

# THE USE OF SPECTRAL INDICES AND SPATIALLY VARYING THRESHOLD SURFACES FOR MAPPING THE EXTENT OF PERENNIAL VEGETATION OVER TIME

Furby, S.L., Renzullo, L.J., Chia, J. and Wallace, J.W.

CSIRO Mathematical and Information Sciences  
Private Bag 5, PO Wembley WA 6193  
Phone: 61 8 9333 6125, Fax: 61 8 9333 6121  
suzanne.furby@csiro.au

## Abstract

Accurate regional-scale maps of the extent and change in area of perennial vegetation are required over large areas of Australia to provide basic information for conservation, land management and for modelling carbon flux and water use. The existence of a spatially and temporally consistent mask of perennial vegetation provides a partitioning of the landscape for monitoring changes within the vegetated areas. In Australia, Landsat imagery has been used in a number of operational regional and national projects to provide maps of 'perennial vegetation' or change in perennial vegetation cover.

In Western Australia's Land Monitor project, a procedure to map and monitor perennial vegetation based on the application of indices and thresholds has been implemented. It has been applied to sequences of normalised Landsat TM data over the southwest agricultural area (24 million hectares).

Discriminant analysis is applied to the TM data to identify optimal spectral indices for the separation of perennial vegetation and other land use types. Thresholds are identified to assign each pixel a probability of having perennial vegetation cover from one to zero. Using summer imagery, it has been found that a common pair of indices can be applied across the whole region, but the thresholds that separate perennial vegetation from other cover types vary spatially with changes in factors such as soil and land cover.

Initially, geographic stratification was applied with constant thresholds estimated within zones, resulting in discontinuities in the thresholds at zone boundaries. A spatially varying threshold surface appeared advantageous. To construct such a threshold surface, sets of sample thresholds were derived at 20km intervals over the region. Surfaces were fitted to these data and a number of surface fitting methods and levels of smoothing were compared.

The paper will describe the calculation of the threshold surfaces and their use in producing the Land Monitor perennial vegetation maps.

## Introduction

Many remote sensing mapping or monitoring applications are based on calculating an index or indices relevant to the application and assigning labels

or interpreting change based on these index values. Examples include tree cover mapping (Danaher et al, 1998; Caccetta et al, 2000; Furby, 2002) and productivity mapping in agricultural areas (Edirisinghe et al, 2000).

In extending these applications from local study areas to regional, national or global scales, the spatial variability of the thresholds used to assign class labels, or the interpretation of index values becomes an issue. A common strategy adopted in such situations is to stratify the region of interest and perform the analyses separately within each zone.

Stratification divides the region of interest into zones that are relatively homogeneous in terms of the factors affecting the application of interest. For example, the thresholds for separating perennial vegetation cover from non-perennial vegetation cover change with different soil types. Once stratification zones are defined, appropriate thresholds are derived separately for each zone. Geology and soil type variations do not always produce sharp zone boundaries in spectral responses. Native vegetation type and spectral signatures may vary more smoothly across broad regions in response to 'ecological gradients'.

Figure 1 shows a mosaic of calibrated Landsat TM imagery for the south-west agricultural area in Western Australia covering an area approximately 1000 km by 950 km. The image becomes progressively 'lighter' and less 'green' further north and east throughout the agricultural area. Although it is easy to see that the central wheatbelt is quite different to the south-west coast, it is less clear where to draw the line, or lines, between these regions. Although factors such as rainfall, soil type, geology, terrain and land use patterns cause the differences, it is their combination rather than a single dataset that drives the differences. In other situations the precise factors that cause the ecological variations may not be known or cannot be adequately modelled. In these cases stratification becomes a subjective manual task. Even when such ancillary datasets are available to automate a stratification process, they may not be at a scale or accuracy appropriate to the application and it may be difficult to digitise all of the appropriate boundaries.

Hard stratification zones can result in consistency problems at the boundaries of the zones. It is generally the case that there is a continuum from one vegetation community or land use pattern to another. In such cases the mapping needs to treat such areas consistently across any stratification zone boundary to be useful at local as well as regional scales.



Figure 1: 2003 Landsat TM mosaic of the Western Australian agricultural area (bands 5,4,3 in RGB). The area shown is approximately 1000 km by 950 km.

In this paper we propose allowing the index thresholds to vary continuously as a function of location, rather than being fixed within stratification zones and changing at the zone boundaries. By allowing the thresholds to vary smoothly, we can recognise the underlying landscape variation without needing to precisely delineate boundaries or even the factors that cause the variation. If the thresholds are constrained to vary in a sufficiently smooth manner the products will be consistent in any local area.

