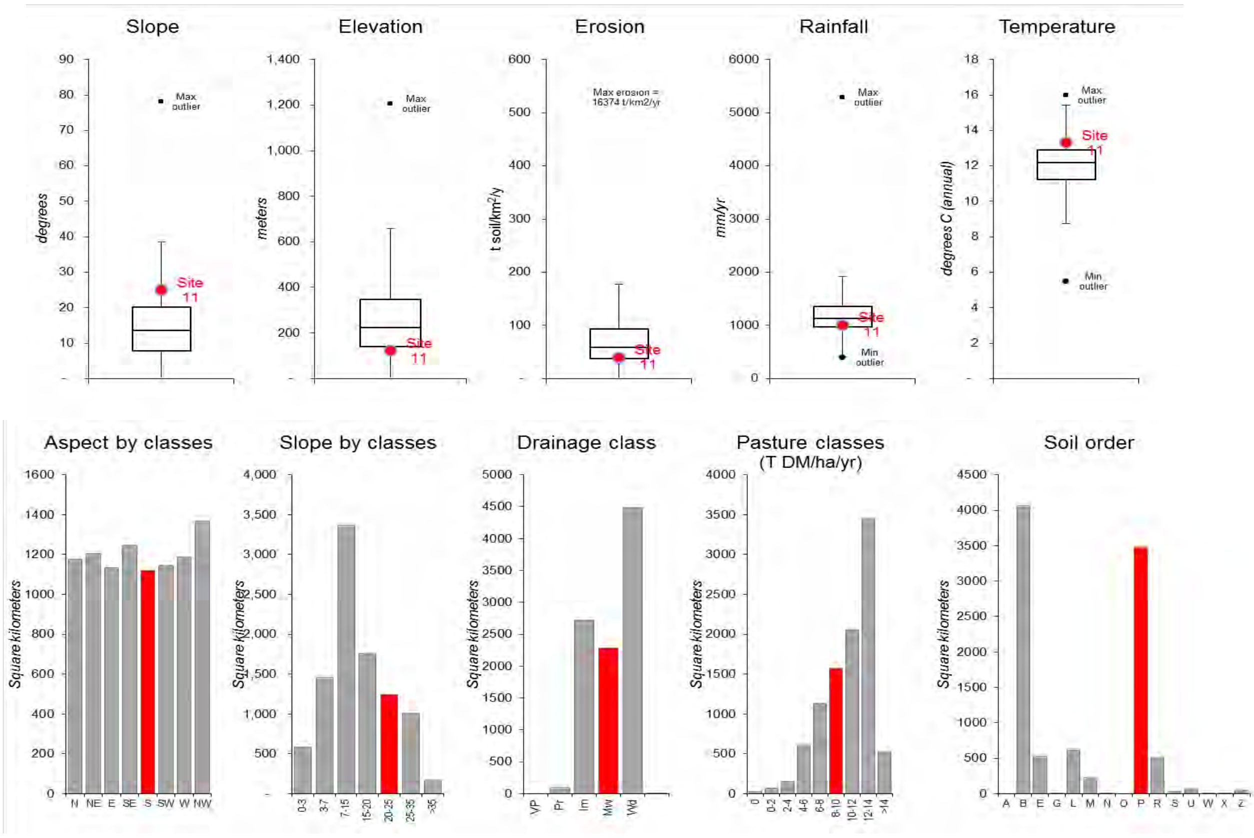


Figure A4 - 59: Representativeness of site 11 within Soft rock hill country (including soft Limestone).

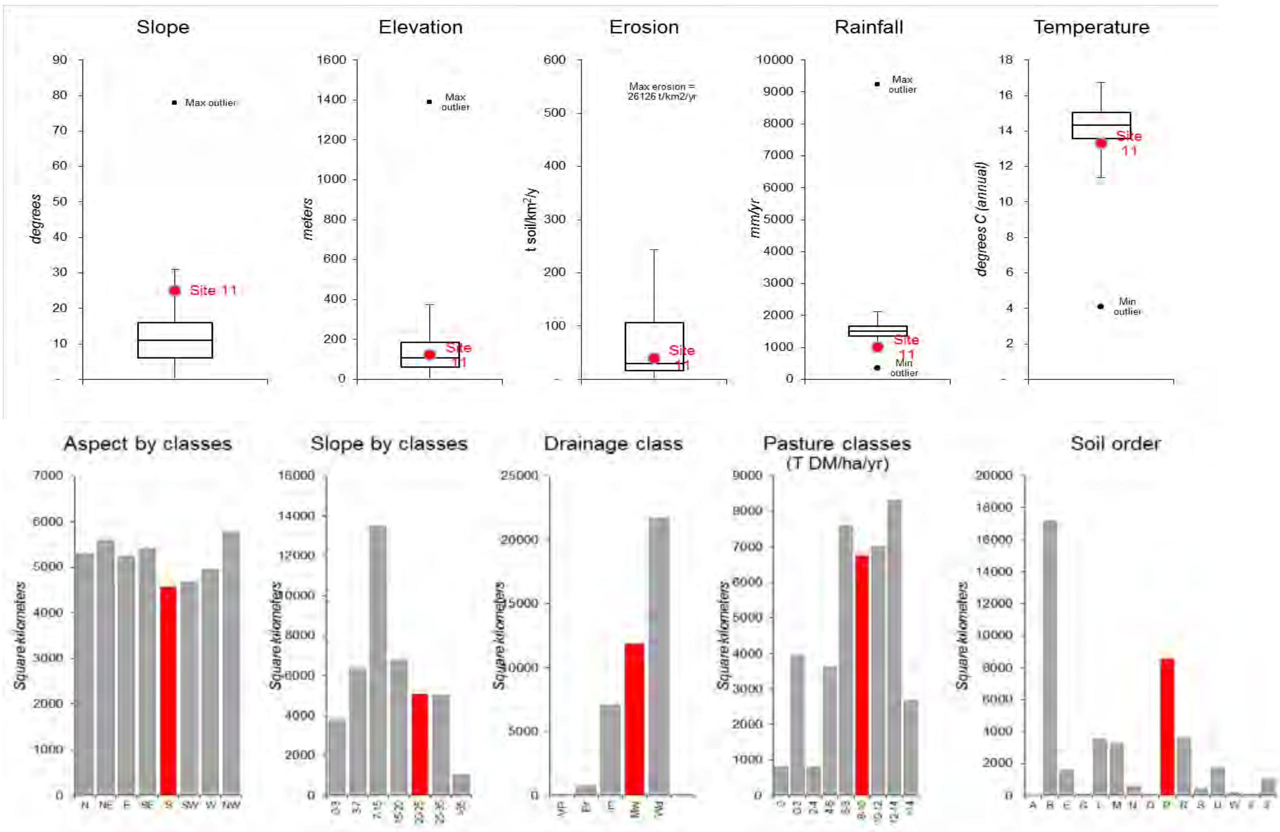


Figure A4 - 60: Representativeness of site 11 within all NZ hill country.

Table A4 - 11: Distance from the median and percent area of Site 11 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Upper slopes within 2km²	Hill country within 2km²	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	-	*0.01 ha*	*0.4 ha*	*31 ha*	*339 ha*	456 km²	*9583 km²*	*4.1 M ha*
Elevation (m)	*107*	**123**	**29**	**37**	x	**35**	**29**	**5**
Slope (degrees)	***25***	22	**21**	**34**	x	**38**	**38**	**44**
Aspect (degrees)	*180*	**180**	x	x	x	x	x	x
Erosion (t soil/km²/y)	*40*	x	x	x	x	**37**	**22**	**5**
Precipitation (mm)	826	**1008**	x	x	x	x	**20**	**13**
Temperature (°C)	-	**13.3**	x	x	x	x	**33**	**34**
Upper slopes	-	x	x	x	**9%**	x	x	x
Hill country type	*7*	x	x	x	x	x	x	**23%**
Soil type	*29fH*	x	x	x	x	x	**4.8%**	**1.1%**
Soil subgroup	*PJT*	x	x	x	x	x	**7.2%**	**4.4%**
Soil order	*P*	x	x	x	x	x	**36%**	**21%**
Slope group	-	20-25°	**53%**	**23%**	x	**14%**	**13%**	**12%**
Aspect group	*S*	S	**64%**	**16%**	x	**13%**	**12%**	**11%**
Pasture (kg DM/ha/y)	*9430*	x	x	x	x	x	**16%**	**16%**
Drainage	*Mw*	x	x	x	x	x	**24%**	**29%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

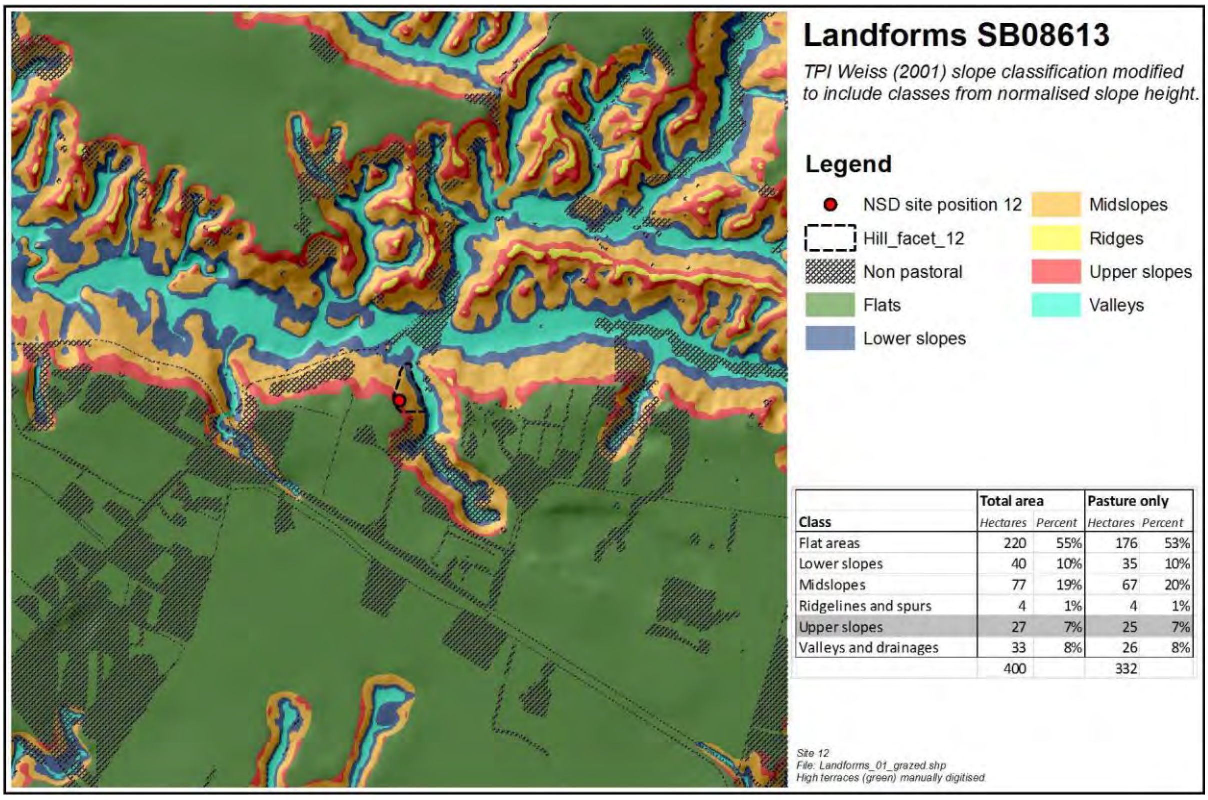
Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 12 (SB08613)

Site 12 located on the slope of a Wanganui dissected terrace gully system, almost directly opposite Site 11 at the same elevation. Hill country type is the same (*Soft rock hill country (including soft Limestone) (7)*), but soil type (Westmere sandy loam, hill soil) is quite different. Soil type is classified as EMT in the NSD, but as either EMM or BMM in the FSL database. NZSC results for hill type and all hill country are not valid (and are therefore not reported).



Class	Total area		Pasture only	
	Hectares	Percent	Hectares	Percent
Flat areas	220	55%	176	53%
Lower slopes	40	10%	35	10%
Midslopes	77	19%	67	20%
Ridgelines and spurs	4	1%	4	1%
Upper slopes	27	7%	25	7%
Valleys and drainages	33	8%	26	8%
	400		332	

Figure A4 - 61: Classification of land forms for site 12 within a 2km² grid.

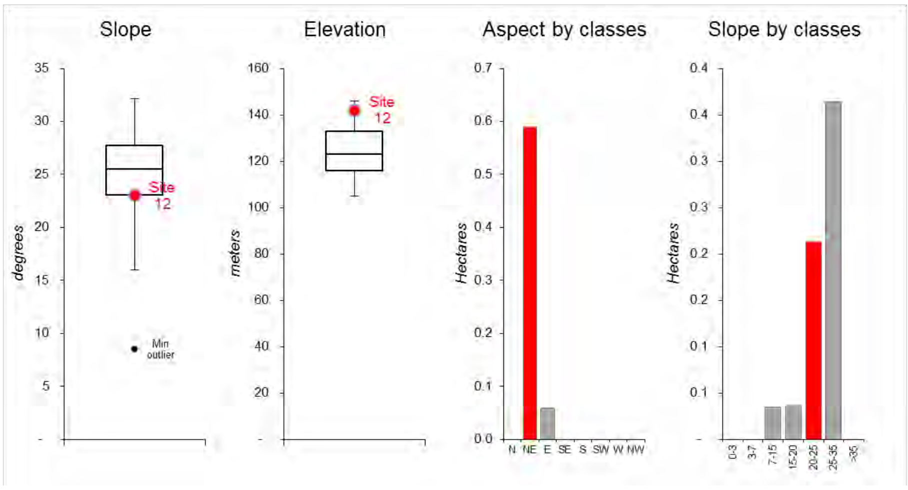


Figure A4 - 62: Representativeness of site 12 within the immediate hill facet.

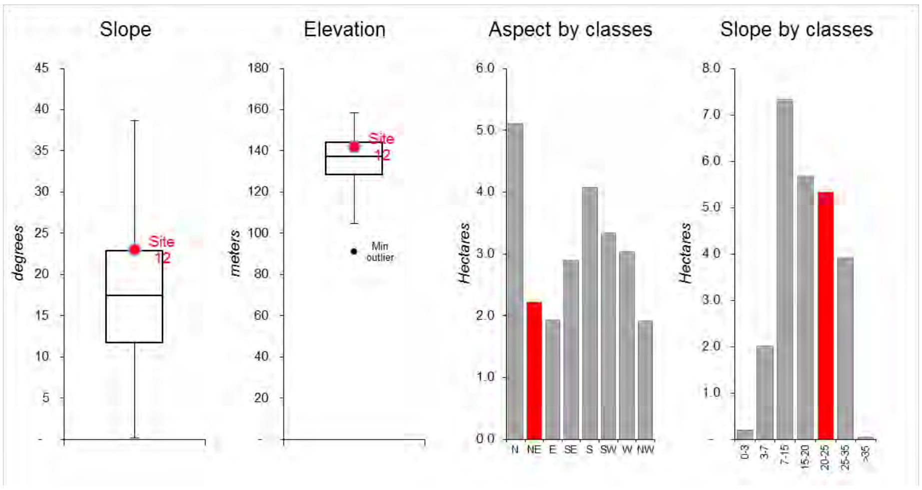


Figure A4 - 63: Representativeness of site 12 within upper slopes located within a 2km² grid.

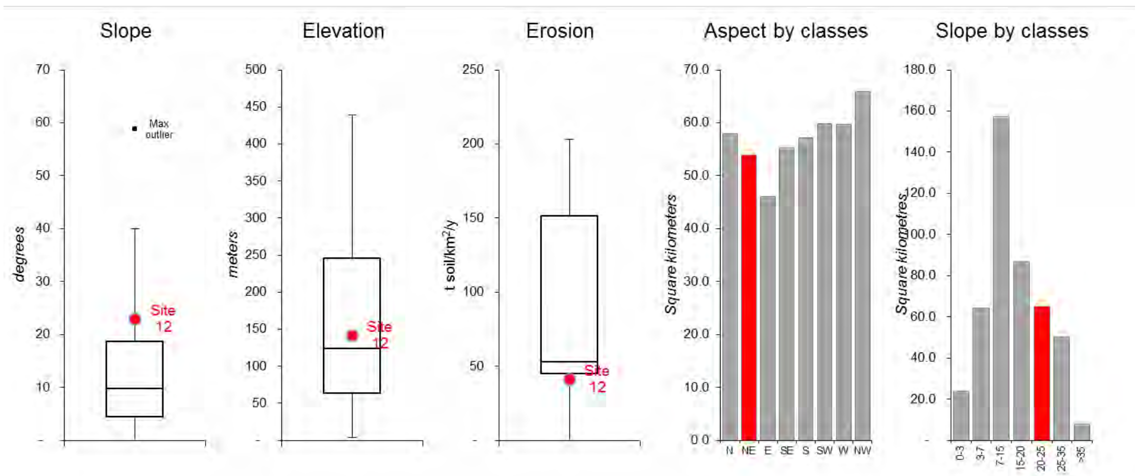


Figure A4 - 64: Representativeness of site 12 within the extent of the same soil type.

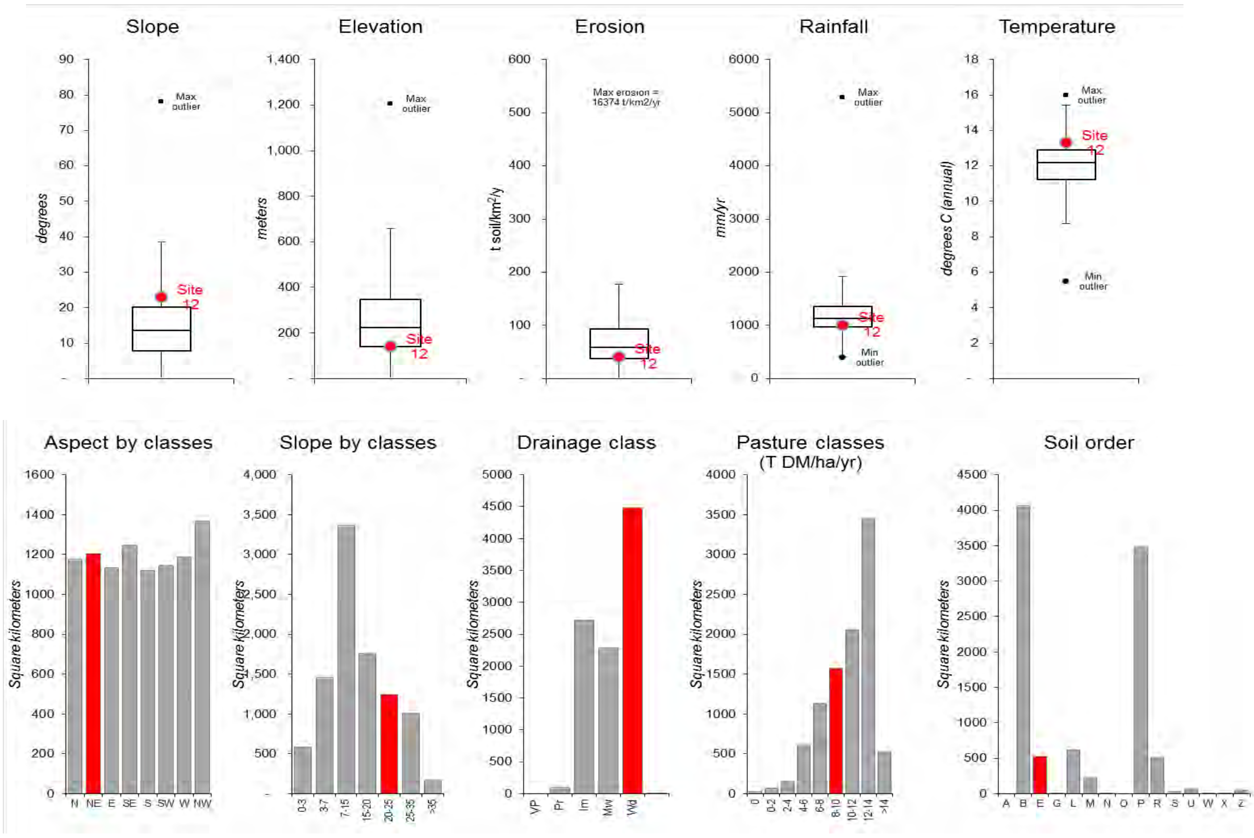


Figure A4 - 65: Representativeness of site 12 within Soft rock hill country (including soft Limestone).

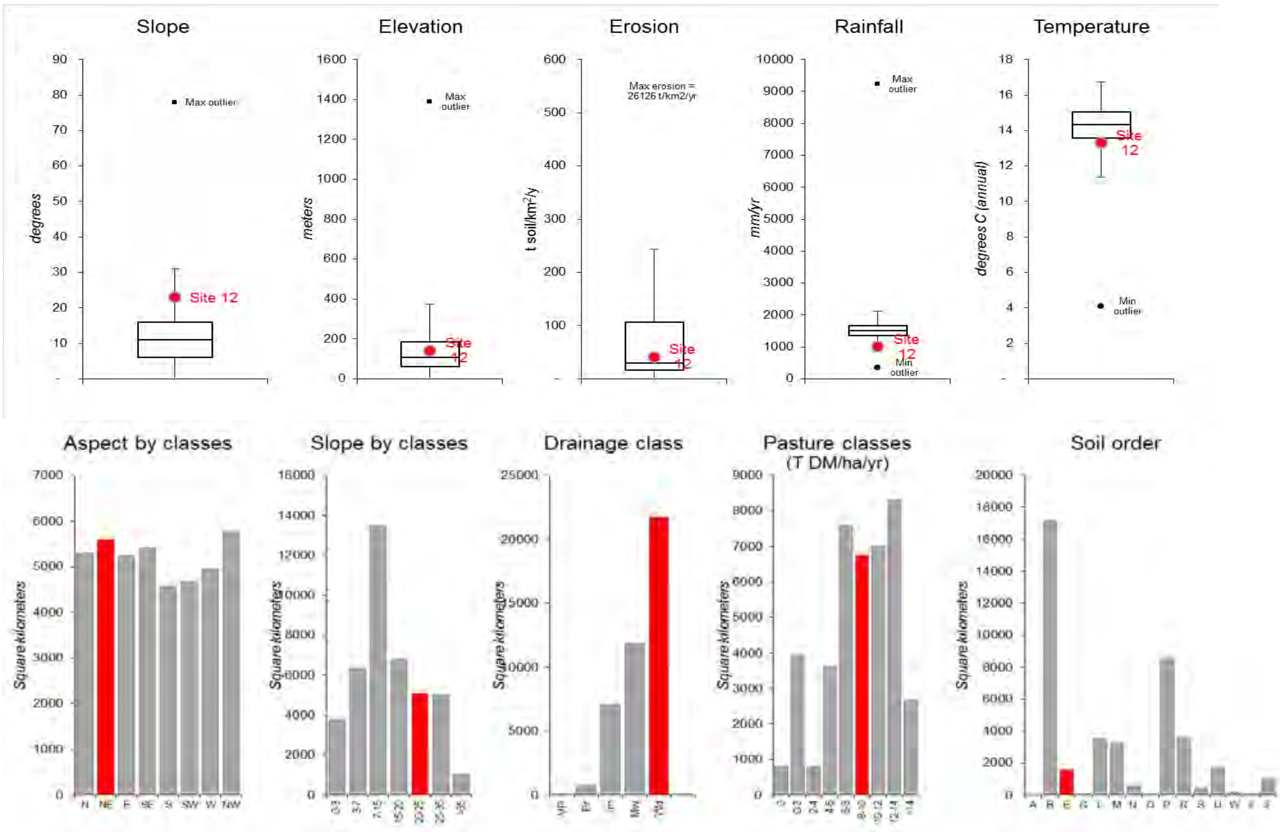


Figure A4 - 66: Representativeness of site 12 within all NZ hill country.

