Terrestrial Microphytic Crusts in Pinon-Juniper Woodland

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A comparison between a Research Natural Area and adjacent land managed for grazing.

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Summary.

This study was designed to provide detailed comparisons of terrestrial cryptogam cover between pinon-juniper (P-J) woodlands of relatively low disturbance in a Research Natural Area (RNA) and adjacent managed areas utilized for livestock grazing.

Largo Mesa, a provisional RNA in Catron Co., New Mexico, was chosen as the study site based on earlier studies on cryptogam and vascular plant communities on RNAs Figure 1 shows the study area. A fence along the eastern boundary has separated the RNA from livestock use for several decades and has provided an optimal setting for comparing disturbance impacts on cryptogam cover. This fence was used as the point of reference in establishing the study sites within each area. Twenty long-term monitoring plots were established each side of the fence and monumented at either end with a 60cm-long rebar. The transects were positioned between pinon or juniper trees spaced 8 -11m apart. Unfortunately, it was discovered that the fence dividing the RNA and managed area had been cut in several spots and the RNA had subsequently experienced some livestock trespass. The effect of the livestock trespass on the state of the RNA cannot be accurately estimated without more information. However, it can be assumed that the grazing pressure was much lighter on the RNA, and, regardless of the impact that the livestock trespass may have had, the monitoring plots that are now established will be useful in assessing the state of the lands in the future.

There were two objectives to this project. The first objective was to establish monitoring sites and compare the cryptogam cover on the RNA and the adjacent managed areas. The second objective was concerned with developing procedures to effectively monitor the development of the cryptogamic crusts.

The percent ground cover was estimated along transects using consecutive small quads ($100cm^2$). Terrestrial cryptogam cover was, on average, 65% higher on the RNA than on the managed area. There was no difference in grass cover between the two areas. Grass cover was not higher in regions where there was lower cryptogam cover. In fact, there was a tendency for areas with high crytogamic cover to have relatively high grass cover. The conclusion of this study supports earlier work completed in 1993 that indicated that grass cover was not particularly correlated with the extent of the cryptogamic cover. Average lichen cover on the RNA transects in 1998 was the same as that measured in 1992 (approximately 5.5%). However moss and algae cover had both declined on the RNA. This may be a consequence of short-term climatic factors or possibly the cattle trespass.

In addition to the comparisons of cover between RNA and managed areas, procedures were tested to measure the rugosity, or roughness, of soil surfaces at a millimeter scale. A suitable measuring device based on a carpenters curve was devised. The hand traced surface profiles were converted into digital format by imaging the original data sheets on a high-resolution flat-bed scanner. The resulting images, scaled according to the original data resolution, were systematically analyzed down each image column to find the row corresponding to the location of the line. The resulting series of row numbers

represents the surface profiles. The variance in the ground surface was calculated and used as a measure of rugosity. The nature of the data indicated that the non-parametric Kruskal-Wallis and Mood median tests were appropriate statistical tests. Using this data it was concluded that, not withstanding the presence of gravel on a surface devoid of cryptogams, the rugosity over a similar distance was statistically and substantially higher on cryptogamic crusts than on ground visually devoid of cryptogams. In addition measurements were taken on well-developed cryptogamic crusts in an entirely different environment, namely the gypsum flats in southern New Mexico. These measurements were included to determine if cryptogamic surface micro-topography varies according to soil type. In this study the rugosity measured on cryptogamic crusts in PJ woodland was very similar to that on the gypsum flats.

We feel that this rugosity-measurement technique has wide application and can be applied in further studies that are directed at investigating the role of cryptogamic crusts in ecological processes. A method of measuring rugosity may be very useful in monitoring the recovery of disturbed sites as well as comparing the effects of different land use practices. Time constraints prevented a direct comparison between the average rugosity encountered on the RNA and the managed area. Future work on refining this procedure should include more measurements on a wider range of crusts and soil surfaces.

As part of the ongoing effort to develop straightforward procedures to monitor cryptogamic crusts in the field the use of ground surface color was considered. An initial hypothesis was that the color of the ground surface would be related to the developmental status, and thus to the degree of rugosity, of the cryptogamic crust. Therefore it was proposed that the use of color may be useful in monitoring cryptogamic crusts in the field. In general it is true that the most developed crusts are darker in color. However, visually, the overall color of the ground surface was a very difficult parameter to estimate. Color charts were useful to describe the colors associated with the ground surface but the lack of uniformity within a field of view made matching color by eye with the degree of rugosity imprecise. Rather, the application of image processing techniques to the digital images of photographs may be more informative. Image processing techniques are usually used on vegetation at a landscape level but the technique can also be applied at a microhabitat level. Some limited, preliminary studies on the acquired images are planned.

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Introduction

Microbiotic crusts are composed of lichens, mosses, liverworts, cyanobacteria, algae, fungi, and bacteria. In this report cryptogamic crusts refer to the larger components of this community that are distinguishable with the naked eye, e.g. lichen, mosses, liverworts and some algae. These living soil crusts reduce soil erosion and contribute to the biomass and nitrogen content of the soil (for reviews see: Harper and Marble 1988; West 1990; Johansen, 1993 Ladyman and Muldavin, 1996). However, there is a theory in the popular literature that cryptogamic cover competes with grass cover and is thus an undesirable component of the range land ecosystem (Savory, 1988).

There were two objectives to this project. The first objective was to establish monitoring sites and compare the cryptogam cover on the RNA and the adjacent managed areas. The second objective was concerned with developing procedures to effectively monitor the development of the cryptogamic crusts.

The first study was designed to provide detailed comparisons of cryptogam and grass cover between areas of relatively low disturbance, specifically Research Natural Areas (RNAs), and adjacent managed areas. Largo Mesa in Catron County, NM, was chosen as the study area. Part of the mesa top at Largo Mesa has been proposed as a Research Natural Area and part is currently managed for livestock grazing. The vegetation is representative of the *Pinus edulis-Juniperus monosperma-Bouteloua gracilis* Association that is widespread in the southwest United States. Hence, research in this area is relevant to many other parts of the southwest.

Long term monitoring transects were established inside and outside of the RNA. The ground cover along each of the transects was estimated so that the cover on the managed area could be compared to that on the RNA. In addition the data from these transects can be used as a baseline for future trend analysis of the region.

Two additional procedures for monitoring cryptogamic crusts were tested. One procedure was designed to measure the rugosity, or surface roughness, of soil surfaces at the millimeter scale. Crust rugosity, which increases over time, is understood to influence water and sediment run off. A high rugosity slows water runoff and reduces sediment loss (Eldridge and Green, 1994). The developmental stage of the cryptogamic surface is important to its physiological function and a measurement that can be related to the functionality of the crust would be an important management tool. The second procedure examined the concept of classifying the extent of the cryptogamic crust by its color. Casual observation of the sandy, limestone and gypseous soils of the southwest has indicated that a well developed cryptogamic crust is of a much darker color than a younger, less developed crust which in turn is of a darker color than bare soil.

Methods

Site selection

Two RNAs were initially selected for study. Largo Mesa RNA is in west-central New Mexico, and Mesita de los Ladrones is in north-east New Mexico. These two mesa-top RNAs had been studied in previous years, and had the potential for grazed and ungrazed comparisons (Ladyman and Muldavin, 1993). At each RNA, nearby areas, having similar elevation, aspect and vegetation, but with current grazing activity were examined for likely comparative sites.

At Mesita de los Ladrones we were not able to match the attributes of the RNA with any other areas nearby. Elevation, aspect, slope, and, particularly, geological substrate, were a combination unique to this RNA. In contrast at Largo Mesa there was a fence that separated the RNA from grazed land which was on the same substrate, slope, aspect and elevation making it an ideal site for comparative studies. In several spots there was evidence of cattle trespass on the RNA. The effects of the trespass on the ground cover is difficult to judge and more information is needed. However, it was assumed that there has been significantly less disturbance over the long term in the RNA than in the managed area. The long term monitoring plots that have now been established will be useful in assessing the state of the lands in the future.

Part 1. Ground cover measurements

Transect establishment

In previous studies, the tree spacing appeared to affect cryptogram distribution (Ladyman and Muldavin, 1993). Based on these studies, a spacing of 8 -12m between live pinon and/or juniper trees was chosen which allows comparisons with previous work. Each transect was monumented with a 60cm-long, tagged rebar at each end for long term monitoring and located using GPS. A typical transect is shown in Figure 1A. The fence line was used as the point of reference for positioning the transects. However, transects were placed at a minimum of 15m from the fence which is far enough away to avoid direct fence affects. Twenty (20) transects were established within 70m each side of the fence. The individual transect positions are shown in Figure 2.

Transect protocol

Approaches to all transects was made from down the slope, and all activities were performed down-slope of the lines. Transects were run from the base of one tree trunk to its nearest neighbor within the 8 –12m spacing guidelines. A miniature quad (10cmx10cm) was used to estimate cover sequentially along each transect (Figure 1B). To expedite the rather tedious surveying procedure the miniature quads were made in blocks of five so that more than one quad could be read before the frame was moved (Figure 3B). Using this quad size, 1% cover is an area of $1cm^2$ (about the size of the operators' thumb nail) which can be readily estimated by eye. The ground cover directly beneath the tree canopy was generally 100% tree litter, therefore the quads were read from the edge of one tree canopy to the other. Given that the lines are 8 -12m long but

that the tree canopy generally extends approximately 1-2m there were between 40-80 quads per transect. Percent cover was estimated within the quadrants for the elements listed in Table 1. Both aerial and basal cover of vascular plants was measured. To compare possible relationships between cover and aspect, ten transects were established at a NW/SE declination and ten at a NE/SW declination.

