Hill country pastures, botanical composition and productive capacity

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Abstract
Botanical composition of pastures is indicative of their dry matter production and nutritive value and so capacity for animal production. Two previous national pasture surveys were conducted in 1935/1940 and in 1987/1988, and one regional survey in 1967/1968, to assess the state of this resource across all land classes. Among many purposes, results from these surveys were used to assess the outcomes of technological advances such as aerial topdressing and oversowing in hill country from the 1950s onwards, and to record changes in the abundance of particular species such as C4 grasses that could indicate effects of climate change, and identify research needs and opportunities. In the 28 years since the most recent survey, there have been many changes in the farm operating environment. This is particularly so in hill country, where other sectors such as forestry and dairy have encroached on traditional sheep and beef land, and poor profitability has forced variable and often sub-maintenance applications of phosphate (P) and sulphur (S) fertilisers. However, the low use of P and S has been partly offset by increased use of nitrogen (N) fertiliser. The declining number of beef cows, substituted by growing dairy and dairy-beef cattle, and the remarkable increase in the per head productivity of sheep are probably the biggest changes shifting the feed demand profile and the ratio of mature: young livestock. These changes affect pasture utilisation. This paper will consider the possible effects of those changes over the 28 years since the most recent national survey of pasture botanical composition, and the future capacity and resilience of this important resource to cope with continuing farm system change, emerging pressures for productivity growth, and regulatory and compliance requirements.

Keywords: hill country pasture, botanical composition, resource status, survey

Key messages:
- Three previous pasture surveys, two on a national scale and one on a regional scale, have characterised botanical composition in pasture and these data were used to identify its productive capacity and trends in that capacity over time, and to inform investment decisions for realising the potential of this resource
- Over the 28 years since the most recent survey there have been large changes in the hill country farm operating environment. These include periods of sub-maintenance P and S fertiliser usage, increased usage of N fertiliser, reductions in stocking rates and increases in number and weight of lambs weaned per ewe, and confinement of sheep and beef to hill country as dairying expanded on to finishing land. Additionally, the numbers of beef breeding cattle have been substituted by beef and dairy-beef finishing and grazing of dairy replacement cattle
- The implications of those changes in management practices over the past 28 years are discussed in the context of current pasture botanical composition, and capacity and resilience for meeting future individual and community economic, environmental and social goals.

Introduction
Hill country pasture in New Zealand represents a major resource that influences the entire pastoral sector, and is a critical part of the economy. There are different ways of defining what constitutes hill country. Topographically, it usually includes LUC (Land Use Classification) classes 4-7 that have limited scope for cultivation and where the main limitation to pastoral farming is soil erosion (Lynn *et al*. 2009). A further definition is that it constitutes low-altitude, rolling to steep lands used for mixed sheep/cattle/deer farming systems. In terms of farm systems as defined in Beef + Lamb New Zealand sheep and beef farm survey data, hill country includes models 2 (South Island hill), and 3 (North Island hard hill) and 4 (North Island intensive hill). Hill country farms cover approximately 4.2 million ha (Smith & Dawson 1976), of which there is approximately 45% in the South Island and 55% in the North Island. There are 6100 land holdings (49% of the 12 370 commercial sheep and beef farms in New Zealand) supporting 28.3 million stock units (55% of the national total sheep and beef stock units), and generating $2.95 billion farm-gate revenue in 2014-15 from sales of lamb and sheep meat, beef, venison, wool and velvet (Beef + Lamb New Zealand 2016; note this figure includes model 1 farms (South Island High Country) as well as models 2, 3 and 4). Traditionally, this sector generated a high proportion of the sheep and beef cattle that were subsequently finished on lowland pastures. Grazed pasture is the base for this

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production and the primary protector of soils on farmed hill country. Its state is critical in catchment integrity, erosion control, and water quality.

The Government's Business Growth Agenda (Ministry of Business, Innovation and Employment, 2015) to double the real value of exports by 2025 requires the primary industries to grow at 5.5% p.a. This will require productivity gains within natural resource constraints. It is timely to review the capacity of hill country to achieve that target, using pasture and soil characteristics as a key indicator of that capacity.

