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MEASUREMENT OF WIND EROSION ON A LANDSCAPE SCALE AT MYRDALSSANDUR

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ABSTRACT

Wind erosion is a major threat in Iceland which has > 20000 km^2 of sandy deserts. The sandy areas have dark surfaces due to their basaltic origin. My goals were to gain knowledge of methods used in measuring the effect of wind erosion and to quantify wind erosion at the Myrdalssandur desert in South Iceland. The study area is a vast unstable sandy area formed by catastrophic flooding events. The area has frequent sandstorms, mostly blowing to the south with northerly winds. During 45 days, wind erosion was measured in an attempt to quantify the materials carried by wind, to analyse the relationship between grain size and aeolian transport, to analyse differences in sand transport on a landscape scale, to identify the main pathways, and to understand the relationship between wind speed, types of soil particles and transport. Only one storm was recorded during the experimental work with an average wind speed of 10 m s^{-1}. The mass of aeolian transport ranged from 364.4 kg m^{-1} to less than 0.03 kg m^{-1}. By looking at the research area and the differences in sand transport within the location, it seemed that the major differences in the erosibility of the surface area were caused by grain size distribution rather than meteorological factors. The presence of a grain size with a diameter more than 8 mm is a result of frequent flooding which brought these heavy materials that powerfully makes the sandy materials in Myrdalssandur poorly sorted. But still the Myrdalssandur desert is under severe erosion. A simple sediment catcher for measuring horizontal mass fluxes of wind-blown particles is described, and a method to calculate the total mass transport rate at the point of observation was explored.

Key words: wind erosion; BSNE; Myrdalssandur; Sahel

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1 INTRODUCTION

1.1 Background

Soil erosion in Iceland is one of the most serious environmental problems facing the country. Vast areas of the country are under severe threat of erosion (Arnalds, Thórarinsdóttir, Metúsalemsson, Jónsson, Grétarsson, & Árnason, 2001). The sandy deserts are seldom reported in the study of large sandy areas of the world (Dugmore, Gísladóttir, Simpson & Newton, 2009). Efforts have been made by the Icelandic Soil Conservation Service to fight against soil erosion since its establishment in 1907 (Arnalds et al., 2001).

The sandy deserts in Iceland cover about 20000 km^2, composed essentially of volcanic materials. The parent material of the sand is mainly basaltic volcanic glass together with porous tephra and basaltic crystalline materials (Arnalds, 2004). The sand has various sources, but is often associated with glacial rivers and margins and volcanic activity (Arnalds, Gisladottir & Sigurjonsson, 2001). Catastrophic floods associated with volcanic eruptions have also been important contributors to the sand sources (Arnalds et al., 2001). The sandy surfaces are unstable and intense aeolian processes cause a widespread redistribution of fine particles into the atmosphere (Arnalds, 2001). Some of these surfaces are expanding, and advancing sand fronts cause losses of rich and fully vegetated areas, replacing them with sandy deserts (Oskarsson, Arnalds, Gudmundsson & Gudbergsson, 2004).

Many efforts have been devoted to the understanding of aeolian processes (Bagnold, 1941; Chepil, Siddoway & Armbrust, 1964; Michels, Potter & Williams, 1997; Pye & Tsoar, 1990). Wind erosion processes, also known as aeolian processes, involve the removal of loose and fine-grained particles from the surface of Earth, their transportation by various processes, and finally the deposition of the particles (Cooke, Warren & Goudie, 1993). There are three main modes of transportation: saltation, creeping and suspension. Saltation is a process by which a particle of sand is raised by strong wind and is carried to a short distance over the surface and collides with other particles when it lands again. Creeping is the rolling of grains, induced by saltation impacts, and the rolling of grains into craters created by removal by saltation impacts. The last process is suspension which is the transportation of fine particles in the air over long distances (Fryrear, Stout, Hagen & Vories, 1991). Saltation particles are dominant in the mass movement of soil on a local scale (less than several meters) (Stout & Zobeck, 1996). Suspended dust particles can be transported over long distances and can be moved at regional, continental, and even global scales (Chadwick, Derry, Vitousek, Huebert & Hedin, 1999).

The effect of wind erosion can be severe and can both be direct and indirect. The direct or on site effects are the removal of topsoil and plant nutrients, which may lead to a decrease in plant growth. As an example, the impact of wind erosion and sand accumulation in Mongolia (Zhao et al., 2006) leads to long term soil infertility, dryness and coarseness. In Sahara, abrasion due to the transport of soil particles does serious damage to crops and to young plants, particularly in the beginning of the rainy season. The damage ranges from reduced growth and plant development to total destruction of the crop (Le Houérou, 1989). The indirect or off-site effects are due to sand cover on fertile agricultural areas which affects crop growth and causes an eventual decrease in the harvest (Michels et al., 1997; Sterk, 1997). Infrastructures can be covered by over-blown sand causing various problems. In extreme cases the land becomes inhabitable because of thick sand cover (Fig.1)**.**

Fig. 1. *Dune encroachment due to effect of wind erosion. The sand carried by wind is transported into the fertile farm land in the southern part of Niger and covered the vegetated area. (Photo: N. Attari, 2009.)*

Fine dust in the atmosphere can cause health hazards to human beings (Buzea, Pacheco & Robbie, 2007). Dust can also affect ecosystem processes at scales ranging from individual plants or even smaller (Field et al., 2009) and on local and regional scales to a global scale, representing biogeochemical connectivity across continents (Peters, Sala, Allen, Covich & Brunson, 2007). In addition to its effects on climate, dust plays an important role in the control of regional and global biogeochemical cycles and dispersal of pathogens. At the global scale, nutrient additions by dust may have stimulated the productivity of oceanic plankton over geological time scales, thus accelerating the uptake of atmospheric CO_2 (Jickells et al., 2005).

Wind erosion as a natural process has been studied intensively for about 80 years. Reliable and precise methodology of measuring wind erosion is important to test and validate erosion models, determine the source of pollutants and for other application (Zobeck et al., 2003).
Attempts have been made to measure wind erosion see (Fryrear, 1987; Hagen, Skidmore & Layton, 1988; Nickling & Neuman, 1997; Zobeck et al., 2003). Equipment for measuring sand storms includes various types of sediment traps. The BSNE sampler developed by Fryrear (1986) is probably the most widely used sampler in wind erosion field research.

1.2 Goals

Due to the complexity of aeolian processes in the Icelandic deserts such as environmental factors (wind direction, cryogenic processes, temperature, topography of the area), measurement on a landscape scale can be used to gain knowledge and to understand wind erosion in Iceland. This information is important for understanding advancing fronts, to predict what effect climatic changes may have on the deserts, and to reconstruct the development of sandy areas.