Table A4 - 12: Distance from the median and percent area of Site 12 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Upper slope within 2km²	Hill country within 2km²	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	-	*0.04 ha*	*0.6 ha*	*31 ha*	*332 ha*	456 ha	*9583 km²*	*4.1 M ha*
Elevation (m)	*107*	**142**	**43**	**16**	x	**5**	**24**	**13**
Slope (degrees)	***23***	22.4	**24**	**25**	x	**34**	**34**	**41**
Aspect (degrees)	***45***	34	x	x	x	x	x	x
Erosion (t soil/km²/y)	*41.2*	x	x	x	x	**28**	**22**	**6**
Precipitation (mm)	762-889	**1008**	x	x	x	x	**20**	**13**
Temperature (°C)	-	**13.3**	x	x	x	x	**33**	**34**
Upper slopes	-	x	x	x	**7%**	x	x	x
Hill country type	*7*	x	x	x	x	x	x	**23%**
Soil type	*WeH*	x	x	x	x	x	**0.3%**	**0.1%**
Soil subgroup	*EMT*	x	x	x	x	x	x	x
Soil order	*E*	x	x	x	x	x	**5%**	**4%**
Slope group	-	20-25°	**33%**	**23%**	x	**14%**	**13%**	**12%**
Aspect group	*NE*	NE	**91%**	**9%**	x	**12%**	**13%**	**13%**
Pasture (kg DM/ha/y)	*9430*	x	x	x	x	x	**16%**	**16%**
Drainage	*Wd*	x	x	x	x	x	**47%**	**52%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

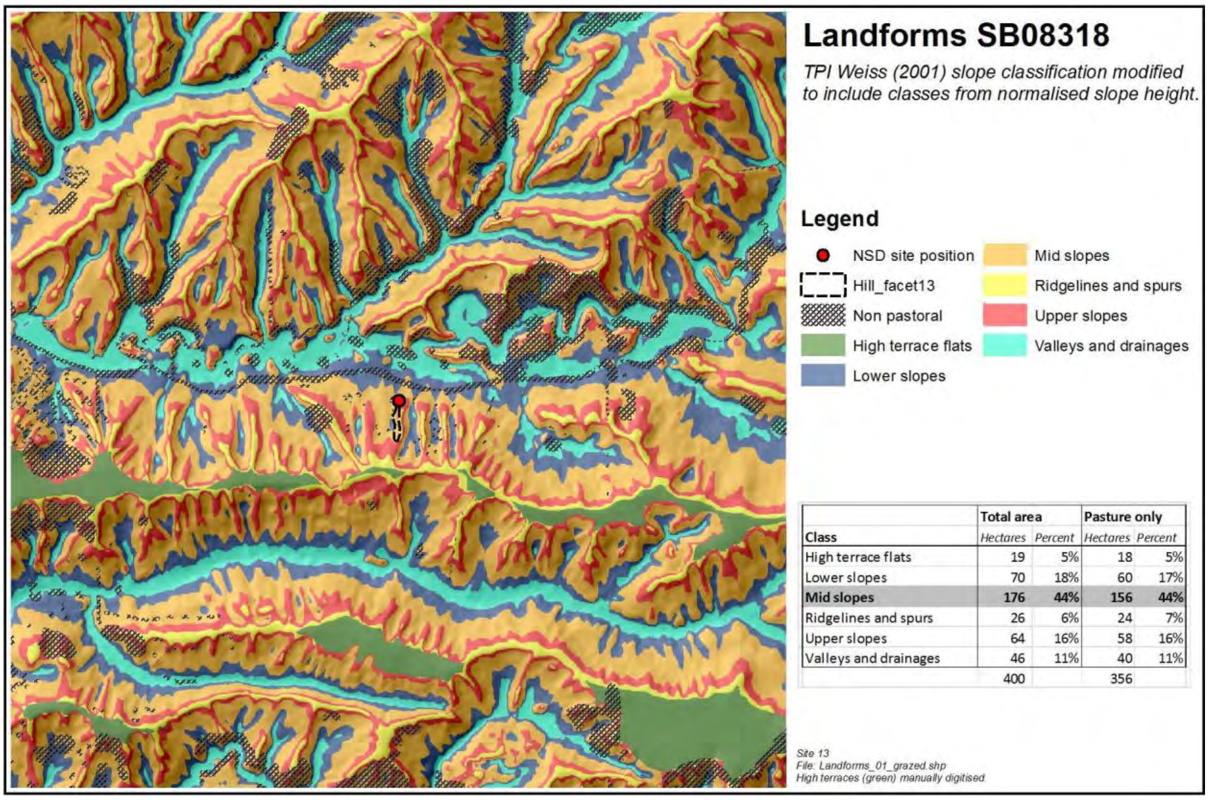
Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 13 (SB08318)

Site 13 is located in Wanganui steep hill country (Kaukatea Valley, Okoia) near the edge of a spur in a midslope postion (Figure 67). Aspect appears to be incorrectly recorded in the NSD (W) – there are no west facing slopes in the immediate area, although strong NW slopes feature within the same hill facet. Soil type – Okoia steepland soil is classified as EPJ in the NSD, but as PJM in the FSL database. There are no EPJ classifications in the hill country component of the FSL database.



Class	Total area		Pasture only	
	Hectares	Percent	Hectares	Percent
High terrace flats	19	5%	18	5%
Lower slopes	70	18%	60	17%
Mid slopes	**176**	**44%**	**156**	**44%**
Ridgelines and spurs	26	6%	24	7%
Upper slopes	64	16%	58	16%
Valleys and drainages	46	11%	40	11%
	400		356	

Figure A4 - 67: Classification of land forms for site 13 within a 2km² grid.

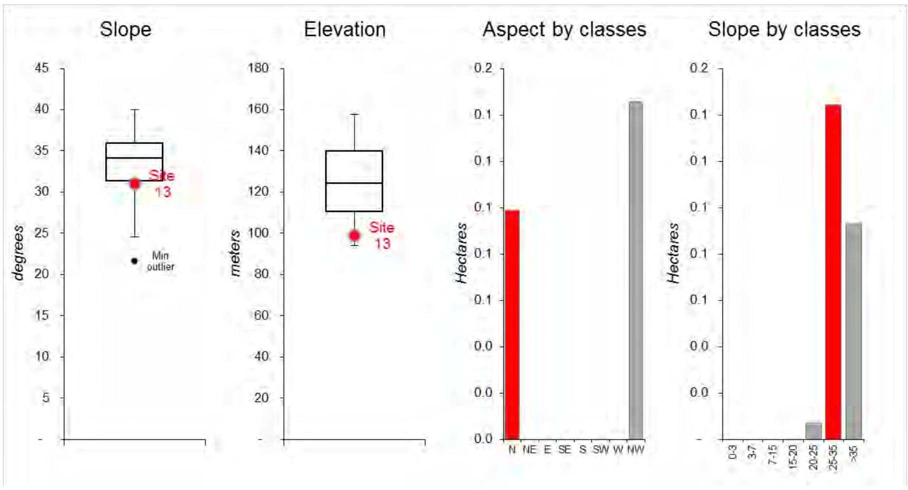


Figure A4 - 68: Representativeness of site 13 within the immediate hill facet.

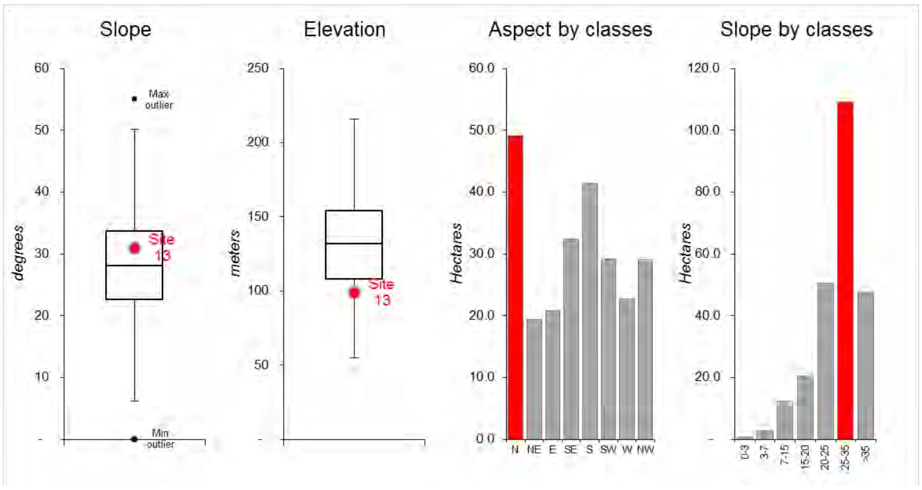


Figure A4 - 69: Representativeness of site 13 within midslopes located within a 2km² grid.

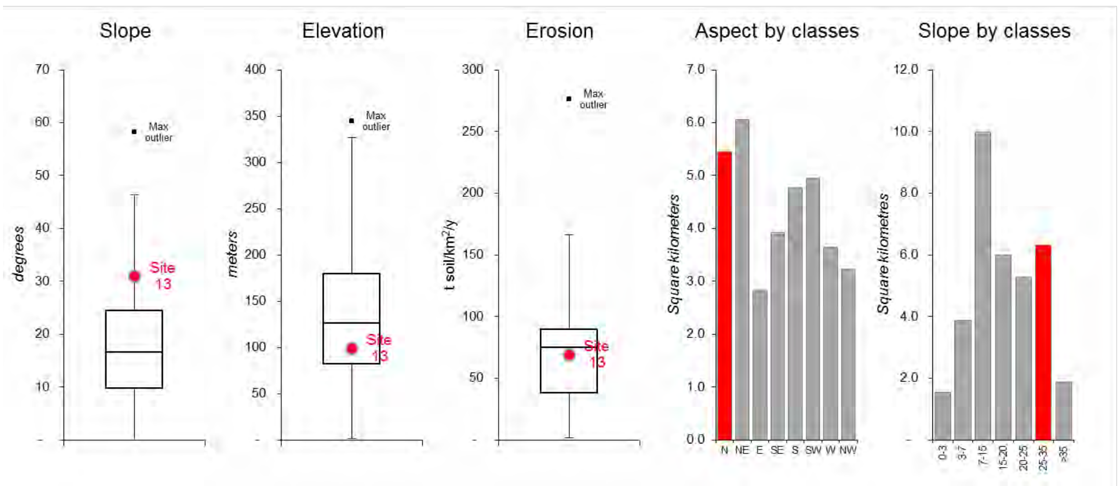


Figure A4 - 70: Representativeness of site 13 within the extent of the same soil type.

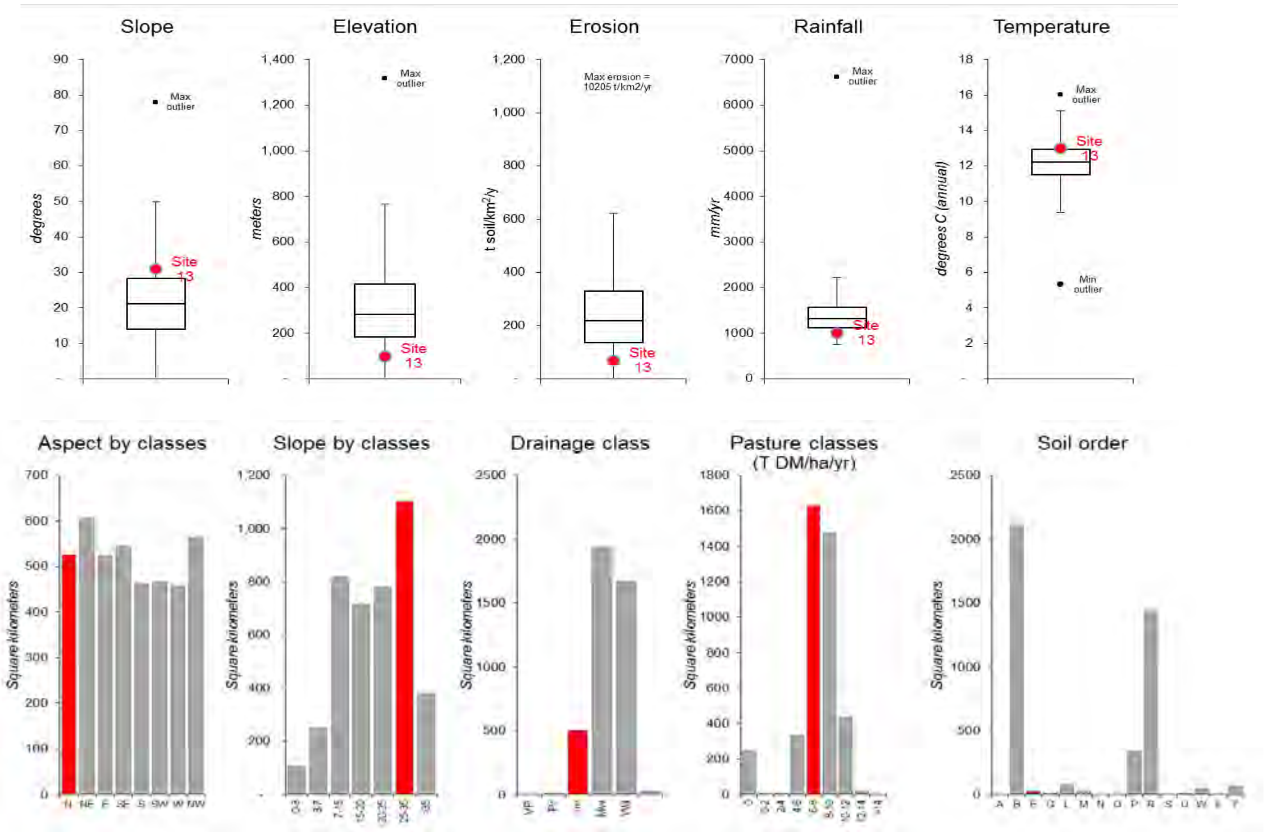


Figure A4 - 71: Representativeness of site 13 within Steep soft rock hill country (12).

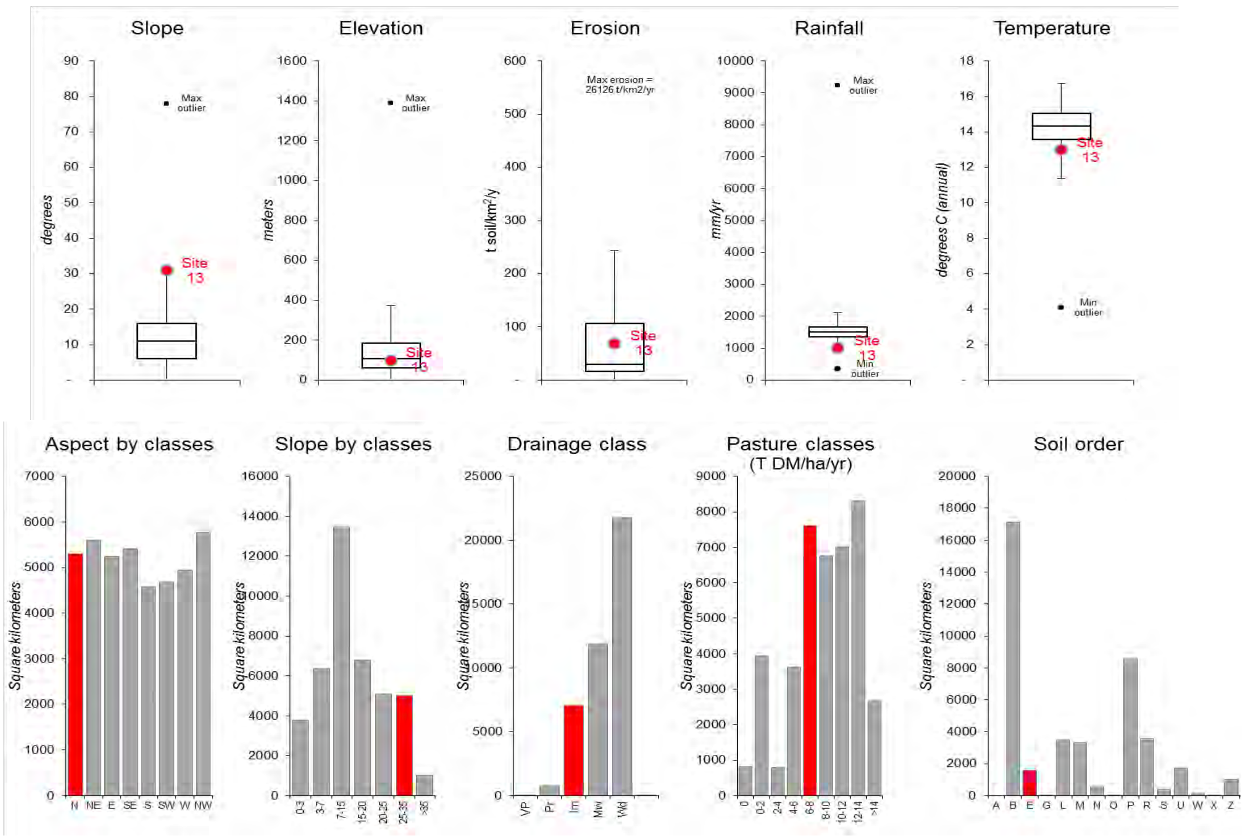


Figure A4 - 72: Representativeness of site 13 within all NZ hill country.

Table A4 - 13: Distance from the median and percent area of Site 13 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Midslopes within 2km²	Hill country within 2km²	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	-	*0.004 ha*	*0.2 ha*	*244 ha*	*356 ha*	35 ha	*4153 km²*	*4.1 M ha*
Elevation (m)	*91*	**99**	**45**	**33**	x	**16**	**42**	**5**
Slope (degrees)	***31***	31	**25**	**15**	x	**39**	**33**	**48**
Aspect (degrees)	*270*	**6**	x	x	x	x	x	x
Erosion (t soil/km²/y)	*69.3*	x	x	x	x	**8**	**47**	**17**
Precipitation (mm)	*965*	**1006**	x	x	x	x	**44**	**49**
Temperature (°C)	-	**13**	x	x	x	x	**25**	**39**
Midslopes	-	x	x	x	**44%**	x	x	x
Hill country type	*12*	x	x	x	x	x	x	**10%**
Soil type	*OkS*	x	x	x	x	x	**0.5%**	**0.1%**
Soil subgroup	*EPJ*	x	x	x	x	x	x	x
Soil order	*E*	x	x	x	x	x	**1%**	**4%**
Slope group	-	25-35°	**59%**	**45%**	x	**18%**	**27%**	**12%**
Aspect group	***W***	**N**	**40%**	**20%**	x	**16%**	**13%**	**13%**
Pasture (kg DM/ha/y)	***6860***	x	x	x	x	x	**39%**	**18%**
Drainage	***Im***	x	x	x	x	x	**12%**	**17%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

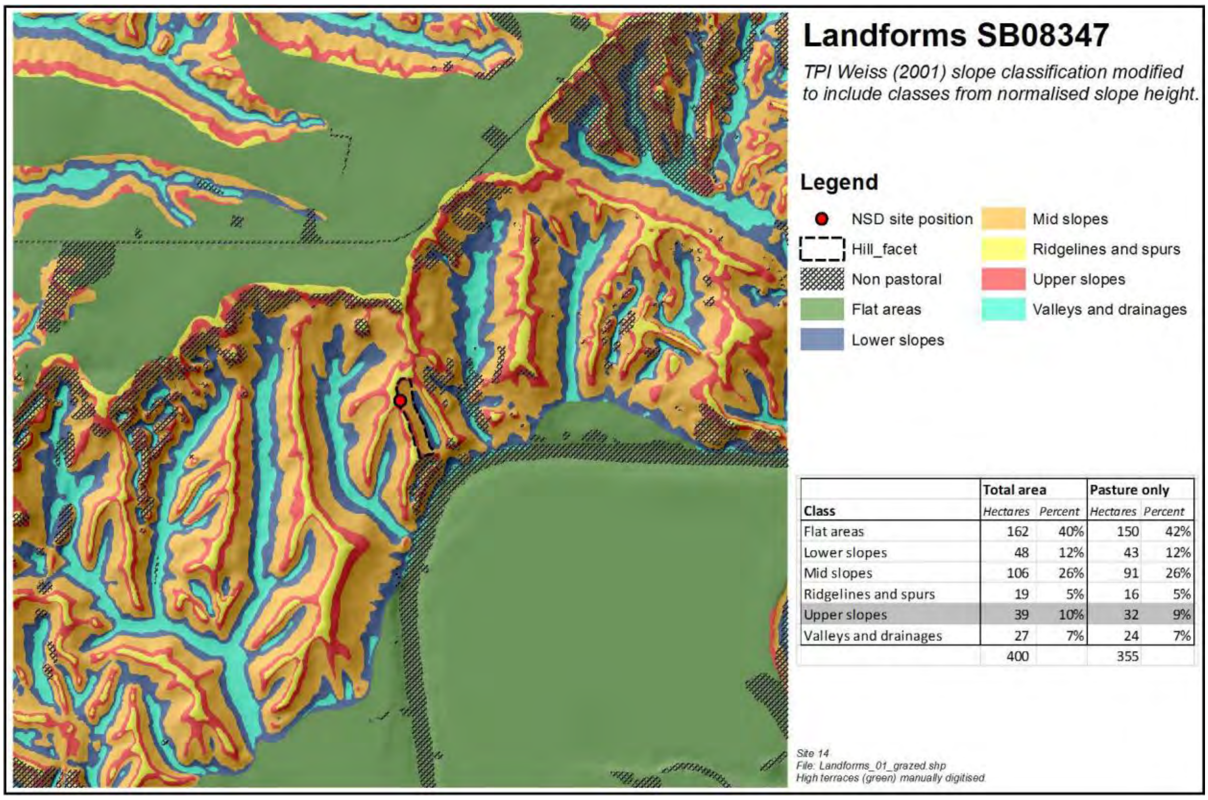
Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 14 (SB08347)

Site 14 is located within a steep scarp slope of a terrace overlooking a river (Figure 73) near Fordell in Wanganui terrace land. The site has an upper slope position just off a spur. The RLA captures the appropriate slope around the site (35°) but there are no nearby slopes with the aspect recorded in the NSD (SE). Soil type is Whangaehu steepland soil (normal steep variant) and hill country type is *Soft rock hill country (including soft Limestone)*.



	Total area		Pasture only	
Class	*Hectares*	*Percent*	*Hectares*	*Percent*
Flat areas	162	40%	150	42%
Lower slopes	48	12%	43	12%
Mid slopes	106	26%	91	26%
Ridgelines and spurs	19	5%	16	5%
Upper slopes	39	10%	32	9%
Valleys and drainages	27	7%	24	7%
	400		355	

Figure A4 - 73: Classification of land forms for site 14 within a 2km^2 grid.

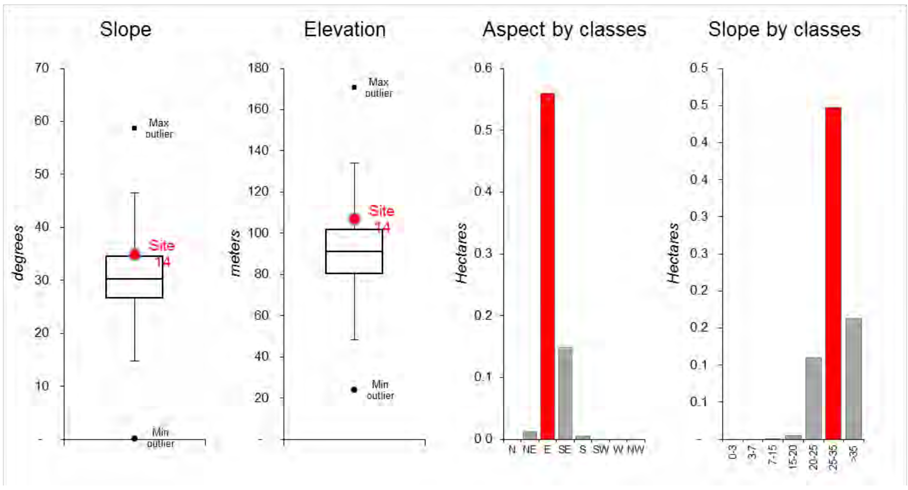


Figure A4 - 74: Representativeness of site 14 within the immediate hill facet.

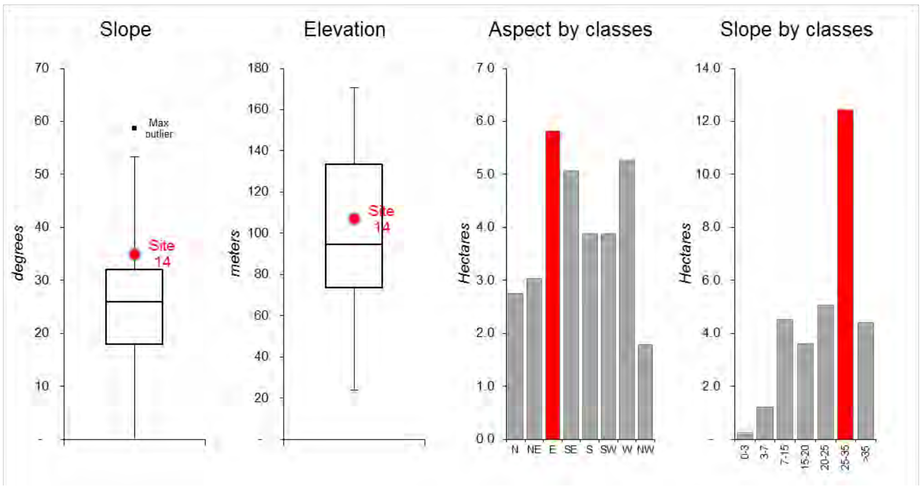


Figure A4 - 75: Representativeness of site 14 within upper slopes located within a 2km² grid.

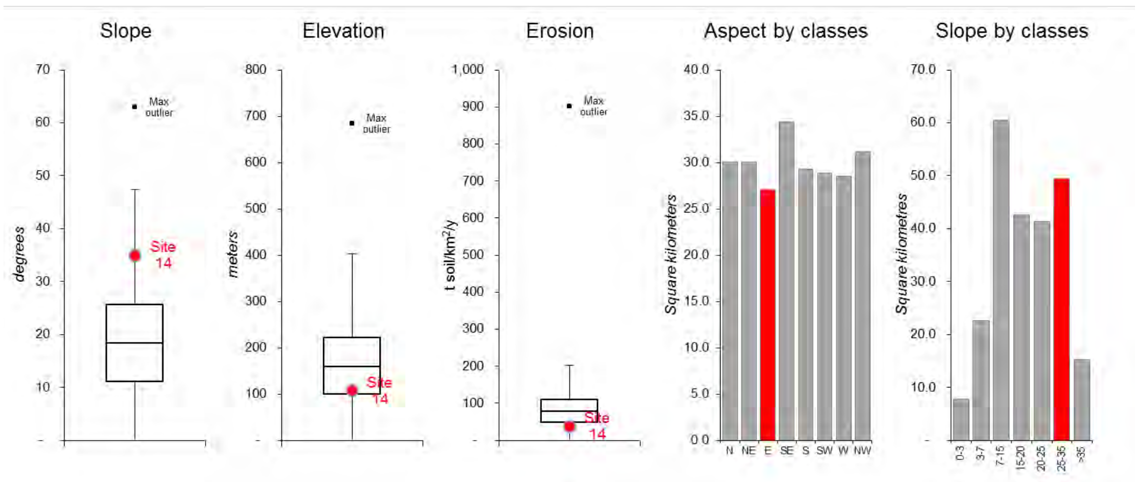


Figure A4 - 76: Representativeness of site 14 within the extent of the same soil type.

