UNITED NATIONS UNIVERSITY
UNU-LRT
Land Restoration Training Programme
Keldnaholt, 112 Reykjavik, Iceland *Final project 2011*

RANGELAND HEALTH METHODOLOGY: A STUDY OF LAEKUR, GUNNARSHOLT, SOUTHERN ICELAND

Paulina Peter Lokongo
Napak District Local Government
P.O. Box 106, Napak
Uganda
plokongo@yahoo.com

Supervisor
Dr Johann Thorsson
Soil Conservation Service of Iceland
johann.thorsson@land.is

ABSTRACT

Rangelands are non-arable areas used primarily, but not exclusively, for grazing livestock such as sheep, goats and cattle. Rangelands cover about one-half of the Earth's land surface. Rangeland health is the degree to which the integrity of the soil, vegetation, water and air, as well as the ecological processes of the rangeland ecosystem, are balanced and sustained. Rangeland health assessment is carried out by measuring attributes and indicators present in the current state relative to an expected norm referred to as the reference state. In this study eight indicators, namely, grass cover, moss cover, surface strength, sward thickness, pedestal heights, bare soil, rock and shrub cover were used to assess a site at Laekur, 3 km south of Gunnarsholt, in Iceland. The indicators were used to evaluate the three processes since they are difficult to measure: Nutrient cycle, Water cycle and Energy cycle. Cryoturbation was added due to its importance in Iceland. At the study site a stratified random sampling scheme was adapted to collect data from three parallel 30m transects, oriented NE-SW. Six 50x50 cm plots were placed perpendicularly at 5 m, 15 m, and 25m. Each site had a total of 18 plots at each site. The reference area has high grass cover 72.6%, moss cover 26.8%, a surface strength of 81.8kNm$^{-2,}$ no bare soil areas, no shrubs, a surface strength of 16.7cm, no pedestals and no rock. In comparison, the lower land with poor condition had less grass cover 9.3%, moss cover 23.6%, change in grass cover into dominant shrubs of 33.7%, a high percentage of emerging bare soil 31.9%, reduction in surface strength of 58.1kNm^{-2}, high sward thickness 6.6cm, high pedestal heights of 9.9cm and high rock percentages of 1.2%. I concluded that the land was in relatively good condition. Bare soil spots are found in both the upper land and the low land, but they are not connected. Signs of disturbances are present in the low land, putting it at risk compared to the reference area and the upper land.

Key words: rangeland; rangeland health; ecological site; landscape attributes; cryoturbation; Iceland

This paper should be cited as:

Lokongo PP (2011) Rangeland health methodology: A case study of Laekur, Gunnarsholt, Southern Iceland. United Nations University Land Restoration Training Programme [final project] http://www.unulrt.is/static/fellows/document/Lokongo2011.pdf

TABLE OF CONTENTS

1. INTRODUCTION 2
2. THE RANGELAND HEALTH BACKGROUND 3
  2.1 Rangeland health methodology 6
  2.2 Rangeland health conceptual models 6
3. METHODOLOGY 7
  3.1 Study Area 7
  3.2 Site description 8
  3.3 Sampling methods 11
  3.4 Data analysis 12
4. SITE ASSESSMENT RESULTS 14
  4.2 State and transition module for Laekur 20
  4.3 General discussion 21
5. CONCLUSION 22
ACKNOWLEDGEMENTS 23

1. INTRODUCTION

Rangelands are described as non-arable areas used primarily, but not exclusively, for grazing livestock such as sheep, goats and cattle. They cover about one-half of the Earth's land surface (Tongway & Ludwig, 2010). Rangelands vary in type and in location. The growing population has exerted pressure on rangelands due to more demand for goods and services. The use of rangelands is intensifying, resulting in extensive rangeland degradation and desertification (Geerken & Ilaiwi, 2004).

Rangeland degradation can reduce the diversity and amount of value and commodities that they provide, and severe rangeland degradation may become irreversible (van den Berg & Kellner, 2005). Activities such as overgrazing, drought, erosion and other human and naturally induced stresses have caused severe degradation in the past, resulting in scientific inquiry and public debate since the 1880s (Pyke, Herrick, Shaver & Pellant, 2002), when there was widespread range degradation and livestock losses. These led to the first attempt to inventory and classify rangelands by scientists where they are now questioning the current utility of the classification method and inventory so as to determine whether and in what respect rangelands are being degraded.

The rangelands in the World are found within arid, semi-arid and dry sub-humid climates, where topography and soils are unsuitable for farming (Thomas, 2008). They are traditionally used for pastoralism, hunting, bush food gathering and firewood, but today also for mining and tourism. Rangelands are affected by heavy grazing, wildfires and intentional use of fire, all which cause changes to various degrees and extents (Kassahun, Snyman & Smit, 2008).

Conditions differ from area to area. To understand and detect changes in ecological and social systems, their states and transitions, stability, resilience and how they relate, a new approach or guide is needed (Yapp, Walker & Thackway, 2010).

To assess rangeland condition, a methodology often referred to as Rangeland Health Assessment can be performed; e.g. (Briske, Fuhlendorf & Smeins, 2005; NRC, 1994; Teague et al., 2008). It provides tools that help land users interpret the landscape and react in time before land degradation becomes irreversible. Rangeland health assessment is about evaluating ecosystem processes using indirect methods to determine whether an ecosystem is at risk or healthy under the current management scheme (Roba & Oba, 2009). Constructing a rangeland health methodology requires understanding of ecosystem processes and how they are expressed in the environment.

Uganda's range lands cover an estimate of 84,000 k m^2, 43% of the total country land area and are home to a population of 6.6 million people (Statistics, 2003). Land degradation is a major threat to Uganda's land resources and agricultural production (National Environmental Management Authority, 2008). This is caused by communal land tenure systems, overgrazing, tree cutting for firewood and charcoal, bush burning, soil compaction from trampling of animals reducing vegetation cover hence rangeland degradation, soil erosion and landslides (Tongway & Ludwig, 2010).

Uganda's rangelands are valued as a source of food and income, and are thus important for the livelihoods of the people. They have increasingly been mismanaged due to resource scarcity and increasing population (National Environmental Management Authority, 2008). An example is the Napak district in the Karamoja region. It is characterised by nomadic pastoralism. The pastoralists keep large numbers of animals and move from place to place, practicing bush burning to allow fresh regeneration of grass and tree cutting (Solomon, Snyman & Smit, 2007). These, combined with climatic factors, increase vulnerability to soil erosion. There is an urgent need to educate people so that they can understand the complexity of the ecosystems and the consequences of their activities to help them detect and understand the signs of land degradation (Raymond et al., 2010).

A rangeland health assessment guide would be a valuable tool for such land interpretation. It would help land managers to manage their land, but also incorporate women and men in the range management programme, as both sexes are actively involved in the land use management. Women would, however, benefit proportionally more from a better management scheme as they usually have the responsibility of finding grazing for animals and to collect firewood, in addition to preparing food and taking care of the children. Improved land management will increase land production, and thus gradually reduce this burden on women (Pender, Nkonya, Jagger, Sserunkuuma & Ssali, 2004). Furthermore, this would open up opportunities for the older female children to go to school to have another life and become the hope of the family (Brown, 1996).

The purpose of this project was to conduct a preliminary rangeland health assessment at a selected site in Iceland, using a well-known rangeland health assessment methodology developed by NRC (1994). This methodology is intended to: provide preliminary evaluation of ecosystem functions and site stability, be a tool to educate people on fundamental ecological concepts and improve communication between groups on ecosystem processes, and provide a basis for early warnings of potential problems so landscapes at risk can be identified and mitigation actions taken.

It is hoped that the method will empower the local communities in Uganda and other countries where land degradation is triggered by land-mismanagement.

This report describes a preliminary landscape assessment conducted at Laekur. Gunnarsholt, based on rangeland health methodology as described in Pellant et al., (2005a) It is intended as a training in applying rangeland health methodologies that may later be adapted to and applied in rural areas of Uganda.

2. THE RANGELAND HEALTH BACKGROUND

Rangeland health is defined as the degree to which the integrity of the soil, vegetation, water, and air, as well as the ecological processes of the rangeland ecosystem, are balanced and sustained (Pellant et al., 2005a). Integrity in this case refers to "maintenance of the functional attributes characteristic of a locale, including normal variability" (NRC, 1994). It has replaced the terms 'range condition' and 'ecological status' that have been used by federal agencies (Pyke et al., 2002).