The main goals of the project were:

- To gain knowledge of methods used in measuring the effect of wind erosion.
- To quantify wind erosion at the Myrdalssandur desert in South Iceland.

More specifically the undertaken study was intended to be an opportunity:

- To measure the amount of soil particles transported by wind at Myrdalssandur.
- To analyse differences in sand transport on a landscape scale and to identify main pathways of sand.
- To analyse the relationship between grain size and aeolian transport.
- To understand the relationship between wind speed, types of soil particles and transport.

2. LITERATURE REVIEW

This project was undertaken to gain understanding of wind erosion processes for practical use in the Sahel region. Therefore this review is provided in general for Iceland and also for the Sahel region.

2.1 Iceland

Three environmental factors induce change in Icelandic soil: (i) frequent volcanic activity and the volcanic nature of the soil parent materials; (ii) the cold maritime climate with intensive cryogenic processes; and (iii) extremely active soil erosion by wind, water, and gravity, aided by cryogenic processes. These factors combined have created vast unstable desert areas that are the source of steady eolian sedimentation in the country (Arnalds & Kimble, 2001).

About or 86% of the Icelandic soil is composed of Andisols. These soils are susceptible to erosion by wind and water and by landslides (Arnalds, 2004). According to the National Survey of Soil Erosion, about 41000 km^2 of Iceland have considerable to severe soil erosion (Arnalds, 2000). The largest area with severe erosion is sandy surfaces, covering about 22000 km^2 (Arnalds & Kimble, 2001).

The texture of the aeolian surfaces varies with the origin of the sand source and distance from the sources. The mean diameter can reach 1 mm in the tephra deposits, but commonly ranges between 0.2 and 0.5 mm in active aeolian areas. The quantity of sedimentation rates range from < 25 g m^{-2} yr $^{-1}$ far from aeolian sources to > 500 g m^{-2} yr $^{-1}$ near or within major sandy areas (Arnalds, 2010). The density ranges from 0.1 to 1 mm with a range in grain density of less than 1g cm^{-3} for pumice grains to nearly 3g cm^{-3} cm for dense basaltic glass (Arnalds & Kimble, 2001). In addition to the sandy areas that are primarily of glacial and glacio-fluvial origin, there are widespread volcanic ash deposits associated with the active volcanic zone in Iceland (Arnalds et al., 2001).

The dust redistributes large quantities of easily weathered volcanic materials which contribute to the equilibrium of ecosystems in the ocean south of Iceland. With climate change (global warming and glacial retreat), it is expected that dust formation will increase (Arnalds, 2010).

Problems of the Icelandic sandy deserts include lack of water holding capacity and the black surfaces become warm and dry on sunny days. Therefore water shortage retards plant growth, which gives Icelandic deserts similar properties to the arid deserts of the world, in spite of the humid climate in Iceland (Arnalds et al., 2001).

2.2 Sahel

A major problem facing sustainable land use in the Sahel is wind erosion. The main drivers behind the erosion process in the Sahel are the i) soil texture which is sandy, ii) low vegetation cover and iii) a long dry season with frequent wind erosion (Ozer & Ozer, 2005). Dust storms cause severe environmental problems in large parts of the Sahel region. Humans contribute to the dust storms through land use system (Zhibao, Xunming & Lianyou, 2000). The loss of the nutrients from the top soil leads to land degradation which also has a negative impact in terms of productivity and low income to farmers (Ambouta, 1994). Research shows that the main factors that contribute to wind erosion are population pressure and deforestation (Ozer, 2000). The characteristics of erosion control measures in the region are mostly based on a low economic cost and methods usually rely on the use of crop residues by farmers as a mean to control wind erosion (Sterk & Haigis, 1997).

The southern part of Niger is characterized by soils of aeolian origin (Gavaud, 1977). Grazing and crop farming (e.g. *Pennisetum glaucum*) are the most common practices on these types of soils. Rapid population growth in recent decades has resulted in the expansion of cultivated land and increasing pressure on grazing areas. A gradual decrease occurred in rainfall between 1970 and 1980 (Pieri & Pieri, 1989). Recent changes in land use systems has increased wind activity, thereby jeopardizing the sustainability of the production systems (Sene & Ozer, 2002). Due to the loss of vegetative cover and the effect of wind, the reactivated sands threaten the existence of several villages, farmlands and many inter-dune basins (Bodart & Ozer, 2009). A gradual increase in the volume of added aeolian dust was experienced during the years 1970 to 1990, reflecting an increasingly fragile natural environment in the Sahel (Ozer, 2000).

Two main wind patterns cause winds that exceed the threshold for soil particle movement during two distinct seasons. During the dry season the area is subjected to dry and rather strong north-eastern trade winds, locally known as *Harmattan*, which may result in moderate transport. Also, during the early rainy season, wind erosion events occur which result in cold air and dust storms. These events don't extend over a long period of time but have an impact on the movement of soil particles (Lebel & Ali, 2009).

Many studies have been made of wind erosion measurement in agricultural fields but less information exists regarding natural forest or grazing land (Tidjani, Bielders & Ambouta, 2009). The soil particles transported by saltation and suspension in Niger have different impacts on the productivity. Vigorous vegetation traps saltating material coming from the surrounding source areas, improves the fertility of fallow sites and leads to the decreasing of upwind areas (Sterk & Haigis, 1997; Sterk & Raats, 1996).

Suspended dust materials can be carried over long distances, resulting in a loss of nutrients and fine particles and thus enhancing regional soil degradation (Barkan, Kutiel, Alpert & Kishcha, 2004; Prospero & Carlson,1972; Westphal, Toon & Carlson,1988). It is estimated that 25 - 37 million mg of windblown dust crosses the Atlantic annually, with considerable amounts deposited into the ocean (Karyampudi et al., 1999). The Sahel also gains nutrient-rich dust deposits. In Niger dust is transported from the Sahara, where it partly settles in the early rainy season. Most of the total annual dust input in south-west Niger is in the early rainy season, whereas the *Harmattan* season contributes only 15% of the total amount (Drees & Wilding, 1993). The compositions of dust deposits are particularly rich in sodium, potassium, magnesium, and calcium, but poor in phosphorus (Herrmann, & Bleich, 1998). It is quite difficult to quantify the balance between input and output of dust due to the lack of reliable data. Areas that are well vegetated gain from dust deposits while degraded land is more susceptible to losses than to a benefit from dust deposits. Since a large area of Niger is degraded nowadays, it is probable that suspension transport contributes to a net loss of soil particles and nutrients (Sterk, 1997).

