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Monitoring of Inter-annual Fluctuations in Population Size and Survivorship of *Koenigia islandica*

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ABSTRACT

Koenigia islandica has a disjunct Arctic and sub-Arctic circumpolar distribution extended southward to several isolated mountain ranges of northren Europe, Asia and North America. The population of this plant on the Isle of Skye at altitude 461-726 m and on Isle of Mull at 385-523 m is the most Southerly in Europe and therefore the most vulnerable and likely to exhibit the impact of climatic fluctuations on numbers and survivorships. *Koenigia* is also an annual, which makes it particularly vulnerable to adverse conditions and exhibits large fluctuations in numbers and survivorships between years. In order to examine population fluctuations and survivorship of individuals a number of permanent transects were set up across stands of this plant on Mull and Skye to monitor inter-annual variations in germination and survivorship for four years. *Koenigia* grows in wet, waterlogged and disturbed habitat. Drying out of sites may kill *Koenigia*. Inter-annual population variation depends upon the seeds produced by the plants during previous year.

Key Words: Population; *Koenigia islandica;* Isles of Mull; Isles of Skye

INTRODUCTION

Koenigia islandica has a disjunct Arctic, sub-Arctic circumpolar distribution extended southward to several isolated mountain ranges of Europe. It is therefore the most vulnerable and likely to exhibit the impact of climatic fluctuations on numbers and survivorships (Crowford *et al.,* 1993). It is typically associated with bare and very mobile substrate that are too unstable for perennial plants to establish and out-compete this very small plant (Rashid *et al.,* 2003), *Koenigia islandica* has also been reported to have a small seed bank, with approximately 90% of the viable seeds in the soil germinating each year (Reynold, 1984a). The average number of seeds produced per plant is usually less than 10 (pers. obs.). The density of colonies is typically less than 50 within squares covering 0.25×0.25 m^2 (Rashid *et al.,* 2003). Colonies are typically small even with the small seed production. One must predict that a number of seeds may be lost through death or being washed out of the area. The aim of the project was to examine population fluctuations and survivorship of individuals of *Koenigia islandica.*

MATERIALS AND METHODS

In order to establish the survivorship of *Koenigia* plants in the field permanent transects were set up, with one on Beinn na h'Iolaire on Mull in 1996 and three on The Storr on Skye in 1997 (Table I). The number of plants recorded in 50×50 cm quadrat was recorded each at 0.5 m intervals along each transect in June and September of 1996, 1997, 1998 and 1999. The number of dead as well as alive plants in each quadrat along the transects was also recorded in August or September.

Five permanent quadrates were set up on the flat gravel terrace adjacent to the permanent transects. An attempt was made to estimate the rate of turnover of individuals over one season using photographs taken of seven 20×20 cm plots with a 35 mm single lens reflex camera with a telephoto lens in each month of the summer of 1998 located within 1×1 m plots. The position of each plant was recorded in each photograph and compared to the previous month and new plants or plants that had disappeared were recorded. The exact position of the plants could be ascertained from the grid and distinctively shaped and coloured stones. The permanent seed bank was estimated by collecting 13 samples of soil from areas where *Koenigia* plants were present, but before they had started to produce seeds in June of 1998 and were sieved.

RESULTS

Inter-annual variations in population size. There was relatively small inter-annual variations between years in the numbers of *Koenigia* along the permanent transects (Fig 1-4). Along transect 1 on Mull the number of plants at the beginning of the season only varied between 655 and 1,883 during the 4 year period of this study from 1996 to 1999 (Table II). There was a more or less similar pattern of variation in initial plant density between years observed along the three transects on Skye, viz an increase in

Table I. Grid references, altitude, aspect and slope of sites where *Koenigia islandica* plants and were sampled from the Isles of Skye and Mull

Site No	Number/Name/Locality	N. G. R.	Altitude (m)	Aspect	Slope (°)
1	256 (Storr-Skye)	NG 494540	690	W	18
2	294 (Bealach a Chuirn-Skye)	NG 487545	500	NW	7
3	271(Bealach a Chuirn-Skye)	NG 487546	500	NW	5
4	Transect-1 (Mull)	NM 453313	460	SW	3
5	Transect-2 (Mull)	NM 453313	460	SW	3