Data Analysis

This approach avoids using average values per transect and thus minimizes the loss of information. Quad cover between the RNA and managed area was compared by the non-parametric, Kruskal-Wallis test. This test was used because the data were not normally distributed, which violates the assumption of the analysis of variance (ANOVA) that the data come from normal distributions. In addition, a variance check indicated that there are significant differences in the standard deviations of the data sets. This violates another assumption that underlies the ANOVA. Transformation of the data did not relieve this situation. Therefore, the non-parametric Kruskal-Wallis analysis test that compares median values instead of mean values was used. Where there was a difference in the percent cover between the two areas the respective covers were correlated using Spearman's Rank Correlation procedure to determine if positive or negative associations existed. The numbers of vascular plant species on each transect were counted to help characterize the individual transects with respect to the overall biodiversity of the areas.

The relationship between grass and cryptogam cover is of particular interest in designing sustainable grazing management protocols. In order to determine if lichen and blue grama grass canopy cover follow similar patterns along the transects the two-term local quadrat variance (TTLQV) method of analysis of spatial pattern was applied (Ludwig and Reynolds, 1988).

Part 2. Rugosity (surface roughness) and color measurements

Procedures to measure the corrugation of the soil (cryptogamic crust) surface were tested using a pin frame. The most satisfactory version was modeled after a carpenter's curve measuring device which measured changes at the millimeter scale. Figure 4 shows the most satisfactory set-up and Figure 5 the least effective set up that was made from carpet pins and a plexiglass holder. The points of the latter proved to be too sharp and the spacing of the pins was not fine enough. The former system appeared to give good results and these data were analyzed in a multi-step process.

In the field the profile obtained by the carpenter's curve measuring device was traced on to a piece of paper. The hand traced surface profiles were converted into digital format by imaging the original data sheets on a high-resolution flat-bed scanner. This process resulted in images of a dark profile curve on a white background. These resulting tiff images, scaled according to the original data resolution, were systematically analyzed down each image column to find the row corresponding to the line location. The resulting series of row numbers represents the originally drawn pattern and were imported into a spreadsheet package for further numerical analysis. The variance in the ground surface was calculated and the difference between the ground surfaces was

investigated. Kruskal-Wallis and Mood median tests were used because of non-normality and inequality of the variances in the data.

On both the managed area and RNA, areas with and without visible cryptogams were selected for study. Some of the ground surface was covered by many small gravels but these were not avoided in our site selection (e.g. at managed area transect 3, see Figure 8 A and B). In addition, measurements were taken on well-developed cryptogamic crusts in an entirely different environment, namely the gypsum flats in southern New Mexico. These measurements were included to determine if cryptogamic crust micro-topography varies according to soil type.

The intensity of the blackness of the surface was compared to a color scale to determine if the shade of the surface was correlated to surface roughness. The color charts were made from paint chip samples and proved to be satisfactory.

Results and Discussion

Part 1. Comparative ground cover studies

A total of 2047 quads were surveyed. Nine hundred and ninety seven (997) quads were surveyed on the managed area and 1050 on the RNA. The difference between the areas is due to the slight differences in transect lengths.

Based on the Kruskal-Wallis test, there was a significantly greater total cryptogam, lichen, and algae cover on the RNA than on the managed area. Considering mean values there appeared to be greater moss on the managed area, however when the median values were analyzed there was statistically more moss cover on the RNA. The difference in the mean and medians can be explained because the data come from a skewed distribution. The managed area group has one transect with a particularly high value but 12 transects have zero, or less than 0.02%, moss cover. The RNA has many more transects on which there is moss cover, but no area has a particularly high cover of moss. Thus, the mean of the managed area is higher than the RNA group but its median is lower. These results suggest that the level of grazing activity on the managed area has reduced the cryptogamic cover.

Basal vegetation, principally blue grama grass, was greater on the RNA, but there was a high degree of variability and the difference was not statistically significant. Therefore the lesser amount of cryptogamic cover on the managed area did not result in an expansion of the grass cover. A positive correlation on a per quad basis between terrestrial lichen cover and blue grama grass cover was found using Spearmans rank correlation analysis (Table 2). However, even though there is a positiverelationship between these two vegetation types it appears that the areas with the highest cover of crytogams is not necessarily the area with the highest grass cover. In Figure 6 the average cover of each transect has been interpolated using discrete radii of 28m. Grama grass cover is represented by shades of green and cryptogam cover by shades of purple. One interpretation of this result is that a productive micro-environment will be beneficial to both grass and cryptogams but that there are areas where the conditions particularly favor one life form over the other.

The two-term local quadrat variance (TTLQV) method of analysis of spatial pattern was applied (Ludwig and Reynolds, 1988) to the lichen and blue grama grass canopy cover. The profiles of the variance plotted against block-size for several of the transects are described in Appendix 1. The selection of profiles presented represent the range of patterns observed. As suggested from the positive correlation between the blue grama grass canopy and lichen canopy (Table 2), there is, on some of the transects, a similar spatial pattern. For example, on RNA transect 1 (see Appendix 1), lichen tends to "clump" in patches 6.2m apart with smaller clumps ~60cm apart. Blue grama grass canopy tends to "clump" in patches 4 m apart with secondary patches both 6.2m apart and ~60cm apart. This loose similarity of pattern is common e.g. on RNA transect 2 where patches of the two cover types are observed at intervals of approximately 4m, with smaller patches at a spacing of approximately 80 cm. On managed area transect 4 there are patches of both lichen and blue grama grass at intervals of 5.6m. However, the smaller clumps of lichens at intervals of about 80 cm is not a characteristic shared by the grass canopy on this transect (Appendix 1). On some transects there was little match between the spatial patterns, e.g. patches of lichen and blue grama grass canopy cover were offset by approximately 20 cm on managed area transect 6.

The variances were often of different orders of magnitude because the percent cover was of different orders of magnitude. However, it is the pattern rather than the absolute values that are of interest. Thus, for some transects, the profiles of the two cover classes were plotted on different graphs so that the patterns could be seen clearly. This is important because in some cases when the variances were plotted on the same scale different conclusions could be reached than when plotted separately. For example, on managed area 1 the dominant clumping for both cover classes occurs at intervals of approximately 5m with smaller patches at 80 cm. When plotted on the same scale it appears that the pattern of the lichen is random and clumping only occurs for the *B. gracilis* canopy. Compare the two Figures on Appendix 1-page 1 to the one Figure on Appendix 1-page 2.

The percent lichen cover on the RNA was very similar to that found in 1992 (Ladyman et al 1993). In 1992 there was 5.9% lichen cover and in 1998, 5.3% lichen cover. However, total cryptogam cover was less in this 1998 study than that in 1992. The total cryptogamic crust cover in 1992 was 8.87% compared to 5.56% in 1998. The difference is due to the reduction in moss and algae, mainly *Microcoleus vaginatis*, cover. It can not be determined whether short term environmental conditions or livestock trespass is responsible for this observation.

In the previous study, gravel had been positively correlated to higher cryptogam cover (Ladyman et al, 1993). In this study there were significantly more gravel on the RNA than on the managed area but, on a per quad basis, there was no positive correlation between these classes of cover (see Table 1 and Table 2).

With respect to aspect, on average, in the area immediately within 1m of a tree's canopy there was a higher lichen cover in the north east (NE) quadrant and more moss cover in the north west (NW) quadrant (Table 3). This is in agreement with the findings in previous years where the NW and NE quadrants had the highest cryptogam cover (Ladyman and Muldavin, 1993). It is also notable that the managed area had This observation implies that shade influences the extent of cryptogam cover. Cryptogams

are poikilohydric in nature and it is reasonable that microhabitats that remain cool during the hottest parts of the day will be most favorable for cryptogam growth.

In general, the vascular plant species diversity was relatively low. Both areas were very similar with respect to the number and type of species. There was generally two forb species and one grass species per transect (Table 4). As mentioned previously, blue grama grass (*Bouteloua gracilis*) was the most common grass (see Table 4 and Figure 7).

Rugosity and Color Studies.

A total of 14 surfaces were measured on ground visually devoid of cryptogams. Where cryptogams were observed, 15 measurements were made on the managed area and 29 on the RNA. Examples of the ground surfaces measured, along with their associated traces, are described in Figures 8 and 9. In addition to measuring the cryptogamic crusts at the pinon-juniper site, 18 measurements were taken on ground with well-developed cryptogamic crusts in an entirely different environment, namely the gypsum flats in southern New Mexico.

As is expected, the Kruskal-Wallis and Mood median tests gave identical results (see Table 5). The variance of the ground that appeared to be devoid of cryptogams was significantly lower than that covered by a cryptogamic crust. The median values for the cryptogamic crusts on the managed and RNA areas were very similar, a median of 88 and 82 respectively. This implies the cryptogamic crusts in both areas were both at, approximately, the same developmental stage. The variance associated with the cryptogamic crust on the gypsum flats was less, but not statistically significantly different from that in the pinon-juniper woodland site (Table 5). Figure 10 A shows a typical area measured on the alkali flats and Figure 10 B describes the associated trace.

It is important to always consider the variance over a specific distance when using it for comparative studies. In this case the distance is the length of the measuring device (13 cm). However, for monitoring purposes the distance chosen should be such that one achieves a representative sampling on the ground.

High rugosity is recognized as having desirable physical attributes with respect to slowing erosion processes, and providing nitrogen and carbon to the soil. Nitrogen fixation rates have been measured on a variety of crust constituents (see Ladyman and Muldavin, 1996) and photosynthetic activity has been measured in *Collema tenax* which is an important component of the microphytic crusts in the southwest US (Lange et al, 1998). Tall pinnacled (pedicelled) crusts had higher carboxylation rates and greater dark respiration than low pinnacled crusts (Jeffries et al. 1989). However, there has been no systematic effort to relate the degree of rugosity, or developmental stage, of the crust with physiological functions. Such studies would clarify whether highly developed crusts are more desirable, from a nutrient cycling perspective, than relatively newly formed crusts.