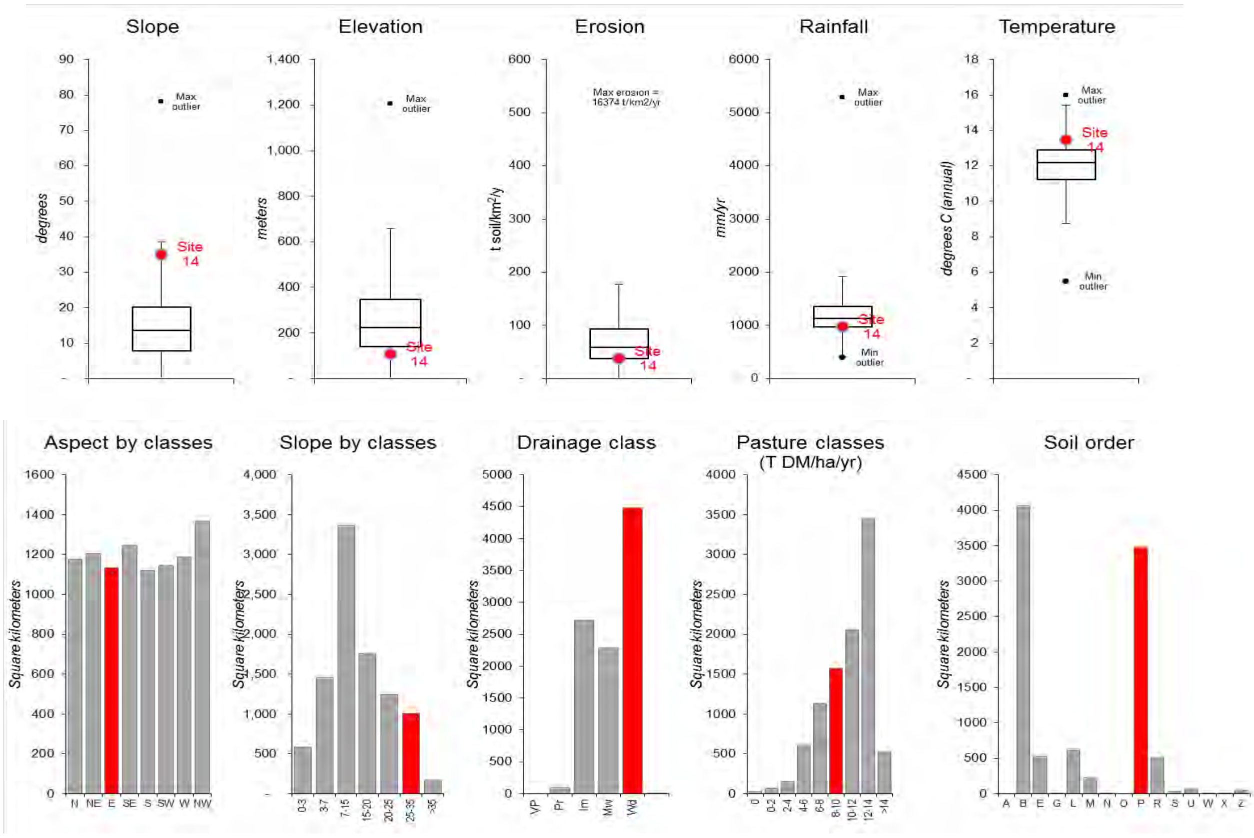


Figure A4 - 77: Representativeness of site 14 within Soft rock hill country (including soft Limestone).

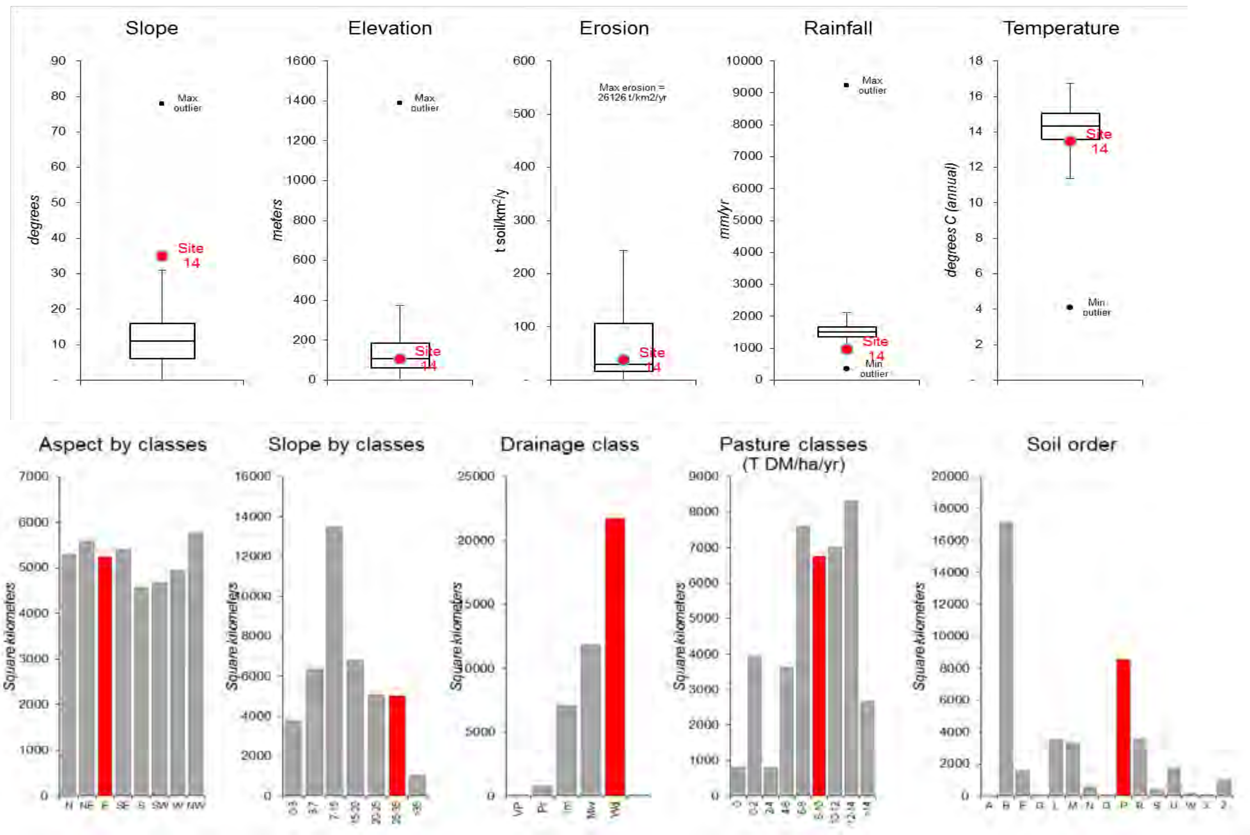


Figure A4 - 78: Representativeness of site 14 within all NZ hill country.

Table A4 - 14: Distance from the median and percent area of Site 14 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Upper slopes within 2km²	Hill country within 2km²	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	-	*0.02 ha*	*0.7 ha*	*32 ha*	*355 ha*	239 km²	*9583 km²*	*4.1 M ha*
Elevation (m)	*73*	**107**	**34**	**8**	x	**23**	**33**	**1**
Slope (degrees)	***35***	35	**26**	**35**	x	**44**	**48**	**50**
Aspect (degrees)	*135*	**105**	x	x	x	x	x	x
Erosion (t soil/km²/y)	*38.2*	x	x	x	x	**44**	**24**	**29**
Precipitation (mm)	914	**976**	x	x	x	x	**25**	**49**
Temperature (°C)	-	**13.5**	x	x	x	x	**36**	**28**
Upper slopes	-	x	x	x	**9%**	x	x	x
Hill country type	*7*	x	x	x	x	x	x	x
Soil type	*WhS*	x	x	x	x	x	**1.2%**	**0.6%**
Soil subgroup	*PIM*	x	x	x	x	x	**9.9%**	**2.9%**
Soil order	*P*	x	x	x	x	x	**36%**	**21%**
Slope group	-	25-35°	**62%**	**39%**	x	**21%**	**10%**	**12%**
Aspect group	*SE*	**E**	**77%**	**18%**	x	**11%**	**12%**	**13%**
Pasture (kg DM/ha/y)	*9430*	x	x	x	x	x	**16%**	**16%**
Drainage	*Wd*	x	x	x	x	x	**47%**	**52%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

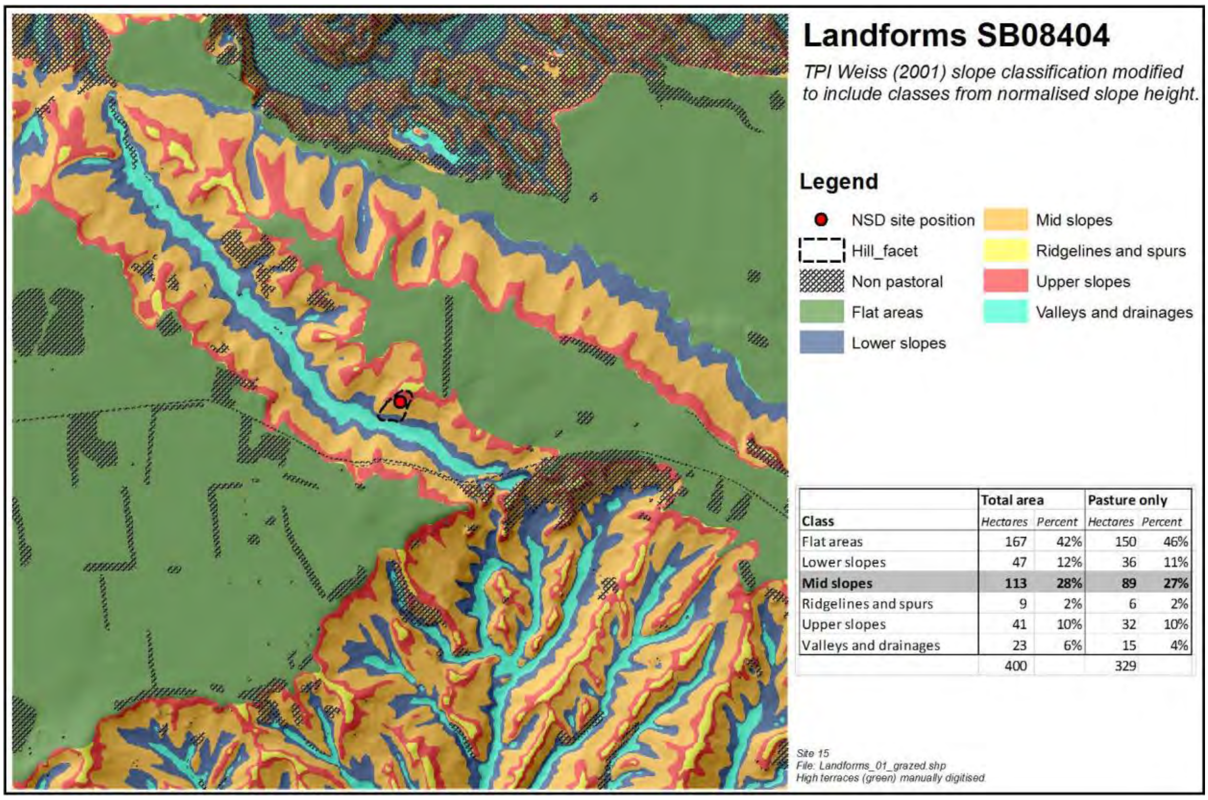
Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 15 (SB08404)

Site 15 is located on a gully slope (Figure 79) in Manawatu terrace land (Table Flat near Apiti). Soil type is Umutoi hill soil (UH), LOT, 640m asl, 1500mm rain, 28 degree slope, 180 (S) aspect, well drained. Soft rock hill country (including soft Limestone) (7).



	Total area		Pasture only	
Class	*Hectares*	*Percent*	*Hectares*	*Percent*
Flat areas	167	42%	150	46%
Lower slopes	47	12%	36	11%
Mid slopes	**113**	**28%**	**89**	**27%**
Ridgelines and spurs	9	2%	6	2%
Upper slopes	41	10%	32	10%
Valleys and drainages	23	6%	15	4%
	400		329	

Figure A4 - 79: Classification of land forms for site 15 within a 2km² grid.

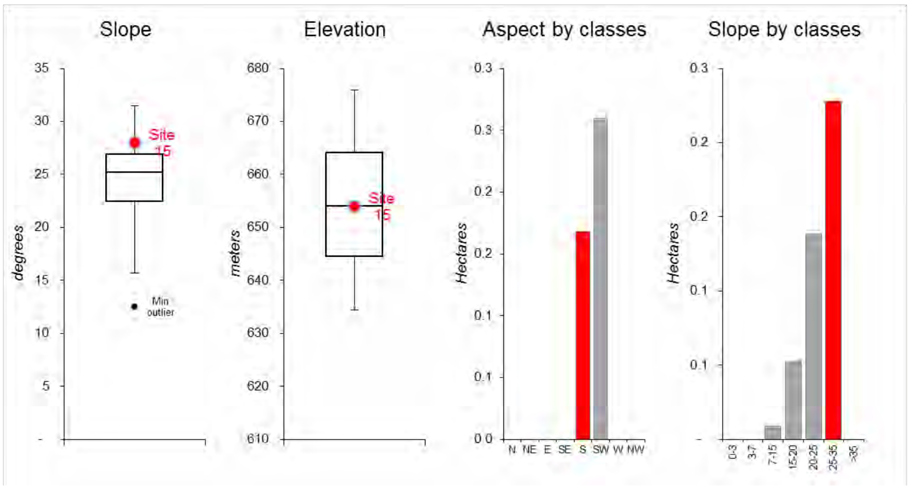


Figure A4 - 80: Representativeness of site 15 within the immediate hill facet.

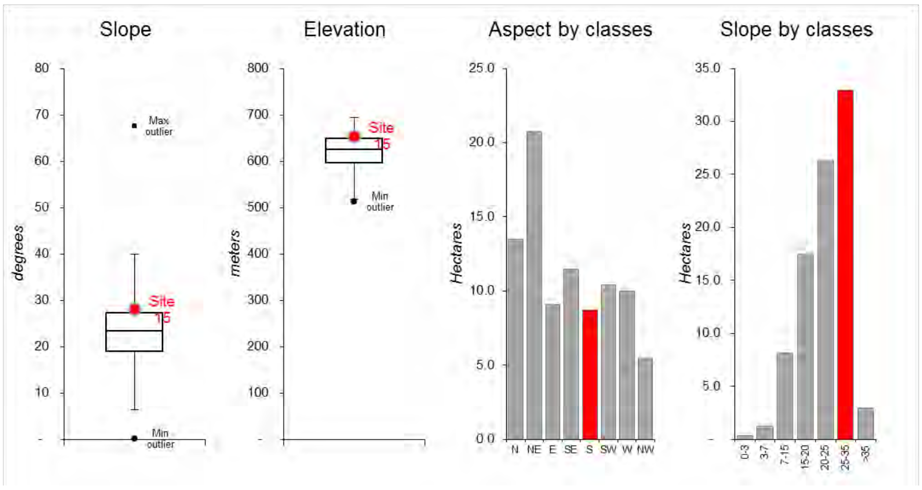


Figure A4 - 81: Representativeness of site 15 within midslopes located within a 2km² grid.

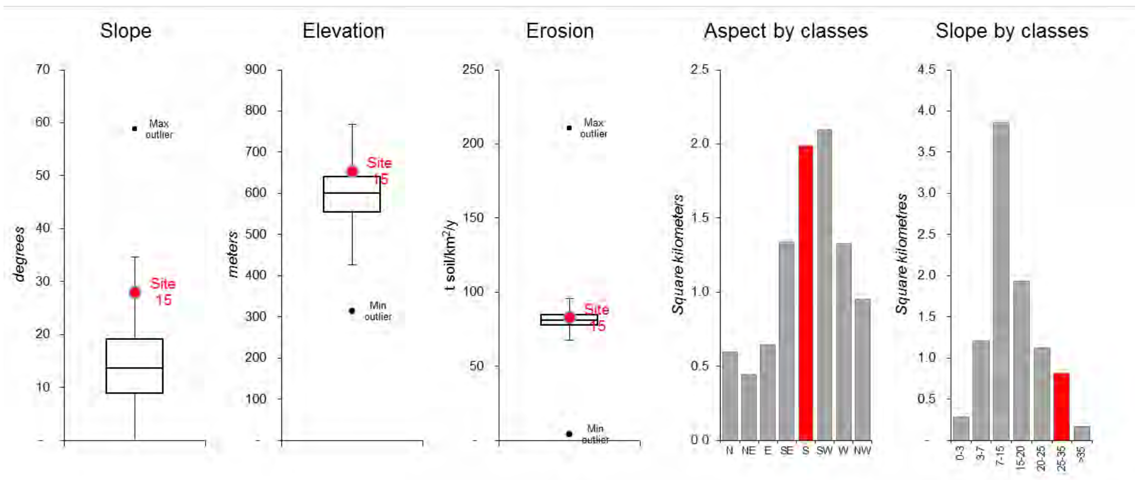


Figure A4 - 82: Representativeness of site 15 within the extent of the same soil type.

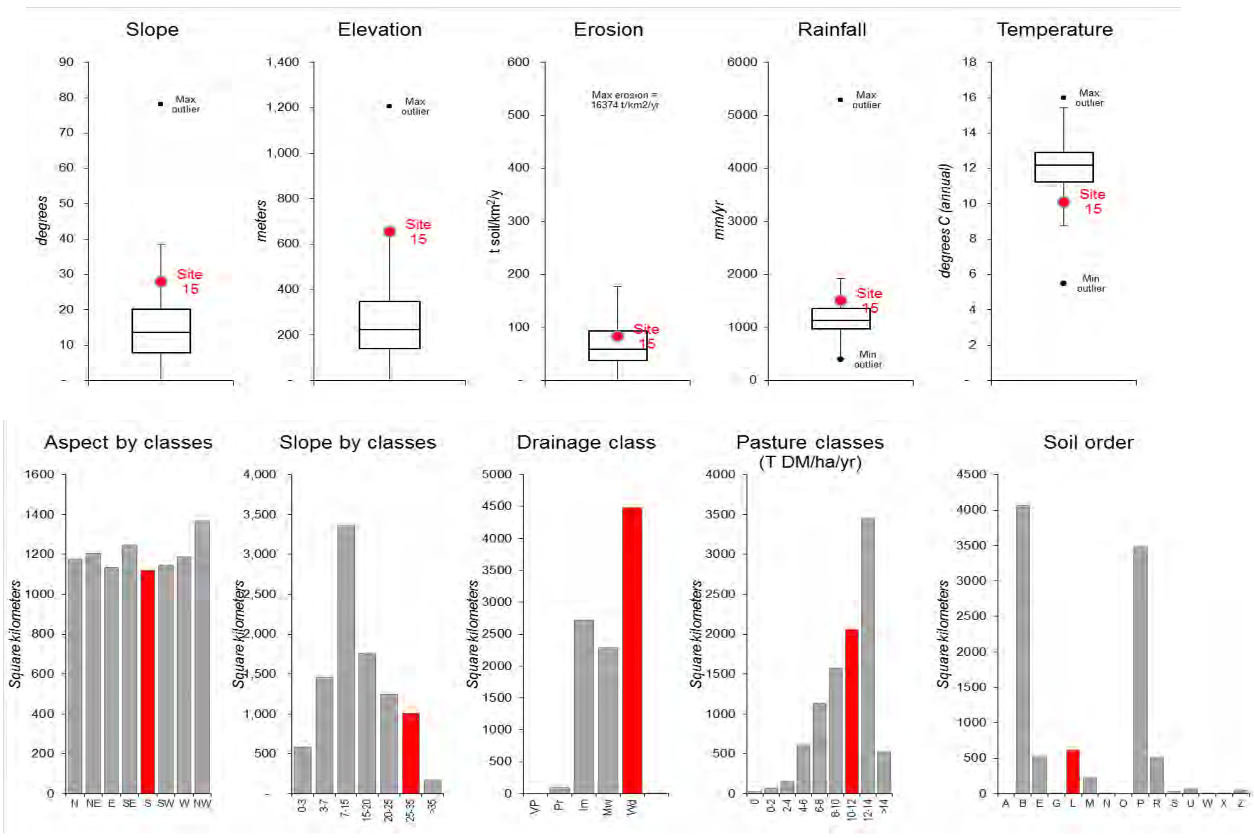


Figure A4 - 83: Representativeness of site 15 within Soft rock hill country (including soft Limestone) (7).

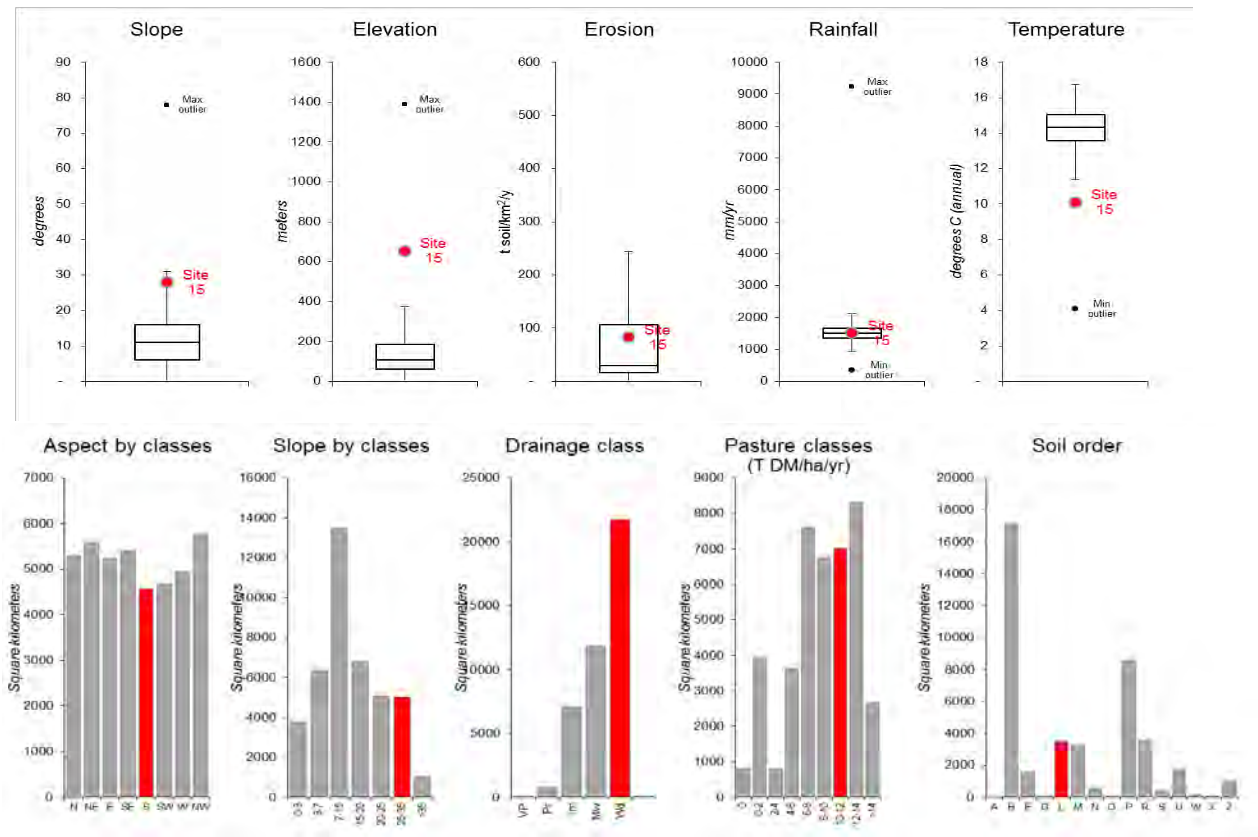


Figure A4 - 84: Representativeness of site 15 within all NZ hill country.