Table II. Number of *Koenigia* plants at the start and end of growing season along transects on Isles of Skye and Mull (M represents missing data)

Year	Isle of Mull			Isle of Skye					
	Transect 1			Transect 294		Transect 271		Transect 256	
	Start	End	%age	Start	End	Start	End	Start	End
1996	1438	64	4.45	_	_	_	_	_	_
1997	1632	89	5.45	940	387	452	161	302	168
1998	665	313	47.06	1504	M	M	M	635	M
1999	1883	264	14.02	421	346	224	64	71	40

Table III. **Monthly rainfall and average mean maximum temperature from Stonoway 294, 271 and 256 represent the transect numbers on the Isles of Skye b) Monthly rainfall from Knock 10-15 miles east from study site on Mull and mean temperature from Tiree (Source of data Lesely Towened)**

Year	1996			1997			1998			1999		
Month	Rainfall (mm)	Temperature (°C)	Survivorship (%)	Rainfall (mm)	Temperature (°C)	Survivorship (%)	Rainfall (mm)	Temperature (°C)	Survivorship	Rainfall (mm)	Temperature (°C)	Survivorshi (%)
May	68	10.8	Missing	85	13.8	41.6% (294)	31	12.7	Missing	103	12.6	82.2% (294)
June	58	14.0		66	13.7	36.7% (271)	73	13.2		105	13.3	33.5% (271)
July	80	15.2		52	17.4	52.6% (256)	95	15.2		70	16.4	64.8% (256)
August	71	16.0		39	18.7		54	15.7		54	16.4	
Year	**1996**			**1997**			**1998**			**1999**		
Month	**Rainfall (mm)**	**Temperature (°C)**	**Survivorship (%)**	**Rainfall (mm)**	**Temperature (°C)**	**Survivorship (%)**	**Rainfall (mm)**	**Temperature (°C)**	**Survivorship (%)**	**Rainfall (mm)**	**Temperature (°C)**	**Survivorship (%)**
May	50	11.14		93	13.4		40	12.13		140	20.7	
June	195	14.25	4.5	35	14.58	5.3	135	14.22	83.3	157	14.9	13.6
July	185	15.27		100.5	16.8		207.5	12.89		152	20.2	
August	95	15.87		39	18.23		292.5	13.3		110	15.7	

population of *Koenigia* in 1998 as compared to 1997 and then a decrease in 1999.

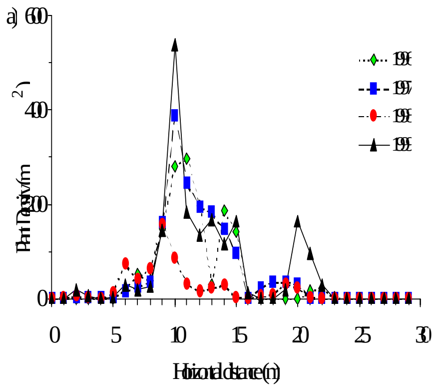
Inter-annual variations in survivorships. Unlike plant density there is a much greater inter-annual variation in survivorship between years (Fig 1-4). Survivorship on Mull was nearly the same during the years 1996 and 1997, (4.45 and 5.45%, respectively), but during 1998 more than 47% of the plants survived though the number of plants at the beginning of the season in this year was fewer. In 1999 the survivorship was again lower at 14.02%.

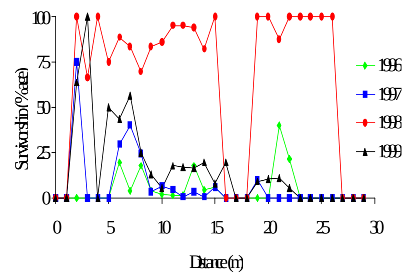
In 1997 all the three transects on Skye showed similarly high levels of survivorship, ranging from 35.6 to 55.6%, which is higher than that observed along transect 1 on Mull during the same year. Unfortunately, it was not possible to refind the marker posts in the mist when transects on the Storr were visited in September in 1998. Some of the marker posts had also been removed by sheep. Hence survivorship data is not available for 1998.