The initial hypothesis was that the color of the ground surface is related to the developmental status, and thus the degree of rugosity, of the cryptogamic crust. For example, observation has suggested that the most developed crusts are darker colored that the most recently established crusts. Therefore, it was proposed that the use of

color could be useful in monitoring cryptogamic crusts in the field. However, visually, the overall color of the ground surface was a very difficult parameter to estimate. Color charts (Figure YY) were useful to describe the colors associated with the ground surface but the lack of uniformity within a field of view made matching color by eye with the degree of rugosity imprecise. For example, in Figure 11, thinner crusts matched "Legacy" and "Ashwood". The patches of the most dense crusts matched "Delta moss" and those with a certain black lichen, which was most likely *Collema tenax*, matched "Night cloud". Although the bare soils tended to match "Woodsy" many times another operator matched the surfaces free of cryptogams to "Legacy". Similarly the percent of an area estimated to be occupied by the respective colors was also operator dependent. Because visual estimations tend to be operator dependent, and largely impractical except at a crude level, image processing techniques applied to the digital images may be more informative and more objective. A very preliminary analysis of the data supports this theory.

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Table 1. Results of the average percent-cover, using all 100cm^2 quad, on the RNA and the managed (MAN) area.

Parameter	Actual Mean (% cover)		Kruskal-Wallis Median Rank		Significance
Number of Quads	1050	997	1050	997	P=
	RNA	MAN	RNA	MAN	
Total cryptogam	**5.56**	**3.47**	**1098.73**	**945.46**	**0.000**
Total lichen	**5.33**	**3.23**	**1087.18**	**951.57**	**0.000**
Total moss	**0.21**	**0.31**	**1046.63**	**1000.17**	**0.000**
Total algae	**0.25**	**0.07**	**1041.79**	**1005.27**	**0.003**
Bouteloua gracilis basal cover	5.30	4.98	1030.89	1016.74	0.585
Forb canopy	0.27	0.24	1029.89	1017.80	0.471
Gravels <1cm	11.46	12.16	1010.13	1038.61	0.275
Gravels 1-2 cm	**3.68**	**2.54**	**1081.08**	**963.89**	**0.000**
Gravels 2-6 cm	**1.11**	**0.67**	**1061.37**	**983.65**	**0.000**
Stones 6-15 cm	0.33	0.66	1021.61	1023.52	0.530
Rocks 15cm-1m	**1.11**	**0.51**	**1031.35**	**1016.26**	**0.009**
Soil	40.94	41.71	1015.69	1032.75	0.514
Sand	3.38	3.73	1023.97	1024.03	0.998
Litter	**25.8**	**28.47**	**992.84**	**1056.82**	**0.014**
Usnea (tree lichen)	0.000	0.001	1023.50	1024.53	0.305
Scat	0.29	0.28	1026.29	1021.58	0.802

Table 2. Spearman's rank correlations between selected ground cover classes. Data was pooled from both the RNA and managed areas.

Correlation	Total Lichen	P=	Total Moss	P=
	Correlation co-efficient		Correlation Co-efficient	
Bouteloua gracilis	0.06	0.0063	0.1	0.0000
Gravel 1-2cm	-0.40	0.0500	ns	
Gravel 2-6 cm	-0.13	0.0000	-0.07	0.0031

Table 3. The average cover per quadrant as related to aspect.

Lichen	NW	SW	SE	NE
RNA	2.3	4.4	7.9	7.1
MAN	3.5	2.5	1.9	2.6
RNA - 7*	2.5	4.4	4.9	7.1

Moss	NW	SW	SE	NE
RNA	0.61	0.02	0.14	0.03
MAN	0.03	0.15	0.07	0.06
RNA - 7*	0.7	0.02	0.15	0.03

Algae	NW	SW	SE	NE
RNA	0.14	0.34	0.2	0.06
MAN	0.03	0.09	0	0.02
RNA - 7*	0.13	0.34	0.11	0.6

*The mean of the RNA sites excluding site number 7 that was in a direct east-west direction. The cover on this line could be included in either the south east or north east quadrants.

Table 4. Vascular plant species observed on the transects at Largo Mesa.

Plant species	**Number of transects with species**	
Forbs	**RNA**	**Managed Area**
Eriogonum alatum	5	2
Eriogonum jamesii	7	4
Descurainia obtusa	0	2
Oxytropis lambertii	0	0
Astragalus mollissimus	2	4
Lupinus kingii	3	3
Hymenoxys richardsonnii	0	0
Bahia dissecta	0	0
Leucelene ericoides	6	8
Lesquerella intemedia	12	12
GYMGLU	1	1
Thelesperma wrightii	0	0
Gutierrezia sarothrae	0	0
Tragopogon sp.	0	1
Mirabilis oxytrophis	1	0
Mirabilis sp.	1	0
Chasmaesyce sp.	1	1
Unidentified rosette MAN 14	0	1
Unidentified rosette MAN 5	0	1
Grasses		
Bouteloua gracilis	20	20
Sitanion hystrix	0	1
BUCDAC	1	0

Table 5. The median variance associated with the micro-topography of the ground surface. I

Kruskal-Wallis Test H = 30.83 DF = 3 P = 0.000

Treatment	N	Median	Ave Rank	Z
Bareground	14	11.75	11.2	-5.12
Gypsum-cryptogam	18	51.48	35.8	-0.59
MAN-cryptogam	15	88.07	51.8	2.60
RNA-cryptogam	29	82.45	46.4	2.46

```
Mood median test. P = 0.000. Individual 95.0% CIs
              ---------+---------+---------+-------
Bareground         (-+---)
Gypsum-cryptogam                (-------+----------)
MAN -cryptogam                         (------+--------)
RNA -cryptogam                  (-----------+--------)
              ---------+---------+---------+-------
```

A

B

Figure 1. A. A typical transect established at the edge of the tree canopy and marked at each end with a 60cm-high rebar. B. Close-up view of the 10x10cm quad used to estimate cover along the transect.

Figure 2. A. Transect locations on Largo Mesa. B. Interpolation of the percent *B. gracilis* cover on each transect. C. Interpolation of the percent cryptogam cover on each transect.

Figure 3. The most effective pin frame used for rugosity measurements.

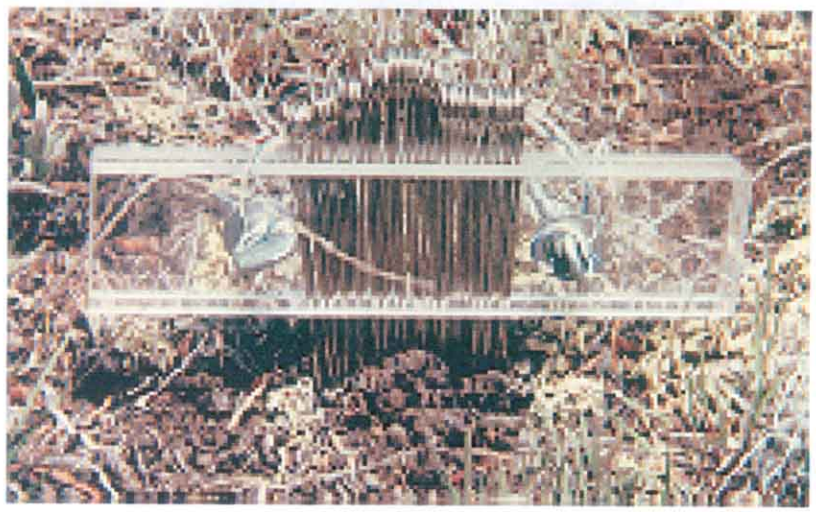
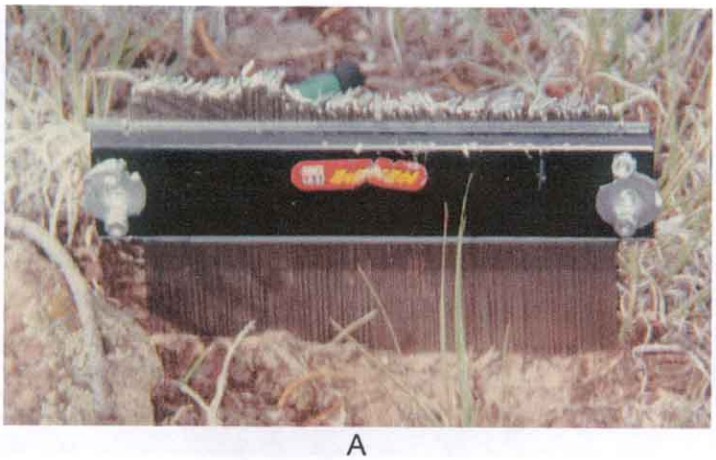
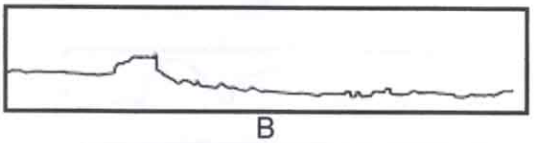


Figure 4. When this pin frame was used for rugosity measurements the pin tips were too sharp and disturbed the crust slightly. The yellow lichen in the foreground is *Xanthoparmelia chlorochroa*.



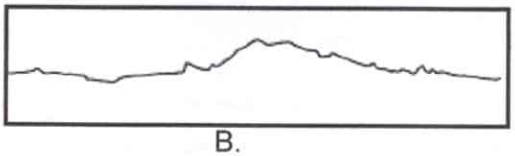
A



B

Figure 5. A. Rugosity-measuring device on a surface that appeared devoid of cryptogams on the managed area at Largo Mesa. B. The trace used to measure variation in the ground surface (see text).

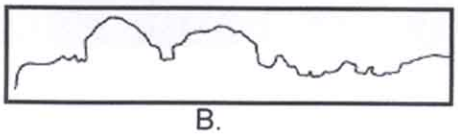
A.