Rangeland health assessments are conducted at ecological sites (see Fig. 1 for an overview). They are predefined areas based on soil, vegetation and climate information, hence providing land managers with tools on which to base vegetative management, restoration, performance criteria and risk assessment, and monitoring decisions (Gibbens, McNeely, Havstad, Beck & Nolen, 2005). This approach has its limitations as the term is based on the previously established concept of range sites, rather than a systematic classification system (NRC, 1994; USDA, 1997)

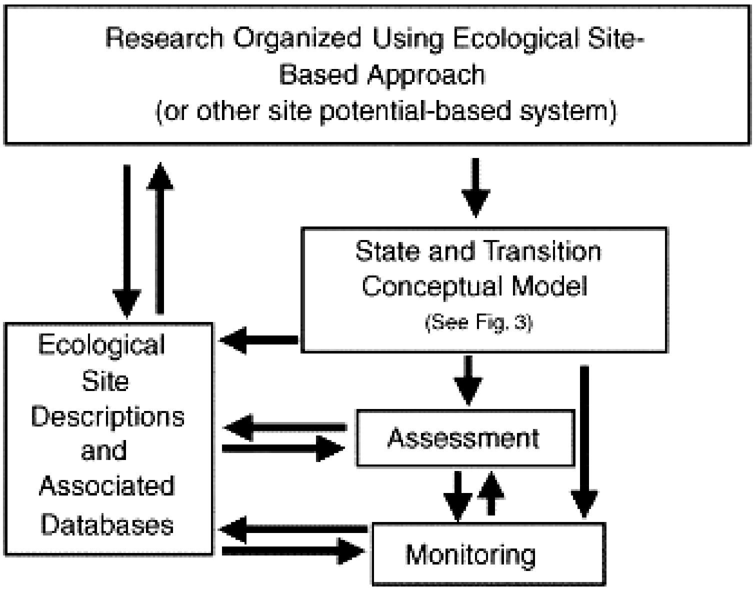

Fig 1. *Framework for organizing, synthesizing, and applying the evolving understanding of arid land ecosystems and five elements and their relationships to each other (Teague et al., 2008).*

An ecological site as defined for rangeland is a distinctive kind of land with specific physical characteristics that differ from other kinds of land in its ability to produce a distinctive kind of vegetation (NRC, 1994; USDA, 1997). It provides more information on ecological processes and dynamics through incorporating state and transition models, which are indeed the precursors for the rangeland health methodology (Herrick, Schuman & Rango, 2006).

The rangeland health of an area is assessed by measuring attributes and indicators of its current functional state relative to an expected norm (reference state). An indicator is a simple index for a difficult to measure attribute (Pyke et al., 2002).

The rangeland health concepts acknowledge the presence of ecosystem thresholds in the system (Krogh, Zeisset, Jackson & Whitford, 2002). A threshold indicator value for irreversible change in ecosystem structure and function was used to determine the health of the rangeland (Fig. 2). The conclusion was that a value of 20% shrub cover was critical for the existence of the area's keystone species, the banner tailed kangaroo rat (*Dipodomys spectabilis*), hence representing the threshold value for that attribute in the Chihuahua desert (de Soyza, Whitford, Herrick, Zee & Havstad, 1998).

Rangeland health assessment is used to estimate the risk of the loss of the rangeland capacity to produce commodities by assessing its ability to maintain internal nutrient cycles, energy flows, plant community dynamics, and intact soil profile, and stores of nutrients and water (NRC, 1994). Rangeland management is important to prevent human-induced loss of rangeland health. Unhealthy rangelands require large investments of time, money and energy to restore (Ferretti & de Britez, 2006). Even with restoration, there may be permanent loss of capacity to produce commodities and to maintain essential processes required in the rangeland. This may result in decreased options to use the rangeland in the future (Tongway & Ludwig, 2010).

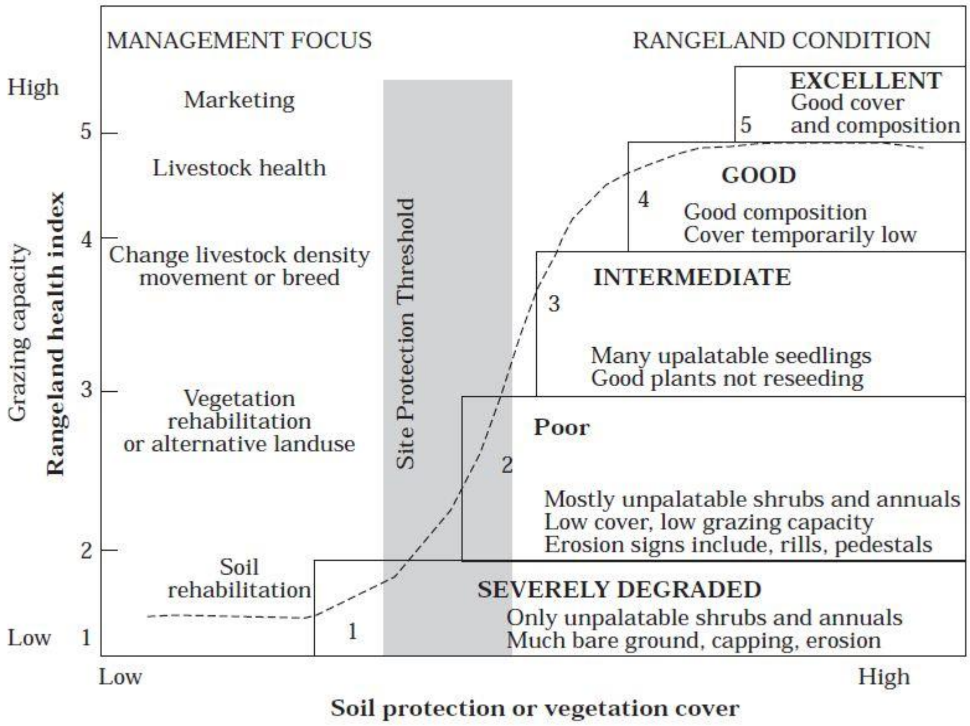

Fig 2. *Rangeland health assessment index, see text for explanation (Milton, Dean & Ellis, 1998)*

The Natural Research Council (1994) stated that rangelands can be placed in three broad categories based on an evaluation of the soils and ecological processes: (1) healthy if an evaluation indicates the capacity to satisfy values and produce commodities is sustained; (2) at risk if the assessment of current conditions indicates a reversible loss in productive capacity and increased vulnerability to irreversible degradation; (3) unhealthy if the assessment indicates degradation that results in loss of capacity to provide values and commodities that cannot be reversed without external inputs.

Rangeland health evaluation requires a study of the soil stability, watershed function, and nutrient cycling and energy flow within the rangeland (Hobbs, 1997). Rangelands can be categorized as healthy, at risk, or unhealthy when two boundaries are defined: (1) the boundary distinguishing healthy from at-risk rangelands and the boundary distinguishing at-risk from unhealthy rangelands (Fig. 2). Rangelands can adapt to changes in their use or management in the environment through alterations in ecosystem characteristics such as plant composition, the amount of plant biomass produced, and the amount of nutrients and the rate at which they are recycled, and the amount and composition of soil organic matter (du Pisani, Fouché & Venter, 1998). The ecological state of the rangeland is the sum total of these characteristics (Eldridge & Koen, 1998). The rangeland ecosystem shifts between different ecological states over time in response to natural or human-induced factors. Such changes may be sudden or they may occur gradually (Reid, Wilcox, Breshears & MacDonald, 1999) .

According to Roba and Oba, (2009) in his study the Kenyan grazing resources were classified into 39 landscape patches and grouped into six landscape type. These classifications included warm, intermediate or cold, in terms of land use. In addition they also recognized that a particular suite of indicators can be useful to land managers in order to detect changes in the rangeland, similar to the approach used by Pellant et al (2005b)

The forum paper by Briske et al, (2011) recommended rotational grazing by focusing on adaptive management and the integration of experimental and experiential, as well as social and biophysical, knowledge to provide a more comprehensive framework for the management of rangeland systems. In the Karamoja region of Uganda, most pastoralists have been using rotational grazing as a management strategy to their rangelands where they move in search of pasture to kraals in the dry season and in the wet season they move back home. This strategy could allow the regeneration of grass/pasture.

2.1 Rangeland health methodology

Rangeland health is a concept describing methodologies where energy, hydrologic and nutrient cycles are assessed, quantitatively or qualitatively. There are a variety of methods that have been applied in order to detect changes in the rangeland; the challenges are to determine whether the changes were natural or due to management or their interactions. In addition rangelands are dynamic; they always respond to climatic cycles, weather, fire, insects, grazing/browsing/soil disturbances by all animals living on the land and other physical disturbances and not just to livestock grazing (Teague et al., 2008)

Rangeland health assessment is about evaluating ecosystem processes using indirect methods to determine whether an ecosystem is at risk or healthy under the current management scheme (Roba & Oba, 2009). Constructing a rangeland health methodology requires understanding of ecosystem processes and how they are expressed in the environment (Fig. 2) (adapted from Milton, Dean & Ellis, 1998).

Quantitative, qualitative and observational procedures, combined with functional status of the selected indicators, are used to derive the rangeland health condition (De Soyza, Whitford & Herrick, 1997). However, the indicators can be more technical to people with little or no knowledge with the rangelands ecosystems.

The boundary between healthy and at-risk defines an early warning line, while an at-risk categorization signals the need to take corrective action or to further investigate the site to determine the seriousness and causes of the degradation (Gollan, Bruyn, Reid, Smith & Wilkie, 2011, adapted from Sadler, Hazelton, Boer & Grierson, 2010).

To determine whether a rangeland is healthy, at-risk, or unhealthy involves evaluation of three main criteria; degree of soil stability and watershed function, integrity of nutrient cycles and energy flows, and the presence of functioning recovery mechanisms.