Density-dependent survival. On Mull there was significant density-dependent survival along transect 1 in 1996, 1997 and 1999 (Fig. 5). In 1998 the survival was much greater on the whole and therefore there was no relationship between survivorship of *Koenigia* plants and the initial density of plants (Fig. 5). On Skye, however, there was no significant relationship between survivorship and starting density of plants on all transects for both 1997 and 1999 (Fig. 5).

Table IV. Rate of turnover of individuals over one season using photographs taken 20×20 cm plots within 1 × 1 m plots

Site	May 24th 1998 Total no of plants	July 22nd 1998 Total no of plants	Alive plants	Dead lants	Survival %age
123 (6,1)	16	14	14	2	87.5
123 (2,7)	12	11	11	1	91.66
123 (3,2)	16	15	15	3	93.75
124 (6,5)	29	31	31	0	106.89
124 (5,8)	22	20	20	2	90.8
125 (5,8)	16	17	17	0	106.25
125 (1,7)	16	14	14	2	87.5





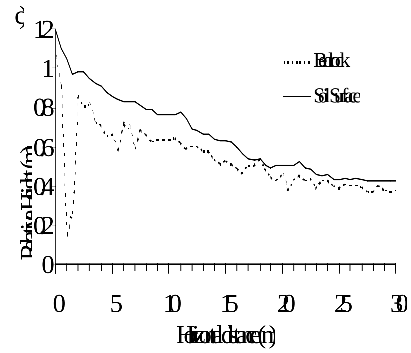
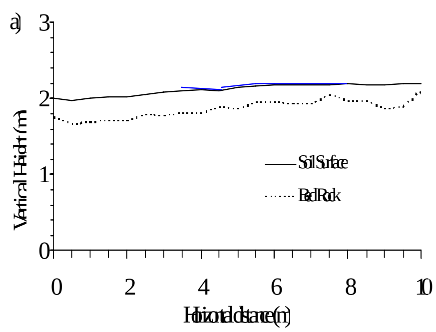
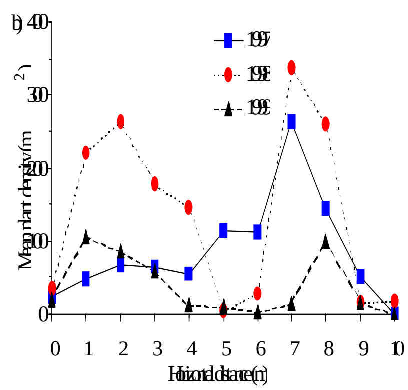


Fig. 1. (a) The mean density and survivorship (b) of *Koenigia islandica* plants along transect 1on Beinn na h'Iolaire on the Isle of Mull in 1996, ' 97,' 98 and '99. The level of the soil surface and the bedrock are shown in (c) Plant density is based on numbers counted in 1 m^2 contiguous quadrats





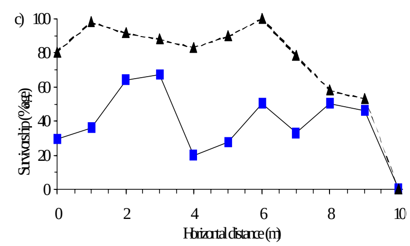
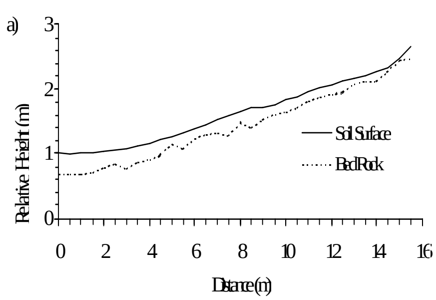
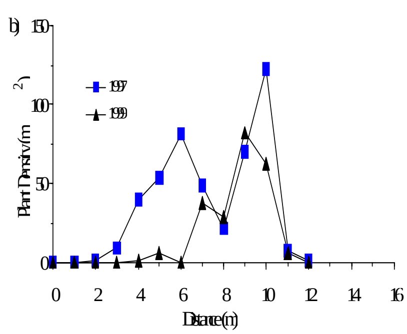


Fig. 2. (a) Shows the level of the soil surface and the bedrock (b) The mean density (c) survivorship of *Koenigia islandica* plants along transects 294 on the Storr, Skye in 1997, 1998 and 1999.. Plant density is based on numbers counted in 1 m^2 contiguous quadrate. Blue line in a) shows the presence of standing/running water.