Table A4 - 15: Distance from the median and percent area of Site 15 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Midslopes within 2km²	Hill country within 2km²	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	-	*0.004 ha*	*0.4 ha*	*89 ha*	*329 ha*	939 ha	*9583 km²*	*4.1 M ha*
Elevation (m)	*640*	**654**	**0**	**31**	x	**34**	**49**	**50**
Slope (degrees)	***28***	27.7	**37**	**29**	x	**43**	**42**	**47**
Aspect (degrees)	*180*	**199**	x	x	x	x	x	x
Erosion (t soil/km²/y)	*83*	x	x	x	x	**13**	**21**	**22**
Precipitation (mm)	1500	**1510**	x	x	x	x	**36**	**1**
Temperature (°C)	-	**10.1**	x	x	x	x	**42**	**50**
Midslopes	-	x	x	x	**29%**	x	x	x
Hill country type	*7*	x	x	x	x	x	x	**23%**
Soil type	*UH*	x	x	x	x	x	**0.09%**	**0.02%**
Soil subgroup	*LOT*	x	x	x	x	x	**6.2%**	**7.8%**
Soil order	*L*	x	x	x	x	x	**6%**	**8%**
Slope group	-	25-35°	**53%**	**37%**	x	**9%**	**10%**	**12%**
Aspect group	*S*	S	**39%**	**10%**	x	**21%**	**12%**	**11%**
Pasture (kg DM/ha/y)	*10300*	x	x	x	x	x	**21%**	**17%**
Drainage	*Wd*	x	x	x	x	x	**47%**	**52%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

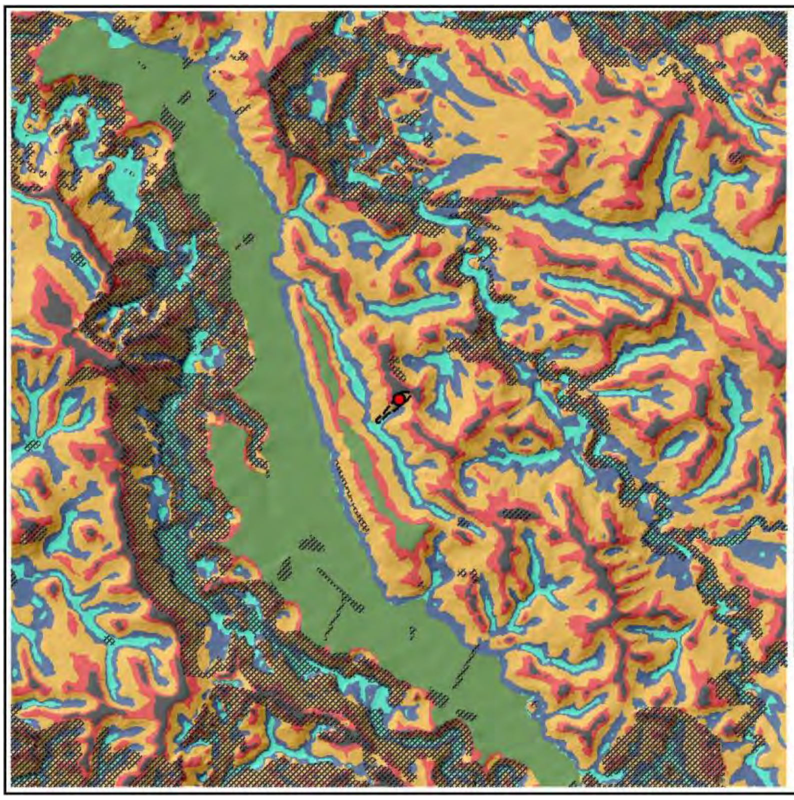
Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 16 (SB08317)

Site 16 is a mid-slope position located within easy Manawatu hill country near Raumai in the Pohangina Valley (Figure 85). Soil type is Makotuku hill soil. NSD NZSC is PIM reclassed to PIT by Schipper et al. (2010). PIT is used in the analysis on the assumption that Schipper et al. have reclassed the soil according to the most up to date NZSC criteria The RLA was difficult to construct because site elevation (229m) would place the location ~200m away on a valley floor, and site slope (22°) would place the location on a crest or drainage. Consequently, RLA values for slope and elevation differ markedly from site values. Likewise, RLA aspect (156°) only just falls within the SE category (hill facet is largely south facing).



	Total area		Pasture only	
Class	*Hectares*	*Percent*	*Hectares*	*Percent*
Flatter areas	46	11%	43	14%
Lower slopes	73	18%	53	18%
Mid slopes	**165**	**41%**	**120**	**40%**
Ridgelines and spurs	23	6%	18	6%
Upper slopes	61	15%	46	15%
Valleys and drainages	33	8%	22	7%
	400		302	

Figure A4 - 85: Classification of land forms for site 16 within a 2km^2 grid.

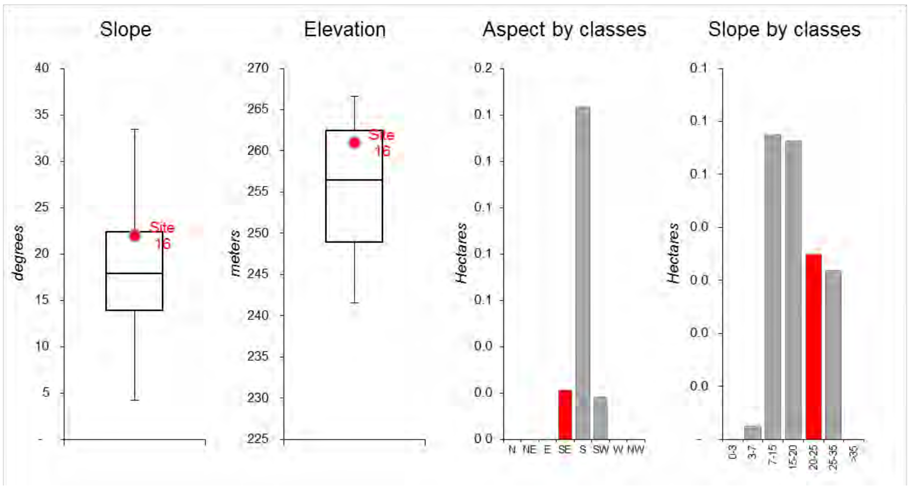


Figure A4 - 86: Representativeness of site 16 within the immediate hill facet.

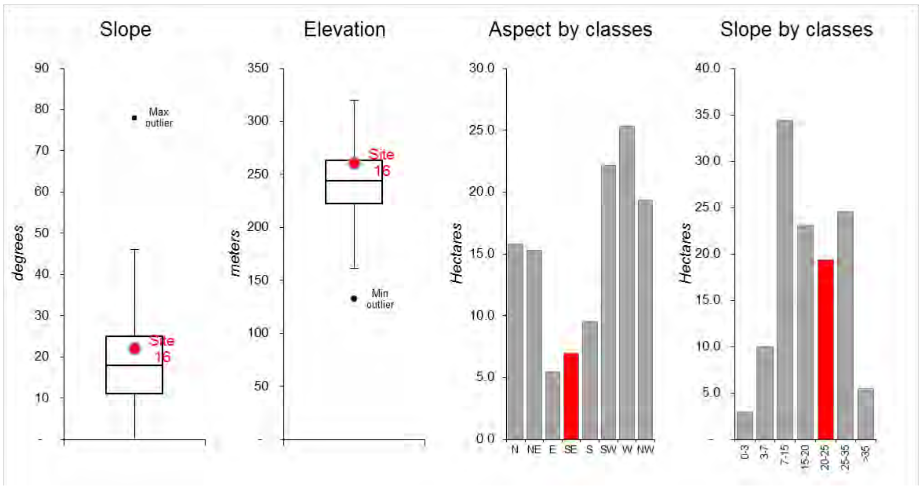


Figure A4 - 87: Representativeness of site 16 within midslopes located within a 2km² grid.

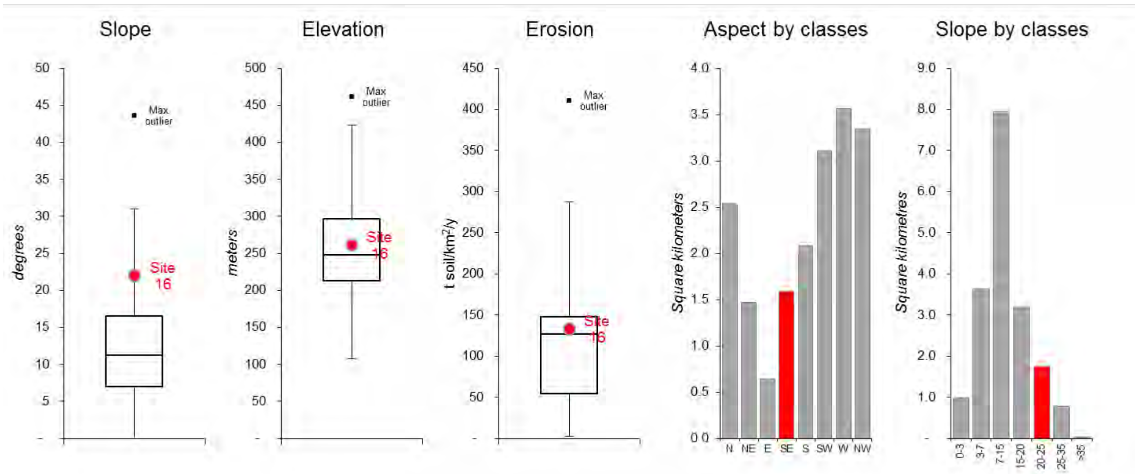


Figure A4 - 88: Representativeness of site 16 within the extent of the same soil type.

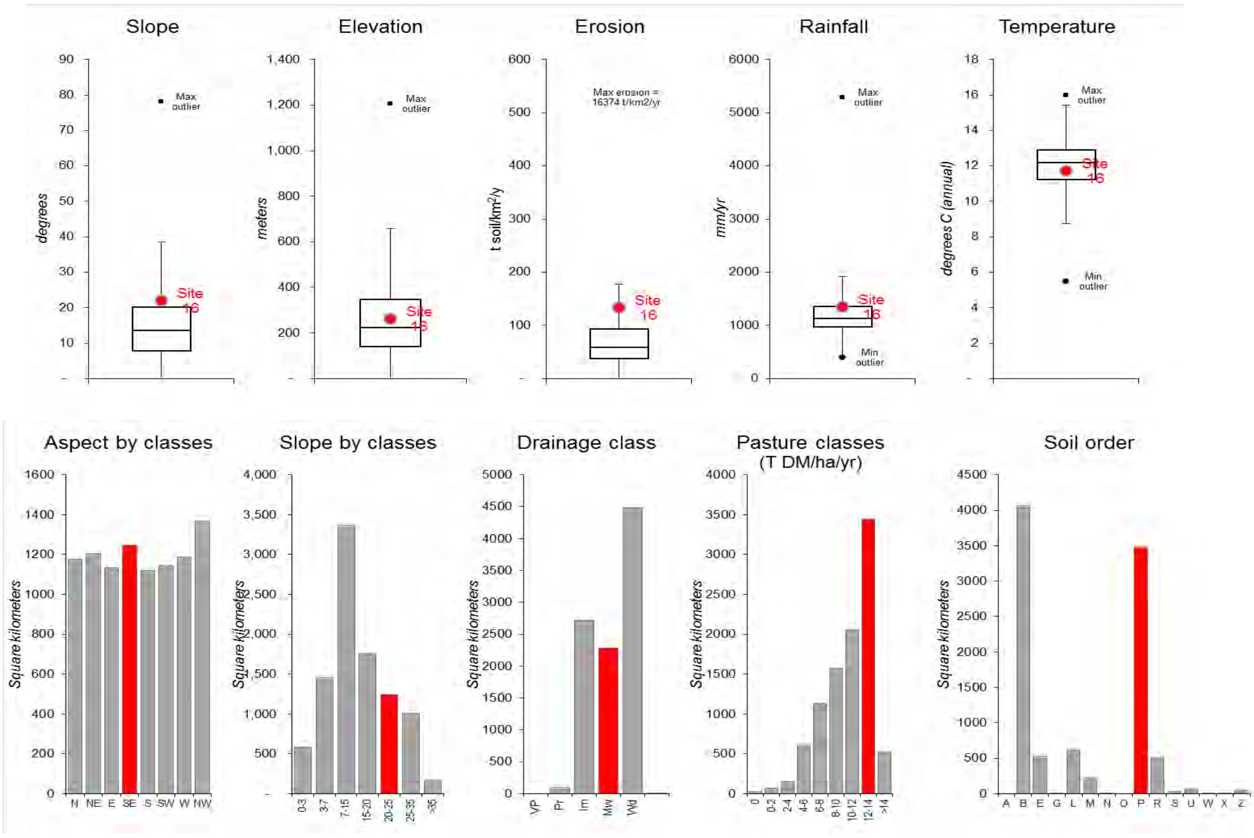


Figure A4 - 89: Representativeness of site 16 within Soft rock hill country (including soft Limestone) (7).

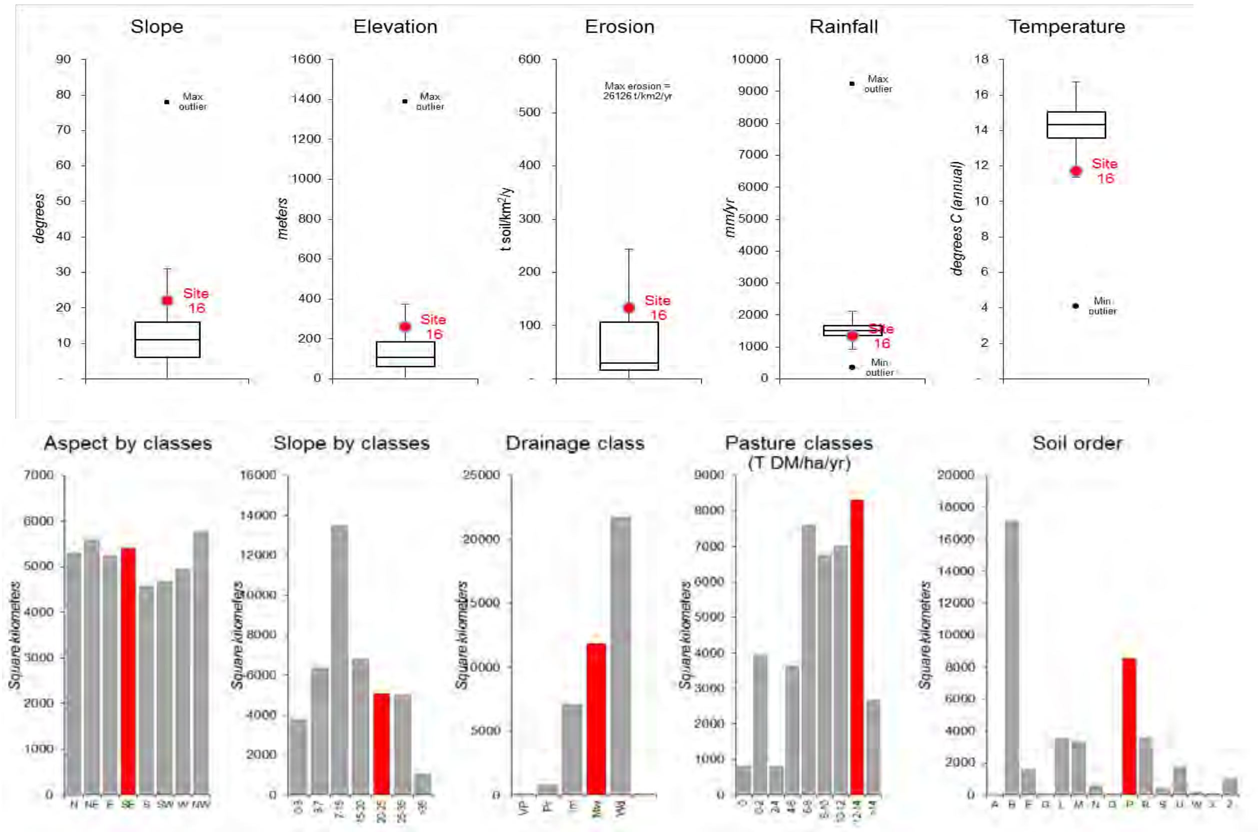


Figure A4 - 90: Representativeness of site 16 within all NZ hill country.

Table A4 - 16: Distance from the median and percent area of Site 16 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Midslopes within 2km²	Hill country within 2km²	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	-	*0.004 ha*	*0.2 ha*	*120 ha*	*302 ha*	18 ha	*9583 km²*	*4.1 M ha*
Elevation (m)	*229*	**261**	**19**	**23**	x	**8**	**9**	**36**
Slope (degrees)	***22***	26.7	**24**	**16**	x	**41**	**31**	**39**
Aspect (degrees)	*135*	**156**	x	x	x	x	x	x
Erosion (t soil/km²/y)	*133*	x	x	x	x	**9**	**38**	**26**
Precipitation (mm)	1143	**1343**	x	x	x	x	**24**	**28**
Temperature (°C)	-	**11.7**	x	x	x	x	**15**	**48**
Midslopes	-	x	x	x	**40%**	x	x	x
Hill country type	*7*	x	x	x	x	x	x	**23%**
Soil type	*MuH*	x	x	x	x	x	**0.2%**	**0.04%**
Soil subgroup	*PIT*	x	x	x	x	x	**5.1%**	**4.5%**
Soil order	*P*	x	x	x	x	x	**36%**	**21%**
Slope group	-	20-25°	**19%**	**16%**	x	**10%**	**13%**	**12%**
Aspect group	*SE*	SE	**12%**	**6%**	x	**9%**	**13%**	**13%**
Pasture (kg DM/ha/y)	*12,000*	x	x	x	x	x	**36%**	**20%**
Drainage	*Mw*	x	x	x	x	x	**24%**	**29%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

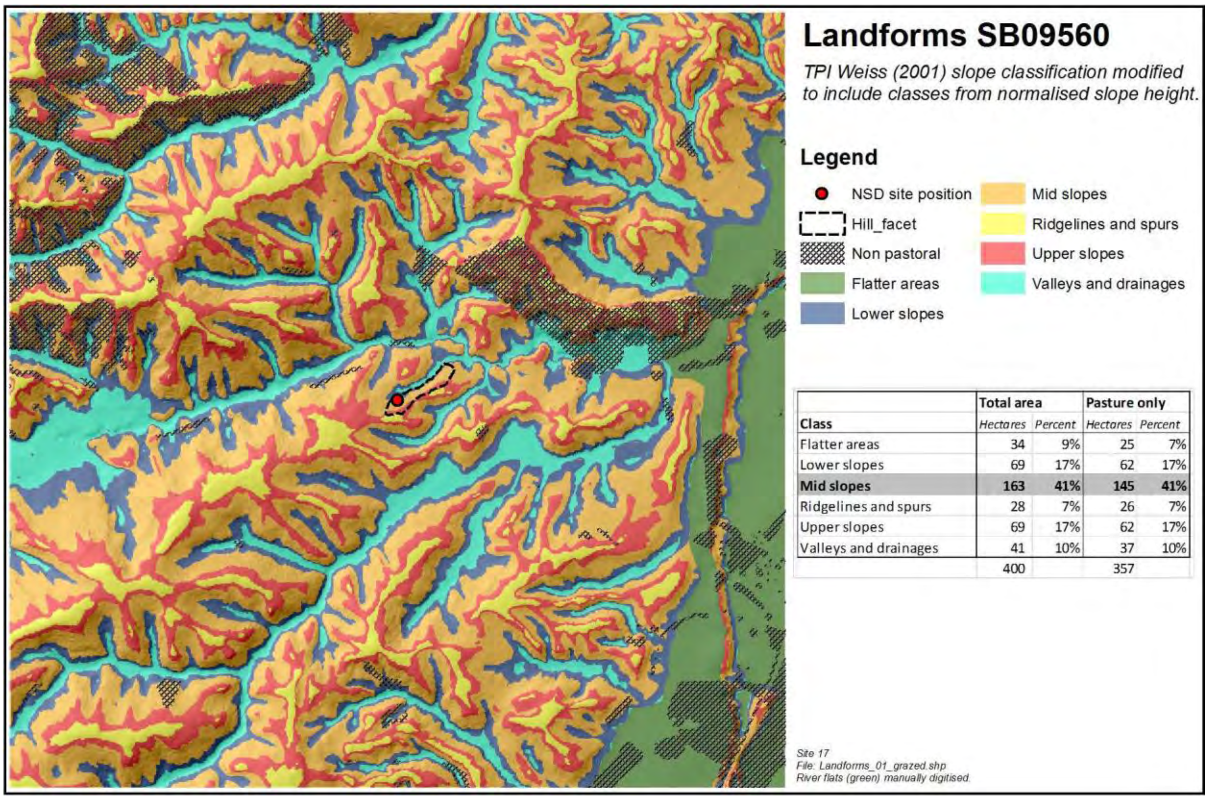
Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 17 (SB09560)

Site 17 is located on the northern face of moderately steep Loess hill country (5) near Mangahao on the eastern side of the Tararua Ranges. Soil type is Matamau hill soil. The NSD soil classification of UYM has been reclassed by Schipper et al. (2010) as PIM. The NSD also describes the site as being located on a midslope. The value for aspect (22°) only just within the North category. Slope (25°) falls on the boundary between categories; 20-25 is used because the majority of surrounding cells are less than 25 degrees (see hill facet). In the FSL Matamau hill soils are classed as BFT which differs from both the NSD and Schipper et al. (2010) reclassification.



	Total area		Pasture only	
Class	*Hectares*	*Percent*	*Hectares*	*Percent*
Flatter areas	34	9%	25	7%
Lower slopes	69	17%	62	17%
Mid slopes	**163**	**41%**	**145**	**41%**
Ridgelines and spurs	28	7%	26	7%
Upper slopes	69	17%	62	17%
Valleys and drainages	41	10%	37	10%
	400		357	

Figure A4 - 91: Classification of land forms for site 17 within a 2km² grid.

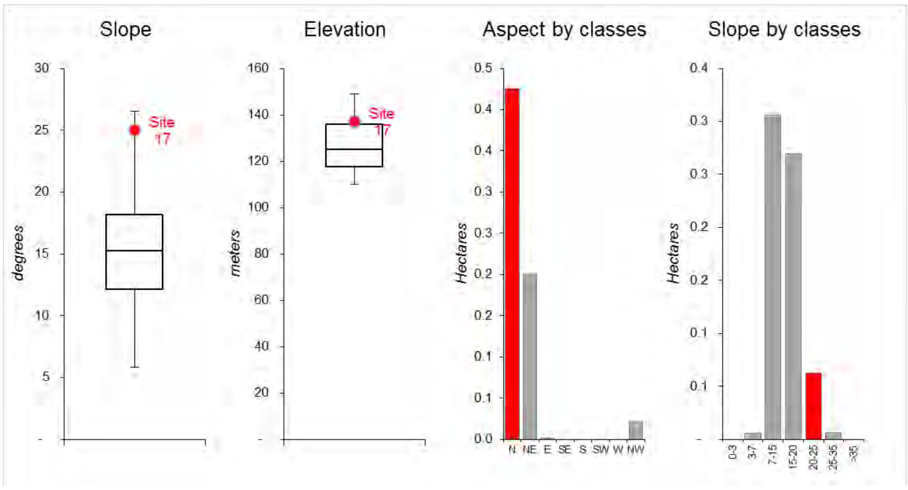


Figure A4 - 92: Representativeness of site 17 within the immediate hill facet.

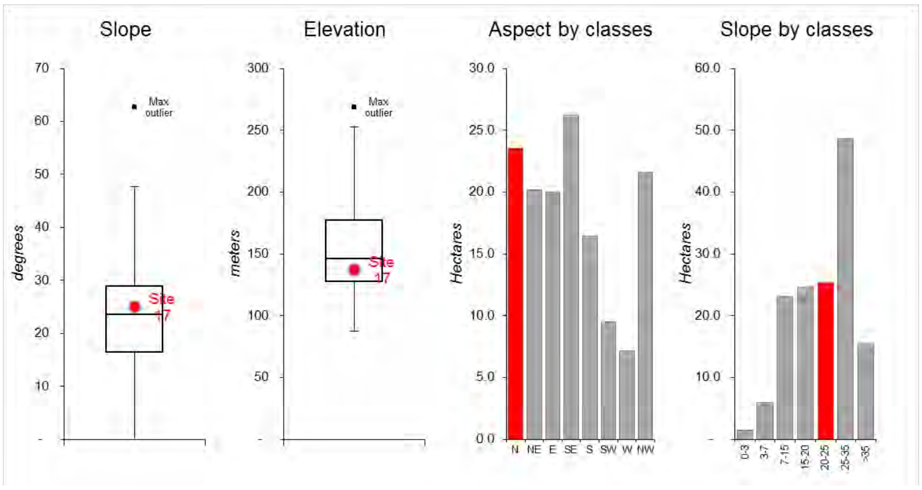


Figure A4 - 93: Representativeness of site 17 within midslopes located within a 2km² grid.

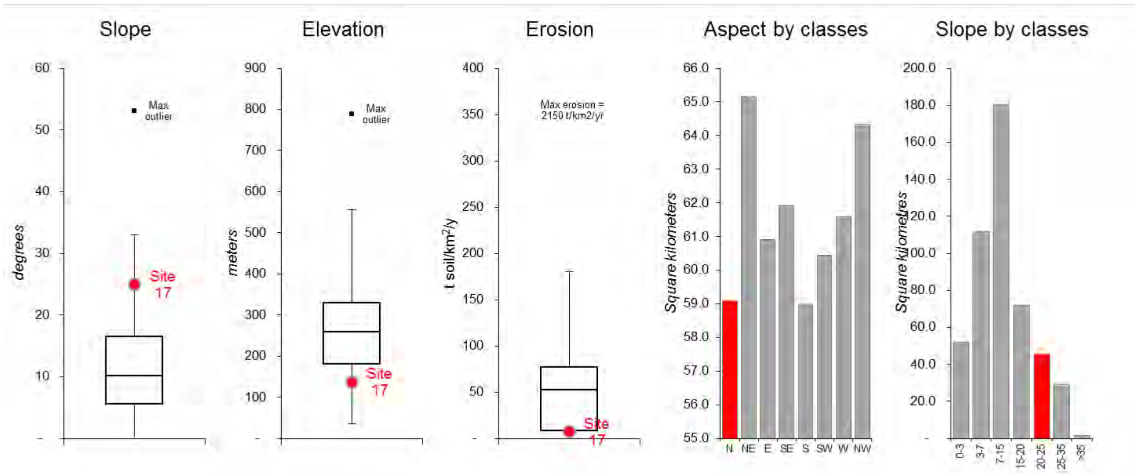


Figure A4 - 94: Representativeness of site 17 within the extent of the same soil type.