2.2 Rangeland health conceptual models

Many models have been developed to describe rangelands dynamics; these include the range succession model (Dyksterhuis, 1949), and the state-and-transition model (Westoby, Walker & Noy-Meir, 1989). The range succession model supports that a given rangeland has a single persistent state (the climax) in the absence of grazing. Succession towards this climax is a steady process. Grazing pressure produces changes which are also progressive and in the opposite direction to the successional tendency. The state-and-transition model proposes that rangeland conditions can be described by a set of discrete states of the vegetation, and a set of discrete transitions between the states. These transitions between states are triggered by natural events e.g., (weather, fire) or by management actions (change in stocking rate, burning, destruction or introduction of plant populations, fertilization, see Fig.3).

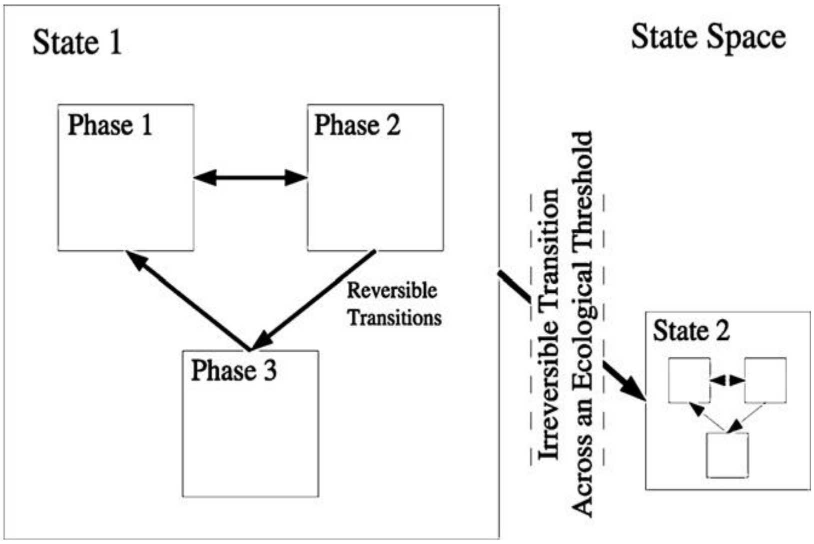

Fig. 3. *State-and-transition model, see text (Sadler et al., 2010)*

The state-and-transition model has gained wide popularity since they were introduced (Ludwig, Tongway, Hodgkinson, Freudenberger & Noble, 1996; Sadler, Hazelton, Boer & Grierson, 2010; Shinneman, Baker & Lyon, 2008; Suding & Hobbs, 2009) . This model is however limited due to the following factors: demographic inertia, grazing catastrophe, competition priority, fire positive feedback and vegetation change that triggers a persisting change in soil condition that may not be reversible on a time-scale relevant to management (Clements & Young, 1997). The weakness of the state-and-transition model is apparent in arid and semiarid rangelands where episodic events are important and influences of grazing and intrinsic vegetation change act intermittently (Ludwig, Wilcox, Breshears, Tongway & Imeson, 2005).

Roba & Oba´s (2009) model of landscape classification integrated the indigenous knowledge; however, it was limited to understanding of the dynamic interactions between soil, vegetation, climate, and animals as being driven by complexities in different environmental conditions in the study area. They were thus faced with similar constraints as are present to a person wishing to promote and adapt rangeland health methodologies to Uganda’s rangelands.

3. METHODOLOGY

3.1 Study Area

Iceland has a fragile ecosystem where livestock grazing combined with highly erodible volcanic soils and a harsh climate have caused extensive vegetation degradation and soil erosion since settlement in A.D. 874 (Arnalds, 1987). This has resulted in a fight against soil erosion as a long-term factor in the history of Iceland. The controlled revegetation of eroded land started about a century ago (Thorsson, pers. com.). The main effort included range improvement by seeding grasses, stone lining, fencing off and application of fertilizers.

The climate of Iceland is maritime with cool summers and mild winters. Freezing and thawing is common in the winter, which results in frequent frost movement in soil, i.e. cryoturbation; hence earth hummocks are ubiquitous (Einarsson, 1963).

3.2 Site description

The study area is located at Laekur 3 km east of Gunnarsholt, South Iceland (Fig. 4). The Laekur area sits on top of one of the many Hekla lava fields in the region. The bedrock is porous, thus there are no surface streams within the area. The vegetation is typical for Icelandic heathlands; grasses, forbs, mosses and small shrubs. Dominating vegetation species belong to *Racomitrium sp*., *Festuca sp*., *Salix sp*. and *Betula sp*.

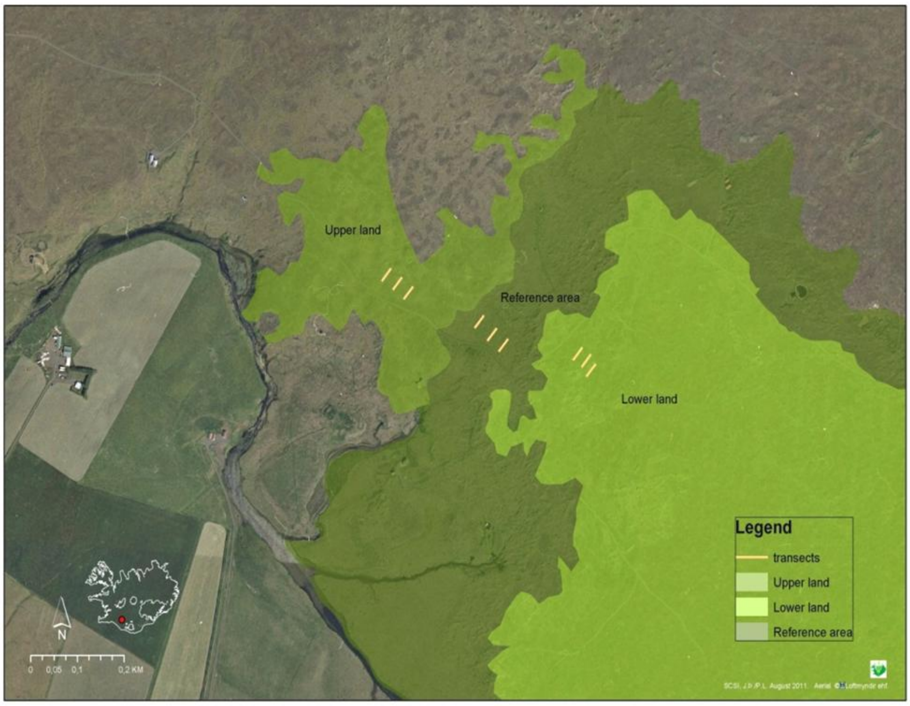

Fig. 4. *Map showing the location of the Laekur site and low land, and the three ecological sites as they are defined in this study, with transects shown.*

The study area was divided into three sub-areas, based on topography and surface characteristics (vegetation composition, erosion; Fig 4). For the purpose of this study, the three sub-areas represent ecological sites and are referred to as the Upper Land, the Reference Area and the Low Land. The Reference Area was used as a reference for the other two areas, as indicated by the name. The largest proportion of the Reference Area consisted of level lush grassland, but also a hill slope. The slope was not a prominent feature in the landscape and not considered a separate landscape feature in this study despite the topographical distinction. Care was also taken to exclude the slope when data were collected. The largest proportion of the Reference Area consisted of level lush grassland. Here it is used as a reference area for the other two areas, as indicated by the name.

Site identification was carried out on 25 June; data were collected on 7-8 July 2011. Photographs were taken during data collection with additional photos taken on 1 September 2011, see Fig. 5-10.

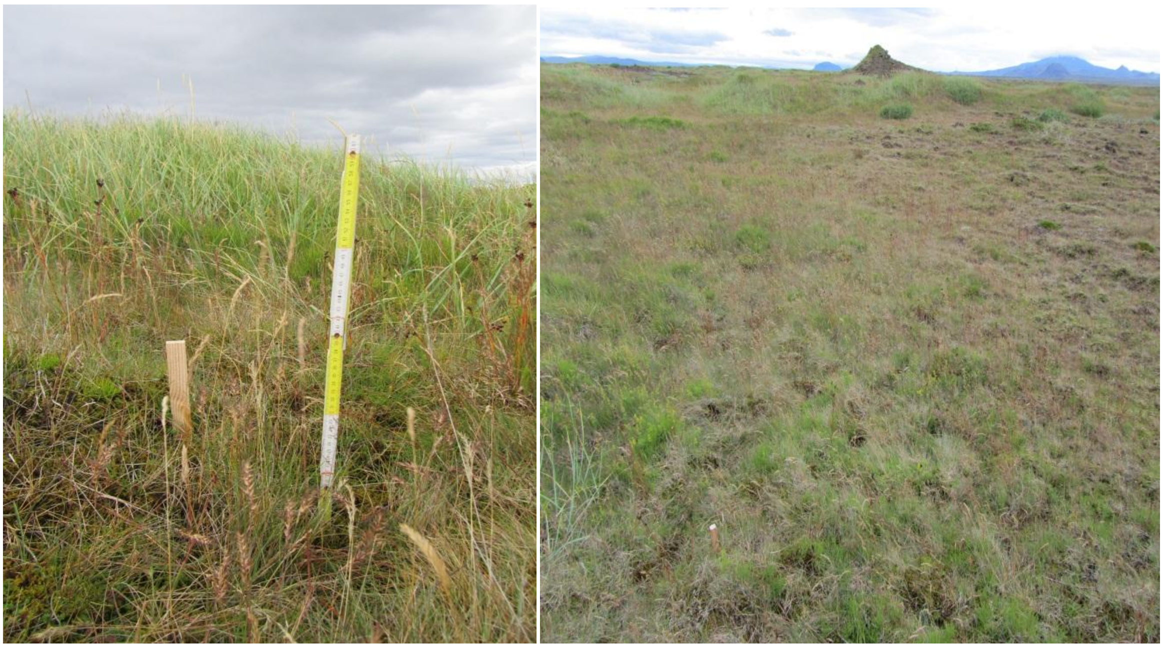

Fig.5. *Vegetation at the Upper Land. Vegetation height (left) and the Upper Land area (right). (Photo: J. Ocaka. 1st Sept. 2011).*