There are data available on air visibility from the past few years, which is monitored at the meteorological stations (Middleton, 1985). However there is a lack of standard systems for measuring dust transport. The meteorological data show only that there was increase in dust storms during the 1970s and 1980s, but dust collection cannot be used to calculate erosion because the sources of wind-borne particles are difficult to pinpoint. It is possible to fingerprint dust sources (Littmann, 1991) but difficult to measure erosion rates from such sources. It is encouraging that results are now coming from the *in situ* wind erosion research in south-western Niger (Bielders, Rajot & Koala, 1998; Chappell, 1998; Goossens & Rajot, 2008; Sterk, 1997).

3. MATERIAL AND METHODS

3.1 Site description

Myrdalssandur (Fig.2) is a large unstable sandy area formed by catastrophic volcano-glacial flooding events (*jokulhlaup*) during the volcanic eruption of the Katla volcano, which is within a large caldera under the glacier (Björnsson, 2009). Active glacial rivers also contribute steadily to the sandy deposits. Myrdalssandur has frequent sandstorms, mostly blowing to the south with dry northerly winds.

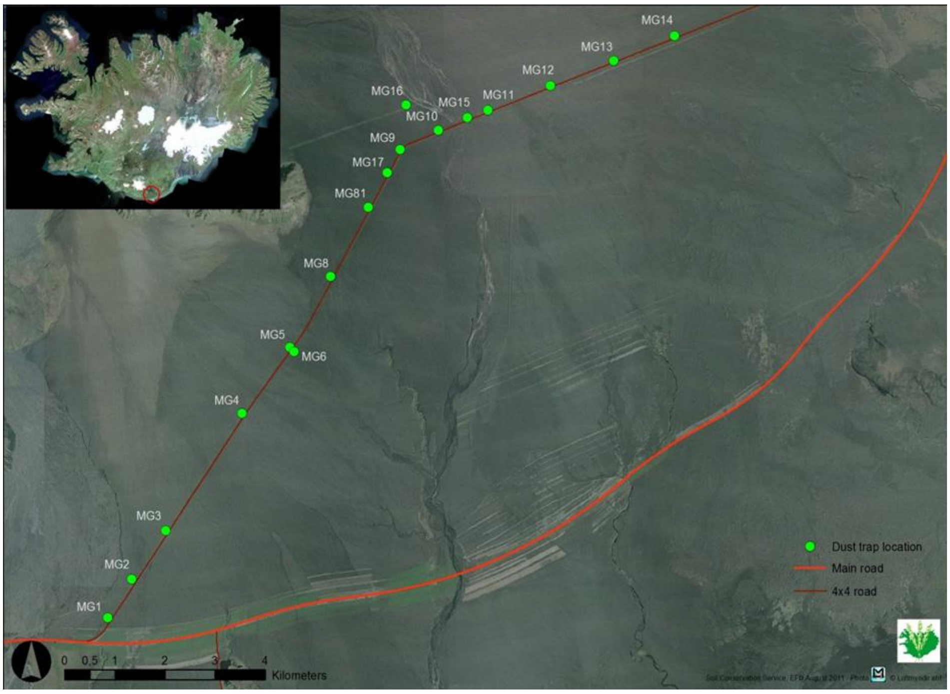

Fig. 2. *Insert map of Iceland shows the location of Myrdalssandur research area. Sampling locations are shown labelled MG1—MG17, along an old abandoned road. At the centre is a dry watering, while at the top near MG16, the watering is periodically flooded with subsequent new sediment deposition. Image Spot (2011), copyright Euro Image.*

3.2 Equipment

The sediment traps used in this study are the so-called "Big Spring Number Eight" (or BSNE) (Fryrear, 1986). The BSNE traps are designed for collecting eroding materials in the field with minimum interference of the wind flow (see Fig.3). They can be described as diffusers; after wind enters the opening, it slows down and sand settles in a pan at the bottom. Air passes out of the trap through a fine mesh at the top (Fryrear, 1986). It is a wedge-shaped sampler with a 60 mesh screen on the top or sides to allow airflow out of the sampler. The BSNE sampler has proven to be a rugged and dependable sampler well suited for remote field locations. A single sampler can collect up to 1.7 kg of airborne material and as little as a few grams from a single erosion event.

Fig. 3. *A Big Spring Number Eight (BSNE) dust trap mounted at 50 cm above ground level (Photo: P. P. Lokongo 6th July, 2011.)*

3.3 Field collection and grain size parameters

The BSNE samplers are easily mounted on poles to allow sampling at multiple heights. In this study, seventeen (BSNE) samplers were placed along a transect of about 20 km across Myrdalssandur (Fig.1). The samplers were placed on transect at different intervals and different heights depending on the topography of the area. A BSNE sampler was placed at seven locations at 50 cm above ground level, others at 60 cm height. The method of using only one BSNE sampler at each location has been termed the "single dust trap method". The height of the samplers at each location was based on assumed aeolian activity, with traps placed at 50 and 60 cm height where activity was assumed moderate with a relatively stable surface, but at 100 cm height close to a very active sand source near a dry river bed (MG 16).

A set of four BSNE were placed at two different locations at 15, 30, 60 and 100 cm heights. At one location BSNE samplers were placed at a height of one meter. The “single dust trap method” assumes that the height distribution for aeolian transport is similar at the same location in Iceland for all storms (Arnalds & Gísladóttir, 2009).

After the occurrence of an erosion event, all traps were emptied and the content was dried and weighed. An additional sample of soil was obtained at each location where the BSNE were placed. The soil samples were dried at 40°C for about three days. The dried soils were sieved to separate the different grain sizes, using range sizes of > 8, 4-8, 2-4, 1-2, 0.5-1, 0.250-0.5, 0.125-0.250, 0.063-0.125, < 0.063 mm (see Table 1*)*. All non-erodible materials like stones and pebbles were excluded from the samples, but large grains of pumice were included as they can be transported by wind. The soil samples were dried and weighed using a classification based on the Udden–Wentworth grain size classification scheme (Wentworth, 1922) (see Table 1).

Table 1. *Size ranges used for sieving samples*.*

#	Size	Wentworth size class
1	> 8 mm	Medium gravel
2	4-8 mm	Fine gravel
3	2-4 mm	Very fine gravel
4	1-2 mm	Very coarse sand
5	0.5-1 mm	Coarse sand
6	0.250-0.5 mm	Medium sand
7	0.125-0.250 mm	Fine sand
8	0.063-0.125 mm	Very fine sand
9	< 0.063 mm	silt

*A scale of grade and class terms for clastic sediments (Wentworth , 1922)

The method of moments statistics was used to calculate the grain size parameters using the Gradistat 14.0 program (Blott & Pye, 2001). The parameters used were the mean size, the sorting that describes the sizes around the average, and the skewness which describes symmetry or preferential spread to one of the averages.