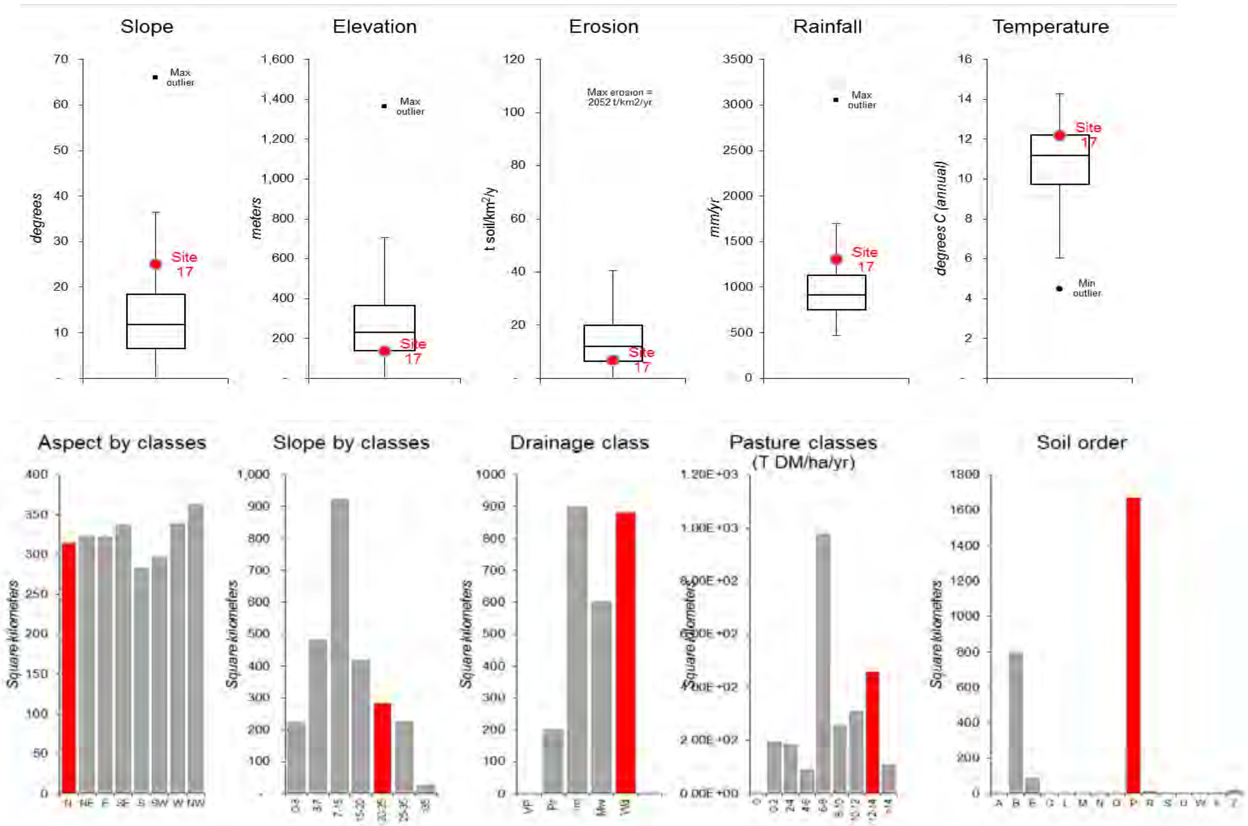


Figure A4 - 95: Representativeness of site 17 within Loess hill country (5).

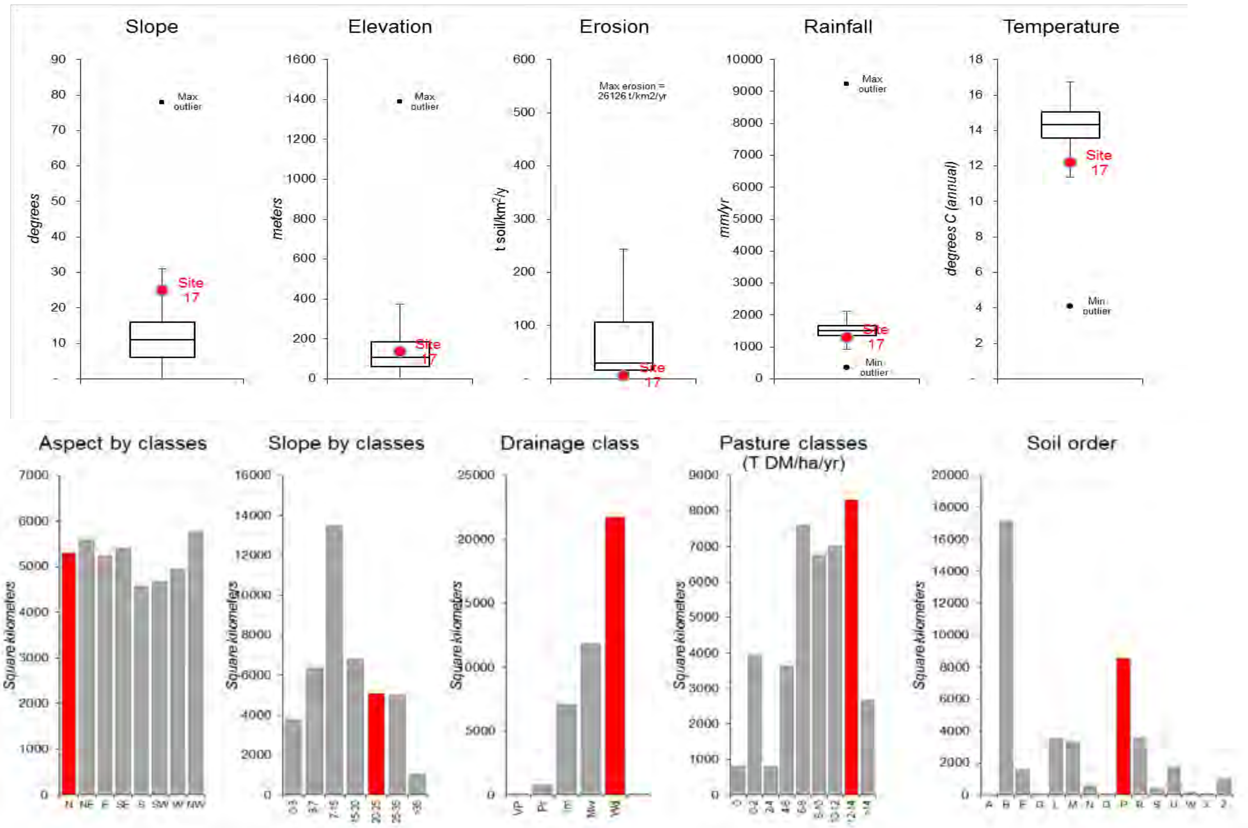


Figure A4 - 96: Representativeness of site 17 within all NZ hill country.

Table A4 - 17: Distance from the median and percent area of Site 17 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Midslopes within 2km²	Hill country within 2km²	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	-	*0.001 ha*	*0.7 ha*	*145 ha*	*357 ha*	492 ha	*2578 km2*	*4.1 M ha*
Elevation (m)	*150*	**137**	**28**	**12**	x	**41**	**26**	**11**
Slope (degrees)	***25***	25	**49**	**6**	x	**44**	**41**	**44**
Aspect (degrees)	*22*	**22**	x	x	x	x	x	x
Erosion (t soil/km²/y)	*6.9*	x	x	x	x	**35**	**23**	**49**
Precipitation (mm)	1400	**1305**	x	x	x	x	**37**	**33**
Temperature (°C)	-	**12.2**	x	x	x	x	**25**	**46**
Midslopes	-	x	x	x	**41%**	x	x	x
Hill country type	*5*	x	x	x	x	x	x	**6%**
Soil type	*77H*	x	x	x	x	x	**2%**	**1.2%**
Soil subgroup	*PIM*	x	x	x	x	x	**0.3%**	**3%**
Soil order	*P*	x	x	x	x	x	**65%**	**21%**
Slope group	-	20-25°	**1%**	**18%**	x	**9%**	**11%**	**12%**
Aspect group	*N*	N	**65%**	**16%**	x	**12%**	**12%**	**13%**
Pasture (kg DM/ha/y)	*12860*	x	x	x	x	x	**18%**	**20%**
Drainage	*Wd*	x	x	x	x	x	**34%**	**52%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 18 (SB09961)

Site 18 is located in Steep soft rock hill country (12) on Te Whanga Station in the Wairarapa. Soil type is Taihape steepland soil (PJM). The site location actually falls within the Loess hill country of Basher et al. (2008), but the surrounding Steep soft rock hill country is used because this is the class that Taihape steepland soils associate with. The NSD describes a midslope position but landform classification places it as an upper slope (Figure 97).

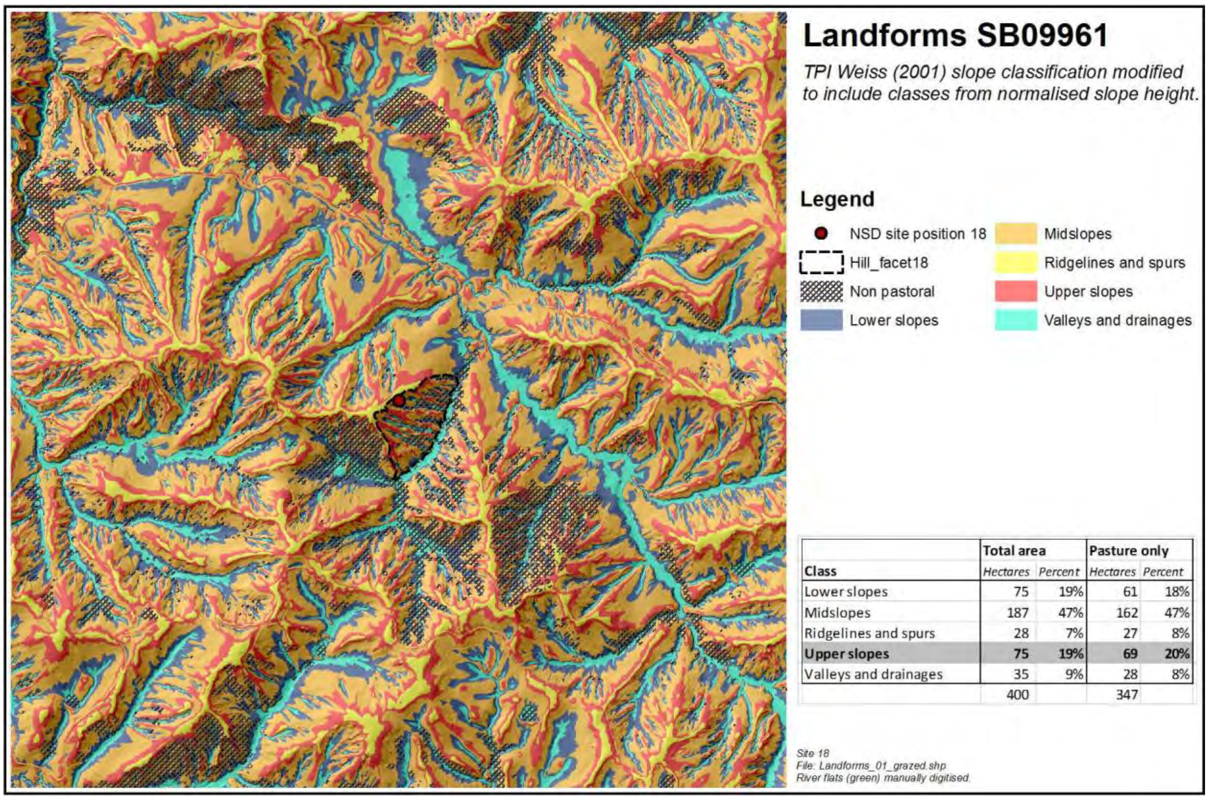


Figure A4 - 97: Classification of land forms for site 18 within a 2km² grid.

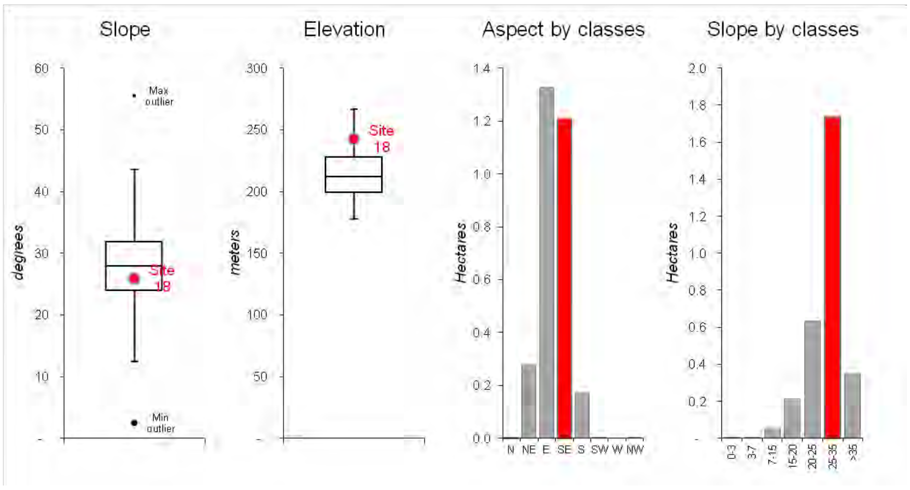


Figure A4 - 98: Representativeness of site 18 within the immediate hill facet.

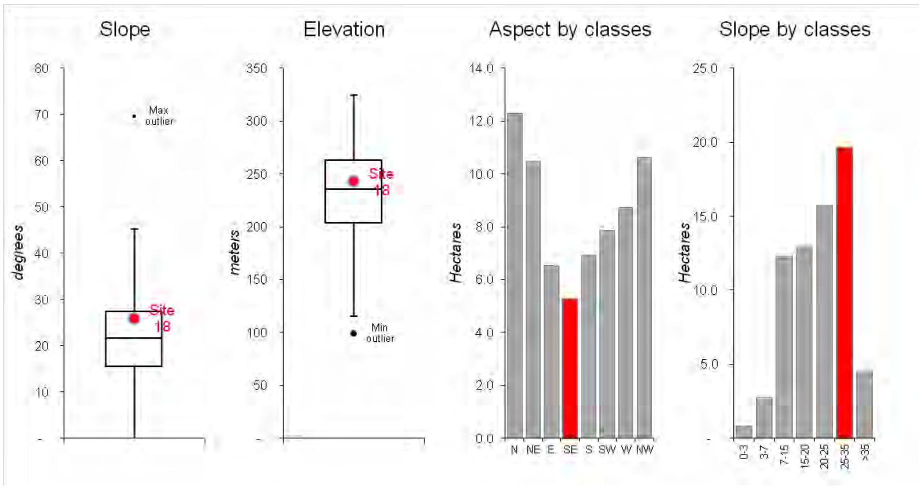


Figure A4 - 99: Representativeness of site 18 within upper slopes located within a 2km² grid.

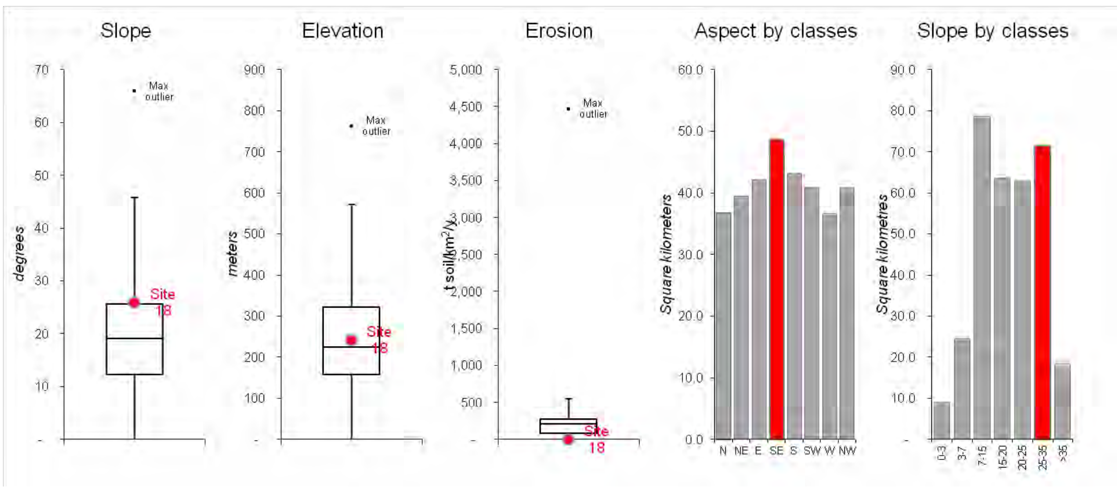


Figure A4 - 100: Representativeness of site 18 within the extent of the same soil type.

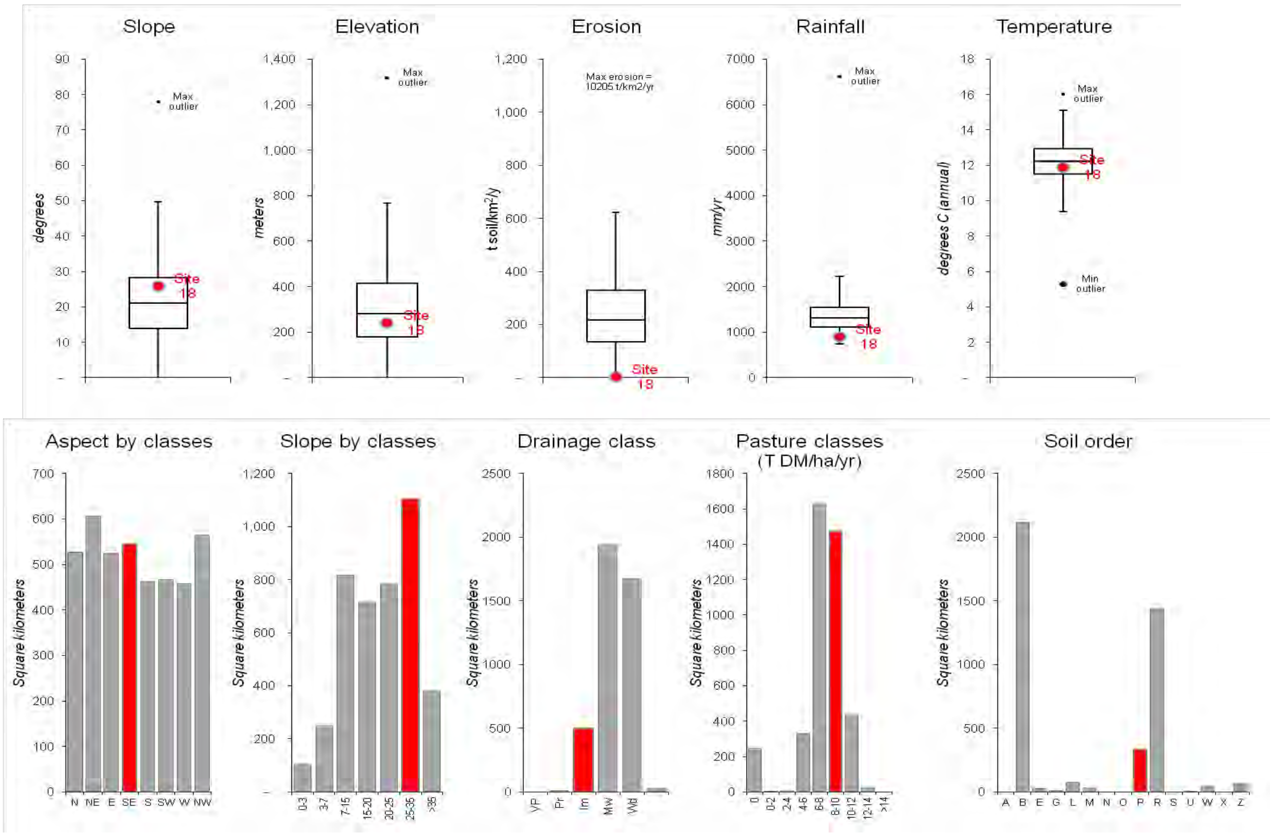


Figure A4 - 101: Representativeness of site 18 within Steep soft rock hill country (12).

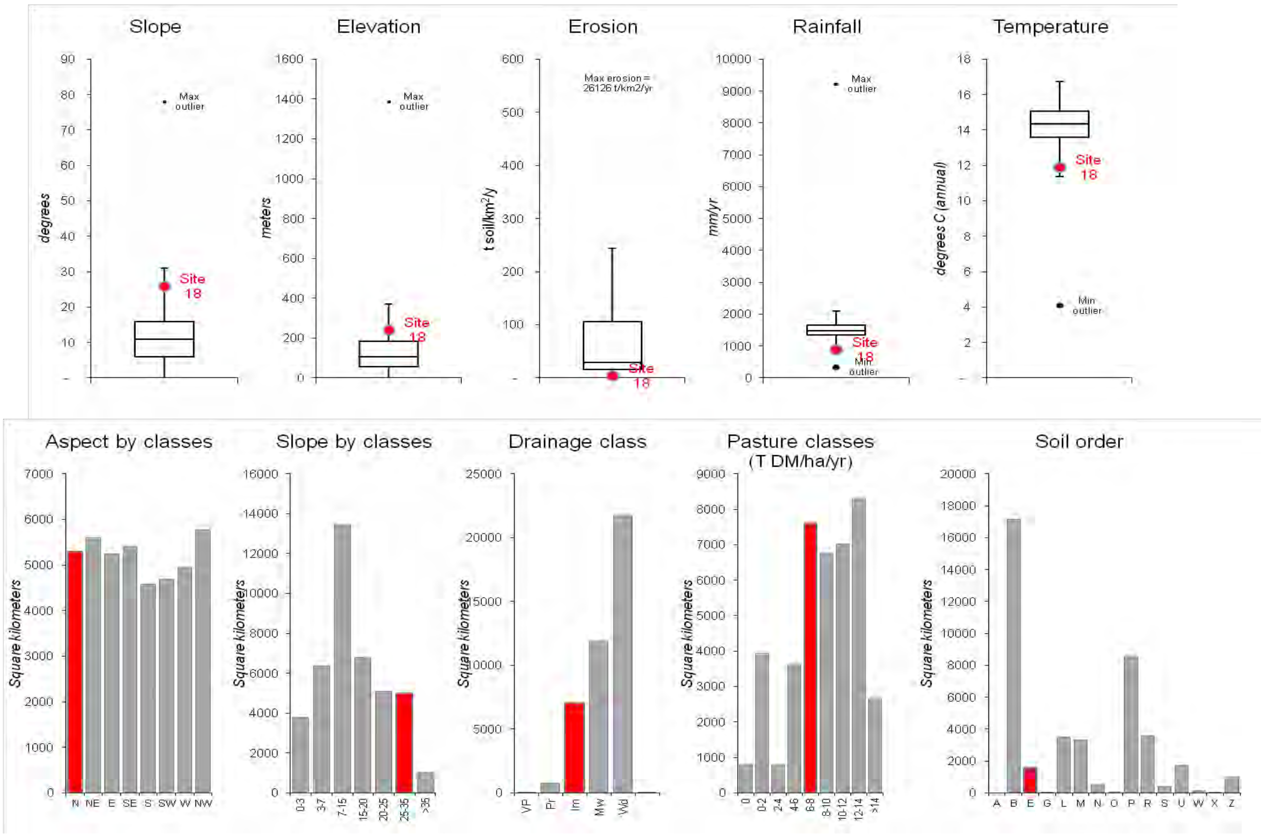


Figure A4 - 102: Representativeness of site 18 within all NZ hill country.

Table A4 - 18: Distance from the median and percent area of Site 18 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Upper slopes within 2km²	Hill country within 2km²	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	-	*0.0004 ha*	*3 ha*	*69 ha*	*347 ha*	328 ha	*4152 km²*	*4.1 M ha*
Elevation (m)	*230*	**243**	**41**	**7**	x	**6**	**9**	**34**
Slope (degrees)	***26***	25.5	**12**	**21**	x	**25**	**18**	**45**
Aspect (degrees)	*122*	**124**	x	x	x	x	x	x
Erosion (t soil/km²/y)	*3.9*	x	x	x	x	**49**	**49**	**49**
Precipitation (mm)	1000	**898**	x	x	x	x	**48**	**49**
Temperature (°C)	11.7	**11.9**	x	x	x	x	**13**	**48**
Upper slopes	-	x	x	x	**20%**	x	x	x
Hill country type	*12*	x	x	x	x	x	x	**10%**
Soil type	*ThS*	x	x	x	x	x	**6.7%**	**0.8%**
Soil subgroup	*PJM*	x	x	x	x	x	**1%**	**2%**
Soil order	*P*	x	x	x	x	x	**8%**	**21%**
Slope group	-	25-35°	**58%**	**29%**	x	**22%**	**27%**	**12%**
Aspect group	*SE*	SE	**40%**	**8%**	x	**15%**	**13%**	**13%**
Pasture (kg DM/ha/y)	*9,430*	x	x	x	x	x	**35%**	**16%**
Drainage	*Im*	x	x	x	x	x	**12%**	**17%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

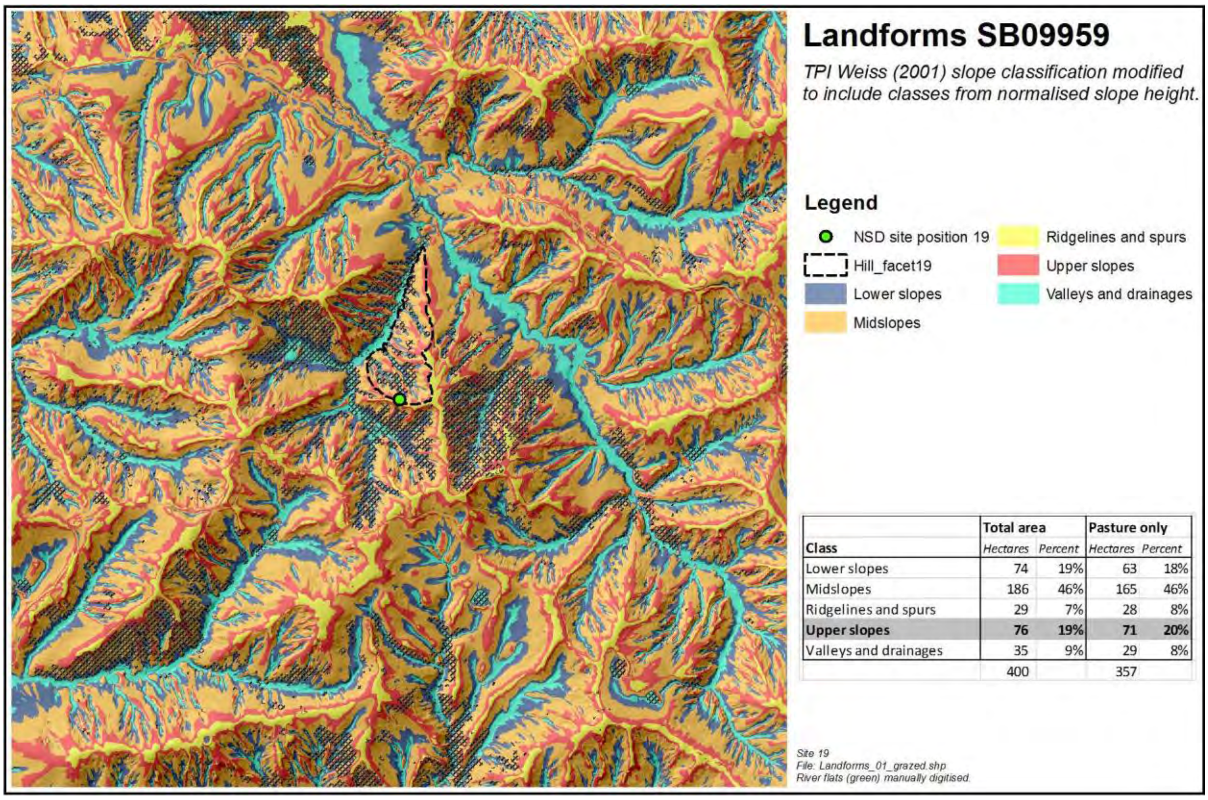
Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 19 (SB09959)

Site 19 is located approximately 300m to the SE of previous site 18 (Te Whanga, Wairarapa), on the opposite side of a valley. Soil type is Taihape steepland soil with a NZSC of EOJ. The NSD describes site position as being a midslope, but position is just off a spur and thus better qualifies as an upper slope. As with site 18, hill country type is assigned as nearby *Steep soft rock hill country (12)*. Both sites also share the same soil type, but somewhat unusually quite different NZ soil classifications.