B.

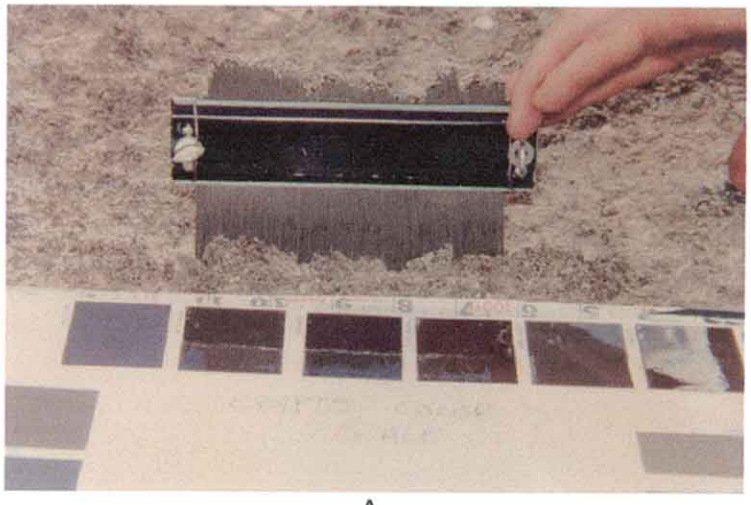
Figure 6. A. Rugosity-measuring device on a surface that appeared devoid of cryptogams but, at the same time, appeared to have significant mico-topographic features on the managed area at Largo Mesa. B. The corresponding trace that was used to measure variation in the ground surface.

A.

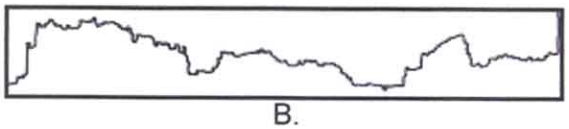


B.

Figure 7. A. Rugosity-measuring device on a highly developed cryptogamic ground surface at Largo Mesa. B. The trace used to measure the variation in the ground surface.



A.



B.

Figure 8. A. Rugosity-measuring device on a highly developed cryptogamic gypsum soil surface in southern New Mexico. The color chart is shown in the foreground. B. The trace used to measure the variation in the ground surface.

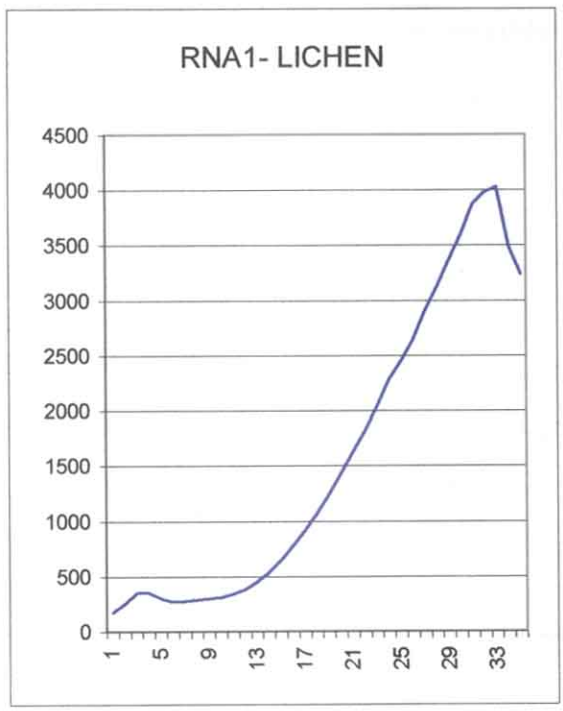
Figure 9. The color chart on the ground surface in southern New Mexico. The colors of the ground surface were matched to the color chart and their percentage cover within a defined area was estimated.

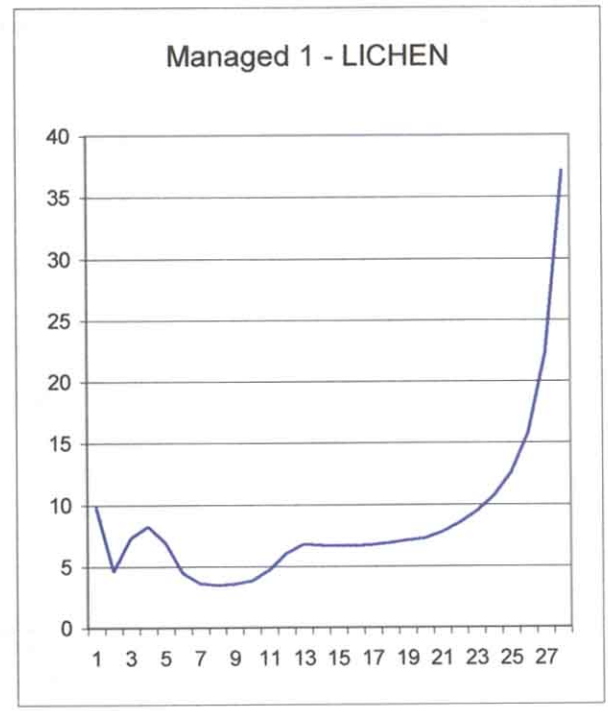
Appendix 1 – An analysis of the spatial pattern of cryptogamic cover and blue grama grass cover.

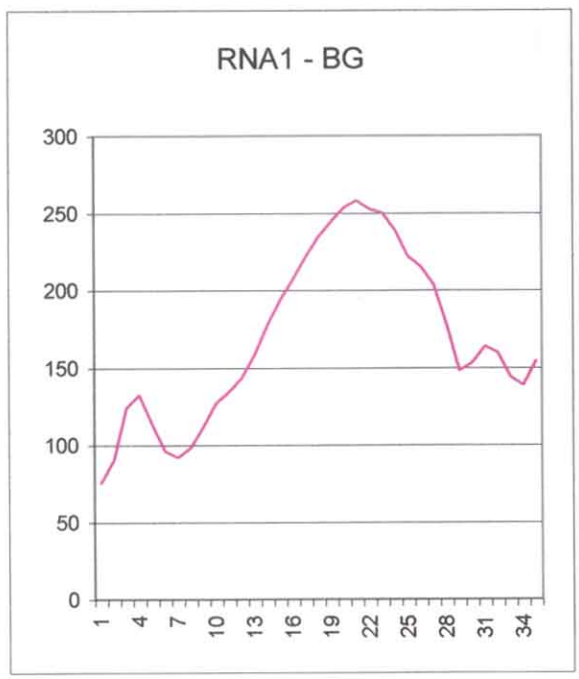
Profiles of two-term local quadrant variance (TTLQV) analysis results are presented for selected transects. The profiles indicate some of the similarities and differences in spatial pattern between cryptogamic cover and blue grama grass cover between trees.

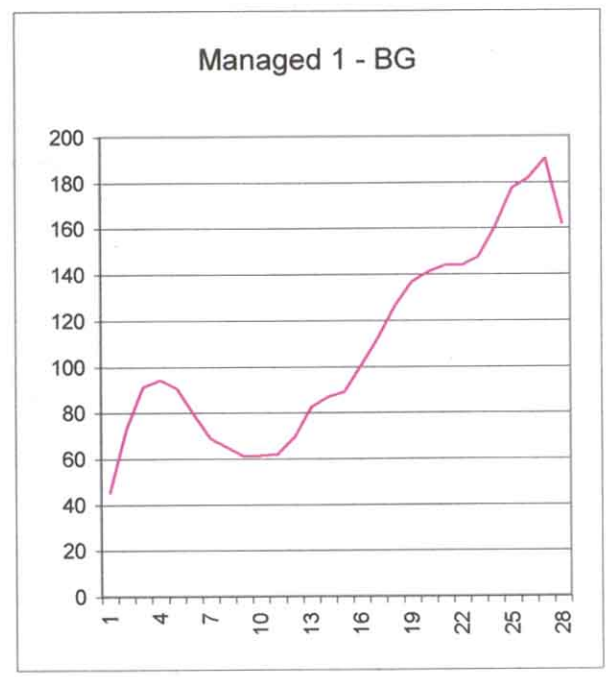
TTLQV analysis of the patterns of lichen and blue grama grass (BG) on selected transects.

Plots of the variances against block sizes.