Hill country pasture is an important national resource. There have been many changes in this sector in the past 3 decades including fewer traditional beef cows and substitution by dairy replacements and dairy-beef; variability in fertiliser applications; an increase in the ratio of growing:mature animals which shifts the seasonal profile of feed demand, and at the same time, limits the availability of mature, low-demand animals suitable for pasture control; greater emphasis on finishing lambs at higher carcass weights within hill country; climate change and increasing evidence of greater variability and higher frequency of climatic extremes. These factors have increased the pressure on this land to perform, despite low profitability. Yet, there has been diminished recognition of the potential of this sector and its broader importance for pastoral farming.

The objective of this paper is to consider how pasture surveys can contribute to an inventory of pasture resource state at a point in time, and if conducted at regular intervals how they might help to assess changes over time. Furthermore, by comparison with research studies, consider how surveys might help determine to what extent actual productivity differs from potential productivity.

Approach

Three previous pasture surveys have been conducted, one in 1935 (South Island)/1940 (North Island), one in 1967/1968, and one in 1987/1988. The 1935/1940 and the 1987/1988 surveys were national in scope, whereas the 1967/1968 was confined to the Manawatu region. This manuscript reviews the approach taken and the findings of the three previous surveys, particularly the

Table 1 Pasture associations described and mapped in surveys of the South Island by Hilgendorf (1935), and the North Island by Madden (1940). Note: The associations were categorised separately for each island, and there is no correspondence between the categories. The North Island associations include an estimate of the area of each association as a percentage of the total land area.

South Island	North Island
Bare land[1]	Perennial ryegrass and white clover dominant (0.4%)
Forest[1]	Ryegrass, white clover, cocksfoot and paspalum dominant (4.2%)
Second-growth lands	Ryegrass, white clover and cocksfoot dominant (2.7%)
Fern and Scrub	Cocksfoot and/or crested dogstail and Yorkshire fog dominant (4.3%)
Pakihi	Paspalum dominant (2.4%)
Tussock[1]	Paspalum, brown-top (or danthonia), and *Lotus* dominant (3.8%)
Tussock with danthonia	Danthonia dominant (12.8%)
Depleted tussock land	Browntop or Danthonia dominant (6.3%)
Irrigated lands	Browntop dominant, some sweet vernal, Yorkshire fog, suckling clover, crested dogstail, and probably danthonia and *Lotus* (14.8%)
Sand-dunes and shingle bars	Ratstail, Yorkshire fog, paspalum, and danthonia dominant generally (0.85%)
Plantations	Swampy areas, flax, raupo, scrub, and aquatic grasses (0.6%)
Short-rotation grasslands	Salt marsh (0.04%)
Short-rotation grass with chewings fescue	Tussock and scattered scrub (2.3%)
Light river flats of Westland	Sandhill country, supporting marram-grass, spinifex, and lupin (0.9%)
Long-rotation Rye-grass	Scrub (9.05%)
Fruit Lands	Forest, dense scrub and eroded country (33.4%)
Long-rotation ryegrass and lucerne	
Browntop Country	
Cocksfoot Country	
Permanent ryegrass dairy land	
West Coast heavy-grazing land	

[1] Bare land, Forest and Tussock accounted for 80%, or approximately 12 million ha, of the total land area

1987/1988 survey, and then considers changes in hill country farm systems during the past 28 years that might have affected the resilience (in this case the ability of pastures and soils to withstand the effects of variability in climate, variability in inputs such as fertiliser, and variability in grazing management) of our hill country pasture and soil resource. It should be noted that these previous surveys included all land classes, not just hill country. This paper focuses on hill country where the main pasture management tools are predominantly subdivision, aerial fertiliser and oversowing, and grazing management. In these situations pasture composition directly affects productivity and profitability because options for pasture improvement through renewal and other interventions such as growing or purchasing supplementary feeds are limited. To illustrate how previous pasture surveys have informed thinking and generated actions at the time, three examples are described below.