Fig. 6. *Bare soil (frost boils, left and soil erosion spots, right) onat the Upper Land.(Photo: J. Ocaka, Sept 1st 2011).*

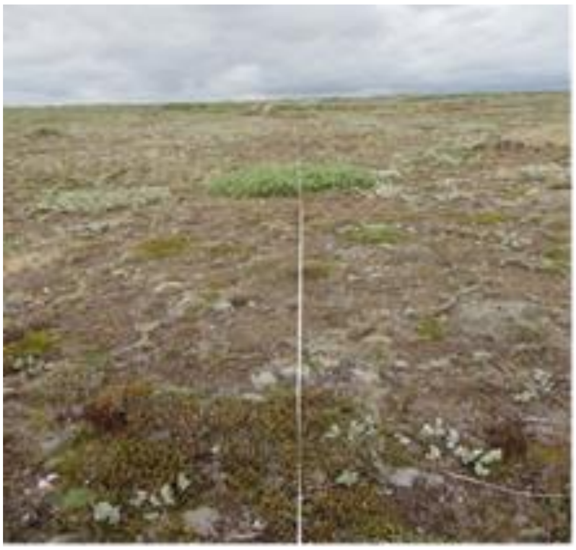

Fig. 7. *Transect at the Lower Land (left) and and sampling frame next to the transect (right).(Photo: A. Balt, July 8th 2011).*

Fig. 8. *Vegetation sampling frame next to the transect on the Reference Area. (Photo: A. Balt, July 8th 2011).*

Fig. 9. *Surface strength measured on the Upper Land (left). Erosion and pedestals on the Upper Land (right). (Photo: A. Balt, July 8th 2011).*

Fig. 10. *Bare soils and pedestals at the Low Land (Photo: J. Ocaka, Sept 1st 2011).*

3.3 Sampling methods

A stratified random sampling scheme was adopted in the field. At each site, three parallel 30 m transects, orientated NE-SW, were established for collecting descriptive base data for each site area (see Fig 4). Their location within each area was selected so it would be representative for the area. At each transect, six 50x50 cm sampling plots were placed perpendicularly 50 cm from both sides of the transect line, at 5 m, 15, and 25 m (Fig. 11). Each site had thus a total of 18 sampling plots. All transect positions were recorded with a handheld GPS unit (Garmin V; Garmin Inc., Olathe, KS) with an estimated precision of 5 m.

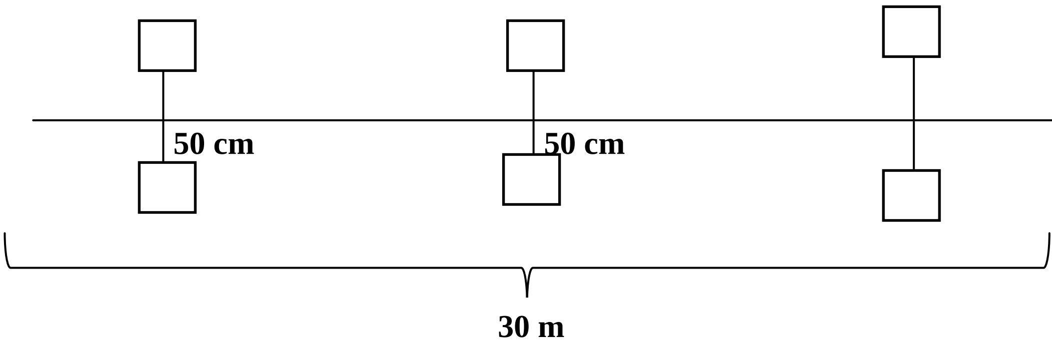

Fig. 11. *The six plots collected per 30m transect measuring 50cm by 50cm on both sides.*

The following vegetation variables were quantified: cover of mosses and lichens, grasses and forbs, and woody species (incl. small shrubs) using Braun-Blanquet cover estimate (Braun-Blanquet, J. 1965); and vegetation thickness. Total cover of bare ground and stones/rock was estimated separately to the nearest 5%. Other measurements included soil strength using a hand held penetrometer (type 0601SA, Eijelkamp, Giesbeek, the Netherlands) with a 5.0cm^{2,} pointed end, and total height of soil pedestals using a yardstick.

Rangeland health assessment aims at quantifying three main ecosystem processes: the energy cycle, the hydrologic cycle and the nutrient cycle. All these processes are closely interrelated. If one is dysfunctional, the others will be correspondingly impaired. The data that were collected represents all these processes to a degree, as is indicated in Table 1. A fourth property was given attention in this study, the surface stability. In high latitude ecosystems like Iceland, temperature driven disturbances such as cryoturbation processes are an integrated part of the ecosystem. These processes affect the three before-mentioned processes and are thus an important factor to consider when rangeland health is assessed. Here this is referred to as the “cryoturbation cycle”; its relationship with the indicator variables and other attributes can be seen Table 2. Each indicator was evaluated and assigned a value of one to five, based on its departure from what is expected for the ecological site when compared to the reference site.

In addition, an estimation of intensity of cryoturbation processes was added, due to their local importance in Iceland. Cryoturbation processes contribute to surface stability and hence affect the energy, nutrient and hydrologic cycle. However, their presence is a very important sign of potential degradation; they are included here because of the underlined importance of adapting methodologies locally.

3.4 Data analysis

The data were analysed using the SPSS statistical software programme (SPSS, 2004). Data were screened for outliers and equity of variance. Means for all three areas were compared with Univariate Anova of Variance followed by Bonferroni Multiple Comparison. When only two areas were compared, a Student’s t-test was applied.

Table 1. *Project data collected from all the 3 transects at each site, eighteen plots per site. Blank spaces indicate that the feature was not present at the site.*

AREA	AREA_2	(%) Grass	(%) Moss	(%) Shrubs	(%) Bare soil	Strength (kNm^2)	Thickness (cm)	(%) Pedestal	(%) Rock
Ref	1	80	20			400	15		
Ref	1	30	70			300	19		
Ref	1	95	5			320	22		
Ref	1	97	3			240	15		
Ref	1	60	40			360	14		
Ref	1	75	25			400	14		
Ref	1	70	30			460	17		
Ref	1	95	5			400	13		
Ref	1	90	10			460	16		
Ref	1	90	10			400	16		
Ref	1	90	10			320	20		
Ref	1	80	10			500	20		
Ref	1	60	40			500	14		
Ref	1	70	30			520	17		
Ref	1	75	25			440	15		
Ref	1	55	45			480	17		
Ref	1	35	65			340	19		
Ref	1	60	40			520	18		
Low	2	5	5	20	70	260		19	
Low	2	5	10	65	20	280		19	
Low	2	5	2	15	48	200		20	20
Low	2	25	10	15	50	260		15	
Low	2	50	15	25	10		40		
Low	2	10	5	10	75	300			
Low	2	5	55	5	35	320			
Low	2	5	10	60	25	280	1		
Low	2	1	50	49		400	6		
Low	2		30	50	20	340	4		
Low	2	10	30	45	15	300	5	16	
Low	2	2	20	60	16	360			2
Low	2	10	60		30	120	2	15	
Low	2	10	77	3	15	400	2	5	
Low	2	10	25	65		340	39		

Table 1 (continued).

AREA	AREA_2	(%) Grass	(%) Moss	(%) Shrubs	(%) Bare soil	Strength (kNm^2)	Thickness (cm)	(%) Pedestal	(%) Rock
Low	2	1	5	40	54	240	5	21	
low	2	3	10	70	17	300	10	13	
Upper	3	75	25			560	16		
Upper	3	30	70			500	17		
Upper	3	80	20			400	10		
Upper	3	60	40			520	5		
Upper	3	90	10			460	15		
Upper	3	30	70			460	10		
Upper	3	70	25			400	3		5
Upper	3	10	75	5		300	5		10
Upper	3	75	15			460	7		
Upper	3	75	25			300	8		
Upper	3	30	70			300	10		
Upper	3	80	20			400	8		
Upper	3	30	70			160	9		
Upper	3	40	60			320	10		
Upper	3	30	70			140	7		
Upper	3	48	40	12		160	9		
Upper	3	5	15	30	50	240	5	9	
Upper	3	20	70		10	200	3		

***Table 2**. Means for each sub area of the Laekur site calculated from Table 1.*

AREA	Grass %	Moss %	Shrub %	Bare soil %	Surface strength kNm^{-2}	Thickness cm	Pedestal cm	Rock %
Reference area	72.6	26.8	0.0	0.0	81.8	16.7	0.0	0.0
Low land	9.3	23.6	33.7	31.9	58.1	6.6	9.9	1.2
Upper land	48.8	43.9	2.6	3.3	69.8	8.7	0.5	0.8

4. SITE ASSESSMENT RESULTS

The line transect method and ocular estimates were selected as they have been shown to be appropriate for monitoring changes in relative species richness (Godínez-Alvarez, Herrick, Mattocks, Toledo & Van Zee, 2009).

