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Field Evaluation of NDVI relative greenness imagery – Broken Hill 2002-03

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Abstract
Trends in modified NDVI values were compared to field observations of vegetation cover changes in a number of representative locust habitats around Broken Hill, NSW, for the period March 2002 to December 2003. Responses in several structural ground vegetation components were graphically compared to local and regional NDVI changes and available rainfall data.

Introduction
The location, amount and sequence of rainfall events in inland eastern Australia has been given primacy among environmental variables in determining the potential for rapid locust population increase and the development of outbreaks (Casimir 1962; Clark 1965, 1972; Farrow 1979; Symmons & Wright 1981; Hunter 1986; Hunter *et. al* 2001; Wright 1987). Locating areas where rainfall has resulted in the growth response of suitable grass/forb ground vegetation has therefore been identified as important in locating incipient gregarious outbreaks at an early stage (Hunter & Melville 1994; Hunter 1989; Hunter & Deveson 2002). The APLC has been using NOAA NDVI relative greenness images since 1998 as an ancillary information source to monitor ground vegetation response to rainfall and to indicate areas where increased locust activity is likely. These images were shown to reliably track the response and decline in greenness after rainfall in typical locust habitats (Deveson *et al*. unpub. 2000). However, there were seasonal and regional differences in the proportional response peaks with a given rainfall. In addition, field surveys showed the suite of plant species involved in the response also varied with landscape and season. For example in spring, vegetative growth after winter rain in northern SA was dominated by Asteraceae, which may be marginal as a food source for locusts, whereas rainfall in summer may produce a wider range of suitable grasses and forbs. Similarly, the intensity of response peak to equivalent summer rainfall in the Riverina and on Mitchell grass areas in Qld varied in terms of the proportion of the range reached.

As a result it was decided to set up a longitudinal study to record details of plant response to assist in the interpretation of changes in NDVI images, particularly in relation to favourable locust habitats. This pilot study ran for 20 months from April 2002 to December 2003, with monthly monitoring visits to a set of study sites. Fortnightly NOAA AVHRR NDVI (National Oceanic and Atmospheric Administration – Advanced Very High Resolution Radiometer) images for the same time period were recalculated to represent current greenness as a proportion of historical range using longterm data supplied).

Methods
Site selection
The experimental design aimed to compare the trend over time in mean relative NDVI index values from several habitat landscapes with changes in a range of vegetation parameters recorded within those landscapes during the observation period. The sampling strategy used nested quadrats ranging in size from 12 – 1250km^2, so that variation at several scales could be compared. Detailed measurement of ground vegetation components and a photographic record was taken for the smallest quadrats, but the degree to which local variation was representative of regional trends was assessed.

Using broad areas that had been designated for the previous study in 1998, three regions (Figure 1) were selected over a range of known habitats near Broken Hill (NSW). Within each of these regional sites four sub-plots were selected to undertake more detailed vegetation. The sub-areas were ~ 2 X 2 km 4km^2, a compromise between a workable vegetation assessment unit, while sampling several image pixels. To extract stable values for relative greenness from the images the blocks needed to overlap a number of ~1 X 1 km NDVI pixels (9 – 12). The twelve detail sub-plot areas were selected according to two basic criteria; that they were representative of broad habitats within the larger sample block (e.g. stony downs, Mitchell grass plains), and that they were within a larger area of uniform habitat type. Within each of these sub-plots a representative central accessible position was chosen as a reference point where photographs were taken at monthly intervals throughout the study period.

The regions within which the sub-plots were selected are to the north, west and east of Broken Hill- at Fowlers Gap, Wilangee Station on the western side of the Barrier Range and near Topar on the Broken Hill-Wilcannia road (Figure 1). They included erosional and depositional surfaces on alluvial fans, stony pediment, narrow floodouts of ephemeral streams and plains. Vegetation included low open shrubland, open and sparse grassland, creekline vegetation and areas subject to heavy stock activity. Fowlers Gap research station is operated by the University of NSW and has a network of rain gauges. It also contains a range of habitat from high rocky ridges to open Mitchell grass plains. The westerly region was sited on the Mundi Mundi Plain at Wilangee, an area frequently infested by locusts. The APLC has carried out control in this area on a number of occasions. The region is typically flat open sparse grassy sediment plains bordered on the east by the Barrier Range where storm runoff feeds several large creeks with occasional sudden runoff. The Topar site lies between the Barrier Highay and the Menindee Road, east of Broken Hill, and includes the Kinalung rail siding and covers parts of several properties. The sub-plots include several sparse Mitchell grass areas and the piosphere of cattle gates and tanks. The eastern region was also chosen for its frequency of locust infestation and range of different vegetation types. Monitoring sites were selected to be representative of regional locust infestation areas. A short description of the vegetation types within each sub-plot is given in Appendix A.

Vegetation observations

Photo sites were set up in each of the sub-blocks to give a visual comparison of change in the landscape with changes in NDVI. The sites were visited, when possible, once a month and photos taken. In addition to photographic records, an assessment was made of vegetation condition and percentage ground cover by type and condition. Separate estimates were made for perennial grasses, ephemeral grasses, forbs and shrubs and the green and dry components of each. An example data record sheet is given in Appendix B. An overall percentage cover was also estimated. This was done using the following parameters;

- 0-5% where diameter of vegetation < 1/5 gap between vegetation.
- 5-15% where diameter of vegetation = 1/4<1/2 gap between vegetation.
- 15-25% where diameter of vegetation =1/2<1 gap between vegetation.
- 25-50% where diameter of vegetation = 1< 2 gap between vegetation.
- 50% where diameter of vegetation > 2 gap between vegetation.

Rainfall figures were obtained from the Bureau of Meteorology for the two sites closest to Broken Hill. For the Fowlers Gap area we were supplied with figures collected from rain gauges placed throughout the research station.

NDVI Imagery

14-day composite NDVI (Normalised Difference Vegetation Index) images from AVHRR instruments on board NOAA satellites with a pixel resolution ~ km^2 have been used to monitor vegetation on a regional and global scale. (Justice *et. al* 1985; Tucker 1986; Prince & Justice 1991; Price 1987). Its great advantages are in the well-calibrated longterm dataset, its regular synoptic view and its low cost to end-users. Image mosaics covering Australia (DEH, 2005) are now available regularly on the Internet, but generally with a time lag of up to 6 weeks. The availability of NDVI composites at a 14-day repeat timescale and within a few days of the end of the capture period (directly from the Western Australian Department of Land Information [DOLI]) enables APLC to monitor vegetation response to rainfall events within 2 weeks of the rain event and to use this information as an active habitat monitoring tool for locust survey or control. Most accessible NDVI imagery, however, is geared to higher biomass ecosystems than those arid environments which often provide suitable habitat for locusts, so small perturbations in vegetation index in these areas are often difficult to detect when swamped by the much larger variations in high cover environments.

In order to detect variation in the sparsely vegetated environments of arid inland Australia, each pixel (1 km^2) NDVI value is converted to a relative index of current condition calculated as a proportion of the historical range of values for that location. This current-state image identifies the level of greenness of an area (pixel) relative to the historical range of brightness values [calculated as ((image - minus minimum value for previous season) divided by maximum difference) * 100)]