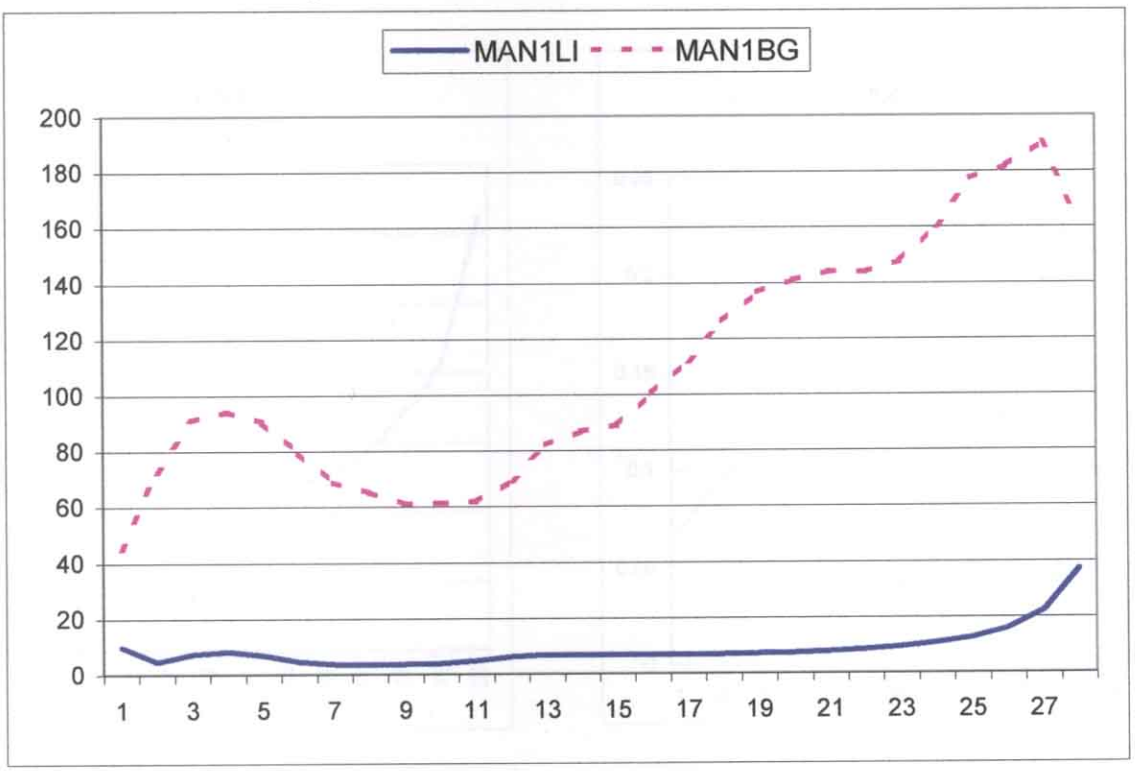


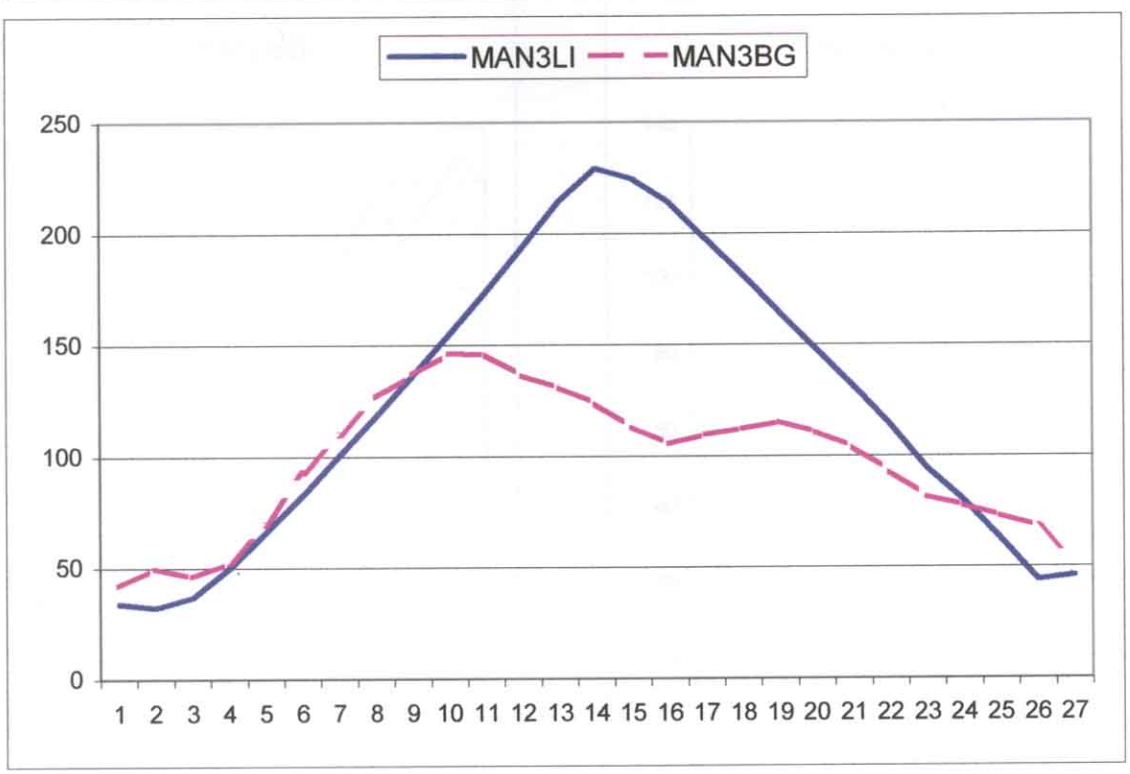




TTLQV analysis of the patterns of lichen (LI) and blue grama grass (BG) on managed (MAN) area transect 1 and managed area transect 3.

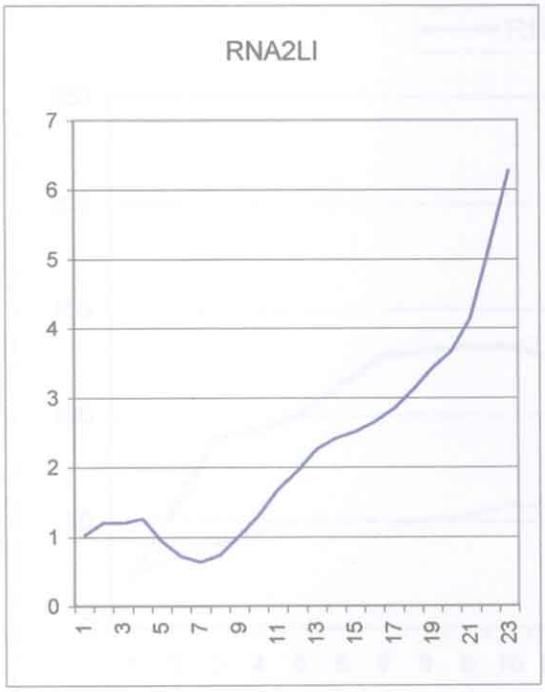
Plots of the variances against block sizes.

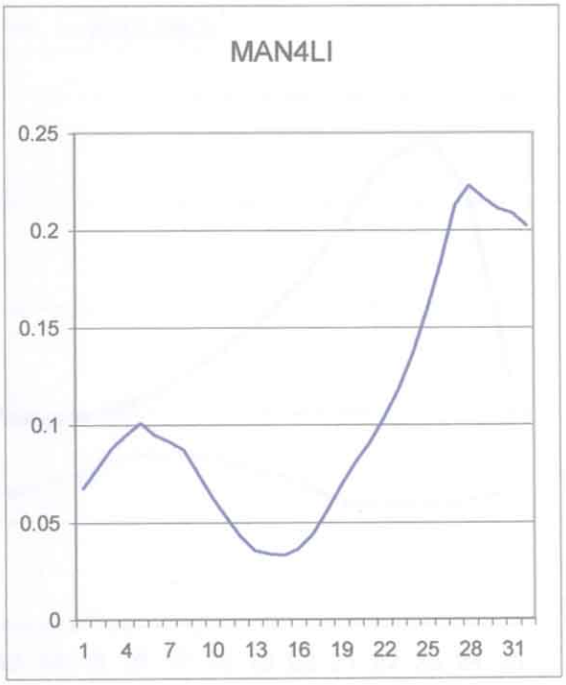


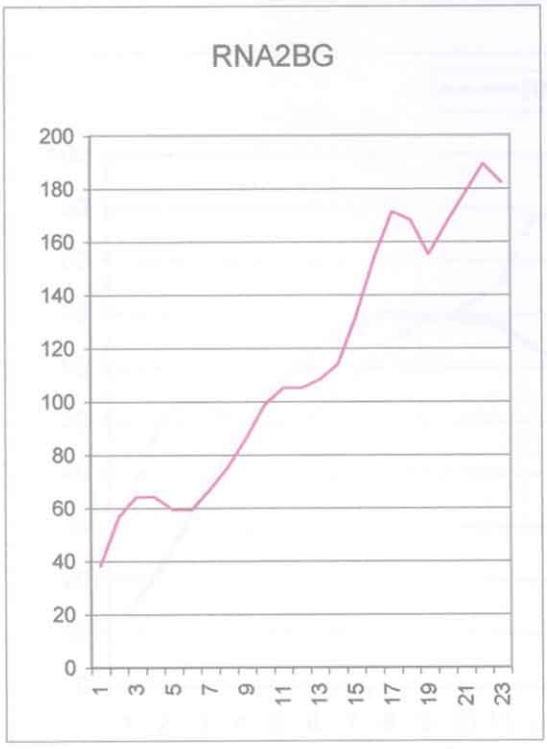


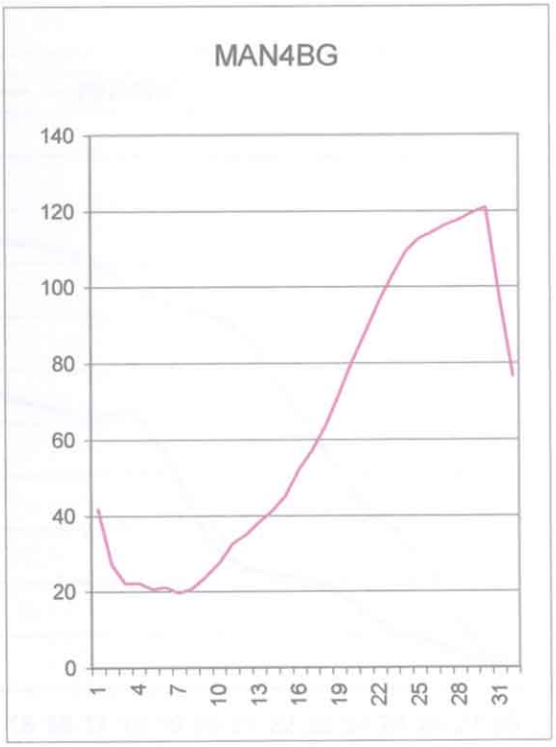
TTLQV analysis of the patterns of lichen (LI) and blue grama grass (BG) on RNA transect 2 and managed area transect 4.

Plots of the variances against block sizes.