	Total area		Pasture only	
Class	*Hectares*	*Percent*	*Hectares*	*Percent*
Lower slopes	74	19%	63	18%
Midslopes	186	46%	165	46%
Ridgelines and spurs	29	7%	28	8%
Upper slopes	**76**	**19%**	**71**	**20%**
Valleys and drainages	35	9%	29	8%
	400		357	

Figure A4 - 103: Classification of land forms for site 19 within a 2km^2 grid.

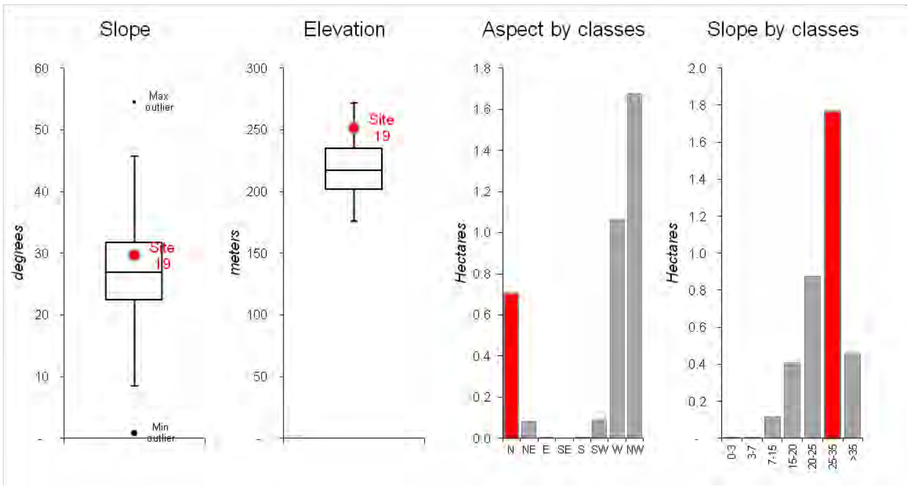


Figure A4 - 104: Representativeness of site 19 within the immediate hill facet.

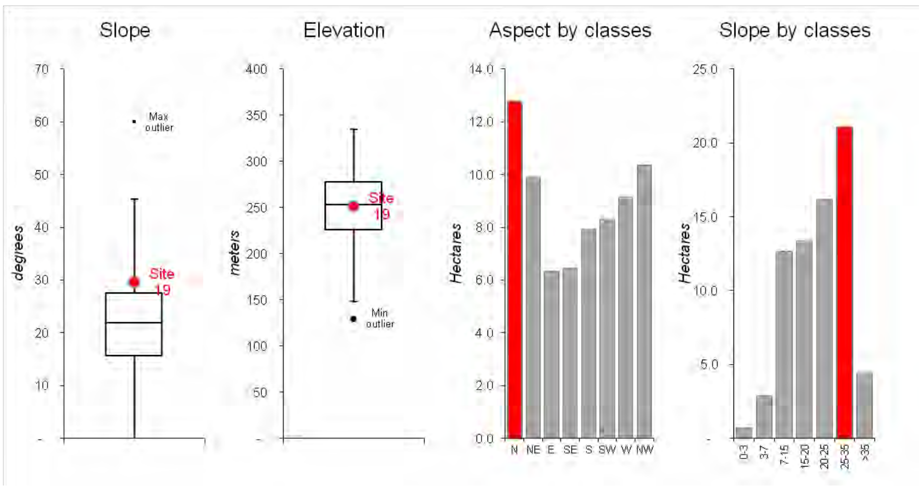


Figure A4 - 105: Representativeness of 19 within upper slopes located within a 2km² grid.

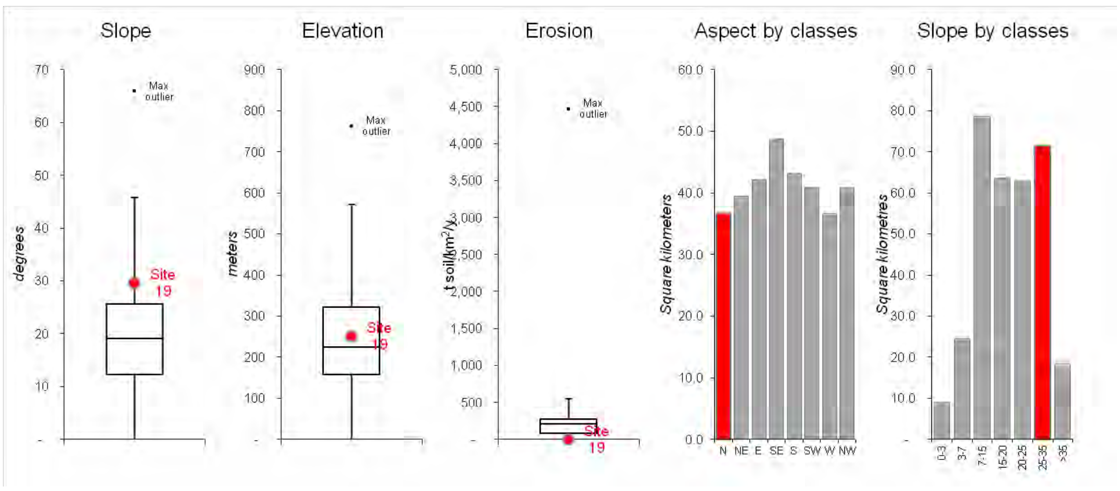


Figure A4 - 106: Representativeness of site 19 within the extent of the same soil type.

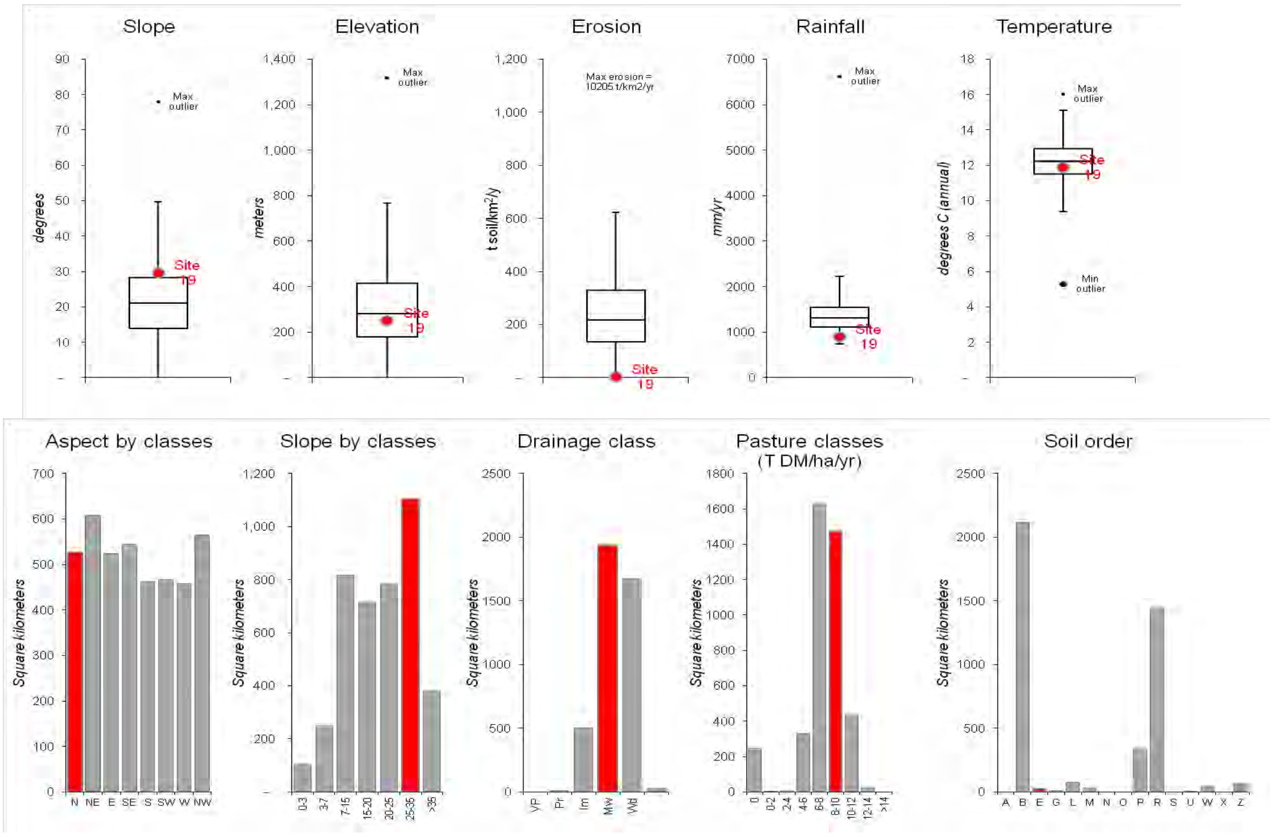


Figure A4 - 107: Representativeness of site 19 within Steep soft rock hill country (12).

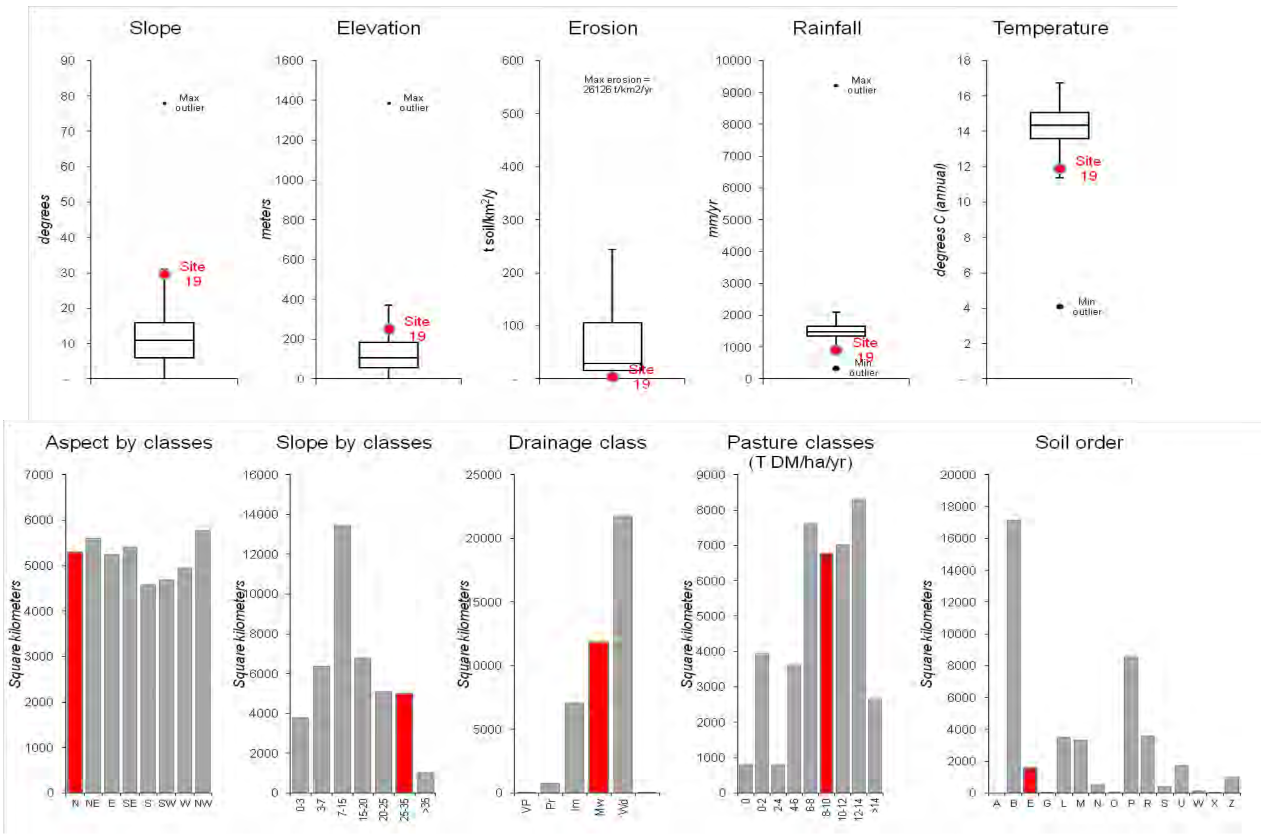


Figure A4 - 108: Representativeness of site 19 within all NZ hill country.

Table A4 - 19: Distance from the median and percent area of Site 19 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Upper slopes within 2km²	Hill country within 2km²	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	-	*0.001 ha*	*3.6 ha*	*71 ha*	*357 ha*	328 ha	*4152 km²*	*4.1 M ha*
Elevation (m)	*240*	**252**	**41**	**2**	x	**8**	**7**	**34**
Slope (degrees)	***30***	29.7	**15**	**33**	x	**36**	**29**	**47**
Aspect (degrees)	*340*	**349**	x	x	x	x	x	x
Erosion (t soil/km²/y)	*4.0*	x	x	x	x	**49**	**49**	**49**
Precipitation (mm)	1000	**905**	x	x	x	x	**48**	**49**
Temperature (°C)	11.7	**11.9**	x	x	x	x	**12**	**48**
Upper slopes	-	x	x	x	**20%**	x	x	x
Hill country type	*12*	x	x	x	x	x	x	**10%**
Soil type	*ThS*	x	x	x	x	x	**6.7%**	**0.8%**
Soil subgroup	*EOJ*	x	x	x	x	x	**0%**	**1%**
Soil order	*E*	x	x	x	x	x	**1%**	**4%**
Slope group	-	25-35°	**49%**	**30%**	x	**22%**	**27%**	**12%**
Aspect group	*N*	N	**19%**	**18%**	x	**11%**	**13%**	**13%**
Pasture (kg DM/ha/y)	*9,430*	x	x	x	x	x	**35%**	**16%**
Drainage	*Mw*	x	x	x	x	x	**47%**	**29%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

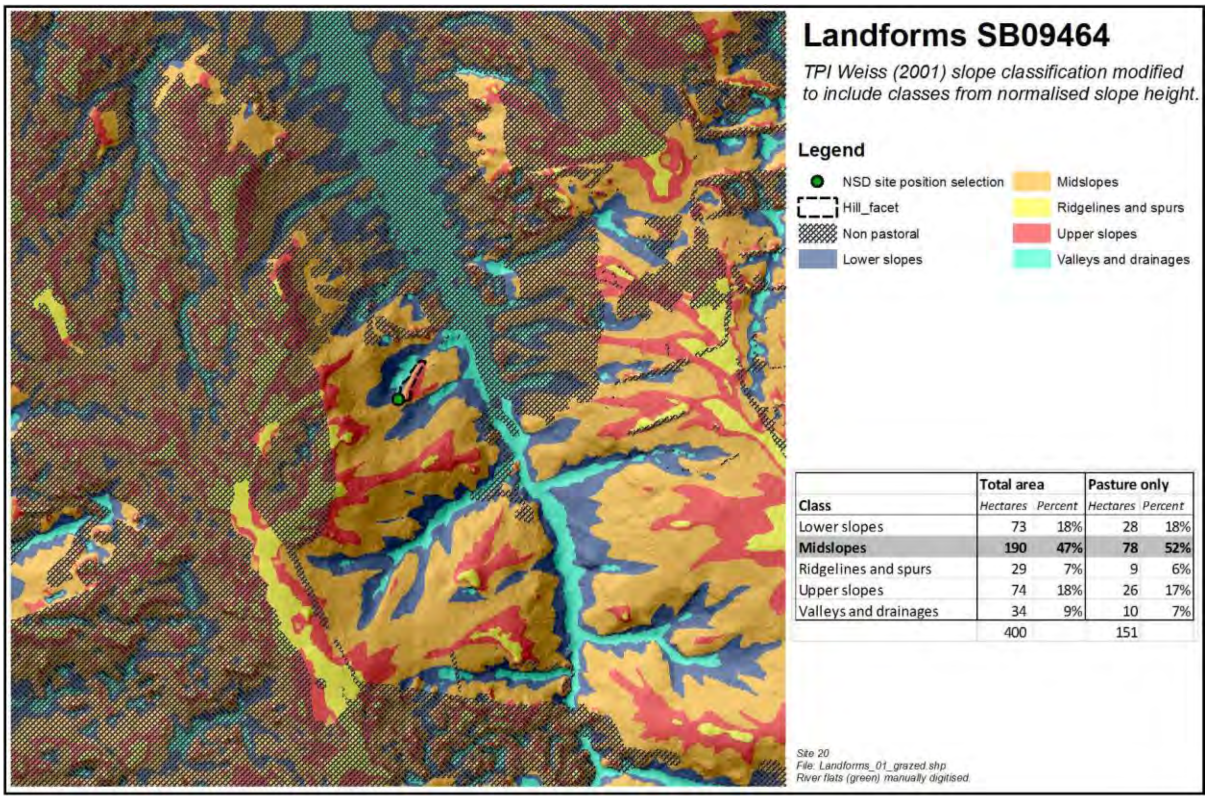
Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 20 (SB09464)

Site 20 is located in Banks Peninsula hill country adjacent to suburban Chrischurch (Cashmere). Only a limited proportion of the $2km^2$ grid qualifies as pastoral hill country (Figure 109). Soil type is Scarborough hill soil. This soil is not recognised in the FSL so the extent of soil type is not analysed. NZSC is PXT. However, no PXT classification occurs within the FSL/NZLRI hill country layer, so is thus not anlaysed. Described by Schipper et al. (2010) as being located on a midslope of a large hill. Hill country type is *Loess hill country (5)*.



	Total area		Pasture only	
Class	Hectares	Percent	Hectares	Percent
Lower slopes	73	18%	28	18%
Midslopes	**190**	**47%**	**78**	**52%**
Ridgelines and spurs	29	7%	9	6%
Upper slopes	74	18%	26	17%
Valleys and drainages	34	9%	10	7%
	400		151	

Figure A4 - 109: Classification of land forms for site 20 within a $2km^2$ grid.

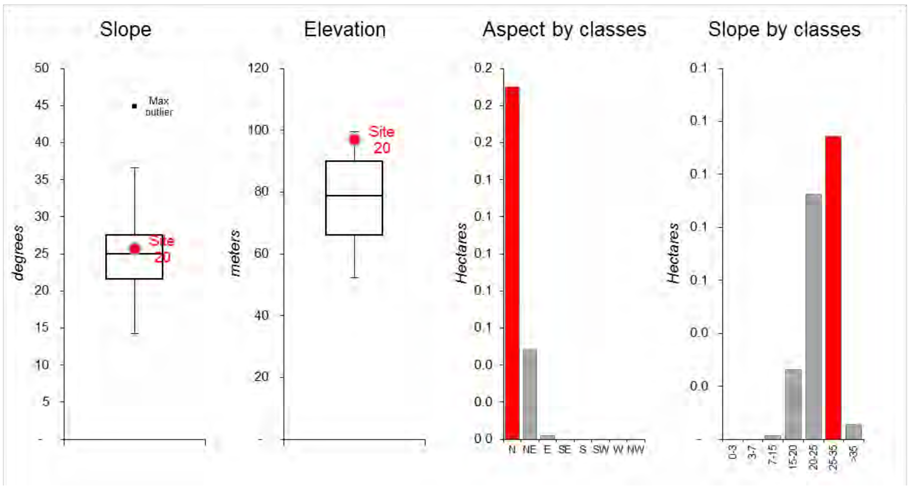


Figure A4 - 110: Representativeness of site 20 within the immediate hill facet.

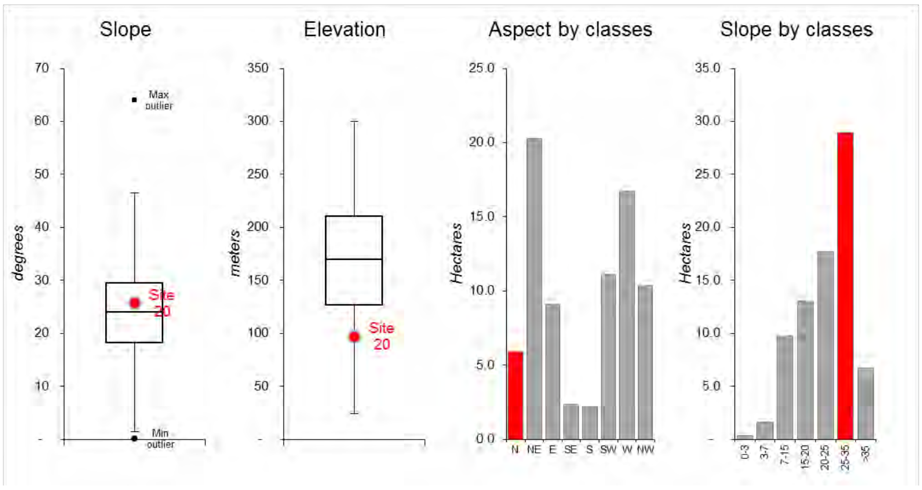


Figure A4 - 111: Representativeness of site 20 within midslopes located within a 2km^2 grid.

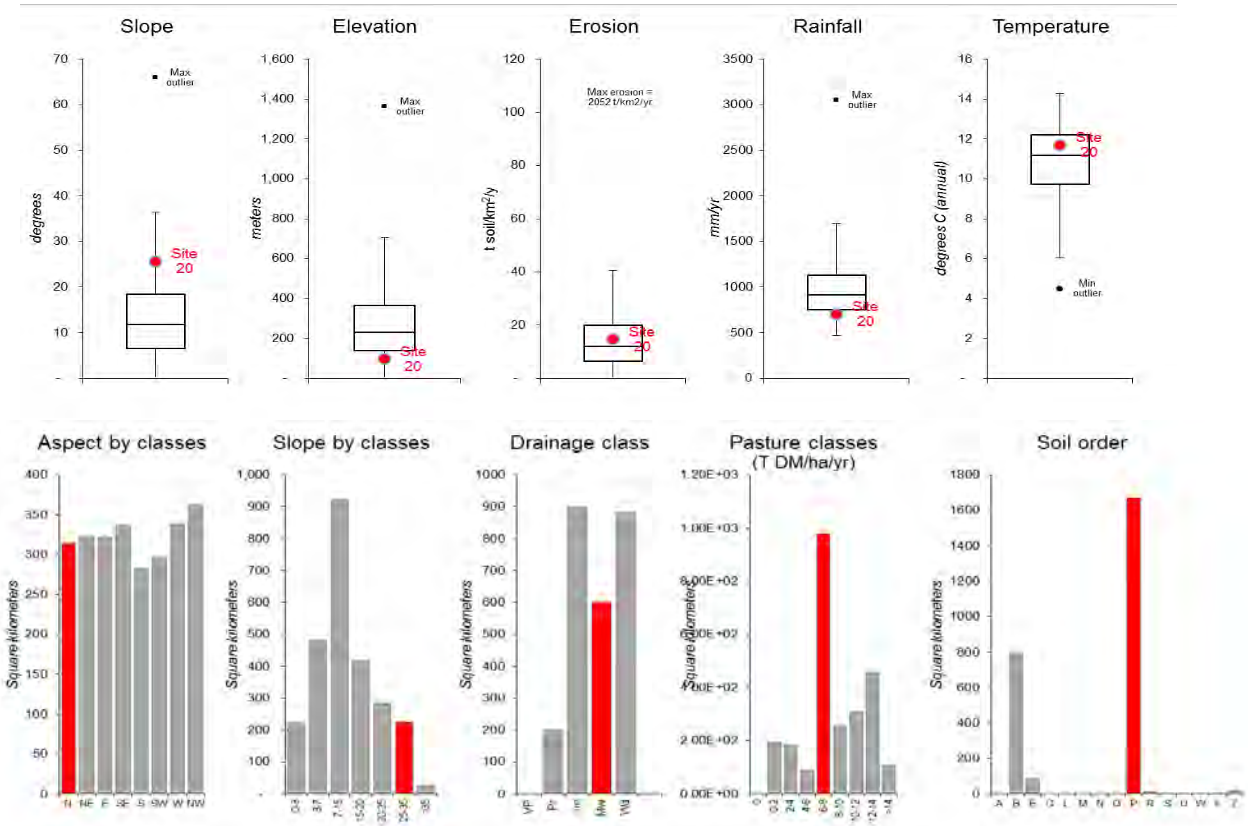


Figure A4 - 112: Representativeness of site 20 within Loess hill country (5).