Meteorological data were recorded at the weather station operated by the Icelandic Road Administration to find the relationship between wind speed and aeolian transport during storms (See Table 2**).**

3.4. Calculation of sand transport

The quantity of material collected in dust traps in an erosion event was used to calculate the mass of sand transport over a 1 m wide transect (kg m^{-1}). The method used to calculate the mass sand transport was developed by Arnalds & Gísladóttir (2009). The method is based on the ratio of eroding material between different heights being rather constant between erosion events at a given location.

Samples collected in a set of four traps at MG 8 and MG 13 were used to calculate the height distribution of the materials. A mean curve was obtained and used to calculate transport distribution for 10 cm height intervals, from a height of 0-120 cm. The amounts for each interval were added together to obtain transport in kg m^{-1}.

Table 2. *Mean temperature (°C), relative humidity (%), wind speed (m/s), wind direction (°), and maximum wind gust (m/s) from 6 of July to 17 August, 2011, by the road weather station at the study site. This table showed the meteorological data collected from the road weather station at the study site. The weather was relatively calm throughout the period of study. It was only on 13th of August, 2011, that a storm event happened. It is highlighted in brown.*

Date	Temperature (°C)	Relative humidity (%)	Wind speed (m/s)	Wind direction (°)	Maximum wind gust (m/s)
6. July 2011	9	88	3.2	132	4.5
7. July 2011	8	94	2.8	170	3.8
8. July 2011	8	91	3.3	169	4.6
9. July 2011	9	89	3.4	182	4.8
10. July 2011	11	78	4.8	231	6.9
11. July 2011	9	85	3.8	184	5.4
12. July 2011	10	95	5.5	111	7.7
13. July 2011	10	93	3.9	121	5.5
14. July 2011	11	88	2	126	3
15. July 2011	12	71	3.7	230	5.5
16. July 2011	11	80	2.8	178	3.9
17. July 2011	12	81	2.9	237	4.3
18. July 2011	11	80	3.1	240	4.7
19. July 2011	12	80	3.5	168	5.2
20. July 2011	10	91	1.1	225	2.8
21. July 2011	11	84	3.5	168	4.9
22. July 2011	11	83	5.2	93	7.3
23. July 2011	10	93	6.7	78	9.6
24. July 2011	11	92	3.6	102	5.1
25. July 2011	10	96	5.3	88	7.6
26. July 2011	11	95	5.3	153	7.4
27. July 2011	10	87	7.2	245	10.3
28. July 2011	11	89	4	228	5.7
29. July 2011	10	95	4.3	127	5.9
30. July 2011	9	91	11.8	67	17.5
31. July 2011	10	89	10.8	71	15.9
1. August 2011	10	93	7.5	71	10.8
2. August 2011	11	94	7.9	82	11.3
3. August 2011	9	93	5.3	61	7.9
4. August 2011	10	97	6.3	55	9.1
5. August 2011	9	91	4	81	6
6. August 2011	10	87	3	205	4.5
7. August 2011	9	84	2.9	230	4.32
8. August 2011	10	82	2.5	229	3.8
9. August 2011	9	77	3	141	4.4
10. August 2011	10	85	3.3	172	5
11. August 2011	11	78	3	147	4.5
12. August 2011	11	70	2.9	103	4.5
13. August 2011	12	53	10.8	342	14.6
14. August 2011	11	75	4.1	118	5.7
15. August 2011	11	89	2.5	115	3.5
16. August 2011	10	93	4.3	62	6.1
17. August 2011	8	94	3.2	30	4.5

4. RESULTS

4.1 Weather conditions

During the time that the research was conducted the weather was unfortunately very calm. The first storm event was recorded on 13th of August almost 37 days after the traps were established. The dust traps were emptied two days after the erosion event*).* The weather condition during the storm was relatively dry with 12°C temperature and the relative humidity 53%. Wind was blowing from the NNW (347°) with an average wind speed of 10.8 m s^{-1} and average maximum wind gusts of 14.6 m s^{-1}.

4.2 Calculation of sand transport during the storm event

An average curve was used to find the coefficient for calculating aeolian transport for each 10cm height interval (using the median up to 120 cm height). The curves were based on the measurement from dust traps at locations MG8 and MG13. Based on the data, the amount of sediment was assumed to be the same for the interval, from 0-10 cm (5 cm median) as for the second lowest interval from 10-20 cm (15 cm median). This methodology is in accordance with research done by Arnalds & Gísladóttir (2009) where they estimated that the maximum sand transport was at a height of approximately 10 cm.

The coefficient obtained from the medium curve was used to calculate sand mass transport in kg of material which was transported over a 1 m wide transect, up to 120 cm height. Most of the single dust traps were mounted at 50 cm height or 60 cm height and the curves and coefficients were adjusted to the dust trap heights, so that dust traps at a height of 50 cm were assigned the coefficient 1 at 50 cm and dust traps at a height of in 60 cm were assigned the coefficient 1 at 60 cm (see Figs. 4 and 5).

4.3 Grain size analysis

The grain size analysis showed that all the locations had a high proportion of sandy material (see Table 3). Only the locations MG10, MG12 and MG13 differed from the others where the proportion of sand and gravel was approximately the same. The materials were namely sand, gravel and mud (very fine particle size mixed with clay). Using the method of Folk and Ward for classifying the material, the mean size identifies coarse sand and very coarse sand except for MG 15 where it was muddy sand. Sorting was classified as poorly sorted; the skewness was fine skewed and coarse skewed except for MG, 16 which was symmetrical. The proportion of grains > 8 mm was relatively low but present in all samples (Fig. 6). Grain sizes with a mean diameter between 2 and 4 mm were present in the entire sample at a relatively high percentage. The grain size < 0.063 mm was limited in all the samples except in MG 16. The reason why this amount of fine materials was a little bit different from the others was because the MG 16 area is an active area for eolian processes close to the river bed.