The remainder of this paper describes how the concept of continuously varying thresholds has been developed and applied to a broad scale perennial vegetation monitoring program. The next section briefly summarises the role of indices and thresholds in the perennial vegetation monitoring methodology used in the Land Monitor project. The following section describes the development of the surface fitting methodology for threshold setting and its application.

### **Indices and Thresholds for Perennial Vegetation Mapping**

The initial methodology proposed for the perennial vegetation monitoring component of the Land Monitor project is the same as that used in the

Australian Greenhouse Office Land Use Change Program (Furby, 2002). The steps are:

1. Rectify, calibrate and mosaic a sequence of Landsat TM images from 1988 to the present.
2. Stratify the study area.
3. Derive indices for discriminating between perennial vegetation cover and the other ground cover types present in the image data.
4. Set thresholds for the allocation of image pixels to one of the following classes for each image date: certain perennial vegetation cover, certain non-perennial vegetation cover and uncertain cover.
5. Use the indices and thresholds to assign each pixel a probability of having perennial vegetation cover from one to zero.
6. Process the sequence of cover class probabilities from all dates using a conditional probability network approach (Caccetta 1997).
7. Reduce the probability images to a binary (i.e. yes/no) 'perennial vegetation cover masks' for each date.

Steps 3 to 6 are repeated for each stratification zone and the results are mosaiced for the agricultural area.

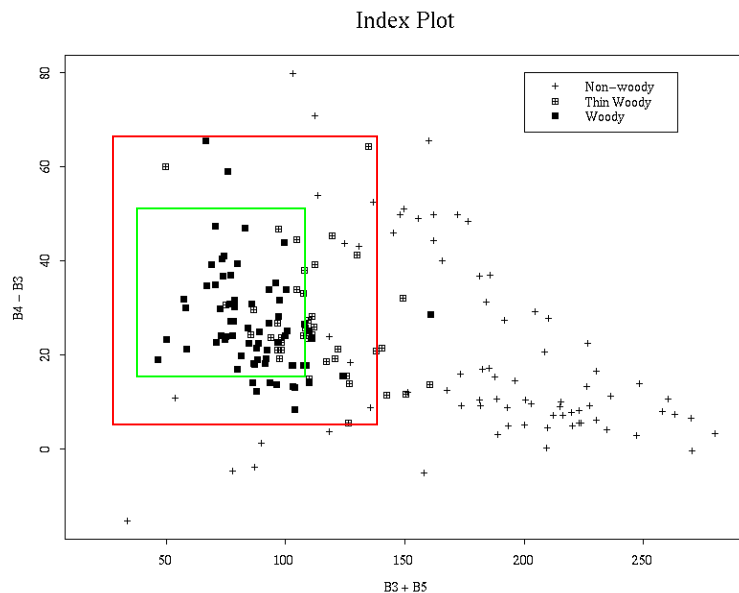


Figure 2: Sample index plot. The area inside the green rectangle shows the range of certain perennial vegetation index values. The area outside the red rectangle shows the certain non-perennial vegetation index values. The area between the red and green rectangles is the uncertain spectral region.

The index derivation process was applied to several different regions within the south-west agricultural area. Results showed that the same two indices could be applied over the whole south-west agricultural area and it is only the thresholds that vary across the region (Furby and Wallace, 1999). Figure 2 shows the index plot with thresholds derived for one such area. Instead of identifying stratification zone boundaries and setting thresholds for each zone, threshold surfaces were obtained for the whole region and used to create the probability images used in the multi-temporal processing. The following section describes how the threshold surfaces were formed.

### **Surface Fitting**

The initial surface fitting investigations were restricted to a 300 km by 200 km area covering six Landsat TM images. Thresholds separating certain perennial vegetation, uncertain and non-perennial vegetation classes were determined by visual inspection for 150 20km by 20km windows across the study area. Specifically, four values (lower and upper certain perennial vegetation area and lower and upper uncertain are) were identified for each of the two indices.

A number of surface fitting methods were investigated including:

- Polynomial regression;
- Inverse distance weighting;
- Radial basis functions (multiquadratic, inverse multiquadratic, multilog, cubic spline and thin plate spline functions);
- Delauney triangulation (an interpolation method rather than smoothing);
- Kriging (including linear, quadratic, exponential, spherical, Gaussian, hole effect and rational polynomial models); and
- Splines (minimum curvature and spline interpolation in GRASS).