The soil, water and vegetation are the basic resources found on rangelands. They are primarily assessed by measuring vegetation and soil attributes (Herrick et al., 2001). In this study I selected indicators which purposely represent the general ecosystem properties that can be related to ecosystem processes and represent ecosystem functions. These processes include; water cycle, nutrient cycle, and energy cycle. As the ecosystem processes can’t be measured directly, a set of attributes are used to assess them. These attributes include soil/site stability, hydrologic function, and biotic integrity (Pellant et al. 2002).

The dataset and summary of site means can be seen in Tables 1 and 2, respectively. The Reference Area had high grass cover of 72.6%, moss cover of 26.8%, surface strength of 81.8kNm^{-2}, and sward thickness of 16.7cm. The Reference Area had no shrubs, no bare soils, no pedestals and no rocks on the surface. In comparison, the Low Land had less grass cover of 9.3%, sward thickness of 6.6cm, and pedestal heights of 9.9cm, rock cover of 1.2% and shrubs of 33.7%, surface strength of only 58.1kNm^{-2} and bare soil cover of 31.9%.

The grass cover averages of the Upper Land did not differ much from the Reference Area, or an average of 48.8%. It also showed a low bare soil and shrubs 3.3% and 2.6%, respectively. The presence of pedestals showed that cryoturbation was present. The Upper Land had the highest average of moss cover, 43.9%.

The site results were used to construct Table 3. There, each attribute is categorized into five categories in Tables 4 to 7: Extreme to Total, Moderate to Extreme, Moderate, Slight to Moderate, and None to Slight, or E-T, M-E, M, S-M, and N-S, respectively. The Reference Area was, by definition, in the best condition and used for comparison of both the Upper Land and the Lower Land.

Table 3. *The positive, negative and indirect association of eight indicators with the respective four attributes. + indicates a positive correlation between process and indicator, - indicates a negative correlation between process and indicator, ±indicates both positive and negative correlation depending on conditions, and 0 indicates no significant correlation. See text.*

Processes	**Grass cover %**	**Moss cover %**	**Shrubs cover %**	**Soil strength kNm^{-2}**	**Sward thickness cm**	**Rock %**	**Pedestals cm**	**Bare soil %**
Energy cycle	+	+	+	±	+	0	÷	÷
Water cycle	+	" +"	+	±	+	0	÷	÷
Nutrient cycle	+	"+ "	+	+	+	+	÷	÷
Cryoturbic cycle	÷	÷	÷	÷	÷	+	+	+

The grass cover was higher in the Upper Land than in the Lower Land ($p < 0.05$), but shrub cover was higher in the Lower Land compared to the Upper Land ($p < 0.05$). No shrubs were present in the Reference Area (see Fig. 12). The grass cover was not different between the Reference Area and the Upper Land ($p > 0.05$), but significantly low in the Lower Land ($p < 0.01$). Vegetation cover is an important indicator for status of the hydrologic cycle, nutrient cycle and the energy cycle. Good cover indicates high infiltration rates, thus minimal surface runoff, i.e. less nutrient and energy loss as materials are retained in the system. Good vegetation cover also indicates that production is high, which adds to site surface stability; vegetation cover is thus an important attribute to evaluate when rangeland health is assessed.

Moss cover was not different between any of the three sites ($p > 0.05$) (see Fig. 13). Mosses do not have roots and do thus not influence water infiltration as higher vascular plants do. They do, however, add considerable thermal insulation to the surface (Thorsson, pers. com.) and are thus important for surface stability in general as cryoturbation is reduced.

Table 4. *Completed Evaluation Sheet of the Laekur site of eight indictors ranked in each transect site with a respective attribute, the departure from Expected the letters E-T, M-E, M, S-M, N-S refer to extreme to total, moderate to extreme, moderate, slight to moderate and none to slight. They are the codes given for each indicator. The letters A,B,C,D are codes for attributes, Energy cycle, Water cycle, Nutrient cycle and Cryoturbation, which apply to each indicator, and the a,b,c are the indicators which are not indirectly applicable to the attribute.*

Indicators	**Reference Area**		**Lower land**		**Upper land**		**Final Ranking**
	Ranking	**Comment**	**Ranking**	**Comment**	**Ranking**	**Comments**	
1. Grass cover	E-T	High percentage of grass cover.	S-M	Little grass cover	M-E	Moderate grass cover	S-M
	A, B, C		A, B, C		A, B, C		
2. Moss cover	S-M	Little moss cover	M	Moderate moss cover	E-T	High moss cover	M
	A, b, c		A, b, c		A, b, c		
3. Shrub cover	N-S	Little shrub cover	E-T	High shrub cover high infiltration	S-M	Very little shrubs	S-M
	A, B, C		A, B, C		A, B, C		
4. Surface strength	E-T	High	M	Very little	M-E	High	M
	a,b, C		a,b, C		a,b, C		
5. Sward thickness	E-T	High	S-M	Very little	M-E	Medium	S-M
	A,B,C		A,B,C		A,B,C		
6. Bare soil	N-S	little	M-E	Meduim	M	Little	S-M
	D		D		D		
7. Pedestals	N-S	little	E-T	Larger	M	Large	M
	D		D		D		
8. Rock	N-S	little	M-E	Medium	S-M	Very little	S-M
	C,D		C,D		C,D		

Table 5. *A summary of attribute ratings for the Reference Area as E-T, because the site had a lot of grass cover, thereby facilitating photosynthesis, and no cryoturbic activity at the site, hence stabilising the soils.*

Energy cycle (A)					**Water cycle (B)**				
5					5				
4					4				
1			2	3	1			2	3
E-T	M-E	M	S-M	N-S	E-T	M-E	M	S-M	N-S
A (5 indicators)					B (5 Indicators)				
Rating: E-T					Rating: E-T				

Table 5 (continued).

Attribute rating for Reference Area.									
Nutrient cycle (C)					**Cryoturbation cycle (D)**				
5									8
4									7
1			2	3					6
E-T	M-E	M	S-M	N-S	E-T	M-E	M	S-M	N-S
C (5 Indicators)					D (3 indicators)				
Rating: E-T					Rating: N-S				

Table 6. *Summary of attribute rating for the Lower Land ranges from M, S-M and M-E, the site had little grass cover, and is dominated by dwarf shrubs, and is covered by a lot of bare soil that facilitates active erosion.*

Attribute rating for Low Land									
Energy cycle (A)					**Water cycle (B)**				
		4	5				4	5	
3		2	1		3		2	1	
E-T	M-E	M	S-M	N-S	E-T	M-E	M	S-M	N-S
A (5 indicators)					B (5 Indicators)				
Rating: M					Rating: S-M				

Attribute rating for Low Land									
Nutrient cycle (C)					**Cryoturbation cycle (D)**				
		4	5			8			
3	8	2	1		7	6			
E-T	M-E	M	S-M	N-S	E-T	M-E	M	S-M	N-S
C (6 indicators)					D (3 indicators)				
Rating: S-M					Rating: M-E				

Table 7. *Summary of attribute ratings for Upper Land ranges from M-E to M in all attributes, the site had some grass cover thus facilitating photosynthesis and plant nutrients availability and hence soil stability. However Cryoturbation activity was M, meaning the site was experiencing some frost heaving and hence losing grass cover and thus developing bare soil showing the presence of erosion.*

Attribute rating for Upper Land									
Energy cycle (A)					**Water cycle (B)**				
	5					5			
	4					4			
2	1		3		2	1		3	
E-T	M-E	M	S-M	N-S	E-T	M-E	M	S-M	N-S
A (5 indicators)					B (5 Indicators)				
Rating: M-E					Rating: M-E				

Table 7 (continued).