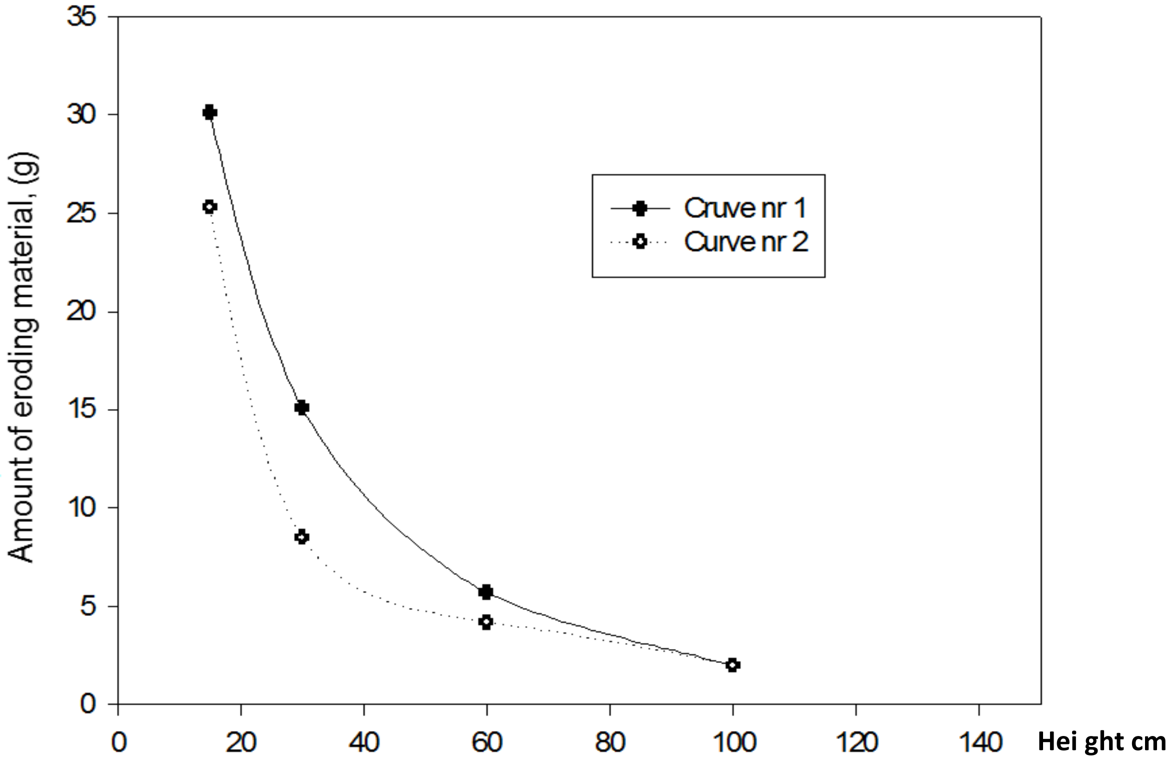

Fig. 4. *Height distribution of aeolian transport of samples collected at locations MG8 (curve n°1) and MG13 (curve n°2) which had four sets of traps at 15, 30, 60 and 100 cm heights.*

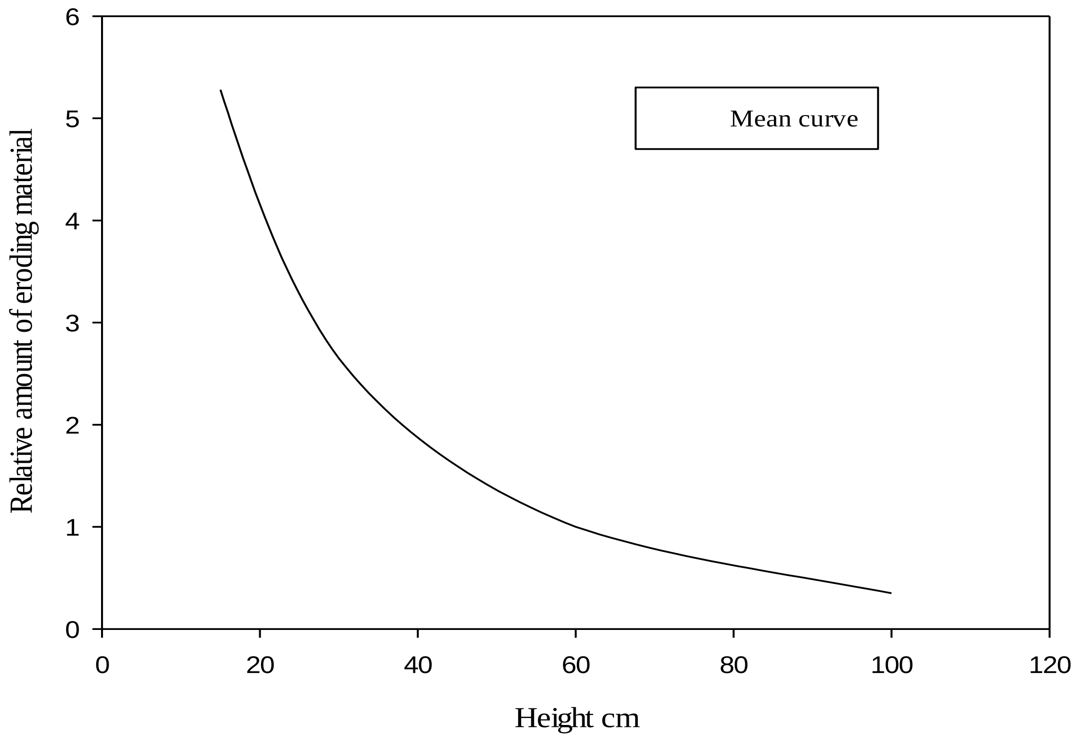

Fig. 5. *Mean height curve of aeolian transport for MG8 and MG13.*

***Table 3**. Summary of grain size parameters of material from surface sample, methods of moments used to calculate statistic.*

location	textural group	Mean(x) (mm)	Sorting (mm)	Skewness (mm)	Gravel (%)	Sand (%)	Mud (%)
MG7	Gravelly Sand	0.851	3.710	-0.174	29.8	68.7	1.5
MG8	Sandy Gravel	0.940	3.675	-0.046	32.2	66.6	1.2
MG9	Sandy Gravel	1.375	3.008	-0.181	42.2	57.8	0
MG10	Sandy Gravel	1.253	3.353	-0.431	48.5	50.0	1.6
MG11	Gravelly Sand	0.620	5.090	0.14	23.8	71.6	4.6
MG12	Sandy Gravel	1.809	4.197	0.108	44.5	55.4	0.1
MG13	Sandy Gravel	1.037	4.326	-0.123	42.3	56.6	1.1
MG14	Sandy Gravel	0.782	4.583	0.121	33.4	64.7	1.9
MG15	Gravelly Sand	0.498	3.223	0.209	13.7	83.4	2.9
MG16	Gravelly Sand	0.702	4.293	0.008	22.9	73.0	3.2
MG17	Gravelly Sand	0.990	4.469	0.287	27.4	72.2	0.3