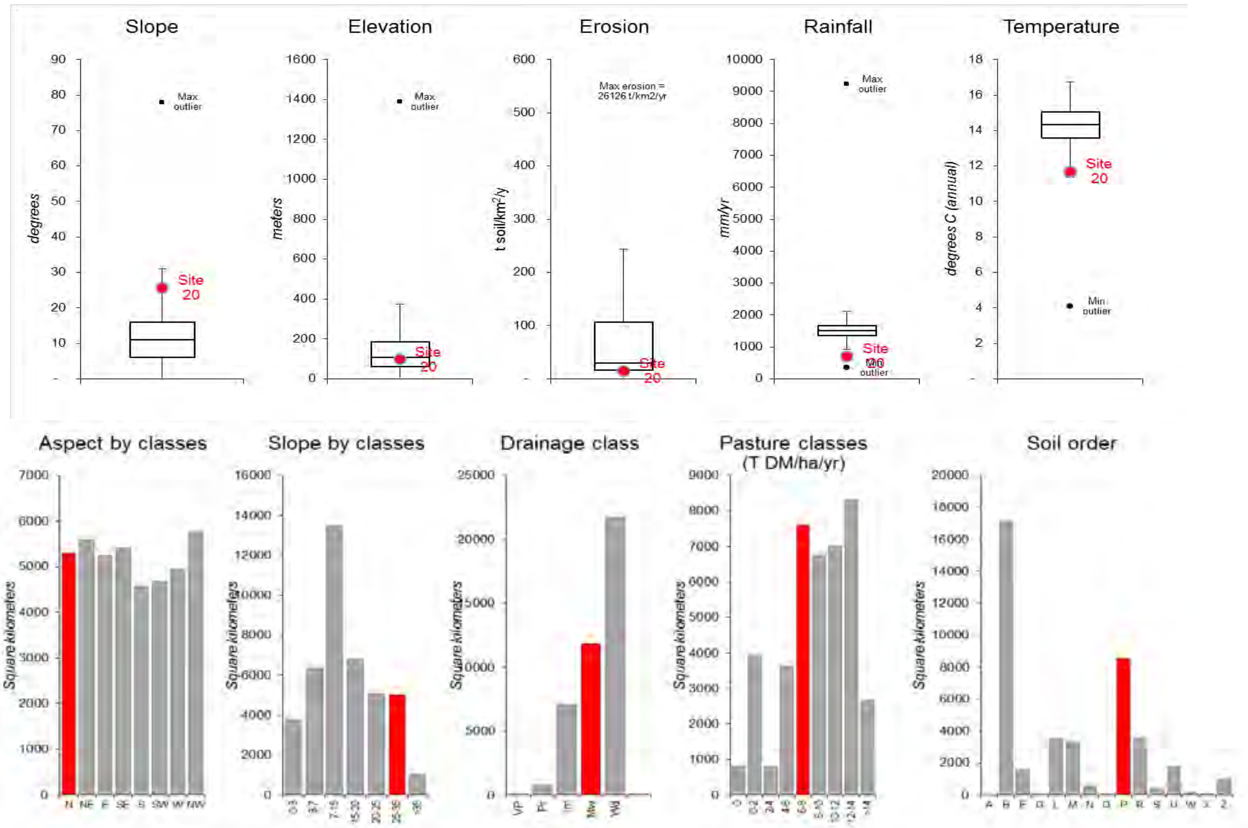


Figure A4 - 113: Representativeness of site 20 within all NZ hill country.

Table A4 - 20: Distance from the median and percent area of Site 20 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Midslopes within 2km²	Hill country within 2km²	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	*-*	*0.003 ha*	*0.2 ha*	*78 ha*	*151 ha*	*-*	*2577 km²*	*4.1 M ha*
Elevation (m)	*120*	**97**	**44**	**36**	x	x	**37**	**6**
Slope (degrees)	***26***	25.7	**6**	**8**	x	x	**41**	**45**
Aspect (degrees)	*10*	**7**	x	x	x	x	x	x
Erosion (t soil/km²/y)	*14.8*	x	x	x	x	x	**11**	**31**
Precipitation (mm)	693	**706**	x	x	x	x	**29**	**50**
Temperature (°C)	-	**11.7**	x	x	x	x	**10**	**48**
Midslopes	-	x	x	x	**52%**	x	x	x
Hill country type	*5*	x	x	x	x	x	x	**6%**
Soil type	-	x	x	x	x	x	x	x
Soil subgroup	*PXT*	x	x	x	x	x	x	x
Soil order	*P*	x	x	x	x	x	**65%**	**21%**
Slope group	-	25-25°	**48%**	**37%**	x	x	**9%**	**12%**
Aspect group	*N*	N	**79%**	**8%**	x	x	**12%**	**13%**
Pasture (kg DM/ha/y)	***7,710***	x	x	x	x	x	**38%**	**18%**
Drainage	***Mw***	x	x	x	x	x	**23%**	**29%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

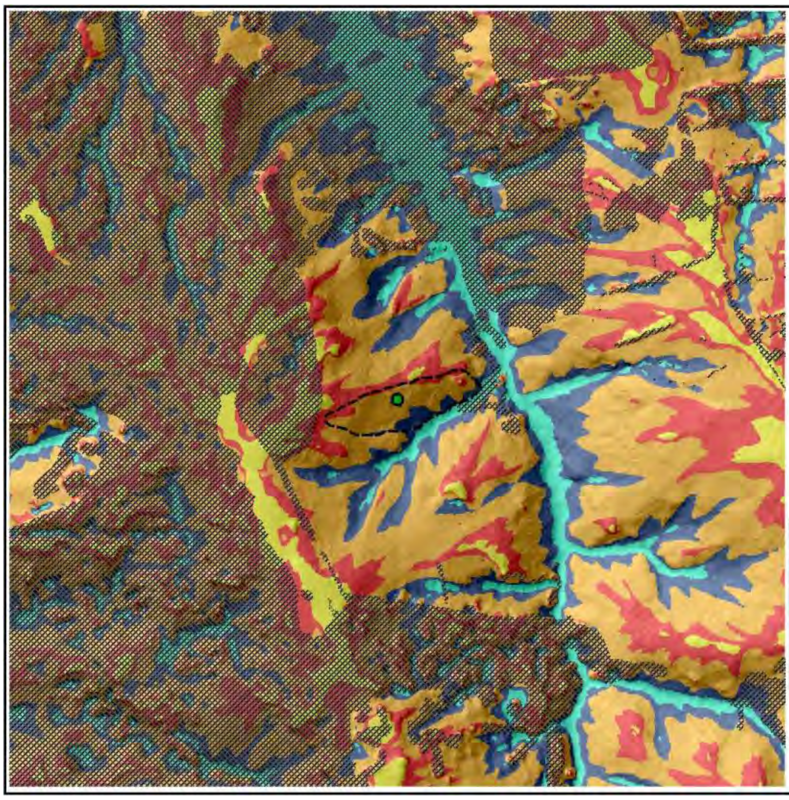
Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 21 (SB09467)

Site 21 is located in the same landscape as site 20 (220m SE of Site 20) (Banks Peninsula hill country adjacent to suburban Chrischurch). Soil type is Otahuna hill soil with an NZSC of PIM. Site location is described as being on the midslope of a large hill, and hill country type is *Loess hill country (5).*



Class	Total area		Pasture only	
	Hectares	*Percent*	*Hectares*	*Percent*
Lower slopes	70	17%	31	18%
Midslopes	**191**	**48%**	**88**	**51%**
Ridgelines and spurs	30	8%	11	6%
Upper slopes	76	19%	30	18%
Valleys and drainages	32	8%	11	7%
	400		171	

Figure A4 - 114: Classification of land forms for site 21 within a 2km² grid.

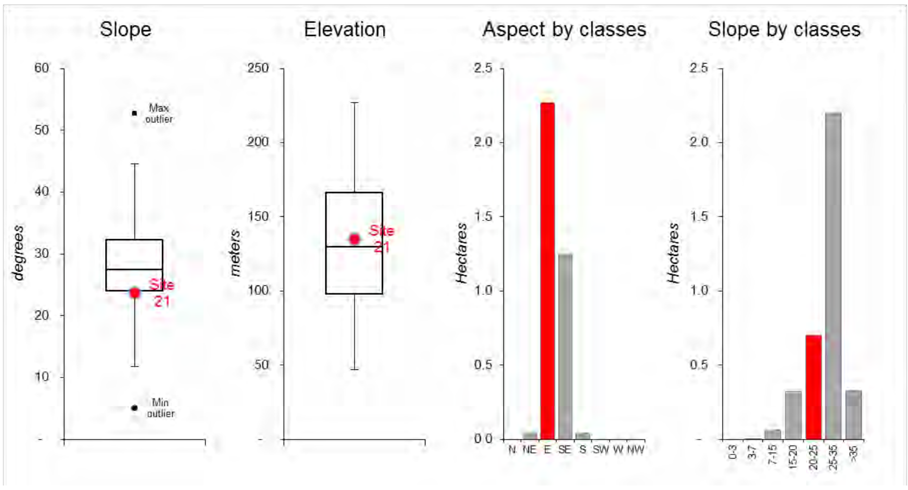


Figure A4 - 115: Representativeness of site 21 within the immediate hill facet.

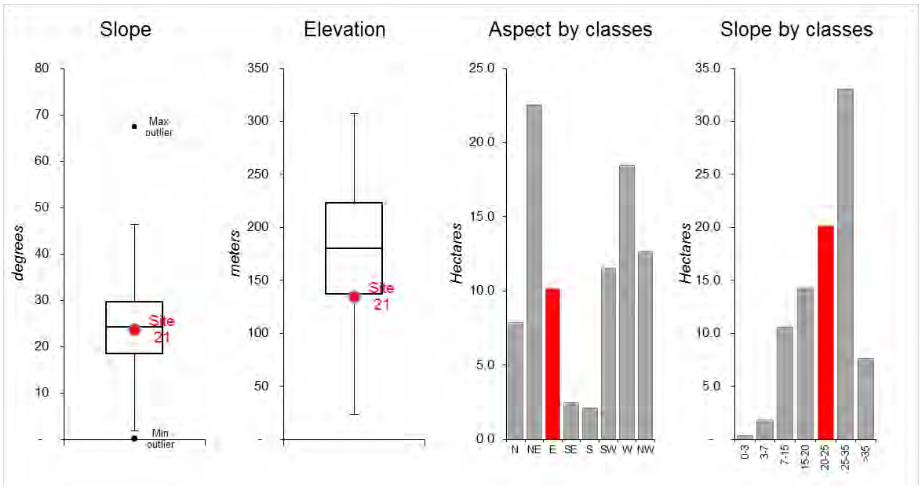


Figure A4 - 116: Representativeness of 21 within midslopes located within a 2km² grid.

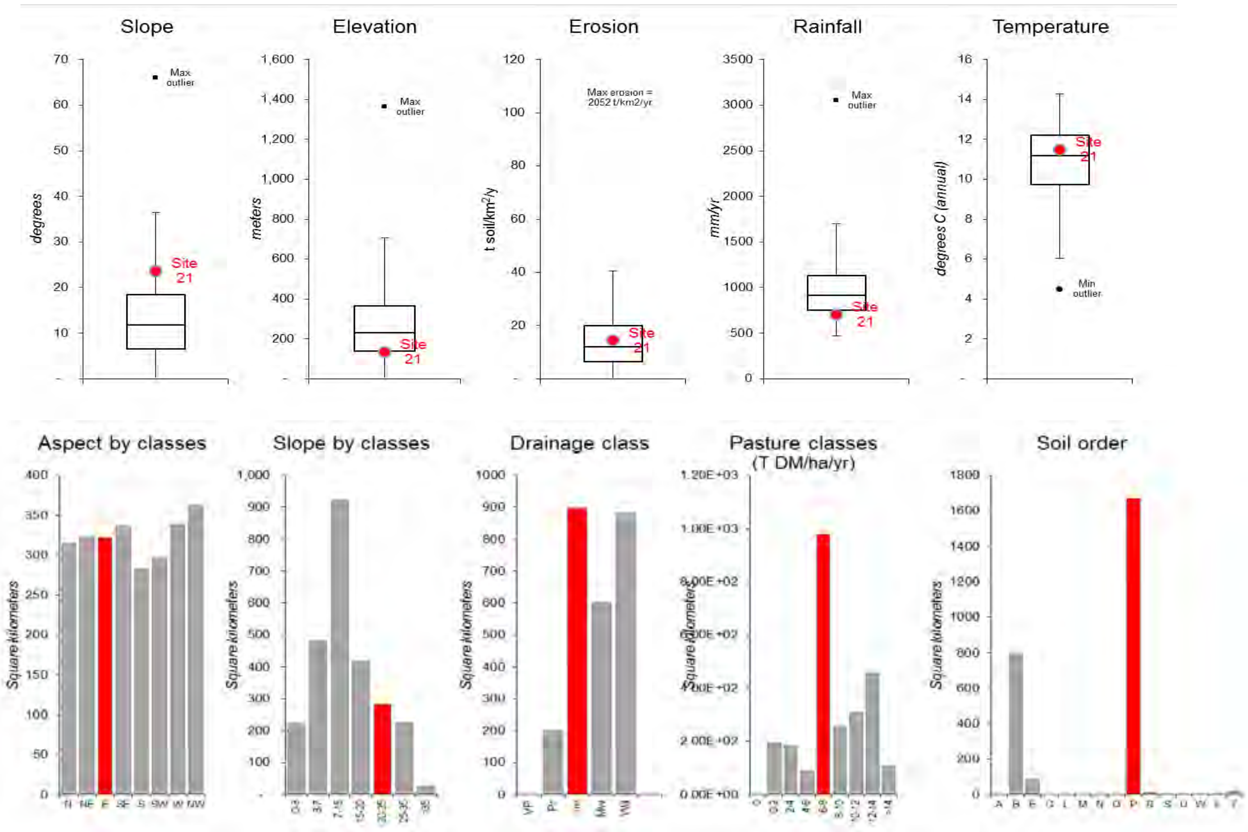


Figure A4 - 117: Representativeness of site 21 within Loess hill country (5).

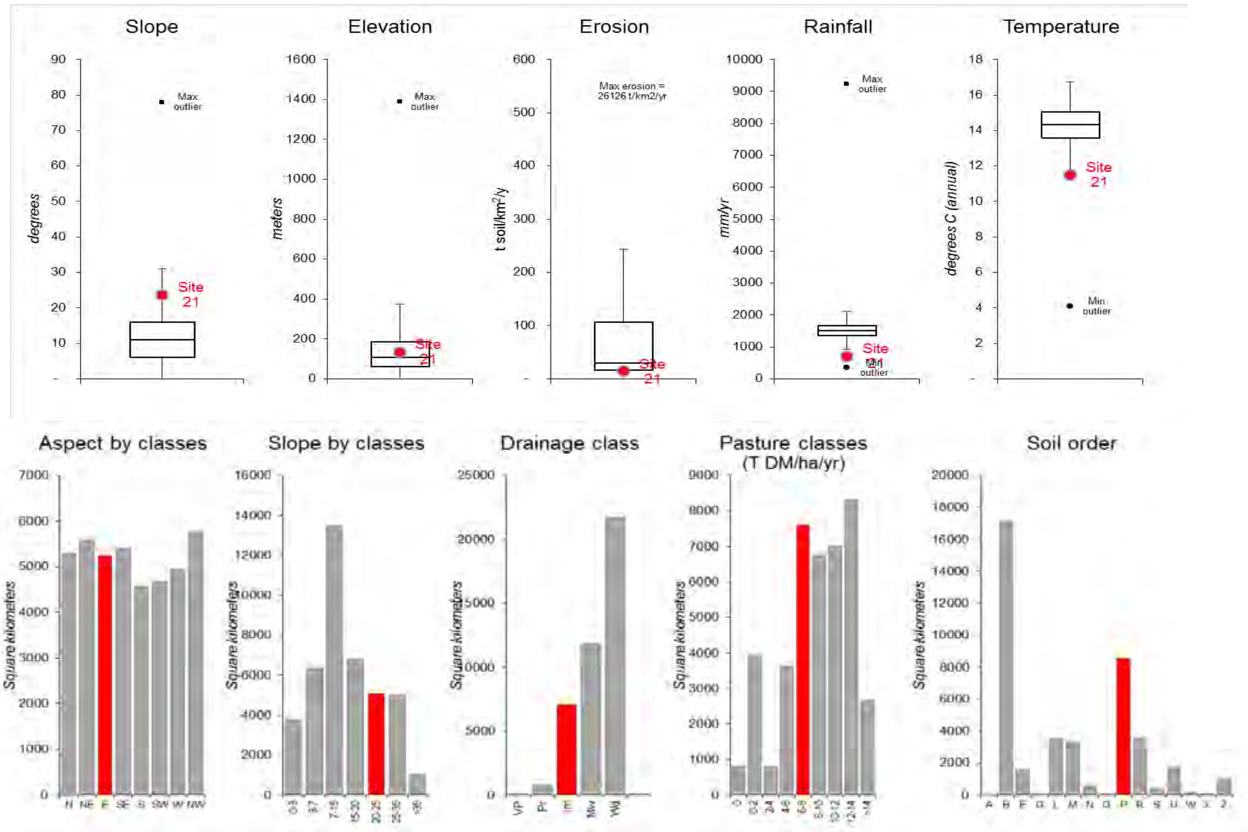


Figure A4 - 118: Representativeness of site 21 within all NZ hill country.

Table A4 - 21: Distance from the median and percent area of Site 21 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only) Hill slope facet	Midslopes within 2km²	Hill country within 2km²	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	-	*0.003 ha*	*3.6 ha*	*88 ha*	*171 ha*	-	*2577 km²*	*4.1 M ha*
Elevation (m)	*230*	**135**	**4**	**26**	x	x	**27**	**10**
Slope (degrees)	***24***	23.7	**27**	**2**	x	x	**38**	**42**
Aspect (degrees)	*90*	**108**	x	x	x	x	x	x
Erosion (t soil/km²/y)	*14.4*	x	x	x	x	x	**10**	**32**
Precipitation (mm)	693	**706**	x	x	x	x	**29**	**50**
Temperature (°C)	-	**11.5**	x	x	x	x	**5**	**48**
Midslopes	-	x	x	x	**51%**	x	x	x
Hill country type	5	x	x	x	x	x	x	**6%**
Soil type	-	x	x	x	x	x	x	x
Soil subgroup	PIM	x	x	x	x	x	**0.3%**	**2.9%**
Soil order	P	x	x	x	x	x	**65%**	**21%**
Slope group	-	20-25°	**19%**	**23%**	x	x	**11%**	**12%**
Aspect group	E	**E**	**63%**	**12%**	x	x	**13%**	**13%**
Pasture (kg DM/ha/y)	7,710	x	x	x	x	x	**38%**	**18%**
Drainage	Im	x	x	x	x	x	**35%**	**17%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 22 (SB09470)

Site 22 is located within the Banks Penninsula hill country near Sumner. Soil type is Godley deep silt loam while NZSC is PXJN. Slope (13°) qualifies this location as rolling downlands. Hill country type is *Loess hill country (5)*. Site position is borderline between mid- and upper slope (Figure 119), but it is described as being located on the crest of a slope, so is assigned to the upper slope category.

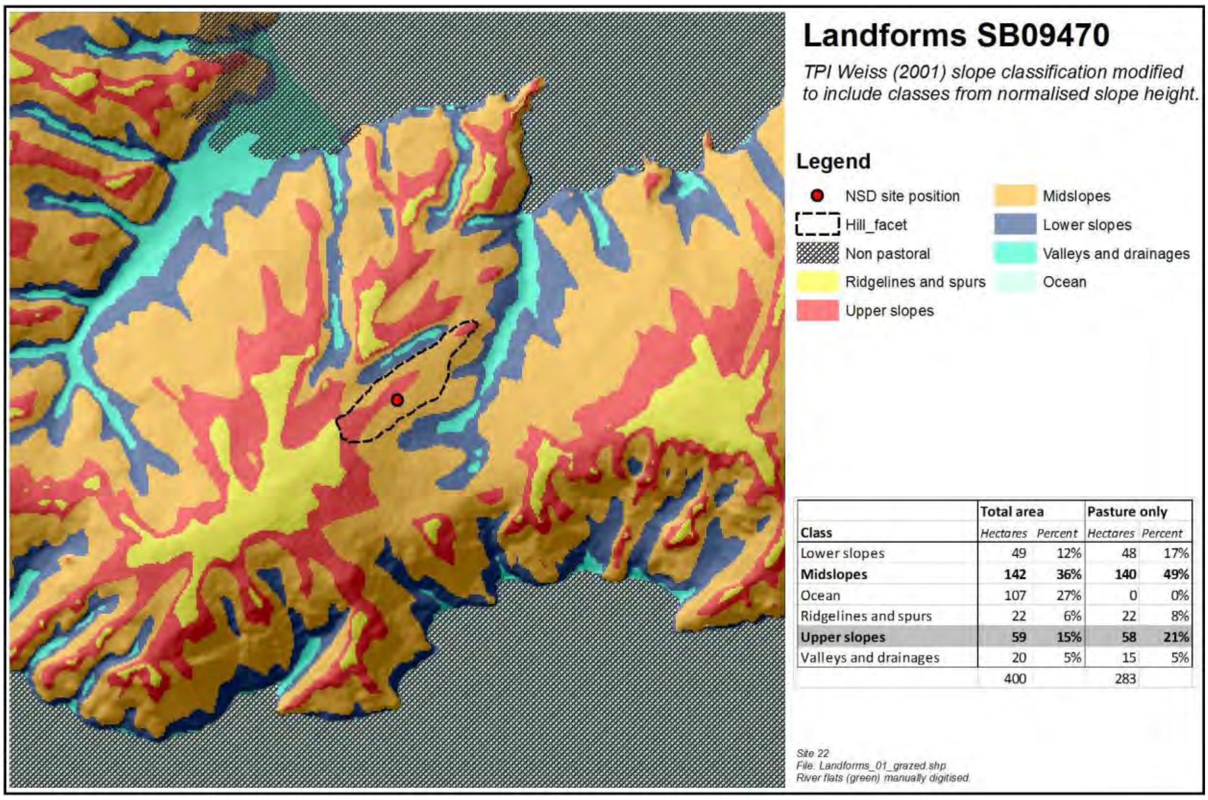


Figure A4 - 119: Classification of land forms for site 22 within a 2km² grid.

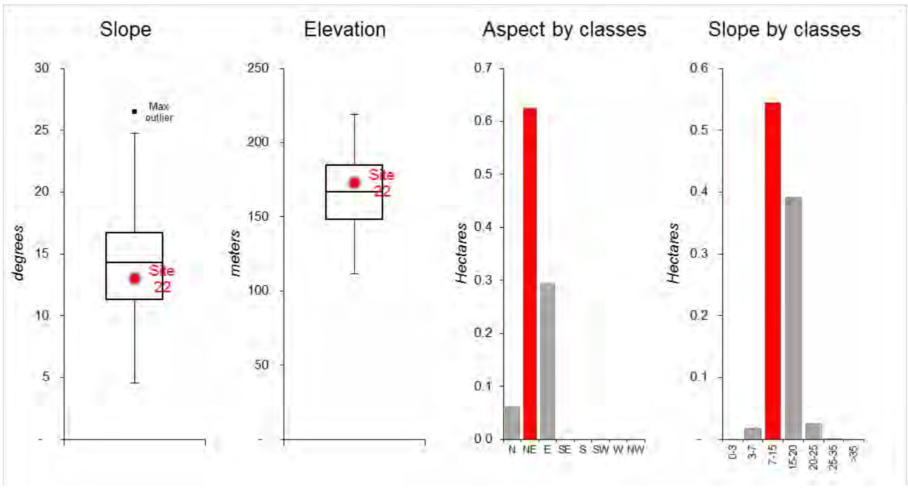


Figure A4 - 120: Representativeness of site 22 within the immediate hill facet.

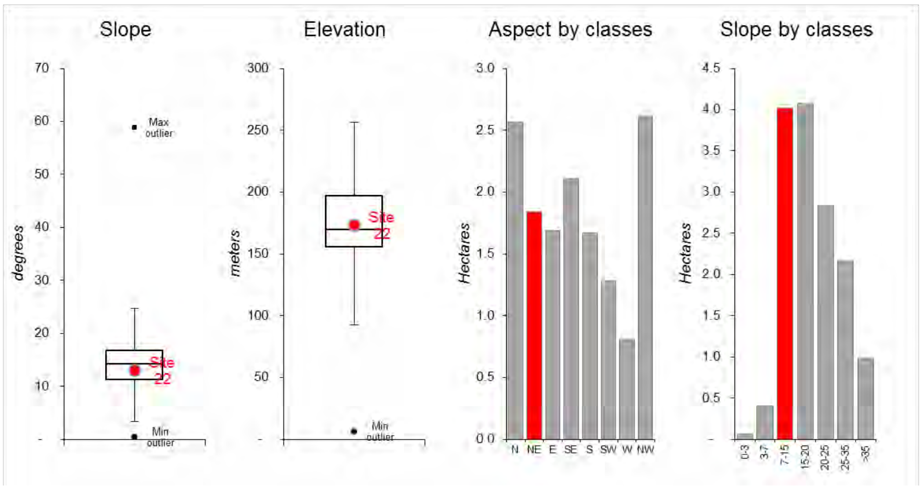


Figure A4 - 121: Representativeness of 22 within upper slopes located within a 2km² grid.