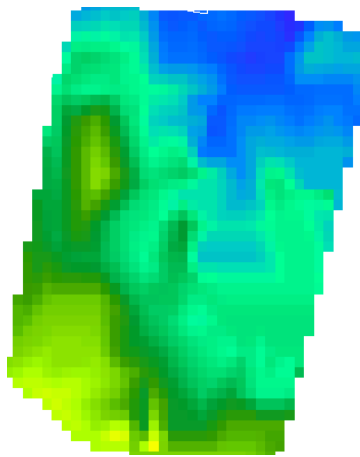
The methods were selected because they were in readily available commercial software packages.

For each method a range of model and/or smoothing parameters were evaluated to determine the optimal parameter settings. The threshold surfaces were evaluated in terms of the overall goodness of fit to the data points and the spatial pattern of the residuals. Table 1 shows a summary of the results for each surface fitting method with its optimal parameter settings for the first index.

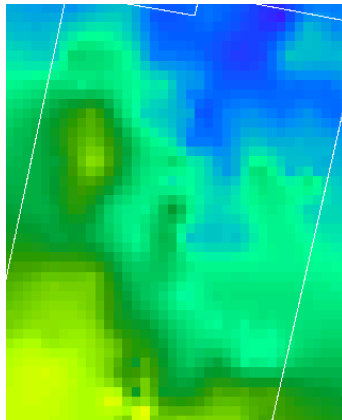
Table 1: Summary of the goodness of fit of the threshold surfaces for the first index

| Surface Type                 | RMS certain perennial vegetation lower threshold | RMS certain perennial vegetation upper threshold | RMS uncertain lower threshold | RMS uncertain upper threshold | Patterns in residuals |
|------------------------------|--|--|-------------------------------|-------------------------------|-----------------------|
| Polynomial Regression        | 5.97   | 5.19   | 6.14                          | 5.73                          | YES                   |
| Inverse Distance             | 4.95   | 5.40   | 5.70                          | 5.92                          | YES                   |
| Radial Basis Functions       | 0.86   | 1.17   | 0.97                          | 1.17                          | NO                    |
| Triangulation*               | 0.98   | 1.20   | 1.12                          | 1.18                          | NO                    |
| Kriging - Exponential        | 2.37   | 2.55   | 2.57                          | 2.63                          | NO                    |
| Kriging - Linear             | 2.37   | 2.54   | 2.56                          | 2.63                          | NO                    |
| Kriging - Quadratic          | 1.83   | 2.07   | 1.95                          | 2.09                          | NO                    |
| Kriging - Spherical          | 2.04   | 2.27   | 2.20                          | 2.30                          | NO                    |
| Kriging - Gaussian           | 5.10   | 5.04   | 5.83                          | 5.64                          | YES                   |
| Kriging - Hole Effect        | 6.32   | 5.86   | 7.32                          | 7.04                          | YES                   |
| Kriging - Rational Quadratic | 4.78   | 4.67   | 5.47                          | 5.21                          | YES                   |
| Splines - Min Curvature      | 0.51   | 0.44   | 0.65                          | 0.54                          | YES                   |
| Splines (GRASS)              | 1.83   | 2.25   | 2.06                          | 2.28                          | NO                    |

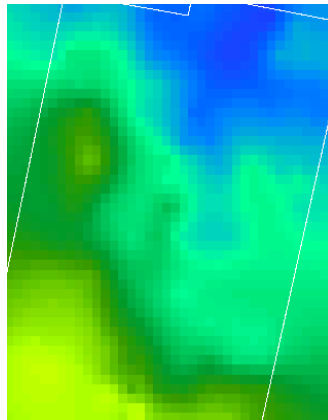
\* The Delauney triangulation procedure is an exact interpolation procedure, not a smoothing procedure. The apparent residuals result from the fact that the output grid cells are not coincident with the original data points.