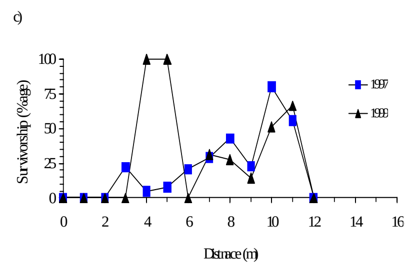


Fig. 3. (a) Shows the level of the soil surface and the bedrock (b) The mean density (c) survivorship of *Koenigia islandica* plants along transect 271 on the Storr, Skye in 1997 and 1999.. Plant density is based on numbers counted in1 m^2 contiguous quadrats

Fig. 4. (a) Shows the level of the soil surface and the bedrock (b) The mean density (c) survivorship of *Koenigia islandica* plants along transect 256 on the Storr, Skye in 1997, 1998 and 1999. Plant density is based on numbers counted in 1 m^2 contiguous quadrats

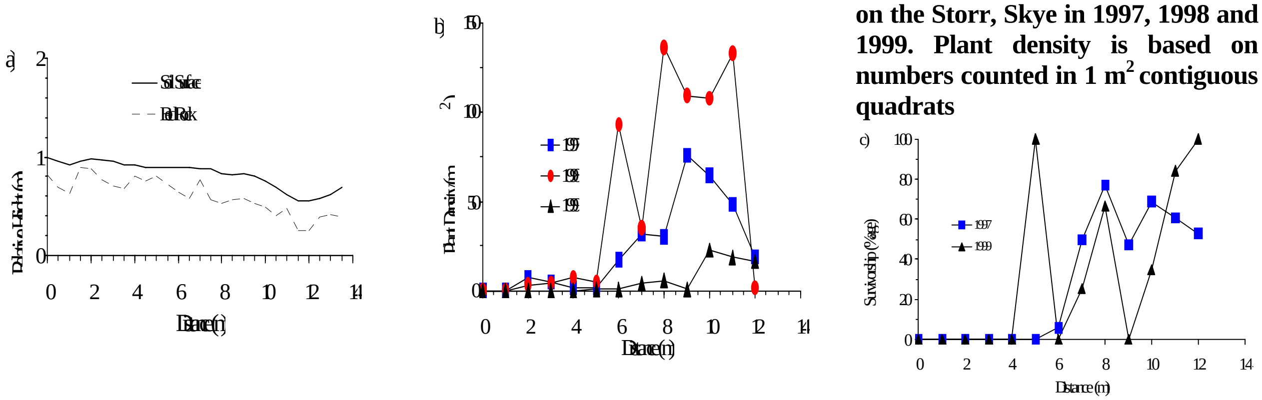


Fig. 5. The relationship between the density (m^2) of the plants and the survivorship of *Koenigia islandica* along transect one in 4 different years on Mull and along transects on the Storr, Skye in 1997 and 1999