1935/1940

The surveys of grasslands of the South Island and North Island, undertaken in 1935 and 1940, respectively, were largely descriptive. In the first of these, while describing the purpose of this ecological survey Hilgendorf (1935) noted:

'Much information regarding a district's productive capacity can be derived from the study of soil profiles, and from chemical and mechanical analyses of the soil and subsoil, and much can also be learned from records of rainfall and temperature. But the most rapid and in some respects the most satisfactory method of describing the producing-capacity of a district, is to state what plants are growing on it, and how well they grow.'

Hilgendorf (1935) described and categorised 21 plant associations largely in accordance with their dominant plant species (Table 1), although in two cases descriptions were based on soil characteristics e.g. sand dunes, pakihi. Each association was described in terms of area and location(s) and mapped. Hilgendorf then described the areas of each association and related these to land use and productivity in six land districts covering the South Island (Nelson, Marlborough, Westland, Canterbury, Otago and Southland). Madden (1940) followed a broadly comparable method to that used by Hilgendorf and categorised 16 pasture types for the North Island according to the dominant species. For example, Type 1, perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) dominant, Type 2 ryegrass, white clover, cocksfoot and paspalum dominant, up to Type 15, scrub (Table 1), and mapped their distribution. A feature of the Madden survey was the inclusion of photographs of the general appearance of the land type and stage of development at the time for each pasture association, and a close-up photograph of the botanical composition. However, these surveys were general in nature and did not quantitatively correlate pasture type with land class.

1967/1968

In the 1967/1968 survey, Brougham *et al*. (1974) used a more quantitative approach, the frequency of occurrence technique, across four distinct topographical and soil type areas of the Manawatu: hill, terrace, flat and sand country (for hill country this was considered to be representative of a larger area than just Manawatu). In total, 150 randomly chosen farms were surveyed and on each farm, 100 tiller plugs were taken along 2 transects of the long dimension of the farm (averaging approximately 2500 m). This was conducted in early spring and again in mid-summer to assess seasonal changes in composition (Table 2). In addition to characterising pasture botanical composition, Brougham highlighted the link between pasture composition and animal productivity, noting that the 'best' hill country farm carrying approximately 17.5 ewe equivalents/ha, had frequencies of occurrence of ryegrass, white clover and browntop (*Agrostis capillaris*) of 43, 51 and 61%, respectively, compared with 2, 29 and 97%, respectively, in the 'worst' pastures. In this survey the relative abundance of browntop was used as a measure of changes that had taken place since the advent of aerial topdressing and oversowing in the 1940s. While there had not been an earlier survey to compare changes over that period, inferences were drawn based on comparison with other land types in the region. The unexpected high prevalence of browntop in hill country, despite considerable applications of fertiliser over the preceding two decades, raised questions (and generated hypotheses) about the effectiveness of these applications in hill country. These questions included the adequacy of fertiliser inputs, that

Table 2 The frequency of occurrence (%) of browntop in Manawatu pastures surveyed in spring 1967 and summer 1968 on four different land classes under grazing by sheep or cattle (Brougham *et al.* 1974).

		Season	
Land class	**Farm type**	**Spring**	**Summer**
Hill	not stated	81	87
Terrace	sheep	51	46
Terrace	dairy	42	34
Flat	sheep	21	19
Flat	dairy	15	17
Sand	sheep	26	19
Sand	dairy	23	23

nutrient cycling in hill country possibly differed from lowland where much understanding of nutrient cycling had been generated, that grazing management systems favoured browntop or that clover was not contributing adequately to fertility build up because of selective grazing pressure and/or insect pests. As a consequence, these factors were addressed in an integrated manner, underpinned by relevant, hill country-specific research at, for example, 'Ballantrae' (Lambert *et al.* 1983; 1986) and 'Whatawhata' (Sheath & Boom 1985) Hill Country Research Stations, and hill country farming practices evolved.