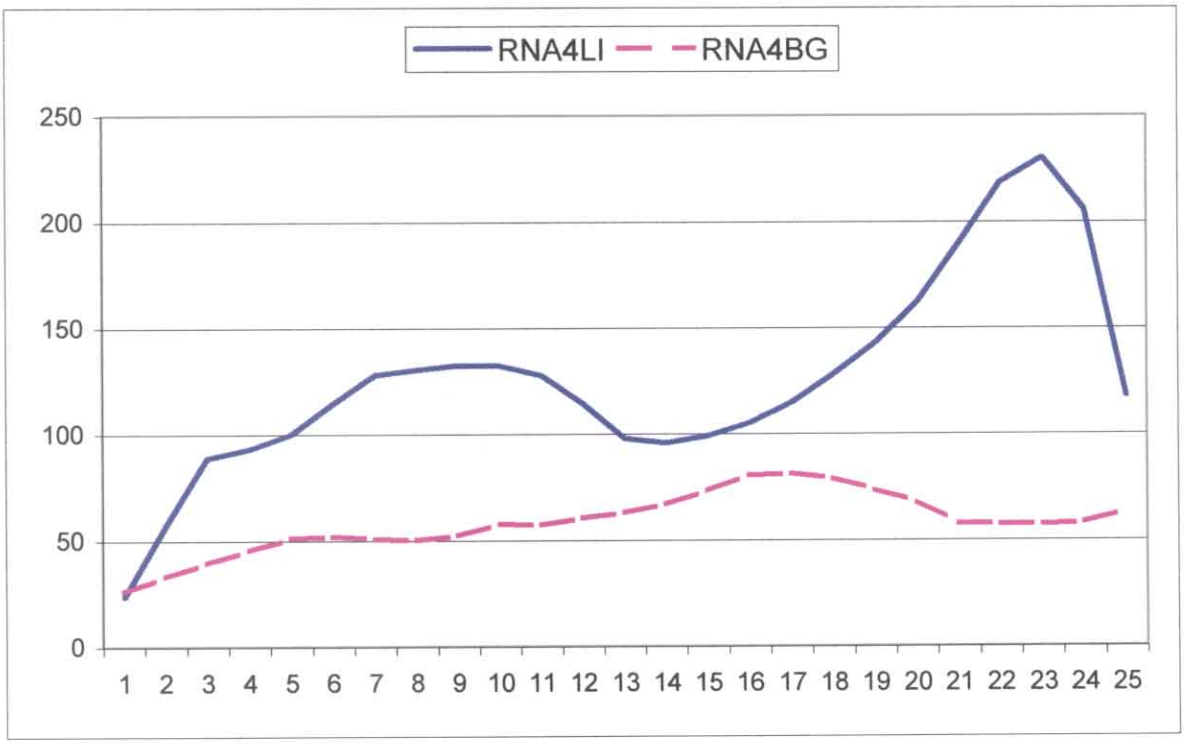


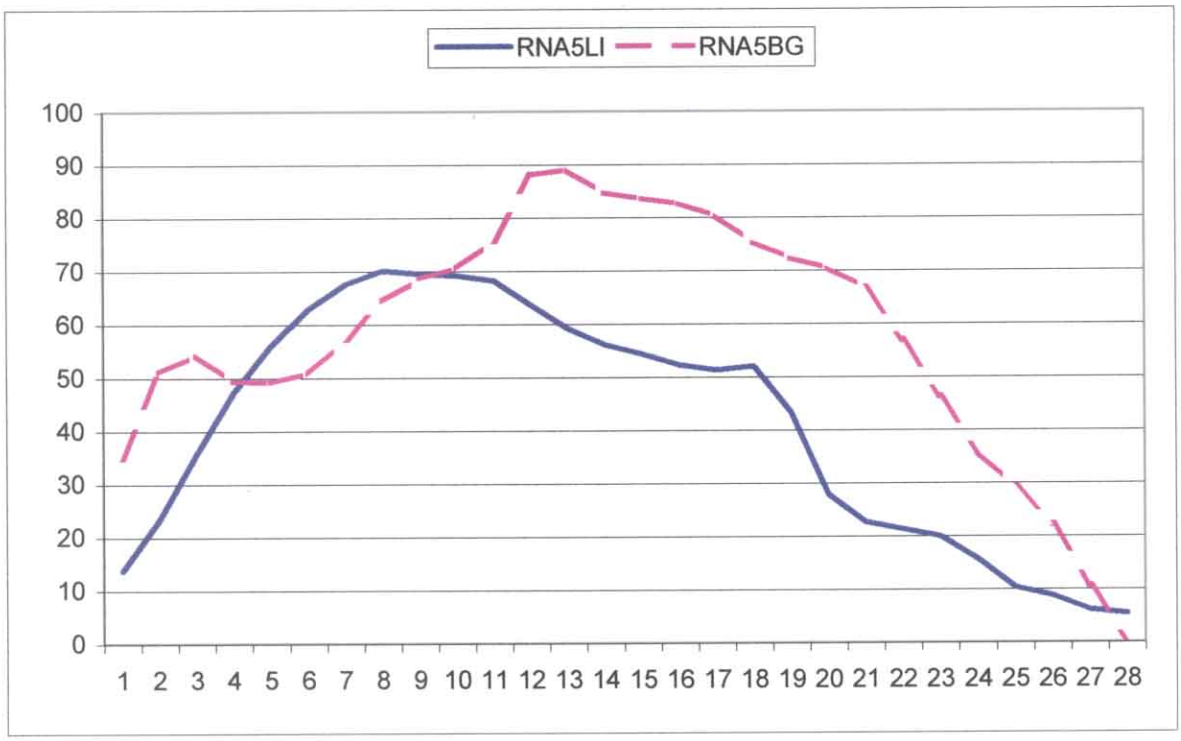




TTLQV analysis of the patterns of lichen and blue grama grass (BG) on RNA transect 4 and RNA transect 5.

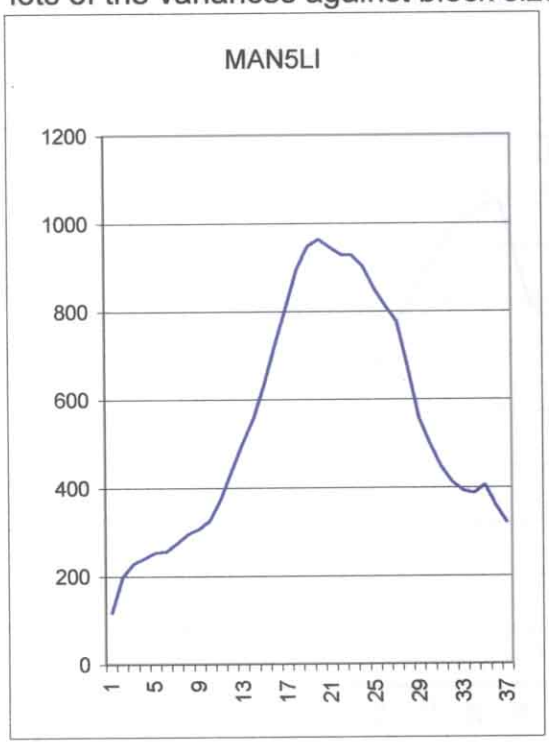
Plots of the variances against block sizes.