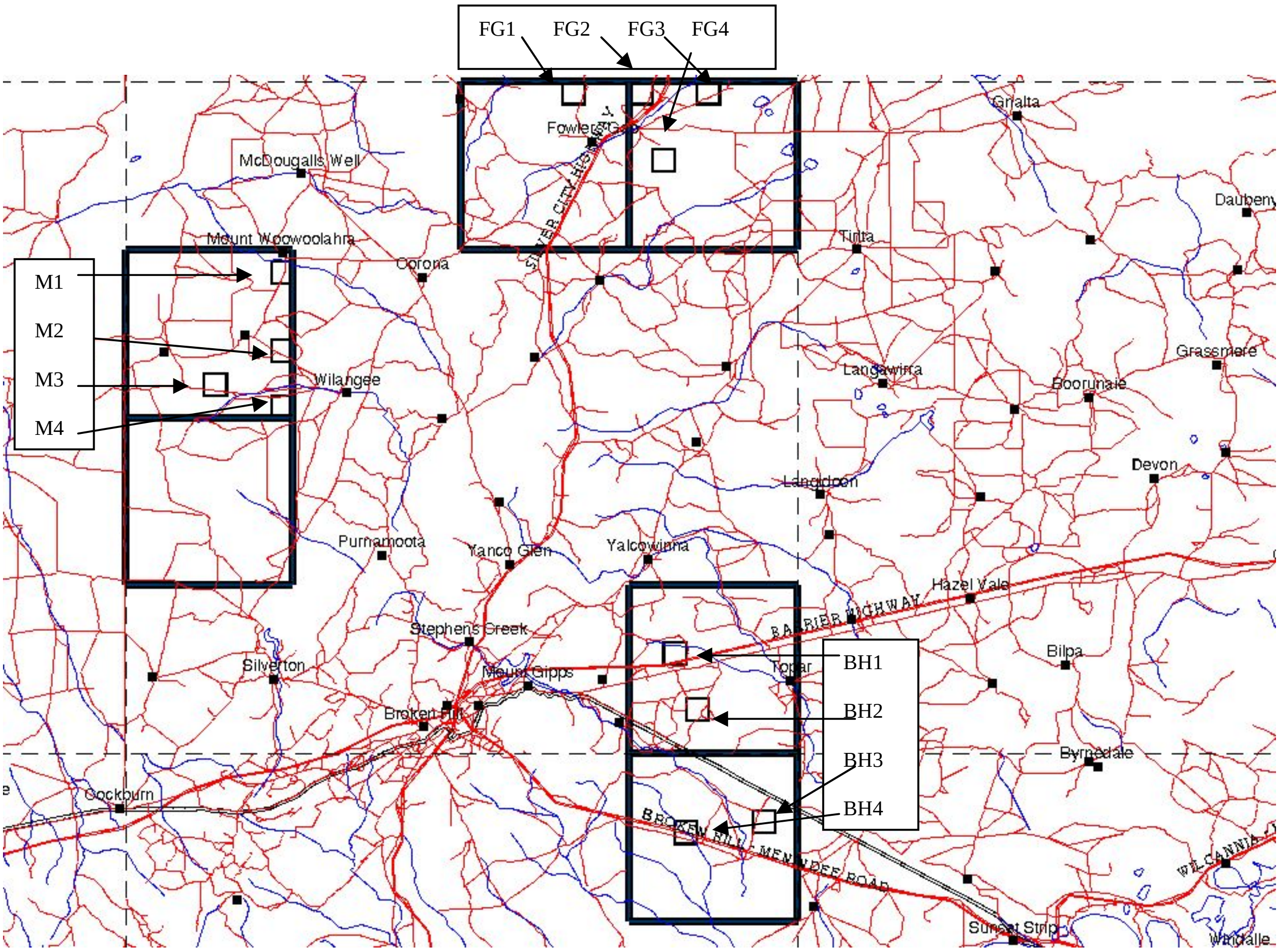

Figure 1. Map showing regional sample sites and individual sub-plots.

Image Data Extraction

The APLC currently receives NDVI images from two sources, the Department of Land Information (DOLI) in Western Australia and the Environmental Resources Information Network (ERIN) part of the Australian Government Department of Environment and Heritage. There are slight differences in the calibration and cloud masking routines in the different image sources. DOLI images were used for this exercise because of the more continuous coverage and the absence of masked values.

The data for each region, and sub-block were extracted using Arc Info GRID software and simple summary statistics generated for each available 14-day time period. The 2x2km block size corresponded to an area overlapping at least part of 9-12 pixels from the NDVI images. A central pixel was identified from the GPS coordinate of the sub-plot centre, and the relative NDVI values from it and the surrounding eight pixels were extracted. The mean value of the relative change index was used to plot the trend in NDVI, and equivalent raw NDVI values were also extracted for comparison of changes between sub-blocks. Values > 100 can occur after heavy rainfall in certain regions, and this is a reflection of calibration errors, terrain induced shadowing and reflection as well as limitations of the recorded historical ranges.

Results

NDVI and terrain

In determining the usefulness of NDVI images to APLC operations an initial visual comparison was made between NDVI images and regional landscape features identifiable on Landsat Thematic Mapper (TM) imagery. This showed that certain terrain produces consistently high NDVI values, for example rocky ridges in the Fowlers Gap area consistently returned high NDVI values, probably as a result of illumination angle, with shadowing from rocky surfaces and ridges. This example shows the importance of some knowledge of underlying terrain when interpreting these images. The uniformity of terrain within sub-plots and variation of vegetation was also assessed from the high-resolution TM images. Features such as large creek lines, floodout areas and larger erosional areas could also be identified.

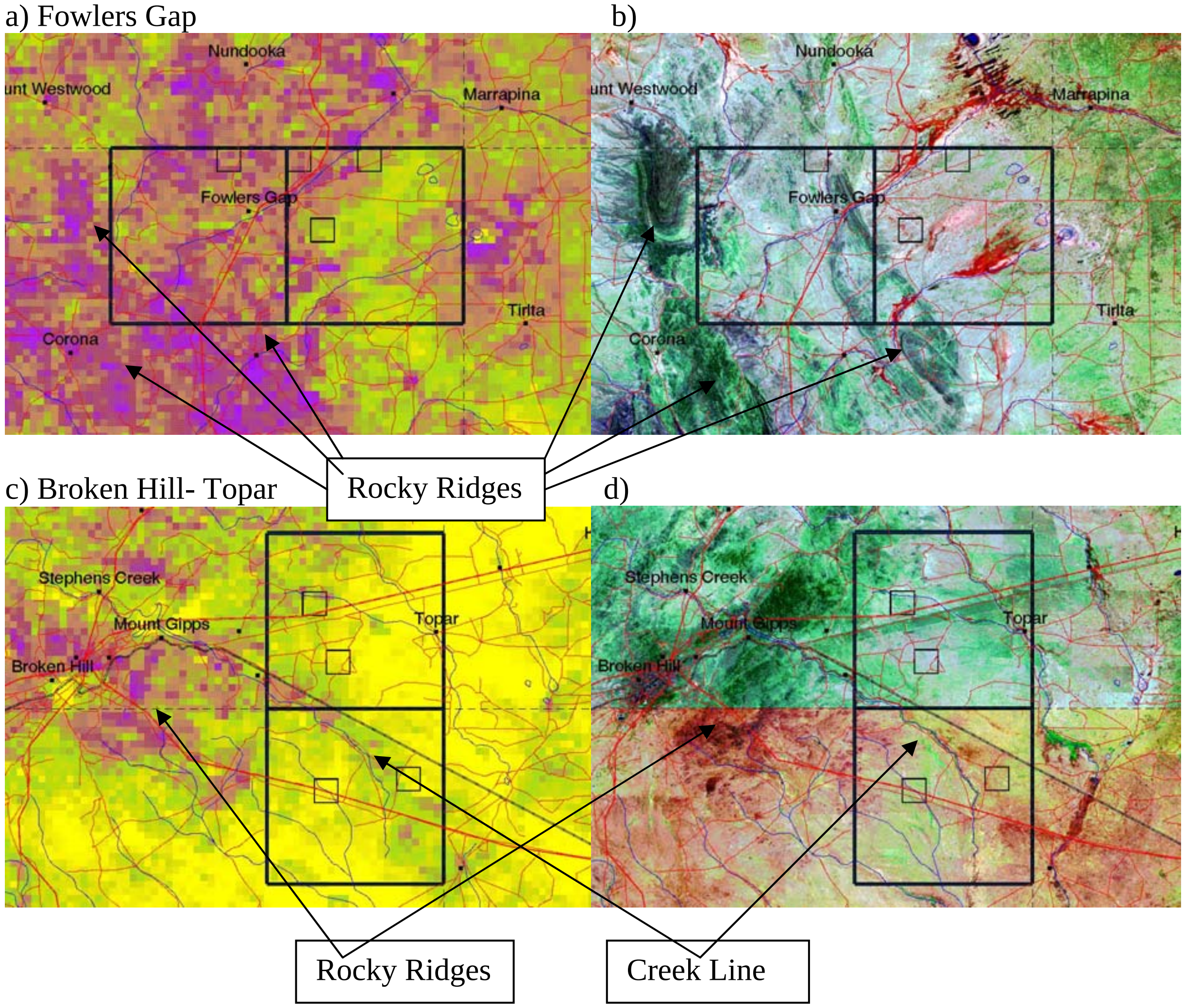

Figure 2) Example NOAA NDVI images (a,c) and corresponding Landsat TM false colour images (b,d) for Fowlers Gap and Broken Hill-Topar trial sites.

Trends in relative NDVI

Comparing data from the different sized blocks within each region shows that the NDVI trend was similar across the entire region and the nested sub-plots all recorded responses representative of the regional response curves. Figure 3, for example, shows the relative NDVI plotted for the entire Broken Hill-Topar region, the north and south halves and for one subplot (SB3). The overall pattern across all regions and all plot sizes reflects the rainfall pattern, with very low values < 20% in all areas during the 2002 drought and a rise during autumn 2003 following rains in February across all areas (Figure 4). Higher NDVI values were maintained over winter and peaked in September 2003 after several smaller falls of rain. The largest single rainfall event occurred in February 2003, with falls up to 80mm at Fowlers Gap, however the local distribution of that rain and the response peak following this was variable between and within the regions.