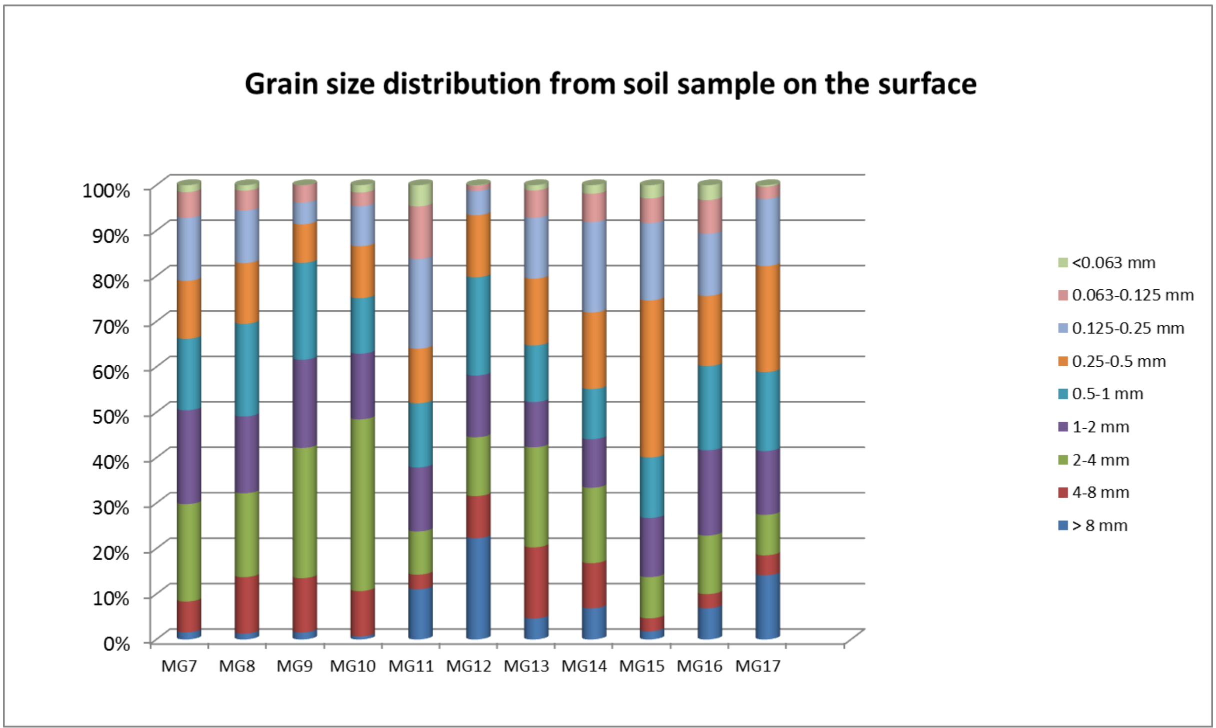

***Fig. 6**. Grain size distribution of surface samples taken on July 6th, 2011*

4.4 Calculated mass aeolian sand transport (kg m^{-1}) for each interval and total

The average curves were used to find a coefficient for calculating aeolian transport for each 10 cm interval (10 cm *100 cm, using the median) up to 120 cm height (see Table 4). The coefficient obtained from these curves were used to calculate sand mass transport in kg of material, which was transported over a 1 m transect, up to 120 cm height.

Example of the calculation from sample collected at 50 cm heights at locations MG 1 is shown in Table 5. The amount collected in a dust trap (e.g. 32.1 g at MG 1) was multiplied by the coefficient for each height range (e.g. 3.89 g for 0 -10 cm) and divided by 1000 to change the amount into kg. To transfer the amount calculated for each height range into sand transport over a 1 m wide transect, the opening slot size of the samplers was multiplied by a factor to represent 1 m transect.

Table 4. *Calculation of mass aeolian sand transport (Kg m^{-1} for each 10 cm interval at each location).*

Location	Height (cm)	Weight (g)	Quantity of sand transported kg m^{-1}
MG1	50	32.1	77.8
MG2	50	1.3	3.1
MG3	50	0.0	0.0
MG4	50	0.9	0.03
MG5	50	5	12.2
MG6	50	150.2	364.4
MG7	50	108	264.0
MG8	15	30.1	13.4
MG8	30	15.1	15.7
MG8	60	5.7	14.4
MG8	100	2	12,5
MG9	60	3.2	7.8
MG10	60	11.7	28.6
MG11	60	3.3	8.1
MG12	60	8.2	20.0
MG13	15	25.3	11.3
MG13	30	8.5	8.9
MG13	60	4.2	10.6
MG13	100	2	12.5
MG14	60	3.1	7.5
MG15	60	3.8	9.3
MG16	100	47	114
MG17	60	2.8	7.1

Table 5. *Example for calculation of sand transport at each 10 cm interval for MG1, which had 32.1 g collected in a trap at 50 cm height.*

Height range (cm)	**Calculated material (g)**	**Transect (m)**	**Height interval (cm)**	**Dust traps opening (cm2)**	**Sand transport kg m-1**
0-10	3.89	100	10	9	18.8
10-20	3.89	100	10	9	18.8
20-30	2.47	100	10	9	11.6
30-40	1.68	100	10	9	7.9
40-50	1.2	100	10	9	5.7
50-60	0.9	100	10	9	4.2
60-70	0.65	100	10	9	3.2
70-80	0.52	100	10	9	2.5
80-90	0.41	100	10	9	2
90-100	0.32	100	10	9	1.5
100-110	0.2	100	10	9	1
110-120	0.12	100	10	9	0.6
					77.8

5 DISCUSSION

5.1 Grain size

The grain size analysis showed that the proportion of sand fraction in surface samples ranged from 50% to 83% in almost all the area. The mean size distribution ranged from 0.5 to 1.8 mm. The sorting was defined as almost poorly sorted. These results showed that Myrdalssandur is a sandy area with coarse grain size when compared to other aeolian areas in the world. The poorly sorted materials are due to the steadily active flooding events which contribute to the sandy deposits. Glaciers rivers produce a large quantity of silt and sand that are transported from underneath the glacial margins. The presence of grains up to 8 mm in the soil sample at Myrdalssandur proves that flooding by glacial rivers appears to be one of the most influential factors in providing the sand source formation in the Myrdalssandur sandy desert. After the flooding a large quantity of sediments is left behind which becomes the source for expansion of the sandy areas. This phenomenon triggers the aeolian processes in this area but it diminishes as gravel starts gradually to cover the surface through the process of selective sorting by the wind. Glaciers typically deposit very poorly sorted sediment because the distance of transport is usually relatively short. As a medium of transport, glaciers are relatively rigid and therefore large pebbles and even huge boulders can be transported almost as easily as smaller sand and silt particles. This is perhaps the case for Myrdalssandur today closest to the glacial margins where we found many particles of diameter > than 8 mm in the soil samples. In general, sediment transported for short distances is more poorly sorted than sediment that has been transported over longer distances.

The soil texture in Niger is sandy and composed mostly of quartz. Quartz grains have a specific density of 2.65 cm^{-3} and are the most common in the aeolian sediment of most countries. In Iceland, due to the volcanic origin, glass and pumice make up an extensive part of the sediment with a density of 1.5- 2.9 g cm^{-3} and 0.5- 1.0 g cm^{-3} respectively (Arnalds, 1990).