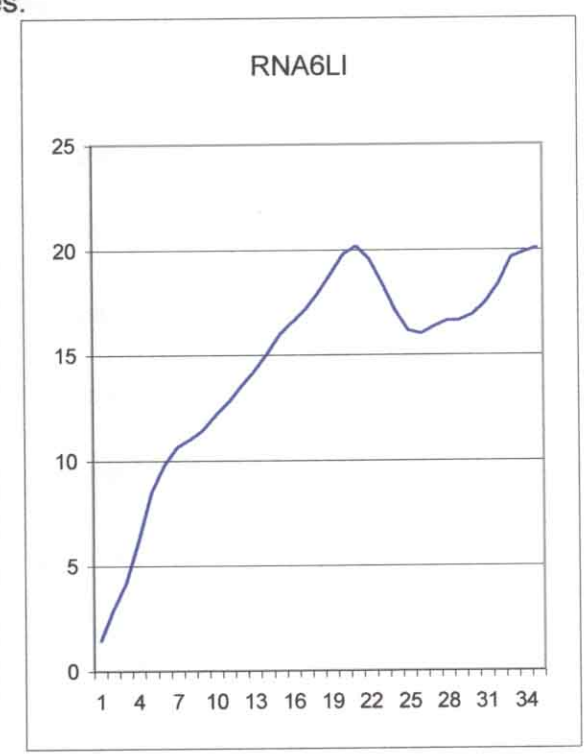


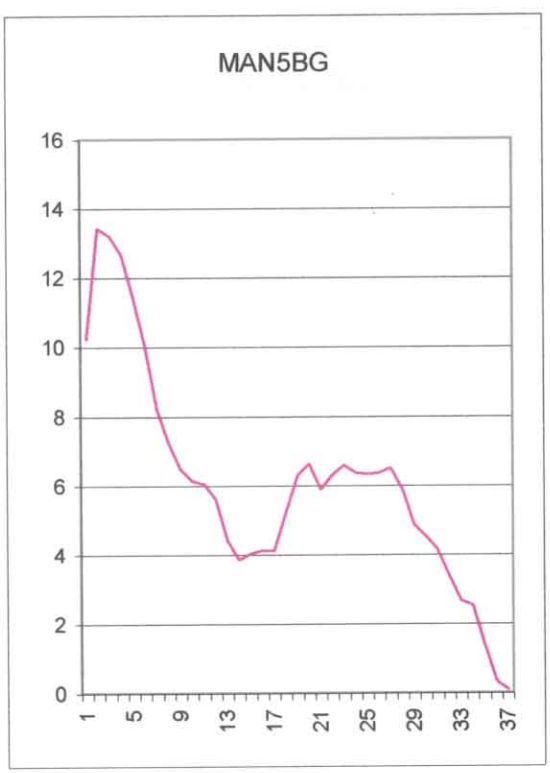


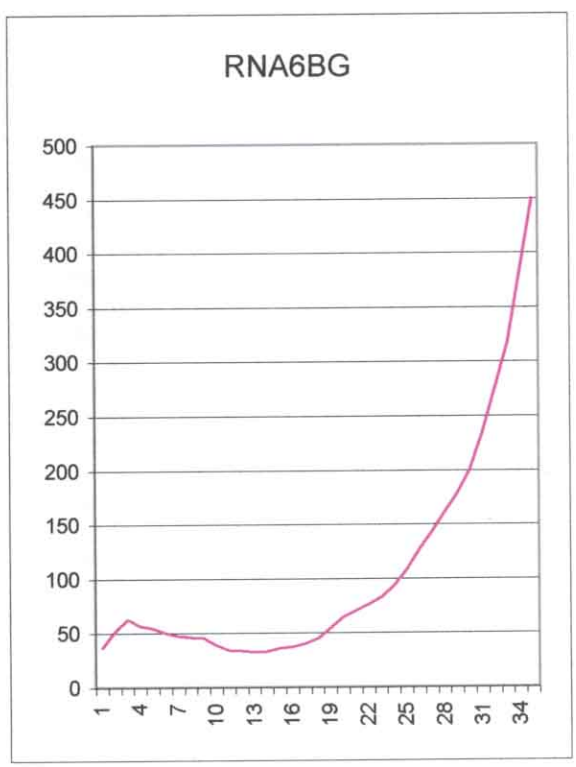
TTLQV analysis of the patterns of lichen (LI) and blue grama grass (BG) on managed area (MAN) transect 5 and RNA transect 6.

Plots of the variances against block sizes.



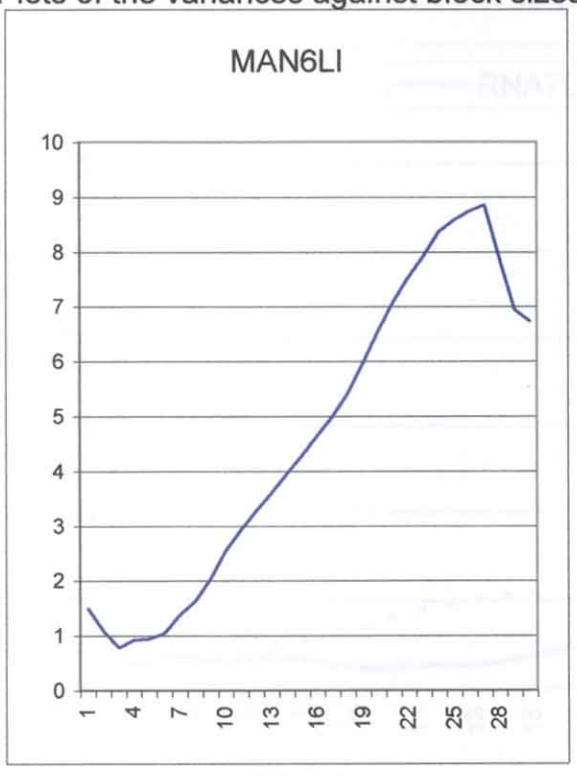


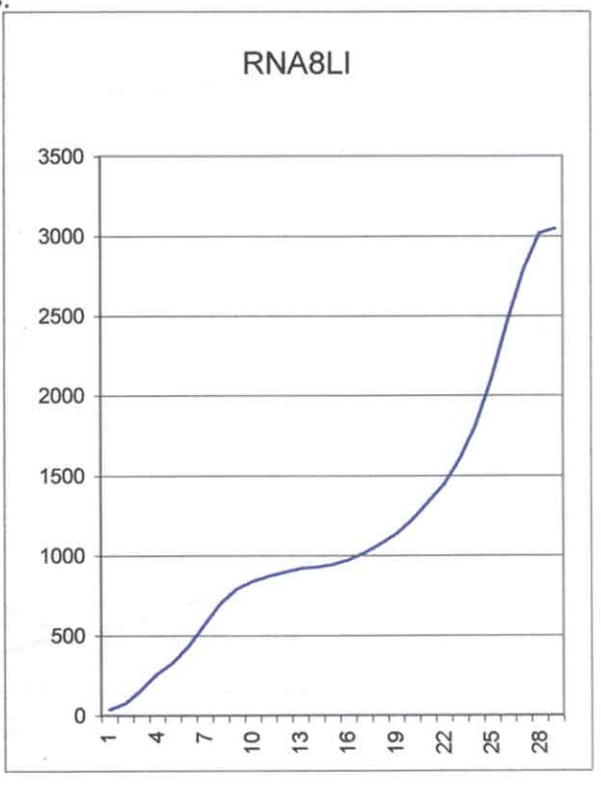


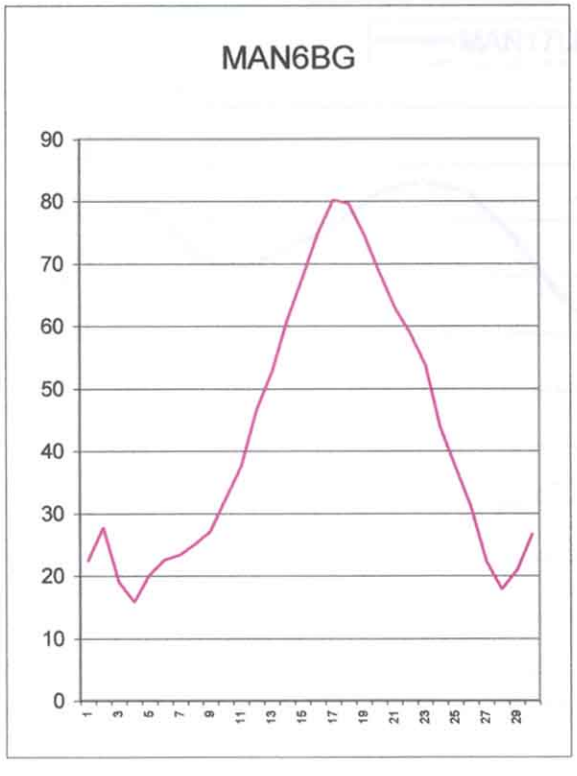


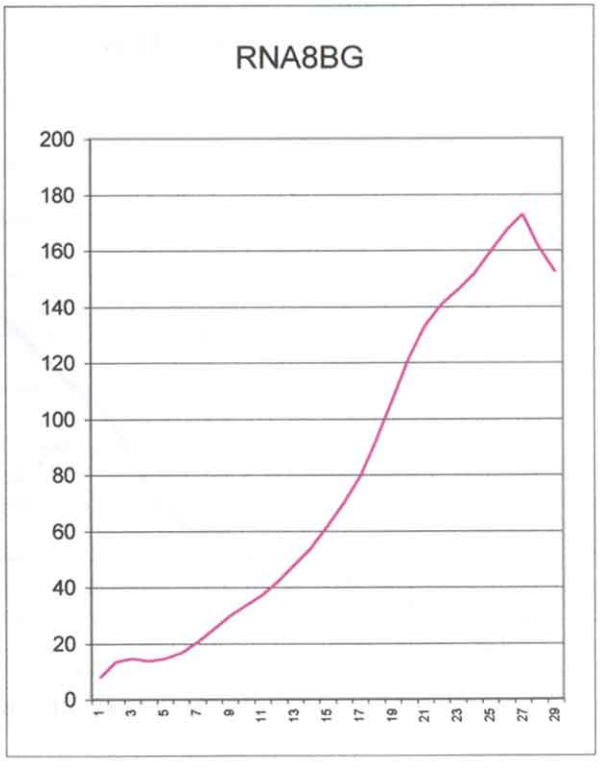
TTLQV analysis of the patterns of lichen (LI) and blue grama grass (BG) on managed area transect 6 and RNA transect 8.

Plots of the variances against block sizes.