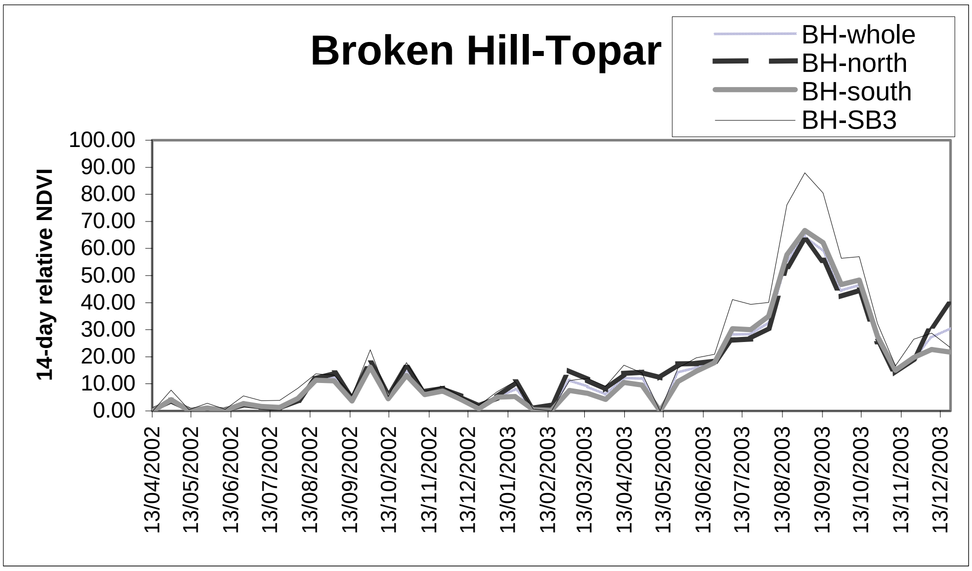

Figure 3. Comparison of trends for different sized sub-samples of the Broken Hill-Topar region, BH-whole (1250 km^2), BH-north, BH-south (625 km^2), BH-SB3 (12km^2).

The figures in Appendix C (Figure 4 as an example) and Appendix D show NDVI trends over time for regional blocks and subplots. Recorded rainfall is plotted along with individual block values in Appendix C where it was available to indicate expected response start points. Appendix C uses photographic records from sub-plots to record the vegetation response in terms of density and floristic components. Detailed vegetation data were recorded for the Wilangee and Topar subplots and are plotted in Appendix E. The cover of green vegetation in each ground cover component is plotted for 9 time periods. During 2002 ground cover comprised completely dry tussocks < 5% cover, but these are not included because NDVI should detect only green vegetation. Shrub and tree cover are not included in the vegetation plots, although they were recorded. Tree cover is considered to be relatively constant, but saltbush did contribute to the overall response on those blocks where it dominates vegetation.

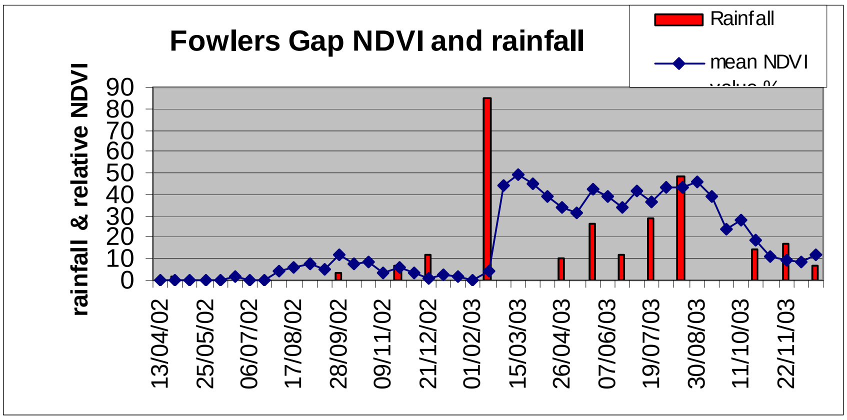

Figure 4. Rainfall (bars) and relative NDVI values for the FG3 subplot at Fowlers Gap.

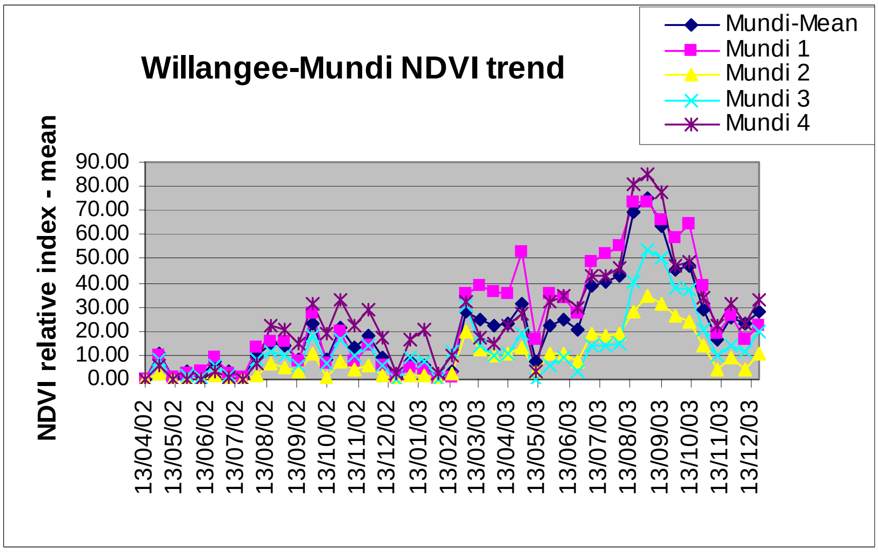

Figure 5. Trend in relative NDVI for all subplots in the Wilangee-Mundi study region.

Vegetation and NDVI

A greening response to rainfall is detectable in NDVI imagery 2-3 weeks after rain and generally reaches a peak during the month following significant rain. While vegetation trends all followed a similar pattern, the proportion of range reached on different habitats after the same amount of rainfall was found to vary widely. A comparison of the response curves for sub-plots within each region in Appendix D shows a range of maximum values from 40% - 90% of potential in the peak response curves in September 2003. This first appeared to be a function of native pasture in poor condition having a low potential cover, however, there appear to be several possible reasons for a site to have reached relatively low values. Heavily grazed, disturbed or denuded sites, with few or no perennial grasses (Fowlers Gap FG4, Wilangee M2) are examples of disturbed sites which only reached <50% of potential, with only sparse forb growth. On the other hand Fowlers Gap FG3 and Topar BH 4 also recorded <50% of potential and these two blocks also retain Mitchell grass tussocks, but there was virtually no perennial grass response at these sites (photographs Appendix C). This pattern could be partly a result of the timing of the rain in late February and the extremely dry conditions before this, as *Astrebla* spp. are summer-growing perennials, or from local variation in the amount of rainfall received before March 2003. The latter is suggested because two other blocks retaining Mitchell grass, Topar BH1 and Fowlers Gap FG2, did reach a higher proportion of potential value (<60%). There was green shooting in most tussocks in these blocks, though there was little further growth during the winter.

Most of the growth response during 2002-03 occurred in forbs and smaller ephemeral grasses (see Appendix C Photos). The sub-plots which reached the highest potential NDVI values were those dominated by bladder saltbush (*Atriplex vesicaria*) at Wilangee M1 and Fowlers Gap FG1 and also on the sparse grass plain at Wilangee (M4). Both saltbush blocks are on low stony hills with little groundcover, and during the 2002 drought the shrubs showed considerable water stress. These sites both produced only sparse forb growth following rains during winter 2003, suggesting that the greening of shrubs themselves were responding in a similar manner to ground cover to produce the high response values. The sparse grass plain at Wilangee (M4) and at Topar (BH3) also reached high values, the result of good forb growth. The absence of perennial grasses at these sites suggests that these sites near full potential greenness from winter forb growth.

The variation in potential greenness within regional sites is partly accentuated by the method used to calculate the relative greenness index. Sites which have lower potential for reasons of floristic composition or land use history may achieve full greenness with ephemeral growth while, after the same total rainfall, sites with a much higher potential for growth, such as Mitchell grass, may only reach half their potential greenness. The potential drawback in using this method to highlight response in sparse vegetation is the possibility of neglecting areas with a higher potential NDVI as likely locust breeding habitat, when they are in the same condition as the poorer sites in terms of amount of green vegetation. This is the result of the use of the relative index in that areas that have a small range in NDVI, because there is very little vegetation even in wetter periods and the maximum NDVI value is reached after the growth of ephemeral grasses and forbs, and there may be little further increase possible. The relative index was designed to emphasise changes in very low cover environments and it succeeds in this, but at the expense of areas with a higher potential range, many of which are also locust habitat. The history of infestations in the region shoes that these degraded areas are important locust habitat, so the emphasis on detecting change is warranted. Examples of the difference in the peak of relative response can be seen in Appendix D.

A potential means of differentiating this problem of interpreting relative potential is to use the actual increase in raw NDVI between consecutive images, since this would show all areas where increases have occurred. This was investigated by calculating the 14-day change from the raw NDVI images received from DOLI (Appendix E). In addition the raw NDVI values for all sub-plots are plotted by region in Appendix G.

The bulk of the vegetation response during the observation period was in the forb component, which responded rapidly to the initial heavy rains (>50mm) and were maintained at a relatively high level on most blocks during winter. The total ground cover in arid regions remains low (usually <25%) even when NDVI values increase to highest historical values.