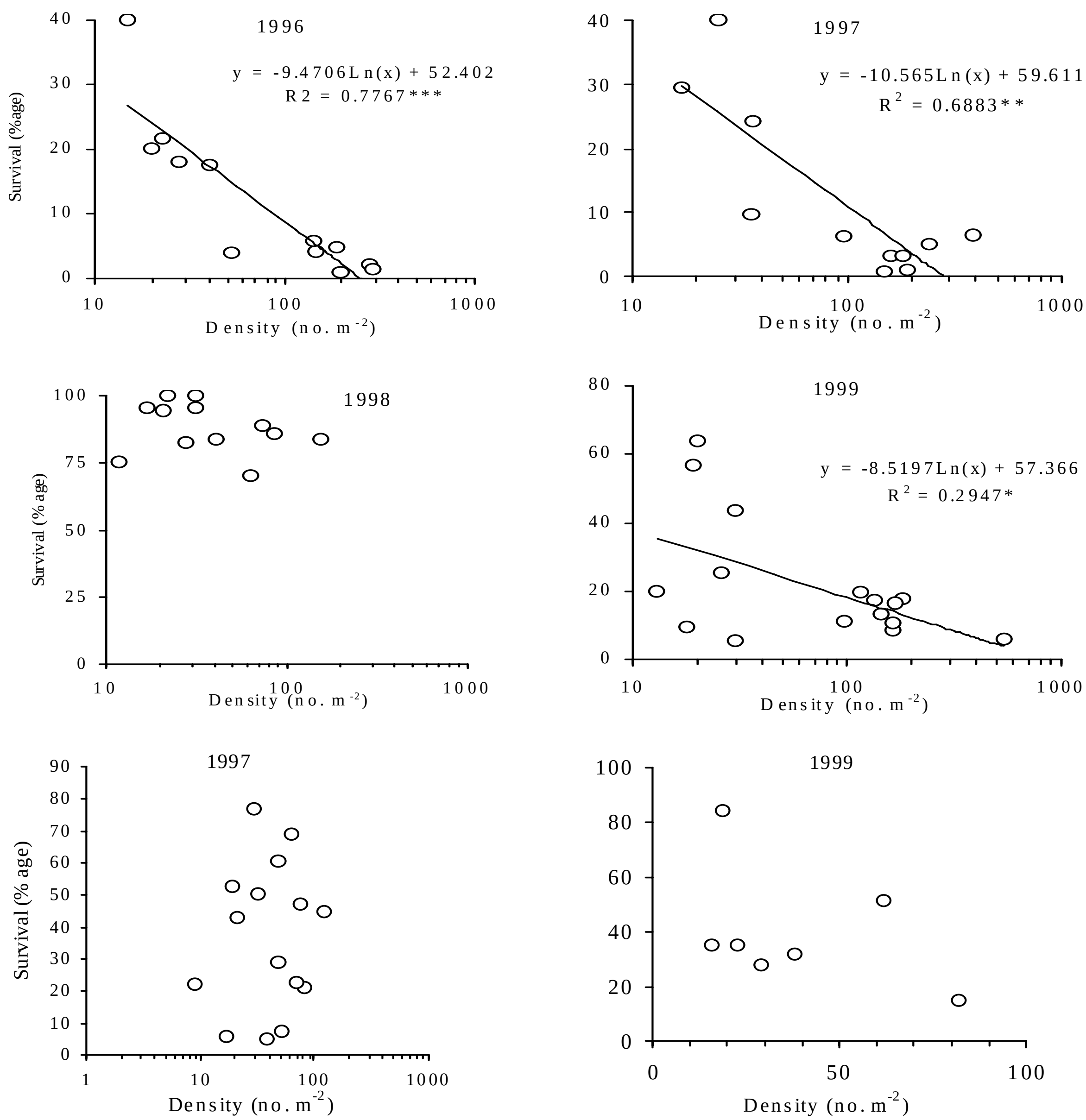
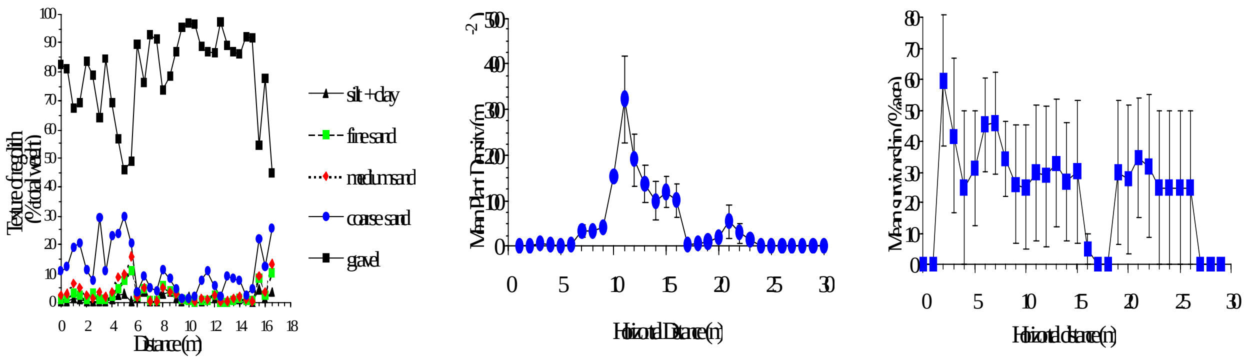


Fig. 6. The particle size distribution of top 2 cm of regolith along part of transect 1 on Beinn na h'Iolaire, Mull and the mean density and survivorship of *Koenigia islandica* plants along the same transect. Mean of 4 years with bars representing one standard error of the mean



DISCUSSION

High levels of moisture in the soil of bare areas may be more favorable for the germination of seeds (Steven & Billings, 1981). The increase in mortality of seedlings in 1996 and 1997 coincided with low rainfall in July which is likely to have resulted in drying out of the soil (Buckland *et al.*, 1997) at the study sites, whereas the much higher levels of survival in 1998 coincided with higher rainfall during July of that year (Table II). Thus the survival of *Koenigia* plants is most closely related to the availability of water (Table III).