Attribute rating for Upper Land									
Nutrient cycle (C)					**Cryoturbation cycle (D)**				
	5								
	4		8				7		
2	1		3				6	8	
E-T	M-E	M	S-M	N-S	E-T	M-E	M	S-M	N-S
C (6 indicators)					D (3 indicators)				
Rating: M-E						Rating: M			

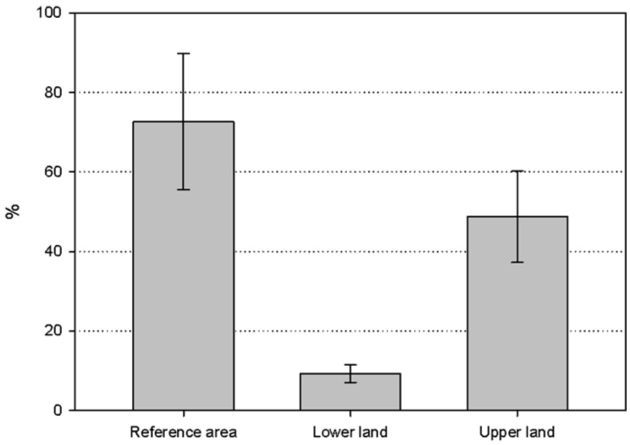

Fig. 12. *Total grass cover for the three areas. Vertical bars indicate standard error of the mean.*

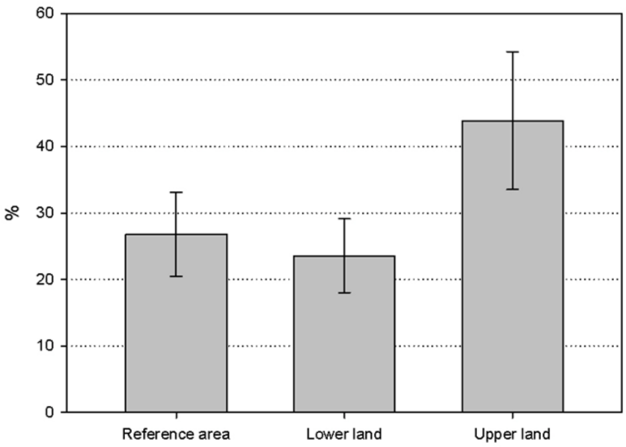

Fig. 13. *Total moss covers for the three areas. Vertical bars indicate standard error of the mean.*

There was a significant difference between the Upper Land and the Lower Land in terms of shrub cover ($P < 0.05$; Fig. 14), Shrub cover is an important indicator for soil stability, as shrubs tend to reduce wind and water erosion, hence enhancing the nutrient, water and energy cycles both directly and indirectly..

Bare soil was not present in the Reference Area but was both in the Upper Land and the Lower Land (see Fig. 15). There was a significant difference between these two areas in terms of bare soil cover ($p < 0.01$). Bare soil is a strong indicator for all four processes taken into account here, the water cycle, the energy cycle, the nutrient cycle and the cryoturbation (see Table 3). Bare soil, wind erosion and runoff, hence losses of nutrients and energy, tend to increase surface instability due to cryoturbation.

Another measure closely related to bare soil is the total pedestal height. Pedestals can be found where bare soils are present. No pedestals were detected in the Reference Area, but were in both the Upper Land and Lower Land (see Fig. 16). They were higher in the Lower Land than the Upper Land ($p < 0.05$), suggesting potentially more nutrient and energy loss caused by particle erosion and instability.

Measures closely related to surface stability and thus pedestal formation include the surface strength and sward thickness. No difference was found between any of the three areas ($p > 0.05$, Figs. 17 and 18).

No rocks were present in the Reference Area, but no difference was observed between the Upper Land and the Lower Land ($P > 0.05$, see Fig. 19).

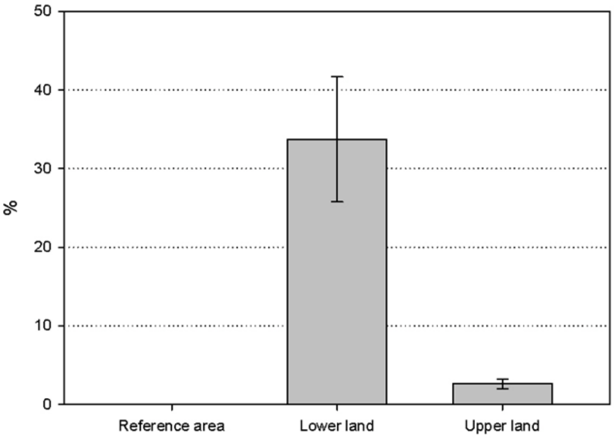

Fig. 14. *Total shrub cover for the three areas. Vertical bars indicate standard error of the mean.*

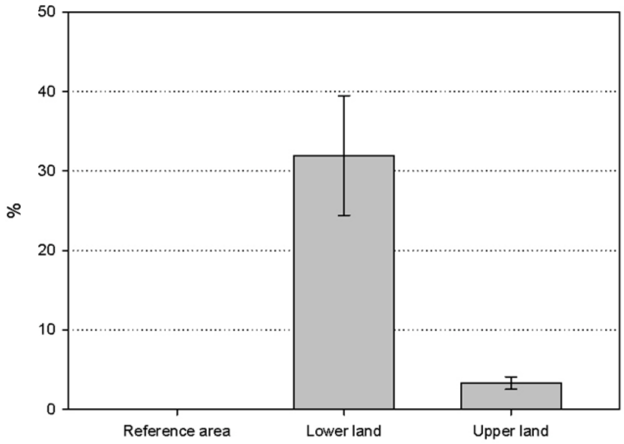

Fig. 15. *Bare soil cover for the three areas. Vertical bars indicate standard error of the mean.*

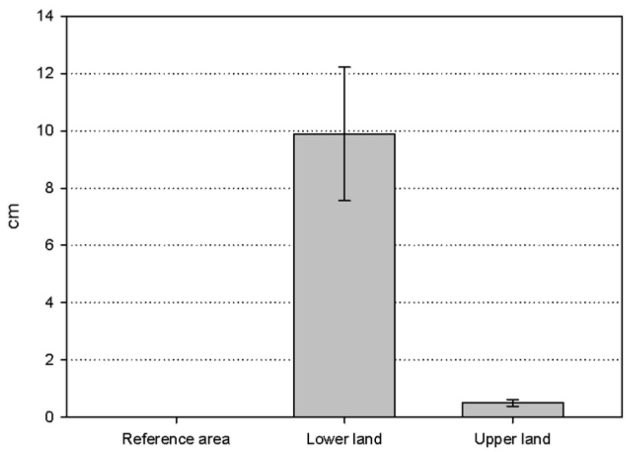

Fig.16. *Total pedestal height for the three areas. Vertical bars indicate standard error of the mean*

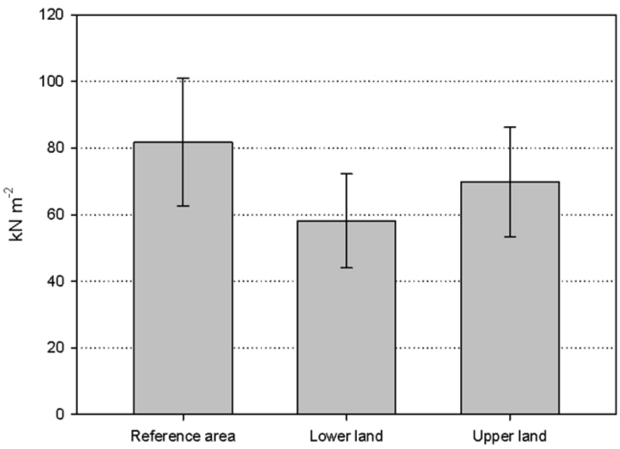

Fig. 17. *Surface strength for the three areas. Vertical bars indicate standard error of the mean*

Land in desirable condition from both an ecological and a pastoral perspective with no accelerated erosion, little bare ground, dominated by perennial grass, and few weeds can be improved by resting or removal of grazing for strategic periods to recover. This has been recommended as a grazing strategy to eliminate or reduce negative impacts of grazing (Ash, Corfield, McIvor & Ksiksi, 2011). This can be related to the Laekur site where grazing was removed to allow its regeneration.

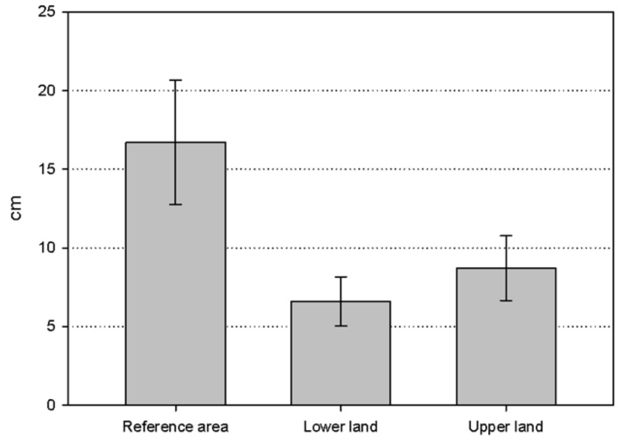

Fig. 18. *Sward thickness for the three areas. Vertical bars indicate standard error of the mean.*

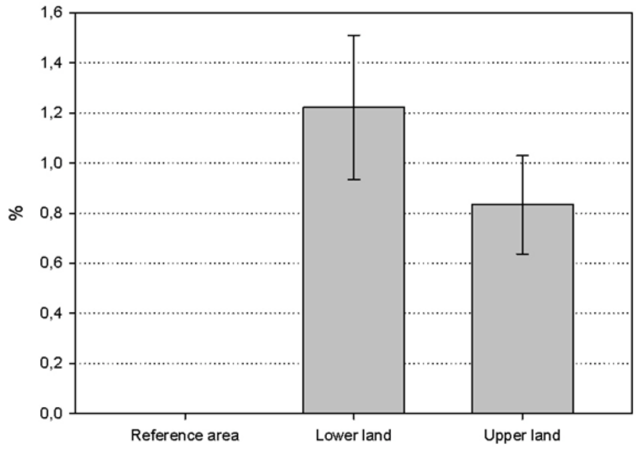

Fig. 19. *Total rock cover for the three areas. Vertical bars indicate standard error of the mean*

4.2 State and transition module for Laekur

The purpose of constructing the module is for future reference of the site and to prioritise the management action needs of the landscape (Ludwig et al., 1996). The module is based on the field surveys in an area that was previously used for grazing. Four stages (S) are identified in the module based on the study site (Fig. 20), S 1, S 2, S3 and S 4. The t is the transition between one stage to another. In the module, S 1 represents the Laekur Reference Area with high grass cover which can support light grazing for some given time. Transition can take place between S 1 and S 2 and/or S 3 as indicated by t 1 to t 3. S 2 had slightly moderate grass cover relative to S 1. S 2 could still support light grazing. S 3 was the Lower Land with a shift from grass land to dwarf shrubs and bare soils tended to appear, hence reducing soil fertility and plant production and increasing pedestals due to frost heaving (cryoturbation). The t2 and t3 transitions were the result of grazing and trampling of animals; if the land in S 3 is continuously grazed it may be forced to shift to the S 4 stage which is unstable, and hence may be difficult to manage. In addition this site needed immediate management action. It was vulnerable to severe erosion (see Fig. 2).