Discussion

This was a pilot study and as such only limited conclusions can be drawn from the results.
No significant locust activity was recorded in this region during the study period. Only very low density isolated adults were seen in the study area was isolated adults so no comparison could be made of breeding events and NDVI, although several of the subplots are known band and swarm locations. A similar pattern of vegetation response occurred in each sub-plot within the regional blocks. The total ground vegetation cover ranged from <5% - 25% in all blocks throughout the observation period. The highest vegetation cover approached the maximum potential NDVI in several sites, suggesting that this may be close to the maximum cover irrespective of rainfall.

A number of factors limit the general applicability of findings from this study. All samples are from the Broken Hill region in western NSW, an arid area with median annual rainfall of less than 250mm. Significant rainfall events occur only occasionally, and may be limited to a single season. The vegetation response to rainfall may be very different here than in other areas in Australia and findings therefore only relate directly to this geographic area. Secondly, during the 20 months there was only one significant rain event and this occurred during late summer, although there were several smaller follow-up falls during the following winter and spring. One of the initial purposes of the study was to compare the response to rainfall at different seasons, however the lack of multiple rainfall events over the study period reduced to comparison of the single event on different vegetation types. Finally, regular monitoring could not always take place due to higher priority operational requirements..

This study supports the reliability of NDVI in detecting vegetation response across a range of habitats suitable for locusts. The response pattern to rainfall begins with small rainfalls on 17 December 2002 detectable at Wilangee, Fowlers Gap and the northern part of the Topar region. Following the heavy rains in February 2003, the response is similar in all plots, and gradually increases to a peak in September 2003. Location-specific rainfall data was only available for the Fowlers Gap sites, so response variation due to differences in local rainfall could not be separated from those due to differences in habitat type. For Wilangee the rainfall recorded at Corona (20km north) was used and for Topar, records from Koralta (50 km northeast) were used. Rainfall events for these two locations were checked against those at Broken Hill to identify if events were regionally widespread, but the amount of rain that fell at individual subplots may have varied widely. In particular, the absence of an abrupt rise at the Broken Hill (Topar) blocks after February 2003 suggests that local rainfall may have been less than that recorded at other locations. The initial response to the February rain at Fowlers Gap and Wilangee reached 40-50% by mid-March 2003, while at Topar this first peak is largely absent. All regions do increase gradually to a peak in September-October 2003 after several falls during winter and spring. The timing of the peak response of relative NDVI within regions is similar, though the proportion of potential varies from 40 – 90% at the peak reached in October 2003. Examining the particular habitat types associated with near maximum NDVI, stony hills with low bladder-saltbush vegetation reached >80% of pixel range. At Wilangee, blocks close to the creek reached the lowest peak (40-50%) suggesting that after floods these areas may carry much denser vegetation. Mitchell grass areas at Topar reached less that half their potential range, suggesting that rain earlier in summer is important or that the southern part of this regional block did not receive the same rainfall as other areas.

The change in raw NDVI values were plotted separately as a possible indicator of the magnitude of response independent of the relative NDVI index. The change between each 14-day image was calculated as a simple difference image between consecutive images. These values were rescaled to ensure positive integer values– values <100 indicate a decline in NDVI between dates while >100 indicate an increase. Appendix D shows the changes in each of the sub-plots at each regional study area. The direction and magnitude of changes at each timestep is consistent in all blocks. The largest differences between blocks occur at the response peaks but are <10 between subplots. The largest measurable difference occurred at Fowlers Gap in March 2003 where the Mitchell grass sub-plots 2 & 3 (FG2 & FG3) rose 21 – 26 raw NDVI values, while the stony saltbush block (FG1, Sb1) recorded an increase of 13. The corresponding rise in the relative greenness index for all sub-plots (appendix D) at this time is more uniform (50-58%) for all except sub-plot FG4 (38%). This pattern is also seen in the Wilangee results, where the difference in change of raw NDVI values is <4 between sub-plots throughout the entire period, but while the saltbush hill sub-plot (SB1) reaches >50% and the plain at Wilangee M1 (Sb3) only 35% of potential value, the creek floodout M3 (Sb1) reaches > 70% of potential. Sub-plot M2 (Sb4) at Wilangee presents a different pattern, having a low relative response to the initial February 2003 rain, but reaches 90% of potential in September 2003. This is an area with scald erosion on Kantappa with no perennial grasses, indicating that degraded sites have a very narrow potential range.

Relative NDVI imagery is a useful tool for monitoring vegetation condition in locust habitat, but this investigation has identified a potential over-emphasis on sites with a low potential range relative to sites with a larger perennial grass component. This index remains more useful than raw NDVI imagery or other common indices (eg current value relative to seasonal expectation). Reference to the NDVI difference imagery (showing the amount of change as positive or negative values) could offset the resulting problems in interpreting vegetation condition, but this does require referring to two sets of imagery. Incorporating more detailed information on landscape (such as rocky ridges) and vegetation type (current vegetation type and grazing status) would also improve the detection of habitat suitability.

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APPENDICES

Appendix A: Brief habitat descriptions of sub-plots

Fowlers Gap

FG1: Situated this block is typical of the higher country throughout this region. Very steep ridges with rocky dry valleys between sparsely populated with salt bush shrubs and few perennial grasses. This is probably in unfavourable locust breeding habitat, but could support adults when green. On West Sandstone paddock.
FG2: Favourable locust habitat with Mitchell Grass the dominant species. Next to the Broken Hill-Tibooburra Rd (Laneway Paddock) with some drainage from road.
FG3: Open Mitchell grass plain. Favourable locust breeding habitat, associated with the drainage of Fowlers Creek. (North Man Paddock)
FG4: Scalded clay pans, heavily grazed. No identifiable dominant species. Possible locust habitat after rain. (Warren Paddock).

Broken Hill-Topar

BH1: Open downs with rocky patches and small drainage lines. On northern side of Barrier Hwy on K-Tank Station. Favourable adult locust habitat with patches of sparse Mitchell grass.
BH2: Open heavily-grazed paddocks with rocky scalds- near tank and gates along fence-line. Areas largely bare throughout the experiment. On Avondale station.
BH3: Mixed perennial grasses and saltbush scrub. Favourable locust habitat. Near boundary with Munka Station.
BH4: Open sparse Mitchell grass downs with large creek line bordering the east. Several small drainage lines throughout block. Locust habitat. Crosses Broken Hill-Menindee Road. Labelled 'Eureka' but may be part of Avondale.

Wilangee-Mundi

Mundi1: Rocky hills with bladder saltbush as the predominant species and largely bare ground. Unfavourable locust habitat. On Mt Woowoolahra Station on road to McDougalls Well from Wilangee.
Mundi2: Tall scrub with open scalds. Bordered by dry creekbed drainage to the southwest. Dense patches of hopbush near creek. On Kantappa Station

Mundi3: Flood out area at western end of Wilangee Ck. Dominated by saltbush. Favourable locust habitat after flood.

Coordinates 141 07 31 26; 141 09 31 26; 141 09 31 28; 141 07 31 28. Centrepoint 141 08   31 27

Mundi4: Open sparse grass plains. Area includes large scalds. Vegetation largely forbs. Known locust breeding area. On Wilangee Station.

Coordinates- 141 13 31 28; 141 15 31 28; 141 15 31 30; 141 13 31 30. Centrepoint 141 14   31 29

Appendix B: Example Vegetation Data record Sheet

APPENDIX B: Example of Vegetation data record sheet.

APPENDIX B: example NDVI Data Record Sheet for Wilangee Area

Date: 16/01/2003

Rainfall over fortnight:

Block	Vegetation Type	Condition GS	G	DO	DGB	GT	Y	D
Will 1	Trees		1					
	Shrubs							
	Forbs		2					
	Perennials							1
	Ephemerals		2					
Will 2	Trees							
	Shrubs	2						
	Forbs		2					
	Perennials							
	Ephemerals		2					
Mt Woo	Trees							
	Shrubs							2
	Forbs		1					
	Perennials							
	Ephemerals							
Kantappa	Trees		1					
	Shrubs	2						
	Forbs		1					
	Perennials							
	Ephemerals		1					

% Cover Values

1 = 0-5% where diameter of vegetation = <1/5 gap between vegetation

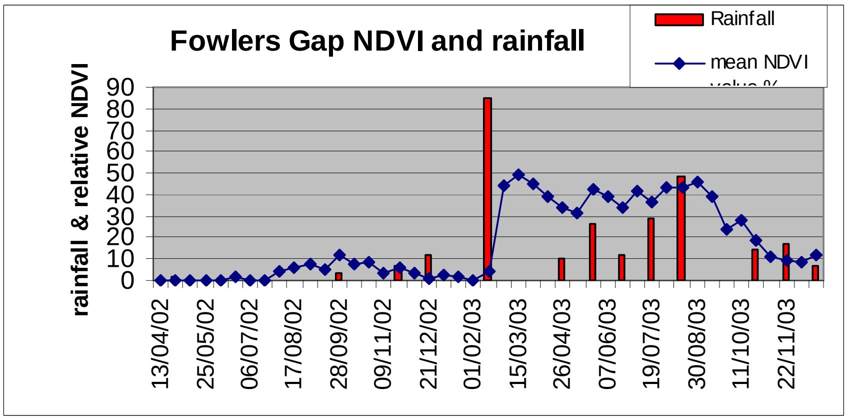
2 = 5-15% where diameter of vegetation = 1/4<1/2 gap between vegetation