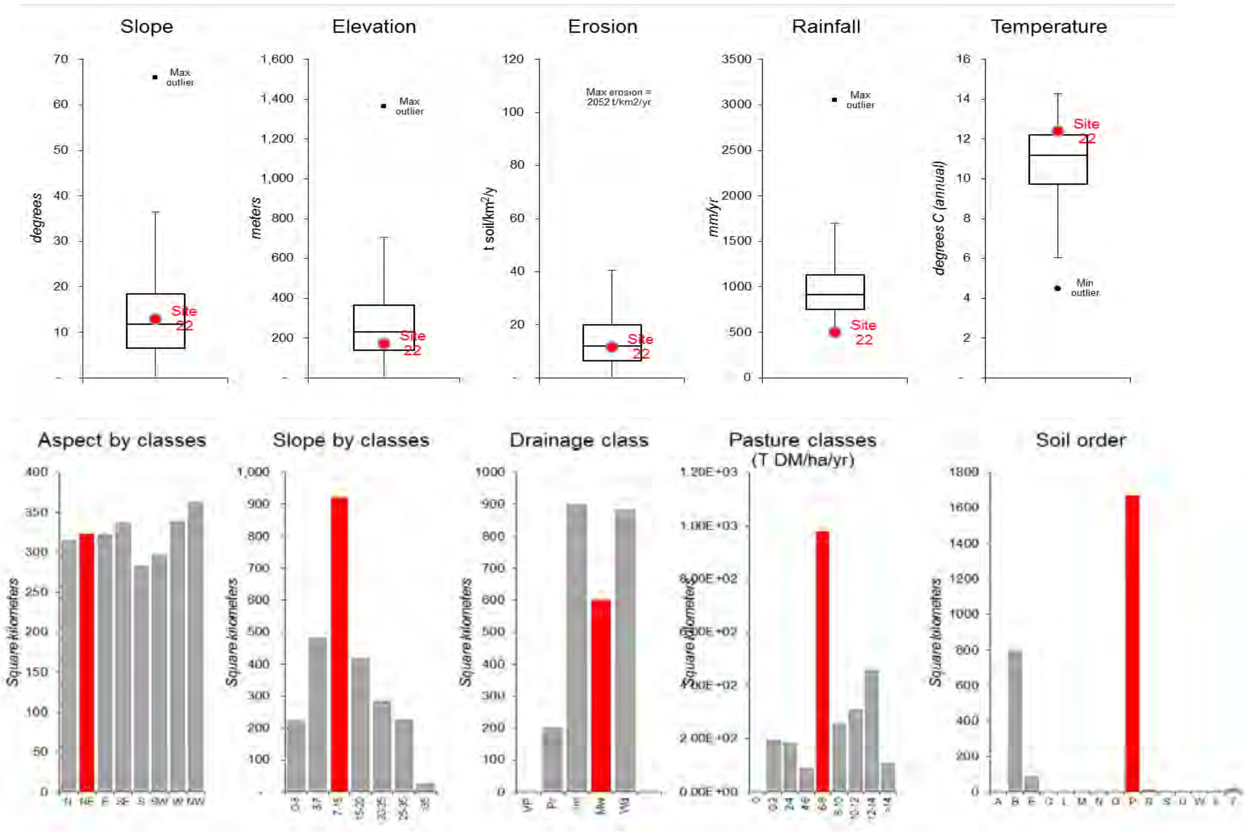


Figure A4 - 122: Representativeness of site 22 within Loess hill country (5).

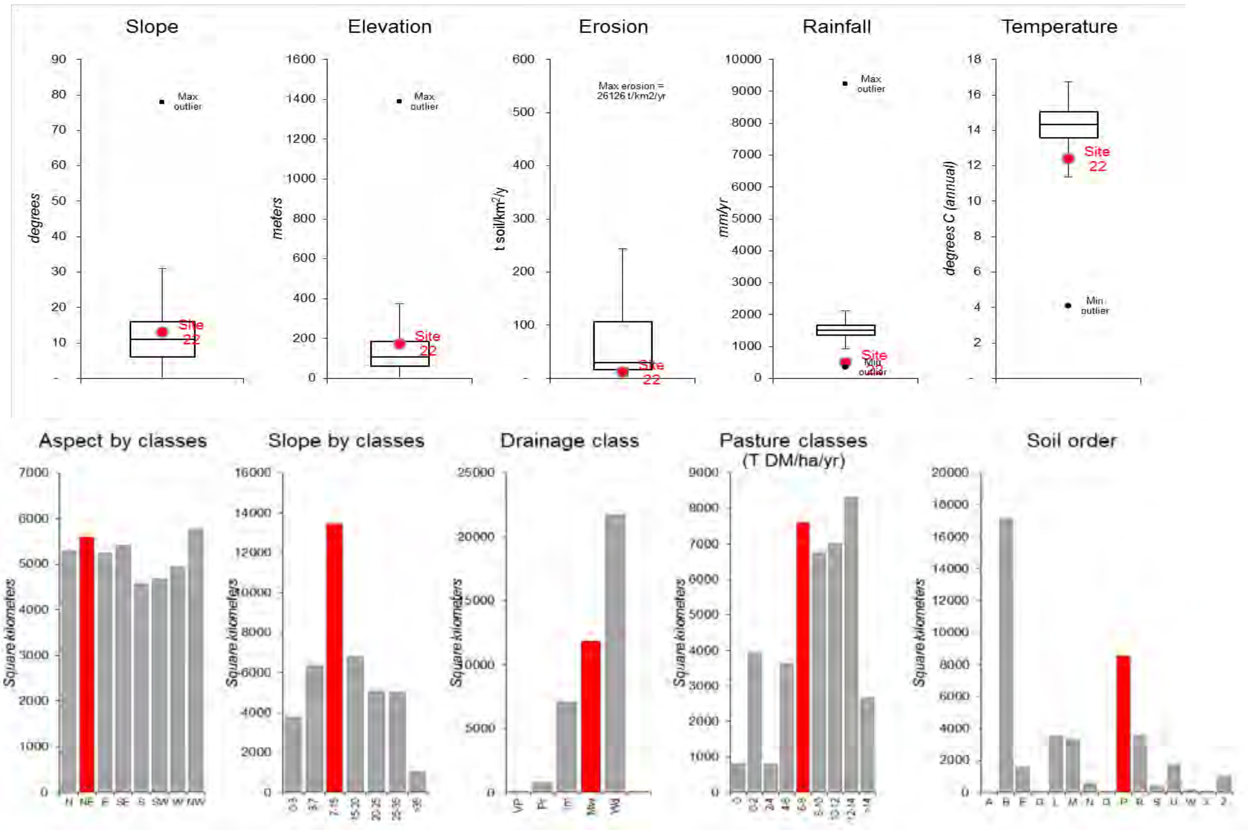


Figure A4 - 123: Representativeness of site 22 within all NZ hill country.

Table A4 - 22: Distance from the median and percent area of Site 22 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Upper slopes within 2km²	Hill country within 2km²	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	-	*0.006 ha*	*1 ha*	*15 ha*	*283 ha*	-	*2577 km²*	*4.1 M ha*
Elevation (m)	*175*	**173**	**9**	**3**	x	x	**15**	**22**
Slope (degrees)	*13*	14	**8**	**7**	x	x	**7**	**11**
Aspect (degrees)	*22*	**54**	x	x	x	x	x	x
Erosion (t soil/km²/y)	*11.7*	x	x	x	x	x	**1**	**42**
Precipitation (mm)	*563*	**499**	x	x	x	x	**49**	**50**
Temperature (°C)	11.7	**12.4**	x	x	x	x	**31**	**45**
Upper slopes	-	x	x	x	**21%**	x	x	x
Hill country type	*5*	x	x	x	x	x	x	**6%**
Soil type	-	x	x	x	x	x	x	x
Soil subgroup	*PXJN*	x	x	x	x	x	**0.7%**	**0.2%**
Soil order	*P*	x	x	x	x	x	**65%**	**21%**
Slope group	-	7-15°	**56%**	**28%**	x	x	**36%**	**32%**
Aspect group	*N*	**NE**	**64%**	**13%**	x	x	**13%**	**13%**
Pasture (kg DM/ha/y)	*7,710*	x	x	x	x	x	**38%**	**18%**
Drainage	*Mw*	x	x	x	x	x	**23%**	**29%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

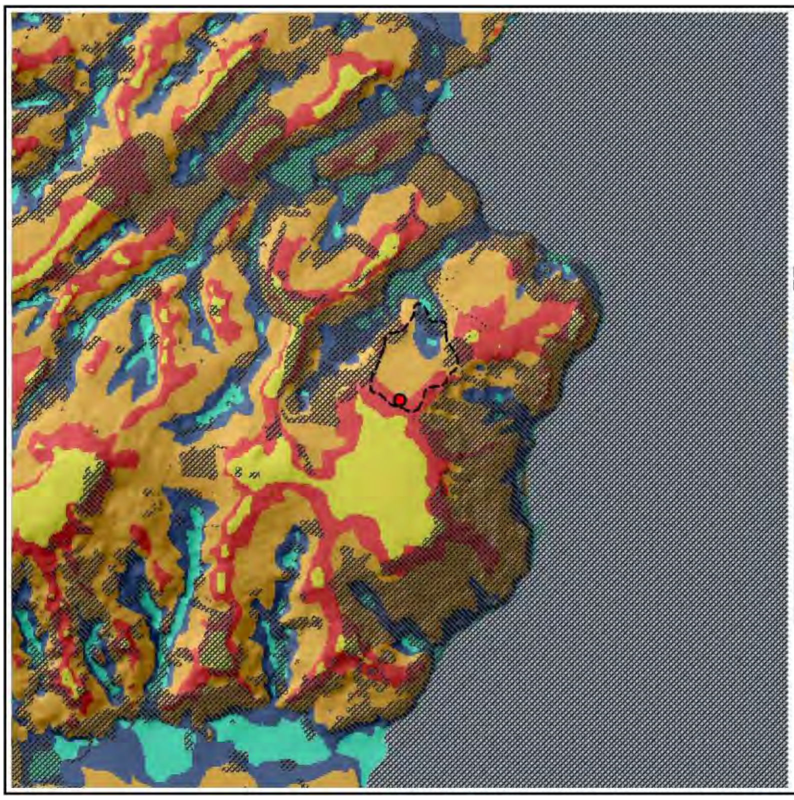
Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

Site 23 (SB09997)

Site 23 is located near Akaroa within Banks Penninsula hill country. Soil type is Pawson silt loam classed as PXM. Slope (9°) is not technically a hill slope, but rather representative of easy rolling land within hill country. Hill country type is Loess hill country (5).



Class	Total area Hectares	Total area Percent	Pasture only Hectares	
Low slopes	49	12%	24	16%
Midslopes	**116**	**29%**	**64**	**45%**
Ocean	149	37%	0	0%
Ridgelines and spurs	20	5%	16	11%
Upper slopes	**46**	**11%**	**30**	**21%**
Valleys and drainages	20	5%	10	7%
	400		143	

Site 23
File. Landforms_01_grazed.shp
River flats (green) manually digitised.

Figure A4 - 124: Classification of land forms for site 23 within a 2km² grid.

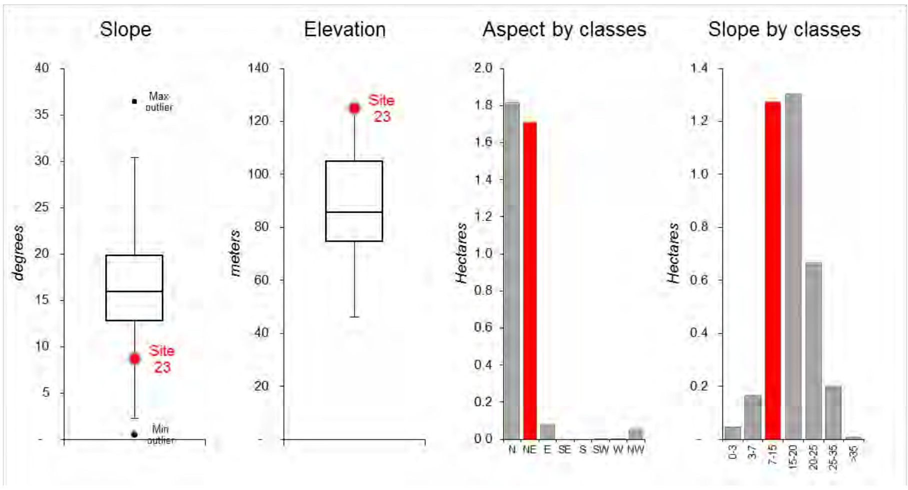


Figure A4 - 125: Representativeness of site 23 within the immediate hill facet.

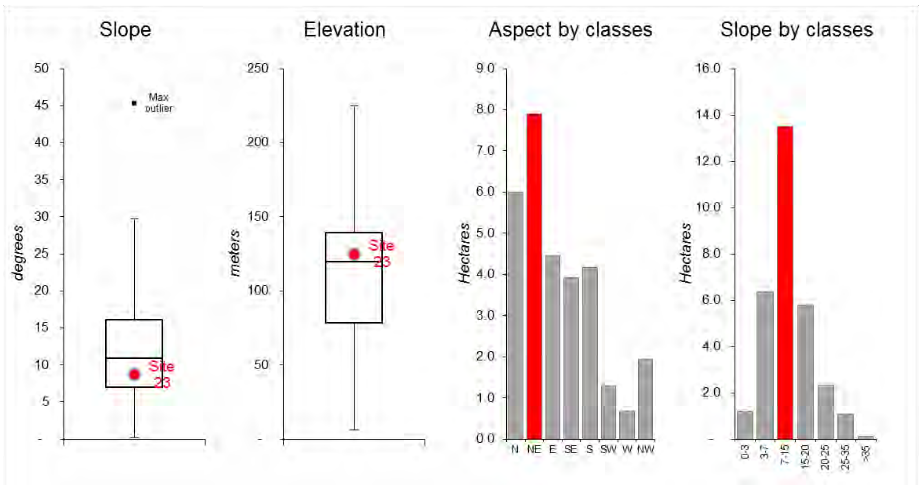


Figure A4 - 126: Representativeness of site 23 within upper slopes located within a 2km^2 grid.

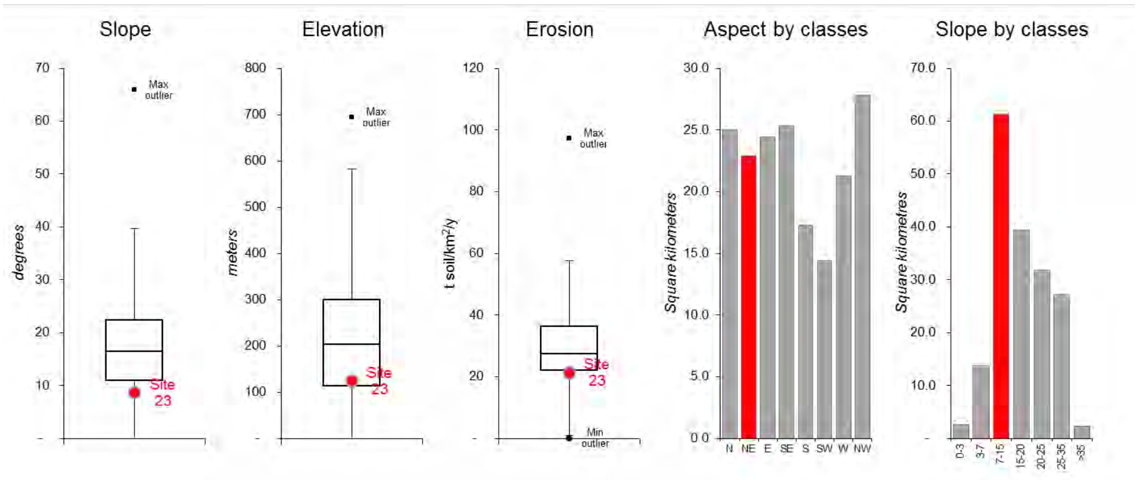


Figure A4 - 127: Representativeness of site 23 the same soil type.

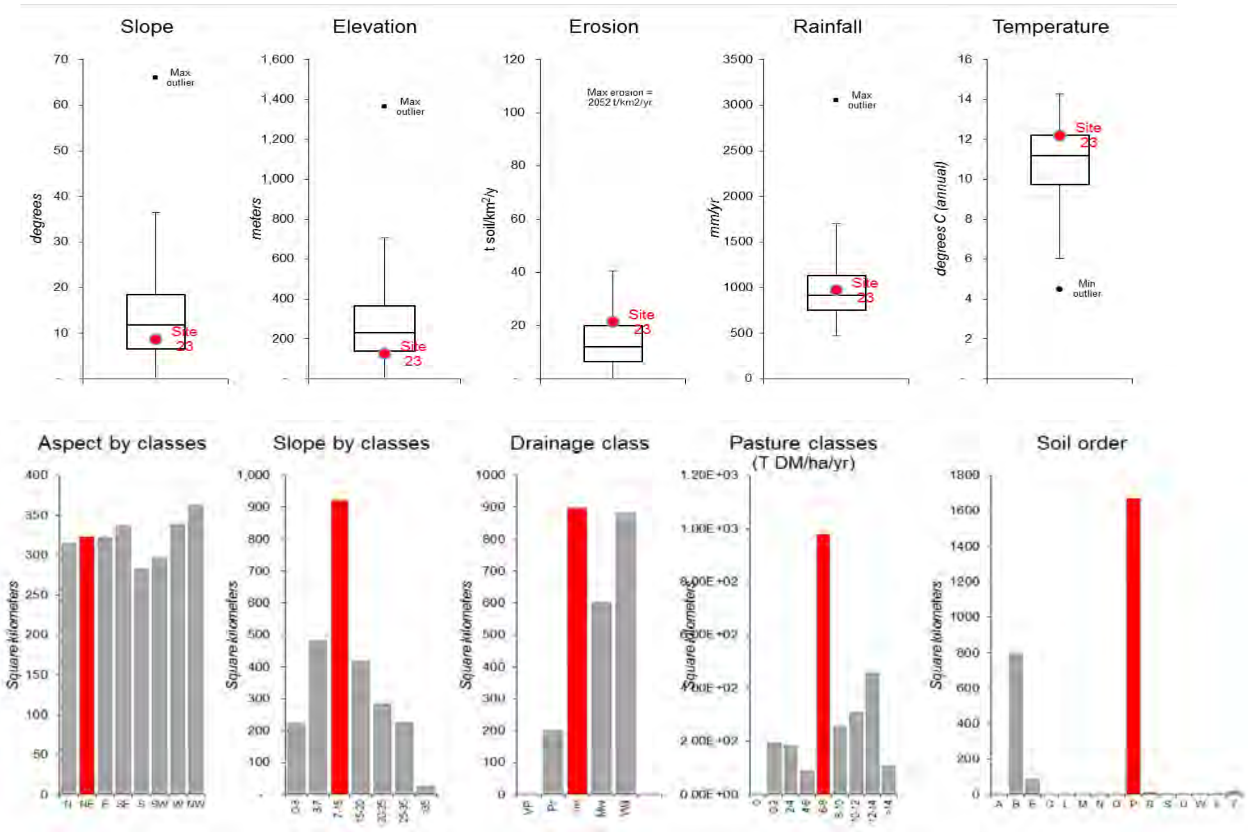


Figure A4 - 128: Representativeness of site 23 within Loess hill country (5).

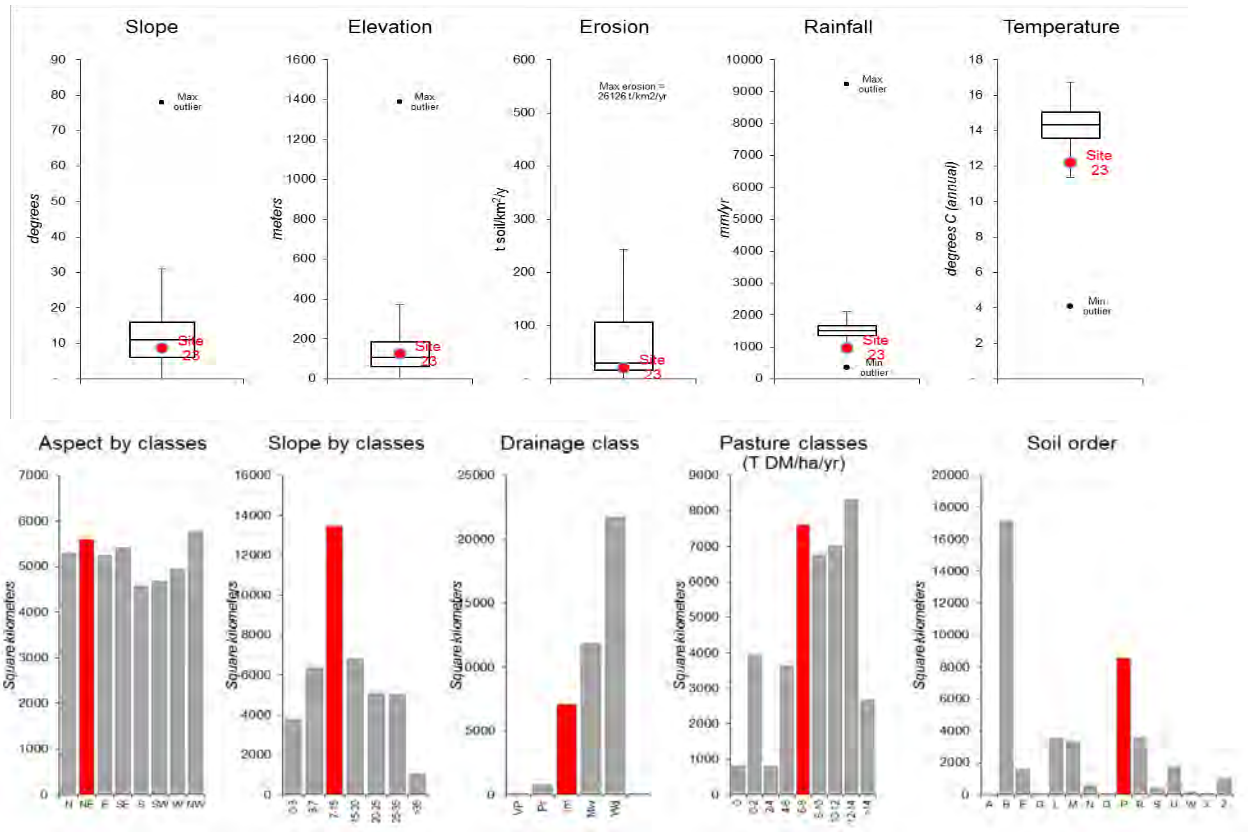


Figure A4 - 129: Representativeness of site 23 within all NZ hill country.

Table A4 - 23: Distance from the median and percent area of Site 23 characteristics according to different areas of representation.

Characteristics	*Site values*	RLA (median values)	Areas being represented (pastoral only)					
			Hill slope facet	Upper slopes within 2km²	Hill country within 2km²	Soil type (within hills)	Hill country type	Hill country all
Eligible total area	-	*0.006 ha*	*3.7 ha*	*30 ha*	*143 ha*	178 ha	*2578 km²*	*4.1 M ha*
Elevation (m)	*90*	**125**	**49**	**5**	x	**21**	**29**	**7**
Slope (degrees)	***9***	8.7	**41**	**14**	x	**34**	**14**	**12**
Aspect (degrees)	-	**25**	x	x	x	x	x	x
Erosion (t soil/km²/y)	*21.3*	x	x	x	x	**28**	**28**	**10**
Precipitation (mm)	980	**971**	x	x	x	x	**9**	**49**
Temperature (°C)	12.2	**12.2**	x	x	x	x	**25**	**46**
Upper slopes	-	x	x	x	**23%**	x	x	x
Hill country type	*5*	x	x	x	x	x	x	**6%**
Soil type	*28eH*	x	x	x	x	x	**7%**	**0.4%**
Soil subgroup	*PXM*	x	x	x	x	x	**28%**	**2%**
Soil order	*P*	x	x	x	x	x	**65%**	**21%**
Slope group	-	7-15°	**35%**	**45%**	x	**34%**	**36%**	**32%**
Aspect group	*N*	**NE**	**47%**	**26%**	x	**13%**	**13%**	**13%**
Pasture (kg DM/ha/y)	*6,860*	x	x	x	x	x	**38%**	**18%**
Drainage	*Im*	x	x	x	x	x	**35%**	**17%**

Numerical values (1, 2, 3, etc.) represent distance from the median (0-50).

Green values < 25 indicate that the characteristic is strongly representative of the population (i.e. falls within 50% of the population distribution). The closer to 0 (the median) the stronger the representation.

Orange values are marginally representative. They fall outside the interquartile range, with distance from the median being >25. Higher the value indicates increasingly marginal representation.

Red values indicate outliers that would definitely not be representative.

Categorical values have not been ranked

x indicates that the variable was not assessed because either the data were not available, or the data were not at an appropriate analysis scale for the area being represented (e.g. it would be inappropriate to use national data to make assessments at RLA and hill facet scales.

References

Basher LR, Botha N, Dodd MB, Douglas GB, Lynn I, Marden M, McIvor IR, Smith W 2008. Hill country erosion: a review of knowledge on erosion processes, mitigation options, social learning and their long-term effectiveness in the management of hill country erosion. Landcare Research Contract Report: LC0708/081. Landcare Research New Zealand Ltd. Prepared for Ministry of Agriculture and Forestry Policy (POL/INV/0708/03).

Milne JDG, Clayden B, Singleton PL, Wilson AD 1995. Soil description handbook. Lincoln, Manaaki Whenua Press, 157 p.

Schipper LA, Parfitt RL, Ross C, Baisden WT, Claydon JJ, Fraser S 2010. Gains and losses in C and N stocks of New Zealand pasture soils depend in land use. Agriculture, Ecosystems and Environment 139: 611–617.