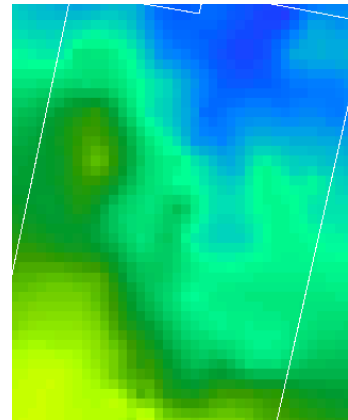
Delauney Triangulation  
(interpolated surface)



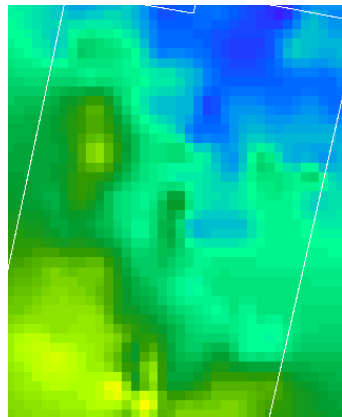
Radial Basis Functions



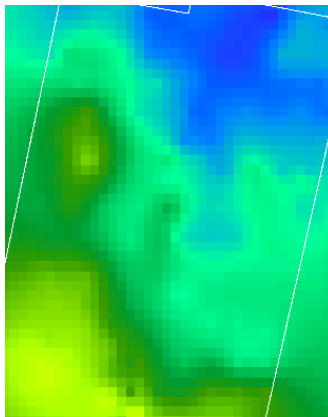
Kriging - Exponential



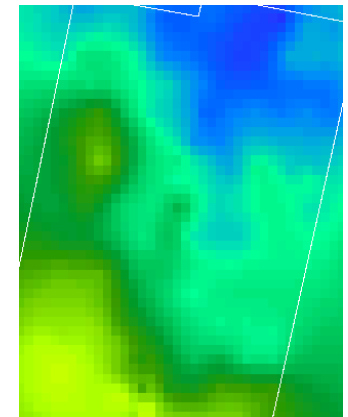
Kriging - Linear



Splines - GRASS



Kriging - Quadratic



Kriging - Spherical

Figure 3: Fitted threshold surfaces for the upper certain perennial vegetation thresholds for the first index. The white boundary shows the extents of the image data. Thresholds outside this region are predicted values.

Surface fitting procedures that leave a distinct spatial pattern in the residuals were not considered further. In general, these surfaces also had the highest

overall residuals. Figure 3 shows several of the better fitted surfaces for the upper certain perennial vegetation threshold for the first index. The interpolated surface from Delauney triangulation is included as an example of an unsmoothed surface. These surfaces are all very similar. Figure 4 shows the residuals between the various smoothed surfaces and the interpolated surface. There are similar spatial patterns in the residuals for all surfaces shown, however the residuals for the surface from the rational polynomial basis function are generally smaller.