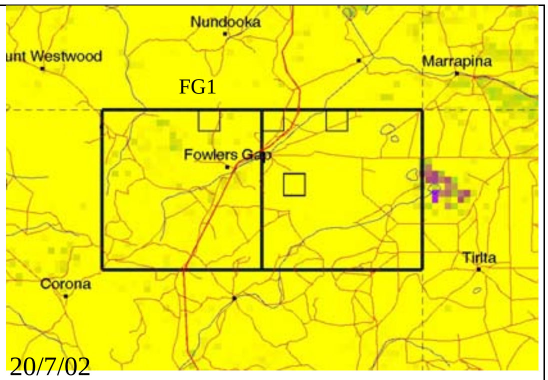
3 = 15-25% where diameter of vegetation =1/2<1 gap between vegetation

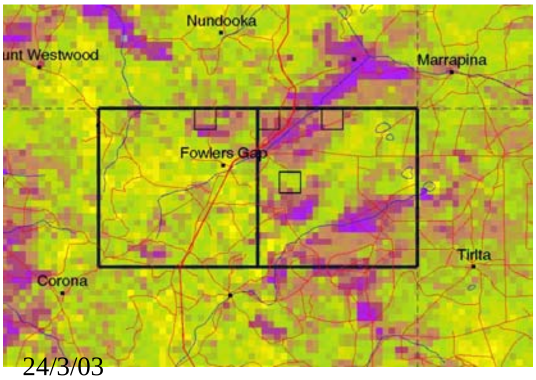
4 = 25-50% where diameter of vegetation = 1< 2 gap between vegetation

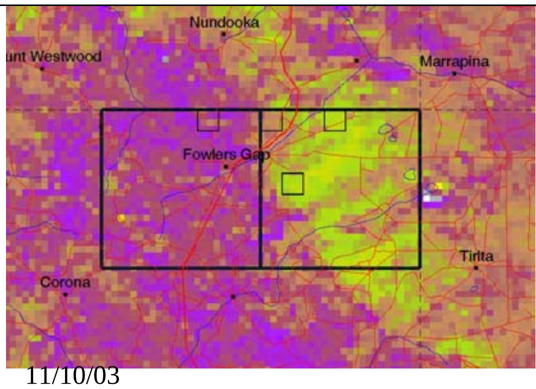
5 = > 50% where diameter of vegetation > 2 gap between vegetation

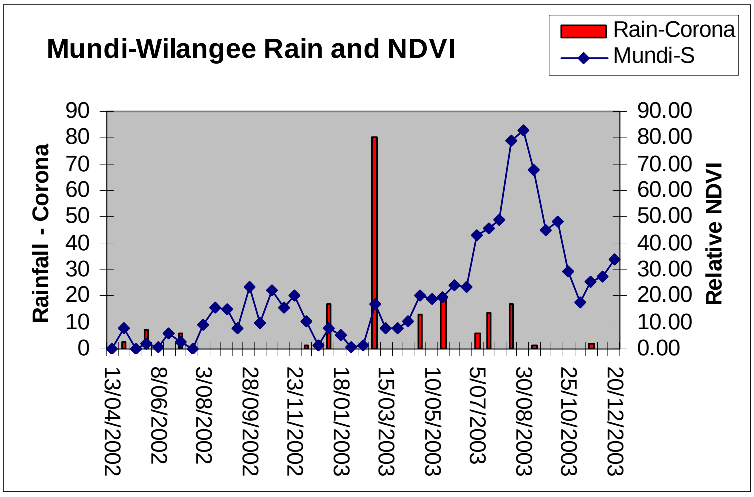
APPENDIX C. Photographic examples of change in subplots with NDVI images.



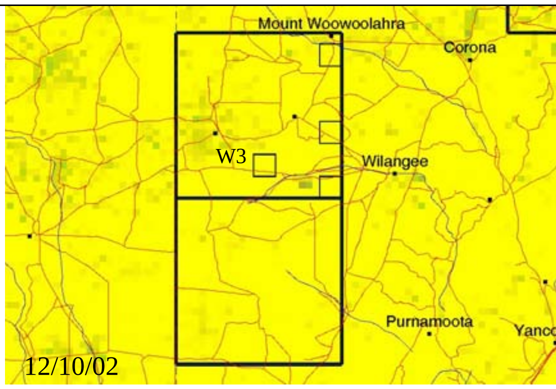




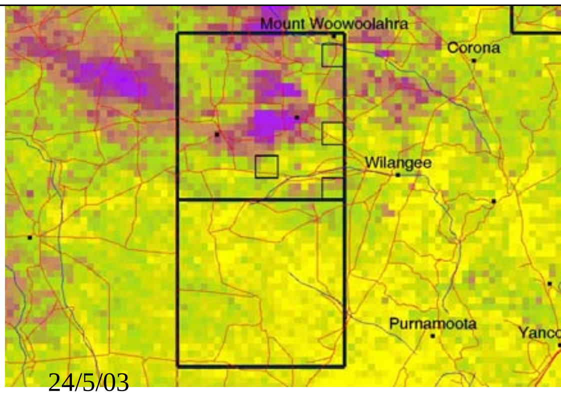



Mundi-Wilangee Rain and NDVI
Rain-Corona
Mundi-S
Rainfall - Corona
Relative NDVI
90
80
70
60
50
40
30
20
10
0
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
13/04/2002
8/06/2002
3/08/2002
28/09/2002
23/11/2002
18/01/2003
15/03/2003
10/05/2003
5/07/2003
30/08/2003
25/10/2003
20/12/2003

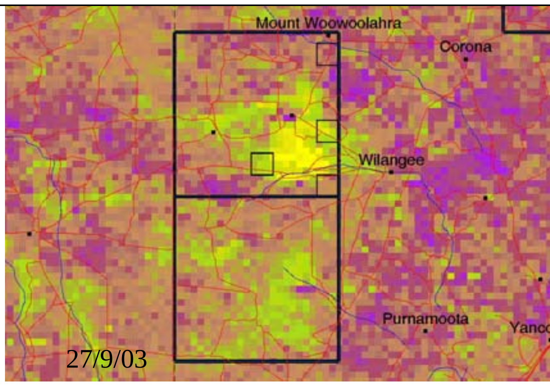

WILL1
14-10-02
15/10/02

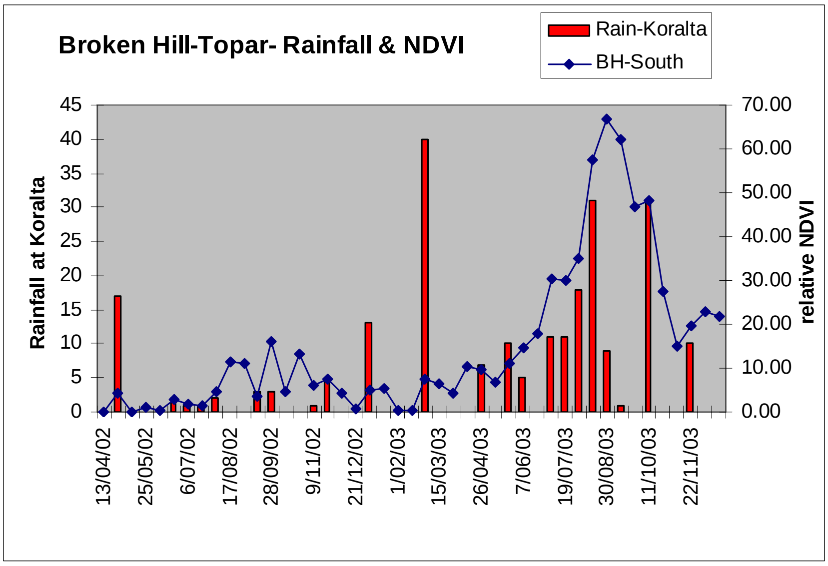

Mount Woowoolahra
Corona
W3
Wilangee
Purnamoota
Yanco
12/10/02


20/5/03

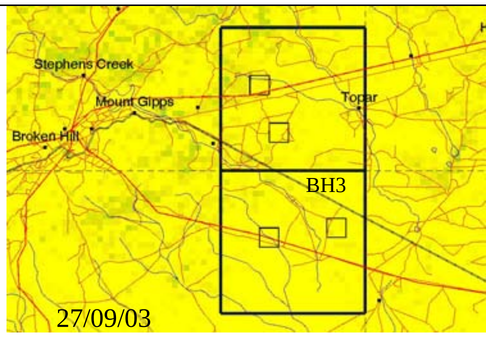

Mount Woowoolahra
Corona
Wilangee
Purnamoota
Yanco
24/5/03


15/9/03

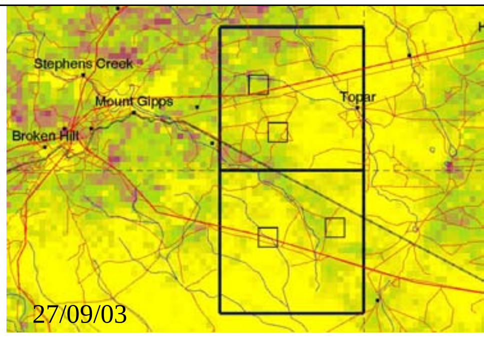

Mount Woowoolahra
Corona
Wilangee
Purnamoota
Yanco
27/9/03


Broken Hill-Topar- Rainfall & NDVI
Rain-Koralta
BH-South
Rainfall at Koralta
relative NDVI
45
40
35
30
25
20
15
10
5
0
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
13/04/02
25/05/02
6/07/02
17/08/02
28/09/02
9/11/02
21/12/02
1/02/03
15/03/03
26/04/03
7/06/03
19/07/03
30/08/03
11/10/03
22/11/03