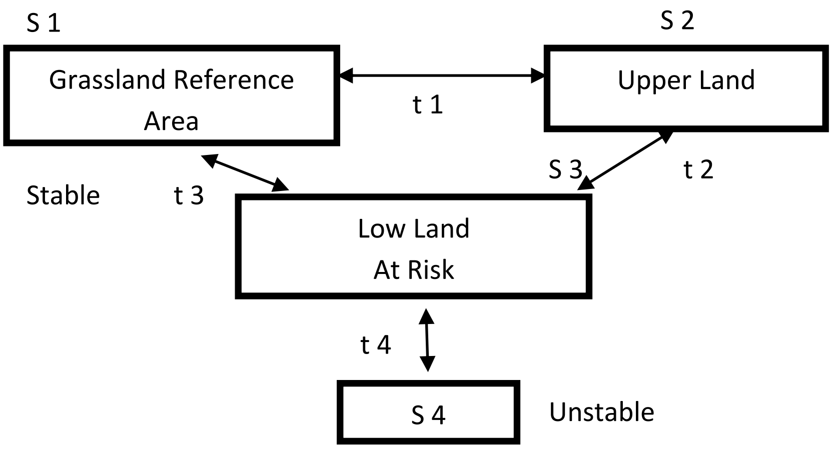

Fig 20. *State and Transition model for Laekur grass land site. S1, S 2, S 3 and S 4 represent sites 1 to 4 and the shift from stage to stage at site 4 with erosion which can be irreversible. t 1 to t 4 indicates time taken to reach the threshold of each site.*

4.3 General discussion

The Reference Area was the best evaluated compared to the other two sites, i.e. the Upper Land which was in good condition and the Low Land that was in a poor condition. The reference site served as the primary reference for the evaluation where all the attributes were functioning and the state at which they will be before or after disturbance occurs to other sites (see Table 2).

The Upper Land was characteristic of land still in a good condition though emergence of bare soil and pedestals had shifted it to an unhealthy state (Pellant & Monsen, 1993). The presence of cryoturbation factors (see Tables 3, 5, 6 and 7) like frost thawing of the land will reduce the capture of energy, recycling of nutrients and reduce the rate of water infiltration into the soil due to poorer soil structure. In Iceland bare soil may still allow some infiltration of water due to the porosity of the soils (*Andosols*), unlike Uganda, specifically the Napak district where the soils are dominated by *Vertisols*. The presence of rock, bare soil and pedestals indicates the occurrence of wind erosion and frost heaving, the soil is exposed to rain drop splash and wind erosion, and this also relates to the selection of the eight indicators to evaluate the three processes and cryoturbation for assessment.

The presence of bare soil, pedestals and rock, and less grass cover on the Lower Land may have affected the energy and nutrient cycle creating a patchy landscape with reduced capacity to capture and retain nutrients, and energy, resulting in unstable soils and less plant production. In arid and semi-arid landscapes such areas function differently. Patchy grounds are useful in capturing and storing water and seeds, hence retaining the resources (Ludwig et al., 1996).

High vegetation cover, soil strength, sward thickness with no bare soils, no pedestals, and no shrubs, as shown in the Reference Area and Upper Land, positively affects the energy cycle, nutrient cycle and water cycle by acting as a resource by becoming the reserve pool. The plants produce leaves and small stems, becoming litter and being recycled into the soil organic carbon and nutrient pools. These are broken and decomposed, and sometimes recycling takes place by microorganisms, hence binding the soils and increasing resistance to erosion.

The presence of surface rock and stones is a general indicator of soil loss by wind or water erosion, but in Iceland it also suggests a high rate of cryoturbation activity which negatively influences soil stability and may accelerate erosion.

The grass cover, moss cover, shrub cover, soil strength and sward thickness were negatively related to cryoturbation as shown in Table 3. Roots bind the soil, hence increasing surface stability, thus reducing wind erosion compared to rocky sites. Rocky sites are unstable, runoff and frost heaving is common, hence creating pedestals. Comparable cryoturbically driven processes are, however, not present in Karamoja.

The moss cover relates to the energy cycle in such a way that energy that will benefit soil fertility and promote soil living organisms is captured. In Uganda and Karamoja particularly moss is not present due to the dry landscape with little moisture content.

The presence of grass cover, shrub cover and sward thickness are related to the water cycle in such a way that they both allow infiltration of water into the soil and protect the soil from wind erosion, see Table 3.

The rock, moss cover, pedestals and bare soil which do not affect or negatively affect water infiltration into the soil therefore do not increase water erosion and poor fertile soils. The soil strength can still be both positive and negative. If the strength is due to root biomass, then it will increase infiltration, but reduce it if it is due to the physical structure.

Grass cover, shrub cover, sward thickness, soil strength and rock are related to the nutrient cycle. Energy captured through material retention or photosynthesis, and water infiltration into the soil, promotes the nutrient function since the living organisms use both water and energy for decomposition of the soil, leading to soil stability and soil fertility (Herrick et al., 2001). The moss cover stabilises the soil by adding an insulation layer, hence potentially facilitating bacterial nitrogen fixation, and thus improving soil fertility and binding soil particles together, as well as increasing soil moisture (see Tables 3, 4, 5 and 6).

5. CONCLUSION

The study area at Laekur showed land in relatively good condition. Bare soil spots were found in both the Upper Land and Lower Land, but they were not contiguous. Signs of disturbance were present in the Lower Land, putting it at risk compared to the Reference Area and the Upper Land.

The area in general appears to be recovering from previous land use, with the exception of the Lower Land. That area is in a questionable state. I recommend some management action be taken so that the condition of the land will not cross a threshold (see Fig. 2) (Yapp et al., 2010). The Lower Land needs application of fertilizers, whereas the Upper Land and the Reference Area do not appear to need imminent attention.

ACKNOWLEDGEMENTS

This research report is the two month field assessment which I carried out at Laekur, South Gunnarsholt, in Iceland in 2011, with the support of my supervisor Dr Johann Thorsson and financial support from the UNU-LRT programme and the Government of Iceland.
My sincere gratitude goes to my supervisor Dr Johann Thorsson for the technical guidance, mentoring, patience and encouragement he rendered to me during his supervision. Special thanks to my course co-ordinators Dr Hafdis Hanna and Dr Berglind Orradottir, and Course Administrator Tobba for their dedication, care, wonderful comments and encouragement in my work which helped me in shaping my ideas and the entire report. My grateful thanks go to all the Lecturers and supervisors at Keldnaholt, Hvanneyri and Gunnarsholt for their ideas on my knowledge and skills, which greatly helped me in coming up with the research topic, objectives and goal.

I would like to take this opportunity to thank the UNU-LRT programme and Government of Iceland for financial support during my course training in Iceland. I sincerely thank my programme Fellows 2011 for their teamwork, company and interactions which made it possible for me to successfully complete this course, especially Suvda, Hadgu, and Nana, and Alta and James for helping me take data photos.

I thank the staff of NEMA, Uganda, especially Beatrice Adimola, Evelyn Lutalo, and Edward for nominating me to attend the programme.

My appreciation to the staff of Napak District, especially the CAO, PPO and CFO for allowing me to come and attend this programme.

My heartfelt thanks go to my family members for taking care of my children, especially baby Aaron; Dad Mr Peter Lominit De Karl, Mama Grace Awate, Kolibi Angelina, and Eva. Sisters Caro, Judith, Petua, Francesca, Hendricka, Christine Teko, Edina, Jennifer, Paska, Anna, Helen, Aleper. Brothers Gabriel, Michael and Joel. Aunties Sabina, Betty Volar, Fausta and Agatha
My husband, Richard Anyama and my children Sarafina Akol, Stella and Aaron Matsiko Mudong for endurance, love, patience and encouragement to me.
My close friends: Regina Kotol, Regina Teko, Diana, Sally, Poly, Aparo Lucy, Teddy, Tino Irene, Hon. Margaret, Hon. Stella, Hon. Beatrice and the EMATD women's group for their mutual support.

REFERENCES

Arnalds, A. (1987). Ecosystem disturbance in Iceland. *Arctic and Alpine Research*, 508-513.