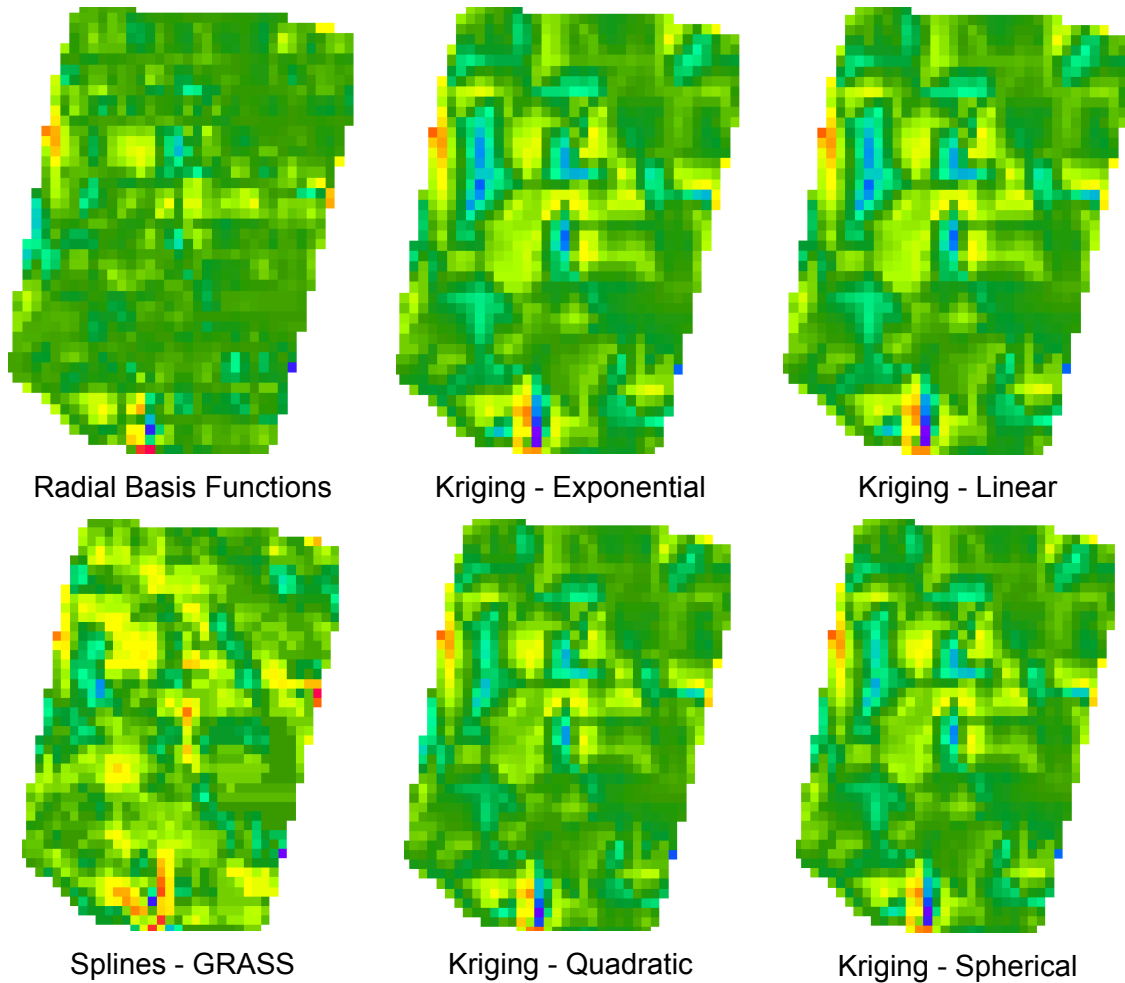


Figure 4: Residuals of the smoothed surfaces from the interpolated surface. Differences of zero are shown in green. Negative differences are shown in yellows and reds (10 counts is bright red) and positive differences are shown in shades of blue (10 counts is dark blue).

Overall, the choice of the initial thresholds and the amount of smoothing has more effect on the final results than the choice of a particular surface fitting method. For the Land Monitor project the radial basis functions (multiquadratic) method was chosen however any of the following other procedures would produce similar final results:

- kriging - exponential, linear, quadratic or spherical models only; and
- spline interpolation in GRASS.

Since adequate (and very similar) surfaces were obtained from several of the methods tested, other more specialised surface fitting methods were not investigated.

## **Conclusions**

This process was used operationally to produce the 'perennial vegetation extent and change' products from 1988 to 2002 for the Land Monitor project (18 Landsat TM scenes at each of 8 time slices).

The process allows thresholds to vary geographically without having to specify, or even know or be able to measure, the factors that cause the variation. This can provide a considerable saving in effort in stratification when the required ancillary datasets are unknown or unavailable at an appropriate scale. It is even possible that the shape of the surface may suggest the key factors that drive the relevant ecological processes.

Underlying the application of this method is the assumption that the images that the index values are derived from are seamless across the region of interest. Shifts in index values at image date edges where there are significant seasonal differences will not be well modelled by smooth surfaces. Some surface fitting procedures, such as splines, allow the use of breakpoints at which the smoothness constraints are relaxed or removed completely. Such methods would be appropriate with the scene edges used as breakpoints.

## **References**

Caccetta P.A., 1997, Remote Sensing, Geographic Information Systems (GIS) and Knowledge-Based Methods for Monitoring Land Condition, PhD Thesis, School of Computing, Curtin University of Technology.

Caccetta, P. A., Allen, A. and Watson, I., 2000, The Land Monitor Project. Proceedings of the Tenth Australasian Remote Sensing and Photogrammetry Conference, Adelaide, Australia, August 2000.

Danaher, T. J, Wedderburn-Bisshop, G. R., Kastanis, L. E. and Carter, J. O. 1998. The Statewide Landcover and Trees Study (SLATS) – Monitoring land cover change and greenhouse gas emissions in Queensland, Proceedings of the Ninth Aus Australasian Remote Sensing and Photogrammetry Conference, Sydney, Australia, July 1998.

Edirisinghe, A., Hill, M. J. and Donald, G. E. 2000. Estimating feed-on-offer and pasture growth rate using remote sensing. Proceedings of the Tenth Aus Australasian Remote Sensing and Photogrammetry Conference, Adelaide, Australia, August 2000.

Furby, S. L. and Wallace, J. F. 1999. A preliminary investigation of using smoothed threshold surfaces to produce spatially consistent bush masks. CSIRO Mathematical and Information Sciences Technical Report.

Furby, S. L. 2002. Land Cover Change: Specification for remote sensing analysis. Australian Greenhouse Office Technical Report 9, Canberra, Australia.