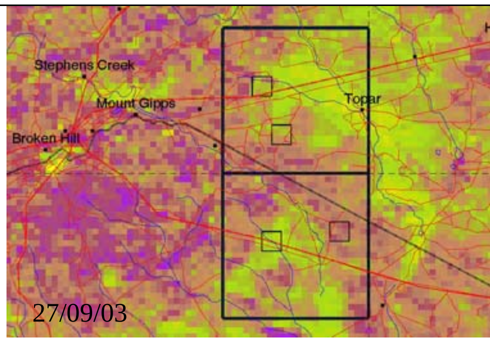

27/09/03


Stephens Creek
Mount Gipps
Broken Hill
Topar
BH3
27/09/03

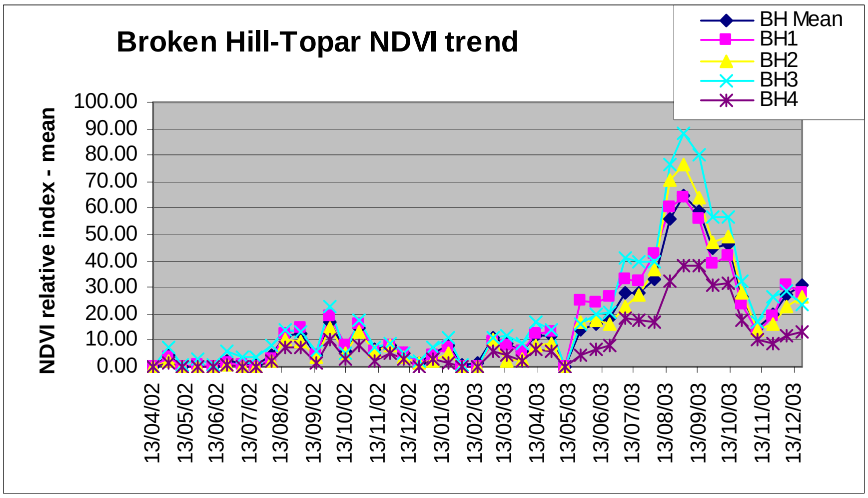

27/09/03

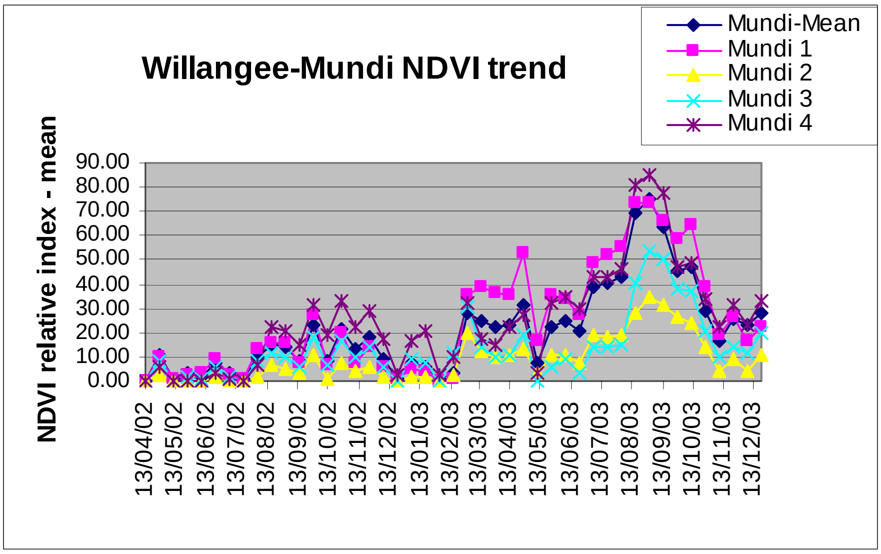

Stephens Creek
Mount Gipps
Broken Hill
Topar
27/09/03

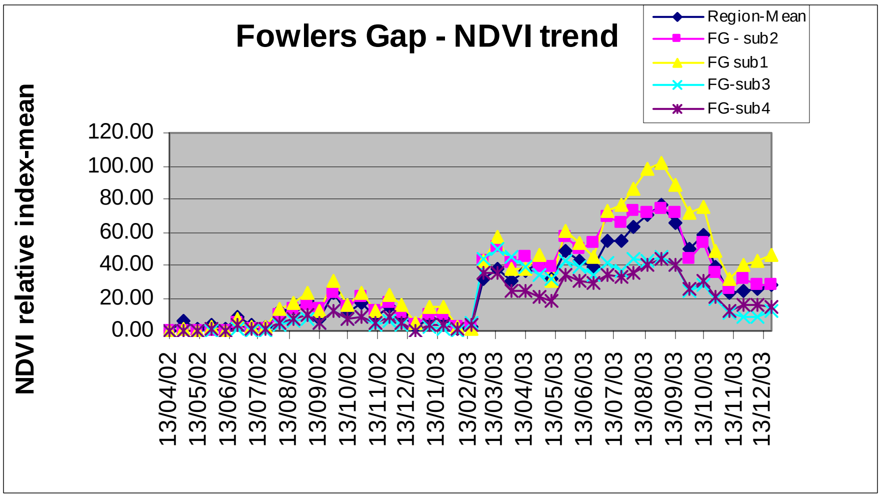

27/09/03


Stephens Creek
Mount Gipps
Broken Hill
Topar
27/09/03

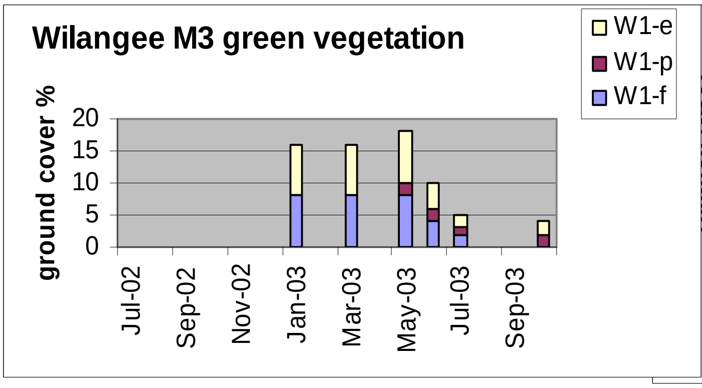
Appendix D. NDVI trends for regions and subplots.
Trend in relative NDVI for subplots and whole area by region.
Mean relative NDVI values as proportion of historical range for each 12 pixel sub-block and entire 1250 pixel region.