Disturbance (Jonasson & Skold, 1983) in general appears to be a powerful force in the maintenance of *Koenigia* populations and the replacement of other tundra plants populations in general. The population of *Koenigia* showed a wide range of initial plant densities along transects. The correlation between survivorship and initial plant density was significant for the years 1996, 1997, and 1999 on Mull, whereas no significant correlation was found during the year 1998 on Mull and in 1997 and 1999 on Skye.

The reason for the significant correlation in 1996, 1997 and 1999 appears to be low rainfall, especially during July (Table III), and the competition for water may be the reason for lower survivorship at higher densities (Reynolds, 1984b). In years or microsites where there is plenty of water, as in 1998 on Mull, the competition for water is so low that rate of survival is exceedingly high. The photographs taken during 24th of June 1998 and 22nd of July 1998 from seven different sites did not show any addition or death of plants during this period. This indicated that all seeds had germinated followed by good survival. Other factors, such as grazing can be correlated with the size of the plant. Plants of *Koenigia* do get eaten, as it was observed during experiments in the green house. Big plants can easily attract sheep whereas the sheep cannot see small sized plants, as they grow amongst the gravel.

Population turnover. Photographs taken on June 22nd and July 24th showed that nearly all plants (96.06%) survived over that time period (number of plants=127) (Table IV). There was virtually no recruitment of new individuals either (2.36%) (Table IV). Given the low rate of turnover of this annual it seems that the vast majority of *Koenigia* seedlings germinate early in the season and very few new individuals are gained or lost from populations as the growing season progresses (Reynolds, 1984a).

A total of 69 seeds were extracted from 13 samples of regolith, which gave a total seed bank of 130 m^{-2}. This is clearly a small permanent seed bank (Reynolds, 1984b) and is insufficient to account for each year's average plant density 772 m^{-2} in the same area. Given that the average seed output is 4.6±0.6 seeds per plant (personal observation) the numbers of plants surviving to the end of season on the transects at Skye will produce enough seeds to produce the number of seedlings at the beginning of the next season. With regard to the population monitored along Transect 1 the number of plants surviving to the end of the growing season would in theory not produce enough seeds to account for the number of seedlings at the beginning of the following season. However, it is possible that a large number of plants that do not survive to the end of season will produce a small number of seeds before they die (Mcgraw & Varvek, 1989). There is also every possibility that this site could be a sink for seeds from elsewhere on the hill. A small population of *Koenigia* plants has established itself on the summit of Beinn na h'Iolaire, which is 100 to 200 m downwind of the main terraces below the summit. The presence of such a population indicates that there may be a significant seed rain maintaining certain populations from well established ones.

Buried seeds will clearly be brought to the surface by frost heave (Amen,1966, Fox, 1983) where there is bare regolith and therefore a buried seed bank may easily re-establish a population by this process (Densmore, 1979). Erosion of old deposits of weathered regolith may also bring a buried seed bank to the surface and potentially establish new populations (Fox, 1983). However, it is most likely that the majority of populations is stable and dependent on the annual output of seeds by extant plants that form the basis for the establishment of the following year's plants with a small contribution from permanent seed bank.

It appears that the presence of frost heave (Jonasson & Skold, 1983) plays a major role in the maintenance of *Koenigia* populations on Mull and Skye by keeping populations of competing species down and facilitating germination of *Koenigia* seeds and a suitable micro-environment for the growth of the plants. The presence of 60 to 80% (Fig. 6) gravel in the weathered regolith appears to be most favourable to *Koenigia* and this type of soil structure will also be maintained by frost heave (Jonasson & Skold, 1983) and subsequent removal of silt fraction by aeolian processes.

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