1987/1988

The 1987/1988 survey was based on 573 farm sites, distributed across five geographical zones of New Zealand (North, Centre and East of the North Island, and North and South of the South Island). This encompassed 109 counties in total and was proportionally representative of Land Use Capability Classes (LUC; a system for categorising land according to its capability to sustain one or more productive uses; Lynn *et al*. 2009) 1-8 (Field, 1989; Field & Roux 1993). This survey was conducted over 3 months in late spring-early summer, but because of the large number and spread of sites it did not include sampling in different seasons to account for different periods of dominance of different species e.g. cool season versus warm season, as did Brougham *et al.* (1974) in the 1967/1968 survey. Categorising on the basis of LUC made it possible to broadly differentiate flat and hill land, something that was not possible from the 1935 and 1940 surveys.

Table 3 The frequency distribution (number of farms in the sample population of 573 farms) of five pasture associations among five different geographical areas of New Zealand (Field 1989).

	North Island			South Island	
	North	Centre	East	North	South
Number of farms	120	115	116	120	112
Pasture associations					
Ryegrass-white clover	14	47	43	39	73
Ryegrass-white clover associations					
Paspalum dilatatum (paspalum)	22				
Bromus hordaceous (soft brome)				21	
Holcus lanatus (Yorkshire fog)	9	10	4	4	
Agrostis capillaris/Anthoxanthum odoratum (browntop/sweet vernal)	31	18	26	17	8
Rytidosperma spp			4		2
Vulpia bromoides (vulpia hair grass)					4
Temperate grass associations					
Holcus lanatus (Yorkshire fog)		8			
Agrostis capillaris (browntop)	20	24	2	18	2
Anthoxanthum odoratum (sweet vernal)	2	6	5	6	19
Festuca rubra (red-fescue)			2		
Sporobolus africanus (ratstail)		1	8		
Rytidosperma spp			9		3
Vulpia bromoides (vulpia hair grass)			3	3	
Subtropical grass associations					
Pennisetum clandestinum (kikuyu grass)	10	1			
Eleusine indica (crowfoot grass)	9				
Axonopus affinis (narrow-leaved carpet grass)	3				
Other associations					
Trifolium glomeratum (cluster clover)				1	
T. striatum (striated clover)					5
Pilosella officinarum (mouse-ear hawkweed)				7	

At each farm site botanical composition was visually determined in 40 cm^2 quadrats at 25 sites along a 1 km transect. Each transect was restricted to a single LUC class. Data from the 25 quadrats were combined to give a representative species profile for each transect.

Results from 1987/1988 were reported in terms of 1) the frequency distribution of five descriptive pasture associations for each geographical zone (Table 3; described as ryegrass-white clover, ryegrass-white clover associations, temperate grass associations, sub-tropical grass associations and other associations); 2) Land Use Capability Class (Table 4; described as ryegrass dominant, ryegrass associations, warm-season associations, moderate fertility and low fertility); 3) the association between pasture type, farming enterprise and productivity, and 4) the distribution of C4 grasses as a potential indicator of climate change. 'Ryegrass-white clover associations were least prevalent in the north of the North Island (14 out of 120 farms) and most prevalent in the south of the South Island (73 out of 112 farms) and ryegrass-white clover and 'ryegrass associations' were most abundant in LUC 1-3, whereas 'low fertility' associations dominated LUC 6 and 7. For hill country, typically LUC's 4-7, while ryegrass dominant and ryegrass associations were the dominant pastures types in LUC 4, moderate and low fertility clearly were dominant in LUC 6 and 7. Field & Roux (1993) also categorised on the basis of stocking rate (more comprehensively than did Brougham *et al*. (1974) in the 1967/1968 survey), and showed the highest stocking rates were associated with ryegrass dominant associations (15.9 stock units (su)/ha), intermediate for ryegrass and warm season associations (11.7 s.u./ha), and lowest for moderate and low fertility associations (9.4 su/ha). They also showed this was partly confounded with animal enterprise because dairy was concentrated on ryegrass dominant pastures and had higher stocking rates than beef or sheep. The 1987/1988 survey also included a specific objective to assess the distribution of sub-tropical (C4) grass species. The prevalence of C4 grasses is influenced by temperature and so is a potential indicator of climate-induced change. C4 grasses have different seasonal growth and nutritional profiles compared with the predominant temperate (C3) grasses and increases in their prevalence would markedly influence farm systems. Field & Roux (1993) concluded that the contribution of C4 grasses remained low, even in the northern zone where they were most common [see Field & Forde (1990) and Campbell *et al*. (1996; 1999) for further discussion relating specifically to C4 grasses]. This low contribution of C4 grasses was recorded in early summer when their abundance could be expected to be rising towards a seasonal peak.