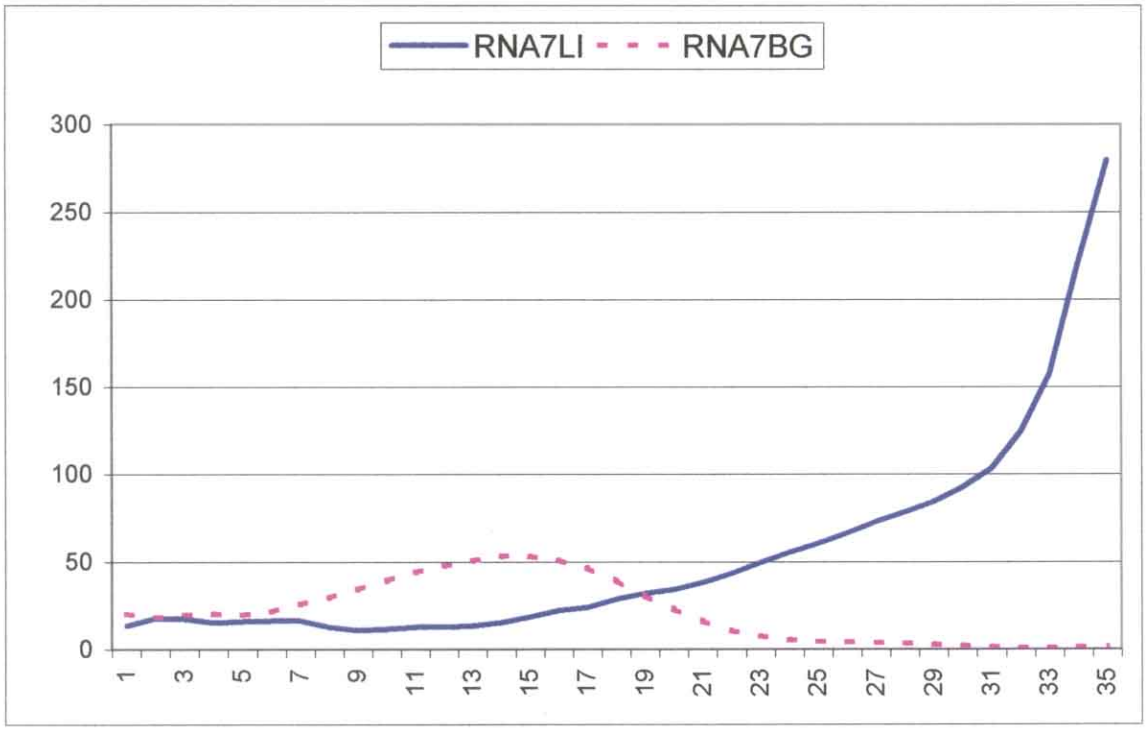


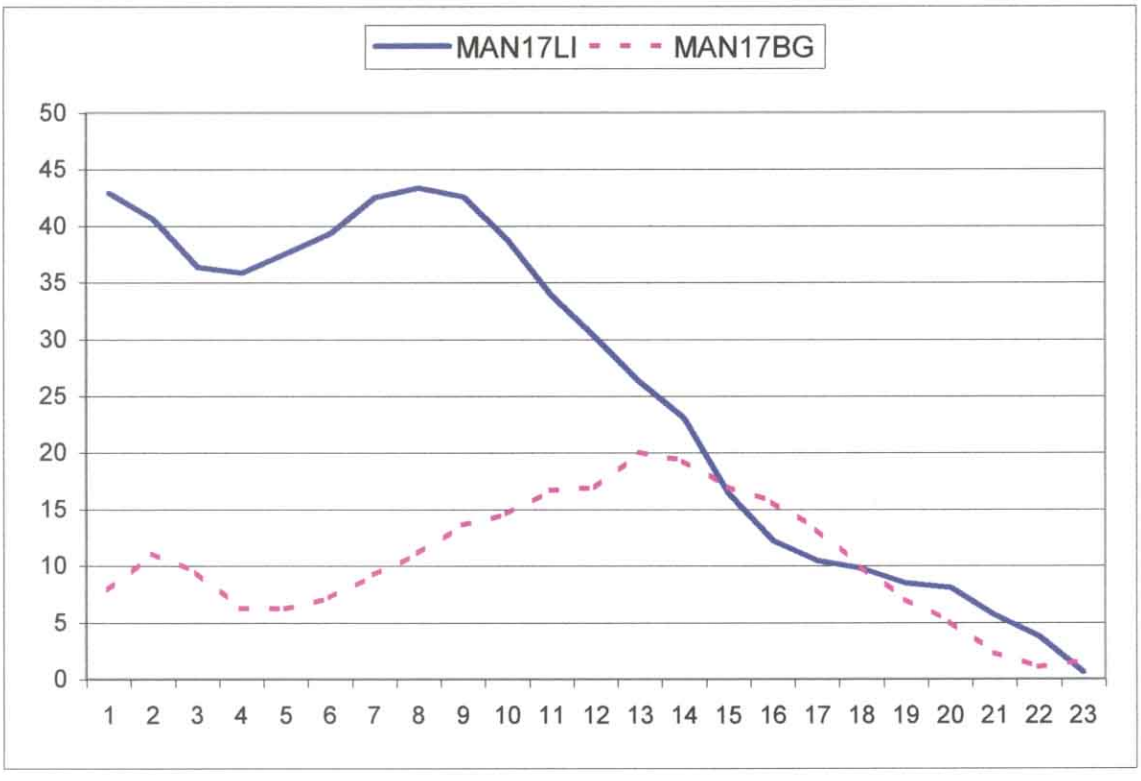




TTLQV analysis of the patterns of lichen (LI) and blue grama grass (BG) on RNA transect 7 and managed area (MAN) transect 17.

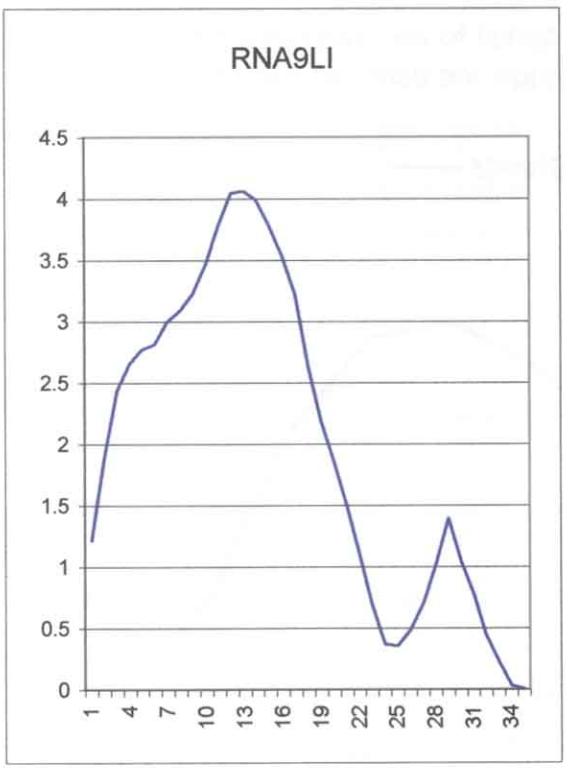
Plots of the variances against block sizes.

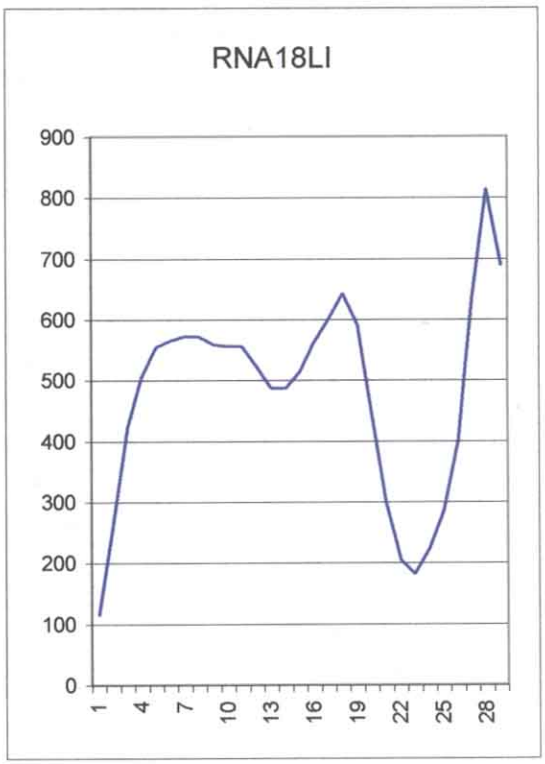


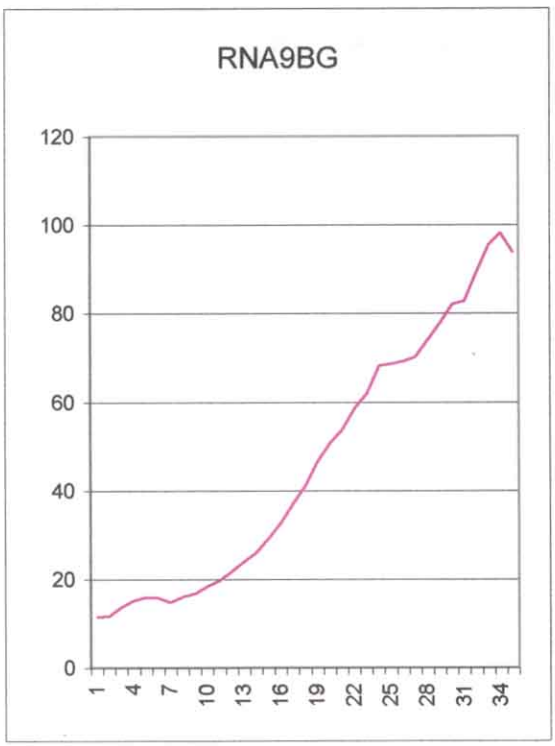


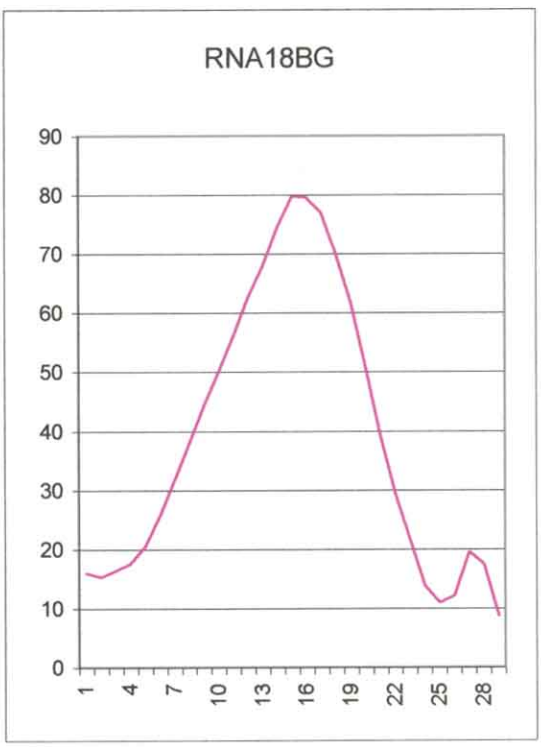
TTLQV analysis of the patterns of lichen (LI) and blue grama grass (BG) on RNA transect 9 and RNA transect 18.

Plots of the variances against block sizes.









TTLQV analysis of the patterns of lichen (LI) and blue grama grass (BG) on managed area transect 18.

Plots of the variances against block sizes.

In this case the main patches of lichen are about 1m apart whereas the patches of blue grama grass are approximately 2.4m apart.