Ash, A. J., Corfield, J. P., McIvor, J. G., & Ksiksi, T. S. (2011). Grazing management in tropical savannas: Utilization and rest strategies to manipulate rangeland condition. *Rangeland Ecology & Management*. Retrieved from
Briske, Fuhlendorf, & Smeins. (2005). State-and-transition models, thresholds, and rangeland health: A synthesis of ecological concepts and perspectives. *Rangeland Ecology & Management, 58*(1), 1-10.

Briske, Sayre, Huntsinger, Fernandez-Gimenez, Budd, & Derner. (2011). Forum Paper Origin, Persistence, and Resolution of the Rotational Grazing Debate: Integrating Human Dimensions Into Rangeland Research. *Rangeland Ecology & Management, 64*(4), 325.

Brown, M. (1996). Barriers to women managers' advancement in education in Uganda. *International Journal of Educational Management, 10*(6), 18-23.

Clements, C. D., & Young, J. A. (1997). A viewpoint: Rangeland health and mule deer habitat. *Journal of Range Management,* 129-138.

De Soyza, Whitford, & Herrick. (1997). Sensitivity testing of indicators of ecosystem health. *Ecosystem Health, 3*(1), 44-53.

de Soyza, Whitford, Herrick, Zee, V., & Havstad. (1998). Early warning indicators of desertification: Examples of tests in the Chihuahuan Desert. *Journal of Arid Environments, 39*(2), 101-112.

du Pisani, L. G., Fouché, H. J., & Venter, J. C. (1998). Assessing rangeland drought in South Africa. *Agricultural Systems, 57*(3), 367-380.

Dyksterhuis, E. (1949). Condition and management of range land based on quantitative ecology. *Journal of Range Management, 2*(3), 104-115.

Einarsson, T. (1963). Pollen-analytical studies on the vegetation and climate history of Iceland in late and post-glacial times. *North Atlantic biota and their history,* 355-365.

Eldridge, D. J., & Koen, T. B. (1998). Cover and floristics of microphytic soil crusts in relation to indices of landscape health. *Plant Ecology, 137*(1), 101-114.

Ferretti, A. R., & de Britez, R. M. (2006). Ecological restoration, carbon sequestration and biodiversity conservation: The experience of the Society for Wildlife Research and Environmental Education (SPVS) in the Atlantic Rain Forest of Southern Brazil. *Journal for Nature Conservation, 14*(3-4), 249-259.

Geerken, R., & Ilaiwi, M. (2004). Assessment of rangeland degradation and development of a strategy for rehabilitation. *Remote Sensing of Environment, 90*(4), 490-504.

Gibbens, R., McNeely, R., Havstad, K., Beck, R., & Nolen, B. (2005). Vegetation changes in the Jornada Basin from 1858 to 1998. *Journal of Arid Environments, 61*(4), 651-668.

Godínez-Alvarez, H., Herrick, J., Mattocks, M., Toledo, D., & Van Zee, J. (2009). Comparison of three vegetation monitoring methods: Their relative utility for ecological assessment and monitoring. *Ecological Indicators, 9*(5), 1001-1008.

Gollan, J. R., Bruyn, L. L. d., Reid, N., Smith, D., & Wilkie, L. (2011). Can ants be used as ecological indicators of restoration progress in dynamic environments? A case study in a revegetated riparian zone. *Ecological Indicators, 11*(6), 1517-1525.

Herrick, Whitford, de Soyza, Van Zee, Havstad, Seybold, & Walton. (2001). Field soil aggregate stability kit for soil quality and rangeland health evaluations. *CATENA, 44*(1), 27-35.

Herrick, J. E., Schuman, G. E., & Rango, A. (2006). Monitoring ecological processes for restoration projects. *Journal for Nature Conservation, 14*(3-4), 161-171.

Hobbs, R. (1997). Future landscapes and the future of landscape ecology. *Landscape and Urban Planning, 37*(1-2), 1-9.

Kassahun, Snyman, & Smit. (2008). Impact of rangeland degradation on the pastoral production systems, livelihoods and perceptions of the Somali pastoralists in Eastern Ethiopia. *Journal of Arid Environments, 72*(7), 1265-1281.

Krogh, S. N., Zeisset, M. S., Jackson, E., & Whitford, W. G. (2002). Presence/absence of a keystone species as an indicator of rangeland health. *Journal of Arid Environments, 50*(3), 513-519.

Ludwig, J. A., Tongway, D. J., Hodgkinson, Freudenberger, & Noble. (1996). *Landscape Ecology, function and management*. Collingwood, Australia: CSIRO.

Ludwig, J. A., Wilcox, B. P., Breshears, D. D., Tongway, D. J., & Imeson, A. C. (2005). Vegetation patches and runoff-erosion as interacting ecohydrological processes in semiarid landscapes. *Ecology, 86*(2), 288-297.

Milton, S. J., Dean, W. R. J., & Ellis, R. P. (1998). Rangeland health assessment: a practical guide for ranchers in arid Karoo shrublands. *Journal of Arid Environments, 39*(2), 253-265.

National Environmental Management Authority, N. (2008). State of the Environment Report for Uganda. Kampala, Uganda.

NRC. (1994). *Rangeland health: new methods to classify, inventory, and monitor rangelands*. Washington, D.C: Natl Academy Press.

Pellant, Shaver, Pyke, & Herrick. (2005a). Interpreting indicators of rangeland health. Version 4. Denver, CO, USA: Bureau of Land Management. Interagency Technical Reference 1734-6.

Pellant, M., & Monsen, S. (1993). *Rehabilitation on public rangelands in Idaho, USA: A change in emphasis from grass monocultures*.

Pellant, M., Shaver, P., Pyke, D., & Herrick, J. (2005b). Interpreting indicators of rangeland health, version 4. Technical Reference 1734-6. US Department of the Interior, Bureau of Land

Management, National Science and Technology Center, Denver, CO: BLM/WO/ST-00/001+ 1734/REV05.

Pender, Nkonya, Jagger, Sserunkuuma, & Ssali. (2004). Strategies to increase agricultural productivity and reduce land degradation: evidence from Uganda. *Agricultural Economics, 31*(2 3), 181-195.

Pyke, Herrick, Shaver, & Pellant. (2002). Rangeland health attributes and indicators for qualitative assessment. *Journal of Range Management*, 584-597.

Raymond, C. M., Fazey, I., Reed, M. S., Stringer, L. C., Robinson, G. M., & Evely, A. C. (2010). Integrating local and scientific knowledge for environmental management. *Journal of Environmental Management, 91*(8), 1766-1777.

Reid, K. D., Wilcox, B. P., Breshears, D. D., & MacDonald, L. (1999). Runoff and erosion in a pinon-juniper woodland: influence of vegetation patches. *Soil Science Society of America Journal, 63*(6), 1869-1879.

Roba, H. G., & Oba, G. (2009). Community participatory landscape classification and biodiversity assessment and monitoring of grazing lands in northern Kenya. *Journal of Environmental Management, 90*(2), 673-682.

Sadler, R. J., Hazelton, M., Boer, M. M., & Grierson, P. F. (2010). Deriving state-and-transition models from an image series of grassland pattern dynamics. *Ecological Modelling, 221*(3), 433-444.

Shinneman, D. J., Baker, W. L., & Lyon, P. (2008). Ecological restoration needs derived from reference conditions for a semi-arid landscape in Western Colorado, USA. *Journal of Arid Environments, 72*(3), 207-227.

Solomon, T. B., Snyman, H. A., & Smit, G. N. (2007). Cattle-rangeland management practices and perceptions of pastoralists towards rangeland degradation in the Borana zone of southern Ethiopia. *Journal of Environmental Management, 82*(4), 481-494. doi: 10.1016/j.jenvman.2006.01.008

Statistics., U. B. o. (2003). *Uganda Bureau of Statistics: a report on the Uganda business register, 2001/2002*: Uganda Bureau of Statistics.

Suding, K. N., & Hobbs, R. J. (2009). Threshold models in restoration and conservation: a developing framework. *Trends in Ecology & Evolution, 24*(5), 271-279.

Teague, W. R., Grant, W. E., Kreuter, U. P., Diaz-Solis, H., Dube, S., Kothmann, M. M., . . . Ansley, R. J. (2008). An ecological economic simulation model for assessing fire and grazing management effects on mesquite rangelands in Texas. *Ecological Economics, 64*(3), 611-624.

Thomas, R. J. (2008). Opportunities to reduce the vulnerability of dryland farmers in Central and West Asia and North Africa to climate change. *Agriculture, Ecosystems & Environment, 126*(1-2), 36-45.

Tongway, & Ludwig, J. A. (2010). Restoring disturbed landscapes: putting principles into practice.

USDA, N. (1997). *National range and pasture handbook.*

van den Berg, L., & Kellner, K. (2005). Restoring degraded patches in a semi-arid rangeland of South Africa. *Journal of Arid Environments, 61*(3), 497-511.

Westoby, Walker, & Noy-Meir. (1989). Opportunistic management for rangelands not at equilibrium. *Journal of Range Management*, 266-274.

Yapp, G., Walker, J., & Thackway, R. (2010). Linking vegetation type and condition to ecosystem goods and services. *Ecological Complexity, 7*(3), 292-301.

APPENDIX 1

Glossary

NEMA National Environment Management Authority

CAO Chief Administrative Officer

CFO Chief Finance Officer

EMATD Empowering Mothers and transforming them into Development

PPO Principle Personnel Officer