Discussion

Surveys versus longitudinal studies

While surveys conducted at intervals indicate broad trends compared with previous (e.g. 1987/1988 compared with 1935 and 1940), or against an expected composition (e.g. in 1967/1968 there was an expectation of a lower frequency of browntop than was actually observed), comparisons are often constrained by differences in survey methodology used and the potential for trends in composition to be influenced at least in part by the sample of sites selected. An alternative approach is a longitudinal study where fixed sites (or research treatments) are monitored over time. Long term monitoring of pasture botanical composition has occurred in the fertiliser trials on flat land at Winchmore, Canterbury (started 1952; Smith *et al*. 2012), on hill country at Ballantrae in southern Hawkes Bay (started 1975, Lambert et al. 1983; 1986), and at Whatawhata, in western Waikato (from the early 1950s, Sheath & Boom 1985). There are long term plots of oversown natural grasslands in alpine Central Otago (Douglas 1970, the so-called 'Cockayne Plots' established in 1920 by Leonard Cockayne and now protected by a QEII National Trust covenant) that are accessible for ad-hoc monitoring. There is a long term grassland experiment in Hertfordshire, UK (the Park Grass experiment, started in 1856; Silvertown *et al*. 2006), but again this is a single-site, semi-controlled experiment

Table 4 The frequency distribution (number of farms in the sample population of 573 farms) of pasture types among land use capability classes (Field & Roux 1993). (Note: The pasture type categories used in this Table differ from those described by Field (1989) and presented in Table 3).

	Land use capability class						
Pasture type	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Ryegrass dominant	8	46	56	23	0	1	0
Ryegrass associations	1	15	44	44	3	44	2
Warm-season associations	0	1	1	9	0	14	8
Moderate fertility	0	3	15	27	1	50	16
Low fertility	0	2	14	17	3	69	36

rather than a broad-based survey that encompasses a range of farming conditions and practices across diverse land types and regions. With limited resources, the survey approach has the advantage of being able to cover a more diverse range of environments, despite the constraints described earlier. Modern technology for permanently recording the location of sites, allows for some of the benefits of longtudinal studies to be captured using a survey approach. A mixed approach that included both fixed sites (e.g. research sites) and farm-based survey would be ideal. Research sites can indicate potentials, for example, of pasture production and botanical composition under controlled conditions, whereas surveys can indicate the extent to which that potential is realised under practical conditions.

Recent changes in farming practices

Over the 28 years since the previous survey, farming practice has changed in many ways. Listed below are some of those changes that could be expected to influence pasture botanical composition:

- Fertiliser usage: fertiliser use is highly variable, ranging from a low of 78 500 tonnes of P in 1988/89 to 218 600 tonnes in 2004/2005 (P. Mladenov, Fertiliser Association, pers. comm.), associated with climatically more favourable years and better returns during the 2000s. Over this period, applications of N fertiliser have increased 10-fold from 37 800 to 397 000 tonnes. During the 20-years 1994/1995 to 2013/2014 there was a near two-fold variation in the mean application of fertiliser per s.u. on sheep/beef farms between the lowest (13 kg/su) applied in 2008/9 and the highest (25 kg/su) applied in 2001/2002 and again in 2004/2005 (Beef + Lamb New Zealand 2015). These statistics are total applications for New Zealand (data specific to hill country are not available), and it is likely that applications on hill country would be even more variable because of lower profitability, and higher costs per unit of fertiliser applied compared with lowland farms.
- Increasing pressure on hill land: the expansion of dairy production and dairy support has used much land previously available for finishing meat-producing animals. There is increasing pressure to finish more sheep and beef animals on these pastures, that previously would have been sold store and transferred to finishing farms
- Changes in sheep genetics: there has been a large increase in the number and weight of lambs produced/ewe lambing, resulting in a 22% increase in the weight of lamb produced per ewe (Beef + Lamb New Zealand 2015). The resulting higher ratio of growing: breeding animals in most farm flocks, has shifted patterns of feed demand affecting the proportions of different stock classes and the way pastures can be managed
- A decrease in the number of beef cows: the beef industry increasingly uses cross-bred dairy-beef animals from the dairy industry rather than traditional beef breeds (beef cattle numbers decreased 18% from 2004-2014 (Beef + Lamb New Zealand 2015). Fewer beef cows, means fewer animals are available to be used for pasture/weed management without major limitation to their productivity. Maintaining quality in hill country pasture in late-spring and summer becomes increasingly difficult as the proportion of growing animals with a high dry matter intake requirement increases in the farming system and the proportion of low-demand (e.g. beef cows) animals decreases
- Provision of services to the dairy sector: hill lands are being used for wintering dairy cows and for rearing replacement dairy heifers
- Climatic changes: already observed, and predicted future changes in climate and weather patterns will affect these pastures. Higher ambient temperatures, particularly on north-facing slopes in summer, changes in rainfall and its seasonal distribution, greater variability and increased frequency of extreme rainfall and droughts, and increasing atmospheric concentrations of CO_2 will all potentially affect pasture botanical composition, soil characteristics and so the resilience of hill land
- Biotic stresses: in the last 15 years clover root weevil has spread throughout the country, affecting the growth of white clover and as a consequence the potential for biological N fixation. White clover in hill country is more vulnerable to changes such as this, and could be expected to suffer proportionally more, and recover more slowly
- Special-purpose pastures: the increasing use of novel species such as plantain and chicory in hill country systems to support intensive finishing obviously influences the botanical composition of the total farm feed supply, but it may indirectly affect pasture utilisation and so composition on the remaining areas of the farm.

Each of these factors alone, and certainly when considering their combined effects, could be expected to influence pasture botanical composition. However, the net effect is difficult to predict because some factors, such as low and variable fertiliser usage, would be expected to have negative effects on the proportions of desirable species, but others may have positive effects.

Future capacity

The specific priorities for assessing the current state of pastures and predicting future capacity are likely to change with each successive survey, but identifying trends over time has broad applicability. In previous surveys the prevalence of browntop and C4 grasses were important questions at the time. Realising the potential of hill country to contribute to the Government's Business Growth Agenda (Ministry of Business, Innovation and Employment, 2015) to double the real value of exports by 2025, is a current priority. With a changing climate this base-line information offers even greater utility. In future, soil characteristics, particularly organic matter may become increasingly important. Soil organic matter is one indicator of soil condition, and soil carbon in particular may be relevant in terms of mitigating greenhouse gas emissions (Parsons *et al*. 2009). There are indications that soil carbon has increased on hill country pastures, whereas it has decreased on dairy pastures (Schipper *et al*. 2007). Similarly, for pasture quality there is a direct connection to current and future greenhouse gas challenges. Inventory calculations of methane emissions are based on dry matter intake of livestock, by species and class. Assessment of pasture quality, a key driver of dry matter intake, would allow for refinement of these calculations by accounting for differences in quality across regions, land classes and farming systems and over time adjustments of these calculations to improve the accuracy of New Zealand's obligations under international agreements. Pasture quality has not been assessed in any previous surveys, although broad inferences have been drawn from the proportions of high nutritive value species such as white clover. Verification of this trend is important to inform policy and practice, as is understanding and predicting the direction of future trends.

Conclusions and practical implications

Since the most recent national pasture survey conducted in 1987/1988, there have been many changes in farm systems and farming practices. Over time, all of these changes could be expected to affect the condition and resilience of the hill country pasture resource. Botanical composition influences pasture production, its seasonal distribution of production and its nutritive value. Characterising this is important for awareness of responses to past changes in management practices and environmental influences, and for identifying future inputs that might be required to sustain or improve hill country pasture. Another important potential purpose of surveys is the opportunity to inform future research priorities. Given the current renewed focus on the potential of hill country, it is pertinent to ask what are the implications of those changes over the past 28 years in terms of current pasture botanical composition, and the future productive capacity and resilience of this important resource.

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