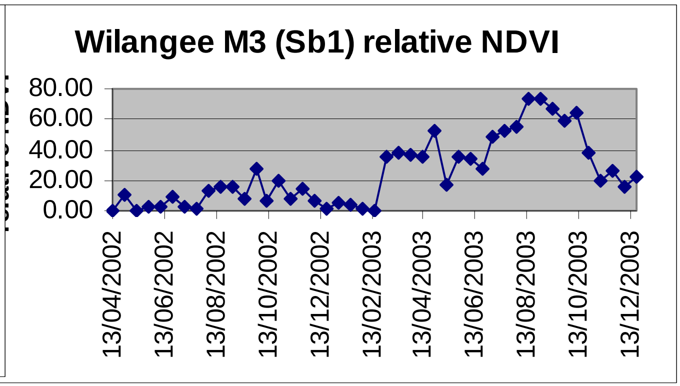


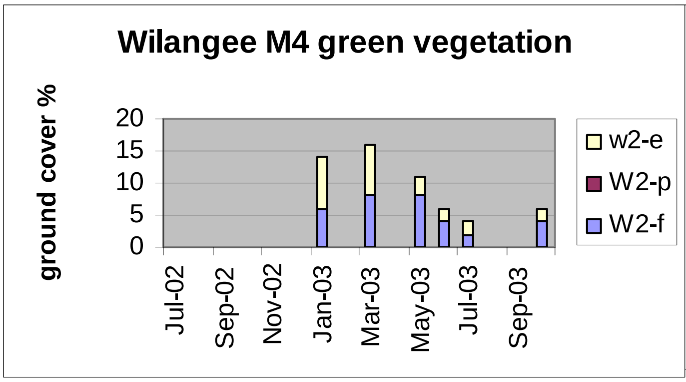


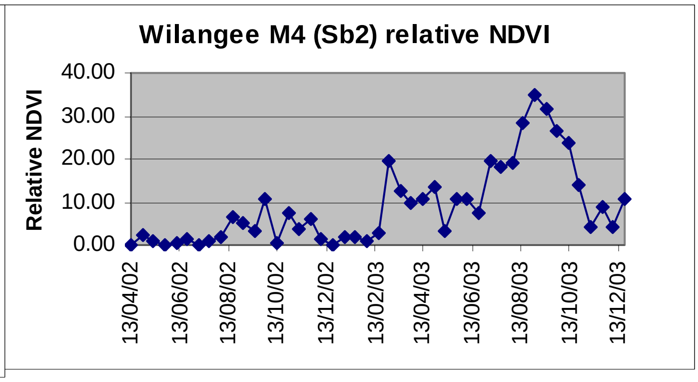


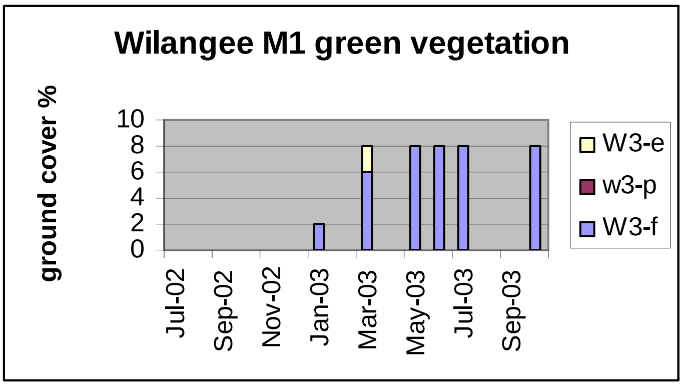
Appendix E. Change in cover of green ground cover vegetation by Sub-plot. Estimated total ground cover of green vegetation by structural components – Ephemeral grasses (e-yellow), perennial grasses (p-purple), forbs (f-blue) are shown in left panels. Relative NDVI trend line shown in right panels.

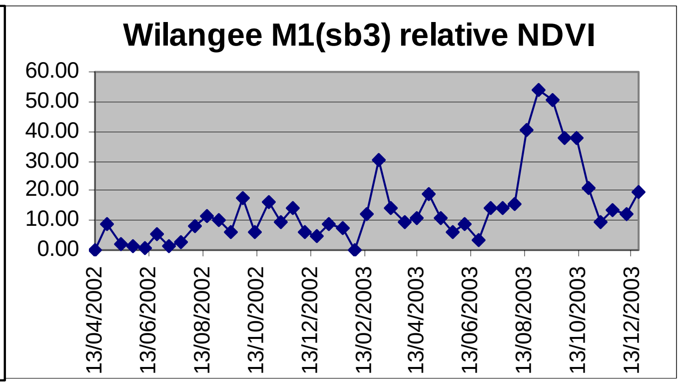


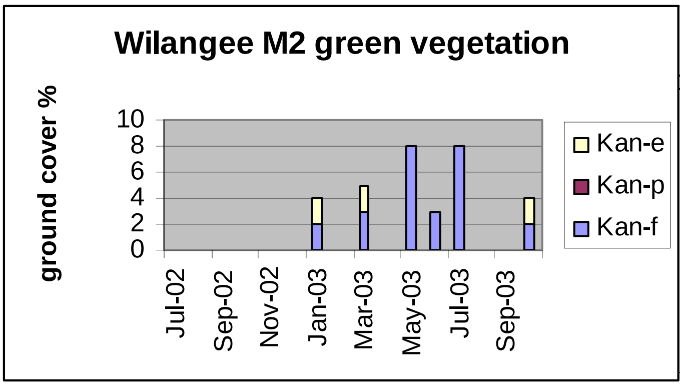


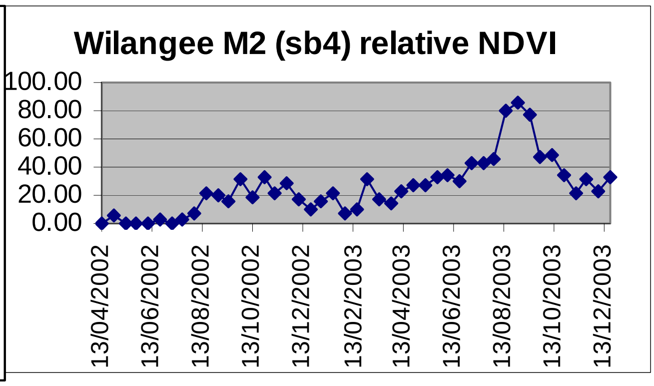


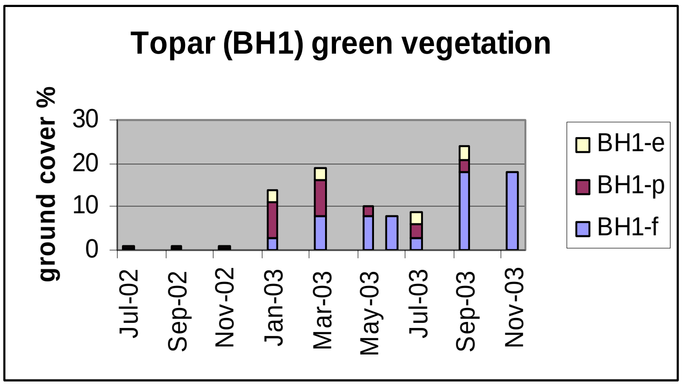


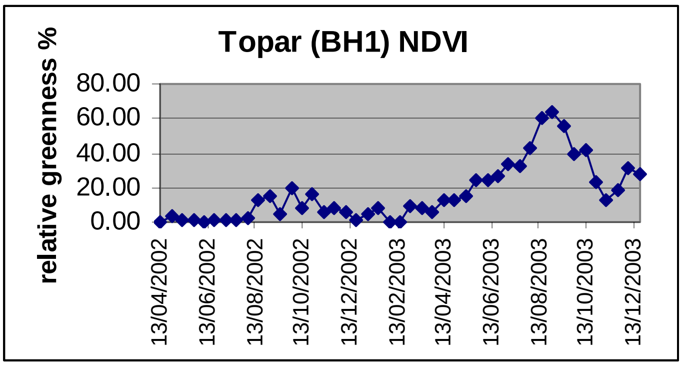


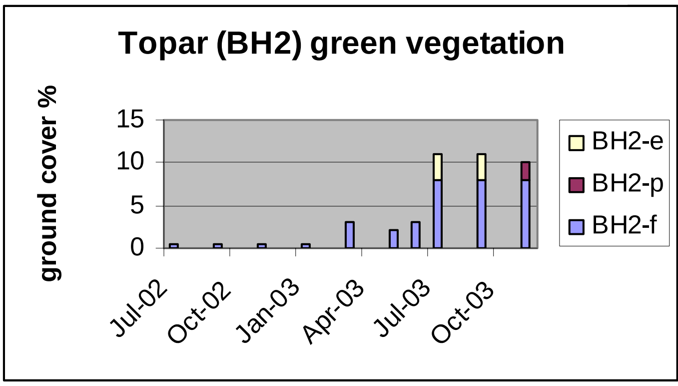


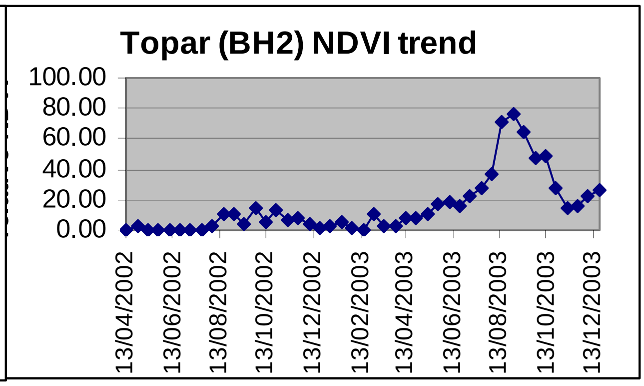


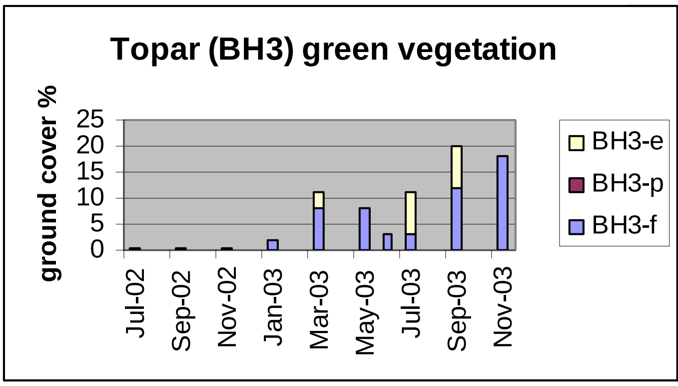


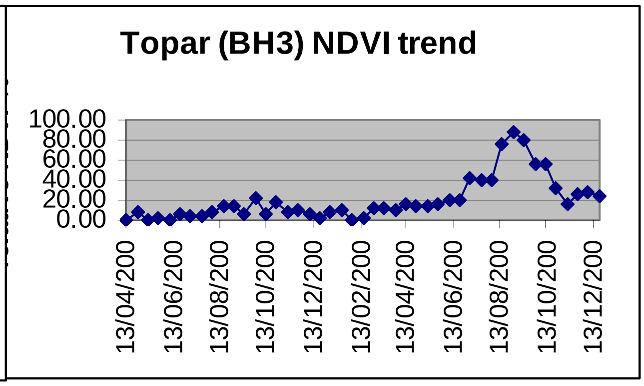

Topar (BH1) green vegetation
ground cover %
30
20
10
0
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Nov-03
BH1-e
BH1-p
BH1-f