5.2 Aeolian transport

One of our objectives was to quantify the mass of sand transport during an erosion event. We measured one storm during August 13th. The results showed that there is considerable variation in sand transport within the research area, reflecting variability at the landscape scale. The quantity of sand transported was up to 364.4 kg m^{-1} in one location while in some places it was as low as 0.03 kg m^{-1} during the storm of 13th August. The average wind speed was 10.8 m s^{-1} during the storm event. A total of 364.4 kg m^{-1} is very high amount for such a low intensity storm, but as an example; Sterk (1997) measured a storm that transported 102.7 kg m-1 in the Sahelian zone of Niger during a storm event with an average wind speed of 10.3 m s^{-1}.

The results showed that the most intense mass transport in this research was not only where there were active sources that transported new materials into the area (river bed) but soil particles carried out during saltation and suspension that were temporarily caught by Lyme grass (*Leymus arenarius*) and then subsequently released during storms as sorted materials.

The quantity of materials at 100 cm above ground collected at MG 16 (47g) during the storm event was considerably higher than at the two locations (MG 8 and MG 13) at the same height (Table 4). The differences in sand transport as seen from the results can be explained in large part by the surface characteristics as grain size distribution, soil erosion, and surface roughness. MG 16 was located near the river bed where fine particles were more dominant than coarse materials. This could be the reason why there were more particles in the traps MG16 than in the two others traps at 100 cm height.

Looking at the research area and the difference in sand transport within the location showed that the major differences in the erosibility of the surface area as shown in the grain size distribution caused the difference in sand transport rather than the meteorological factors. This conclusion is in accordance with the result from Stout (2007) when he measured wind erosion in two areas with similar weather conditions but different surface types.

5.3 Height distribution of collected materials

As mentioned earlier, grains are transported by wind in three ways, by surface creeping, saltation and suspension. The majority of grains are transported by saltation, but the upper limit of the saltation layer is often considered to be about 30 cm, but can go higher depending on the topography of the area (Pye & Tsoar, 2009). In this study the mean curve from the measurement of dust traps placed at 15- 100 cm height showed that the saltation layer reached above 30cm, both on the south and northern sides of the road. The quantity of materials collected at MG 6 and MG7 at 50 cm height were respectively 150.2 and 108 g, indicating that the saltation height extended well above 50 cm. The proportion of grains carried by saltation decreased with height, while the proportion of grains carried by suspension increased with height. This was shown from the composition of materials collected in MG 8, 13 and 16.

The large amount of material collected south of the road at MG 6 suggested that the road and Lyme grass may trap sand temporarily. After an erosion event the accumulated materials are blown along the road, causing a sorting effect.

5.4 Further applications of methods and equipment used

In order to study wind erosion processes in the field on a large landscape scale, adequate measurement techniques are needed. During our study the emphasis was to gain understanding and knowledge of wind erosion process and methodology to measure wind erosion for practical use in Niger.

A simple sediment catcher for measuring horizontal mass fluxes of wind-blown particles is described, and a method to calculate the total mass transport rate at the point of observation was developed. The fact that the distribution of sediments by height and the mean height was very similar where more than one set of samples were obtained from a set of four dust traps supported the credibility of the single dust trap method in this reseach. However, it is not known if height distribution curves are so consistent between storms at the same location in the Sahel. Therefore, it is important to study height distribution curves in the Sahel before applying the single dust trap method. The low cost of applying the method is a benefit that would justify such research and an additional benefit is the simplicity of using the method.

5.5 Factors that may affect the results

The reseach lasted only for 45 days which is a short time for field measurements where weather conditions can vary considerably over a year and between years. The inter – annual variability of parameters such as temperature, relative humidity, and wind speed can only be ascertained from long term data obtained using standard methods (Lal, 1993).

The fact that no measurements were made of surface creep may also have affected the accuracy of the result for total sand movement. Estimates of mass transport may be biased when creep is not measured since 7-25% of soil movement can be moved by creep (Chepil, 1945).

6. CONCLUSIONS

In this research, new methods have been used in an attempt to gain understanding of wind erosion processes for practical use in the Sahel region. It is important to be able to estimate erosion on a landscape scale and to predict erosibility based on environmental factors. These results add valuable information to our knowledge and skills on how to use the Big Spring Number Eight dust traps to measure the effect of wind erosion and to quantify wind erosion sandy desert. Sandy desert like the Myrdalssandur desert which is prone to particle loss is most prone to saltation (river side). This is in agreement with the result of Gomes, Rajot, Alfaro & Gaudiche (2003) who mentioned that sandy soils are most prone to nutrient-rich particle losses and saltation. Unfortunately, these soils are generally those that are already poor in fine particles from the start. In order to reclaim or prevent the irreversible degradation of these soils, it is of the utmost importance to understand why there are differences in sand transport on a landscape, the main pathways of sand, the relationship between grain size and aeolian transport, and the relationship between grain size and aeolian transport

The method used to quantify wind erosion is simple and can be well applied in Niger where wind erosion is today one of the most important factors contributing to land degradation. The fact that the distribution of sediments by height at the same location is very similar where more than one set of samples obtained from a set of four dust traps supported the credibility of the single dust trap method. This research was also an opportunity for me to explore the use of the single dust trap method in Niger in an attempt to study the height distribution of aeolian transport.