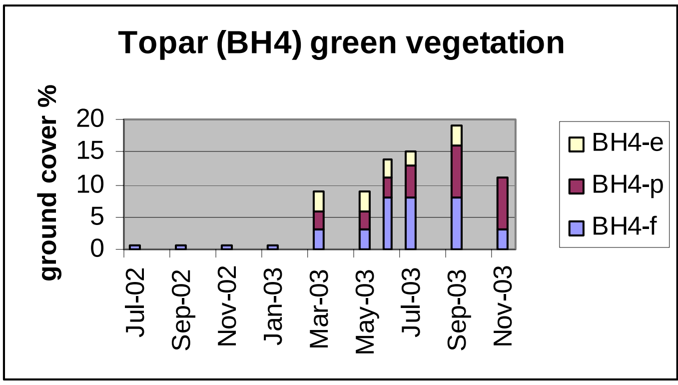

Topar (BH1) NDVI
relative greenness %
80.00
60.00
40.00
20.00
0.00
13/04/2002
13/06/2002
13/08/2002
13/10/2002
13/12/2002
13/02/2003
13/04/2003
13/06/2003
13/08/2003
13/10/2003
13/12/2003

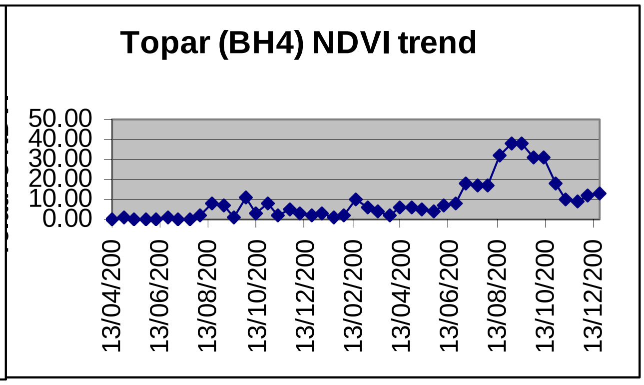

Topar (BH2) green vegetation
ground cover %
15
10
5
0
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
BH2-e
BH2-p
BH2-f


Topar (BH2) NDVI trend
100.00
80.00
60.00
40.00
20.00
0.00
13/04/2002
13/06/2002
13/08/2002
13/10/2002
13/12/2002
13/02/2003
13/04/2003
13/06/2003
13/08/2003
13/10/2003
13/12/2003

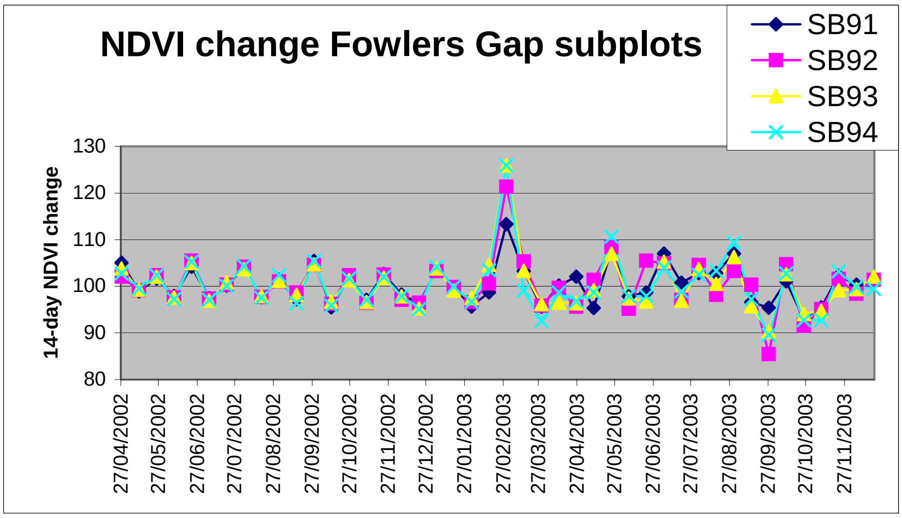

Topar (BH3) green vegetation
ground cover %
25
20
15
10
5
0
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Nov-03
BH3-e
BH3-p
BH3-f

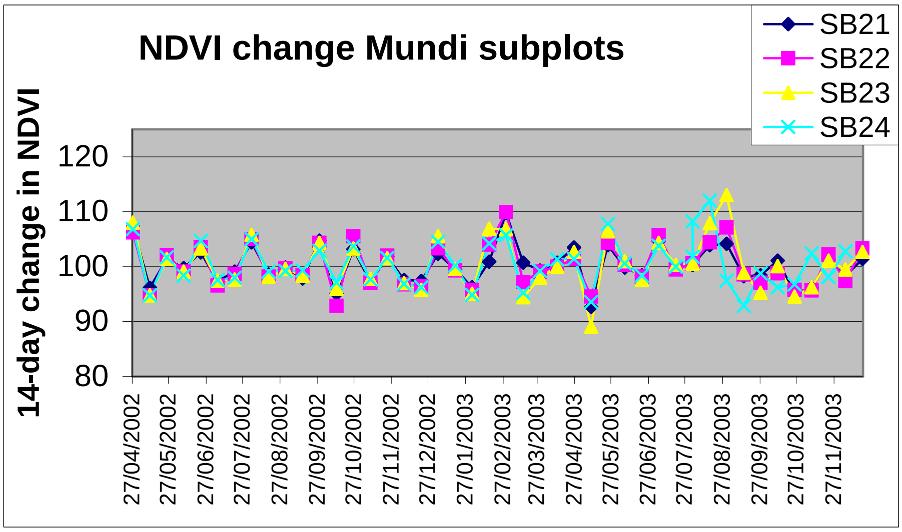

Topar (BH3) NDVI trend
100.00
80.00
60.00
40.00
20.00
0.00
13/04/200
13/06/200
13/08/200
13/10/200
13/12/200
13/02/200
13/04/200
13/06/200
13/08/200
13/10/200
13/12/200

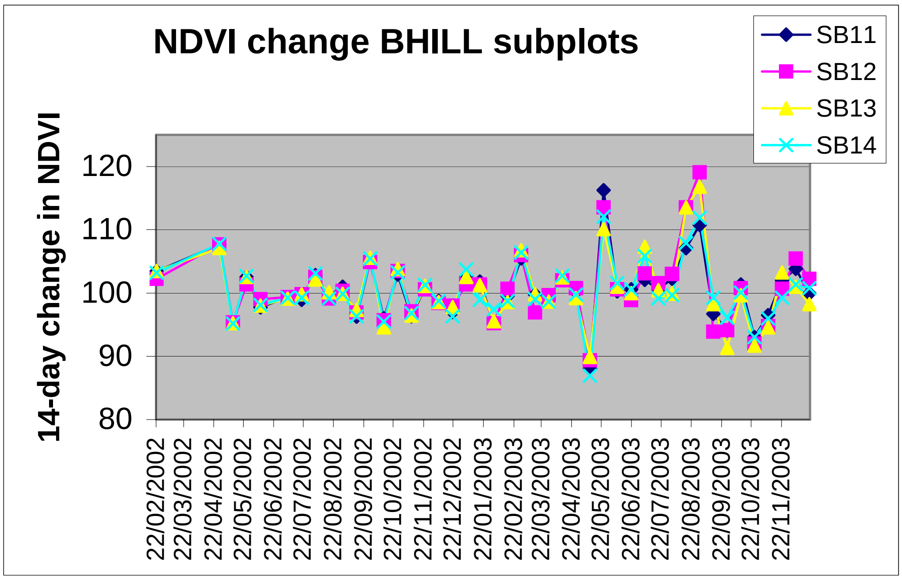

Topar (BH4) green vegetation
ground cover %
20
15
10
5
0
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Nov-03
BH4-e
BH4-p
BH4-f


Topar (BH4) NDVI trend
50.00
40.00
30.00
20.00
10.00
0.00
13/04/200
13/06/200
13/08/200
13/10/200
13/12/200
13/02/200
13/04/200
13/06/200
13/08/200
13/10/200
13/12/200

Appendix F. 14-day change in relative NDVI trends for subplots of all regions. Change calculated as difference between consecutive images, scaled to 100 as the no-change value.







Appendix G: Trend in Raw NDVI values by sub-plots within regions
Raw NDVI is the adjusted NDVI values from DOLI NOAA-16 and NOAA-17 images.