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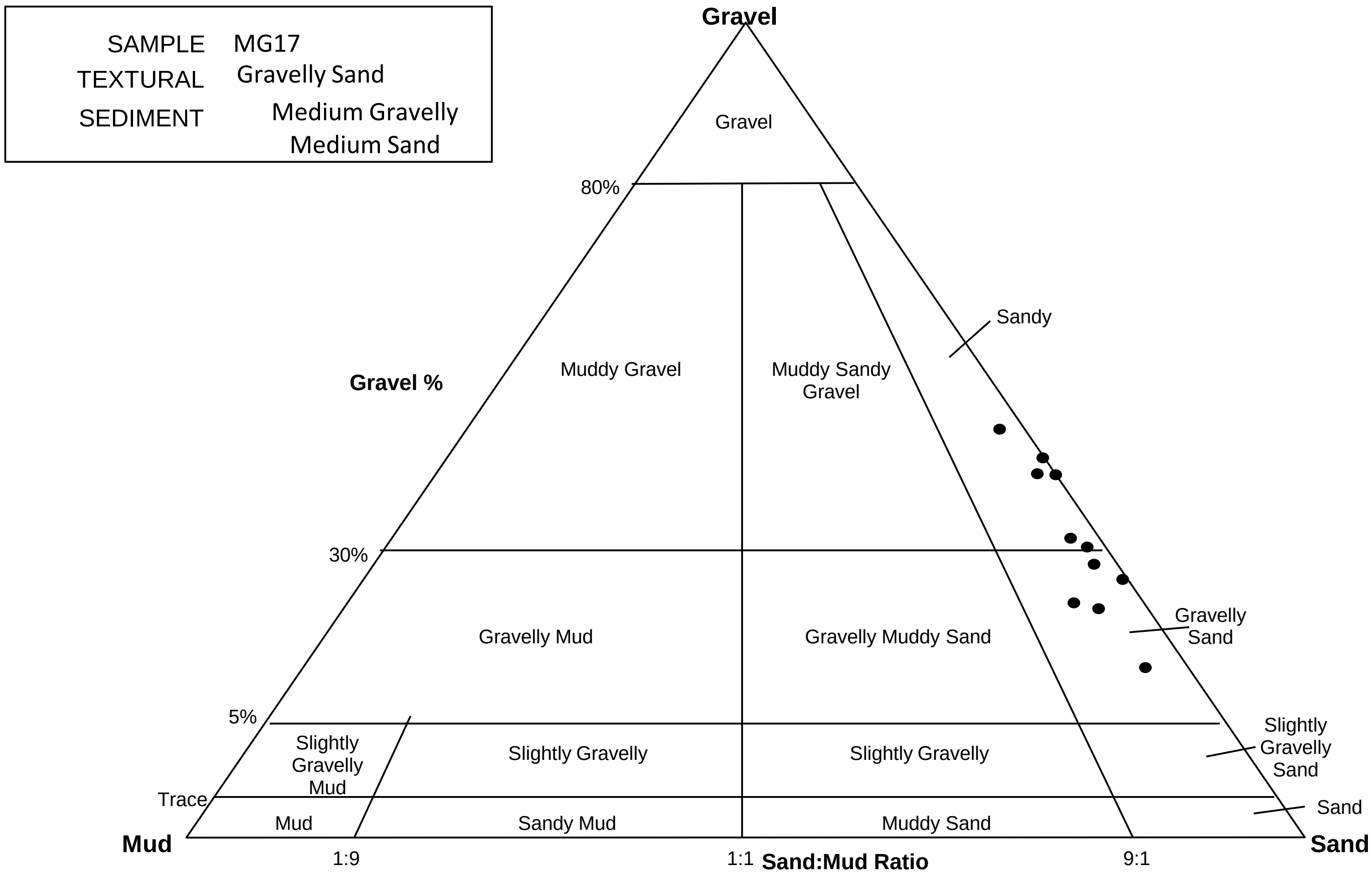
APPENDIX 1



Gravel Sand Mud Diagram. This figure describes the textural group of all the 11 soil samples. The black dot shows the sample. Five samples belonged to gravelly sand while six to sandy soils.

APPENDIX 2

Location, collector, the different diameter sizes used in sieving the soil sample and the weight of each grain size.

Mýrdals MG			height	weight	> 8 mm	4-8 mm	2-4 mm	1-2 mm	0.5-1 mm	0.25-0.5 mm	0.125-0.25 mm	0.063-0.125 mm	<0.063 mm
Date	location	Collector	cm	g	g	g	g	g	g	g	g	g	g
9.7.2011	MG1	FN137	50										
	MG2	FN132	50										
	MG3	FN142	50										
	MG4	FN144	50										
	MG5	FN158	50										
	MG6	FN143	50										
	MG7	FN139	50	103.43	1.62	7	22.11	21.33	16.22	13.19	14.32	5.81	1.58
	MG8	FN141	15	104.02	1.35	12.91	19.19	17.58	21.18	13.91	12.02	4.55	1.25
	MG8	FN115	30										
	MG8	FN116	60										
	MG8	FN117	100										
	MG9	FN133	60	107.68	1.66	12.8	30.7	20.81	22.83	9.1	5.09	4.12	0
	MG10	FN130	60	105.54	0.72	10.51	39.8	15.21	12.88	12.05	9.28	3.16	1.7
	MG11	FN122	60	106.44	11.68	3.41	10.06	14.9	14.93	12.71	20.85	12.26	4.94
	MG12	FN129	60	109.73	24.27	10.1	14.08	14.81	23.54	14.88	5.83	1.27	0.09
	MG13	FN119	15	104.03	4.75	16.2	22.77	10.29	12.88	15.19	13.85	6.21	1.2
	MG13	FN128	30										
	MG13	FN138	60										
	MG13	FN131	100										
	MG14	FN136	60	104.96	7.18	10.37	17.36	11.17	11.53	17.63	20.79	6.5	1.98
	MG15	FN157	60	106.55	1.9	3.05	9.66	13.85	14.18	36.8	18.09	5.81	3.1
	MG16	FN135	100	105.08	7.2	3.25	13.48	19.62	19.39	16.17	14.29	7.74	3.44
	MG17	FN120	60	105.72	14.78	4.62	9.33	14.72	18.22	24.44	15.48	2.82	0.35

APPENDIX 3

The date, location, trap numbers, height at different location where the different Big Spring numbers eight were located and soil samples were taken.

date	location	Traps	collector	height	soil sample
6.7.2011	MG1	LBHI 1	137	50	
6.7.2011	MG2	LBHI 26	132	50	
6.7.2011	MG3	LBHI 30	142	50	
6.7.2011	MG4	LBHI 11	144	50	
6.7.2011	MG5	LBHI 27	158	50	
6.7.2011	MG6	LBHI 10	143	50	
6.7.2011	MG7	LBHI 4	139	50	soil sample
6.7.2011	MG8	LBHI 10	141	15	soil sample
6.7.2011	MG8	LBHI 32	115	30	soil sample
6.7.2011	MG8	LBHI 28	116	60	soil sample
6.7.2011	MG8	LBHI 16	117	100	soil sample
6.7.2011	MG9	LBHI 31	133	60	soil sample
6.7.2011	MG10	LBHI 3	130	60	soil sample
6.7.2011	MG11	LBHI24	122	60	soil sample
6.7.2011	MG12	LBHI5	129	60	soil sample
6.7.2011	MG13	LBHI 7	119	15	soil sample
6.7.2011	MG 13	LBHI 5	128	30	soil sample
6.7.2011	MG 13	LBHI 2	138	60	soil sample
6.7.2011	MG 13	LBHI 2	131	100	soil sample
6.7.2011	MG 14	LBHI 3	136	60	soil sample
6.7.2011	MG 15	LBHI 33	157	60	soil sample
6.7.2011	MG 16	LBHI 34	135	100	soil sample
6.7.2011	MG17	LBHI 29	120	60	soil sample