Title: **Remote diagnosis of early desertification with panchromatic, high-spatial resolution images. A feasible solution for sustainable use of shrublands.**

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Running title: Diagnosis of early desertification for sustainable use

Introduction

There is an immediate need for policy decisions on how to detect, prevent and/or adapt to desertification and land degradation in general (Reynolds et al. 2000). Monitoring shrublands in time to detect early deterioration is an unresolved subject in most cases. Most of our knowledge about the dynamics of these systems comes from relatively restricted areas, including relatively small exclosures of major herbivores in order to draw meaningful comparisons about their effect on the plant canopy (Brown & Waller 1986).

Identifying early desertification in shrublands requires the selection of adequate “signs”, or relevant process-related parameters or monitorables to quantify the processes occurring at early stages of land degradation. Changes in Net Primary Production (NPP) have been indicated as conceptually adequate metrics (Schlesinger et al. 1990) and remote-sensing techniques have been applied to the analysis of the changes in time of aboveground NPP-related spectral vegetation characteristics in grazing gradients (Pickup et al. 1993, Pickup et al. 1998.

Alternatively, the evaluation of changes of aboveground NPP (or surrogate indicators) in space seems to offer greater possibilities (Okin 2001, Couteron & Lejeune 2001). Low (500<height<700m) aerial views of the vegetation in semiarid shrublands exhibit a spotted/banded pattern, where darker clumps or patches correspond to the shrub components interspersed on a background of lighter tones corresponding to open-space soil or herbaceous sparse vegetation.

In a previous paper (Ares et al. 2002), we presented metrics derived from Fourier spectral theory that allow inspecting high resolution aerial photographs with the aim of detecting patterns in the structure of the plant canopy related to shrubland degradation by domestic grazing. The technique makes use of gray-palette aerial photography digitized to a spatial resolution of 1.5 m or less.

In this study we develop the technique further in order to interpret early desertification processes in domestic grazing systems in the shrublands of the southern Argentinian Monte. Specifically, we tested the following hypothesis:

1. Early desertification can be triggered by domestic herbivores reducing or favoring some life forms or modifying their distribution in the plant canopy. This would imply that there is a component of spatial vegetation patterns related to the pattern of domestic herbivore use.

Materials and Methods

Description of the area. Observations on the spatial arrangement of plant canopies were conducted in an area of about 300 km^2 centered at 42º 38’S, 65º 23´W in the southern Patagonian Monte (Chubut Province, Argentina, Figure 1).

Field survey. Two sets of aerial photographs ($\times$ 36 exposures) from the fields were obtained on 05-29-02 and 07-31-02 with a regular auto-focusing 36 mm optical camera (Canon EOS 500N). The camera was mounted on the outside of the cabin of a 2-seat ultra-light plane flying at 660 m above ground level, such that it would obtain nadir-oriented exposures when remotely triggered from the inside of the cabin. Target geo-positions were selected according to a systematic design involving three stages of domestic grazing impact as inferred from the distance to the local (property boundary) single watering point (Far : 4000-5000m, Medium: 2000-3000m, Near: <1000m) in each of four paddocks at each of three *estancias* (Figure 2).

Image digitizing and processing. Negative exposure films (Kodak Color Film 100-7) were converted to positive copies (150.2 $\times$ 101.0 mm). Copies were digitized to a gray palette (binary 8 bit/byte integers, digital values: 0-255) with a desk-page scanner (Umax-Astra 3400) at resolutions 75, 150, 300 and 600 dpi. We characterized the spatial pattern of vegetation by means of the Fourier signature *S/N*, (signal/noise ratio) developed in previous studies (Ares et al. 2002). The *S/N* metric refers to the spatial arrangement of a linear data vector, combining the evaluation of their departure from a random distribution, and the relative size of the "peak" values along the data string. Anisotropy in spatial distribution can be evaluated by inspecting the variation of *S/N* ratios in data transects with diverse spatial orientation.

The null Hypothesis 1 (no grazing effect upon plant spatial distribution) was tested on the photograph set obtained at 05-29-02 by comparing the frequency distributions of *S/N* values at Far, Medium and Near positions (12 exposures $\times$ 20 transects $\times$ 4 spatial resolutions = 960 values/position) by means of a non-parametric chi-square test (Crow et al. 1993).

Results

Hypothesis 1: Grazing modifies the spatial pattern of the vegetation canopy. Figure 3 shows the frequency distributions of *S/N* values corresponding to Far, Medium and Near positions (see also Figure 2) at spatial resolutions ranging from 0.09 $\times$ 0.09 m to 0.72 $\times$ 0.72 m, as well as the chi ^{2} values quantifying the differences among positions. Far-Near histograms are different at all sampling resolutions. In other cases, there are also marked differences between Far-Medium and Medium-Near positions. The changes observed in the histograms corresponding to all sampling resolutions consist in the increase of the frequencies at the central range of *S/N* values at the expense of lower-class values.

Discussion

In a previous paper (Ares et al. 2002) we showed that the *S/N* ratio decreases in areas severely impacted by grazing, because shrub patches are disrupted and spatially disorganized into smaller units, fragments of remnant patches, etc. In this study, where early stages of desertification were observed, the average *S/N* ratios do not diminish with increasing grazing impact, but their frequency distribution shifts significantly towards a reduced frequency of low values and an increased frequency of central values. These trends are consistent with an increasing shrub encroachment, as reported for similar shrublands (Beeskow et al. 1995, Klausmeier 1999). The examples shown in Figure I-1 indicate that the *S/N* ratio can be used to characterize the spatial structure of the plant canopy in relation with these changes. Figure I-1a-b show that the *S/N* metric can quantify the degree of heterogeneity of a spatial distribution in comparison with that of a theoretically random one. Figures I-1c-f show that the *S/N* ratio also quantifies the contrast between emerging structures (shrubs, low trees) with respect to a background of lower structures like those corresponding to perennial grass biomass.

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Dr. M. Bertiller contributed with ideas and comments at various stages of the study. Dr. C. Ibarra supplied technical assistance in developing the flight procedures and protocols. Funds were supplied by Agencia Nacional de Promoción Científica y Tecnológica (FONCYT), Project BID 1201/OC-AR PICT-99 #08-06027 and GTZ-Universität München-CENPAT-UNPSJB, "Erfassung und Abschätzung von Desertifikationserscheinigungen in Patagonien". Interferometric techniques for the calculation of the DEM of the study area were made available for the scope of this project by the Remote Sensing Data Center (DFD) of the German Aerospace Center (DLR). Special thanks are given to A. Roth for software support. The European Space Agency (ESA), DLR and Comisión Nacional de Actividades Espaciales (CONAE) from Argentina supplied satellite images.

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Figure legends

Figure 1. Location of the study site in South America, Argentina.

Figure 2. Flight plan and surveyed positions along a transect including three paddocks (*estancias*) at the Southern Patagonian Monte. Lower inset shows a 3-D view of the area with characteristic geomorphology patterns.

Figure 3. Frequency histograms of all *S/N* values corresponding to transects on photographs taken on 05-29-02. Chi-square values above the P<0.05 significance level shown in bold.

Figure 1

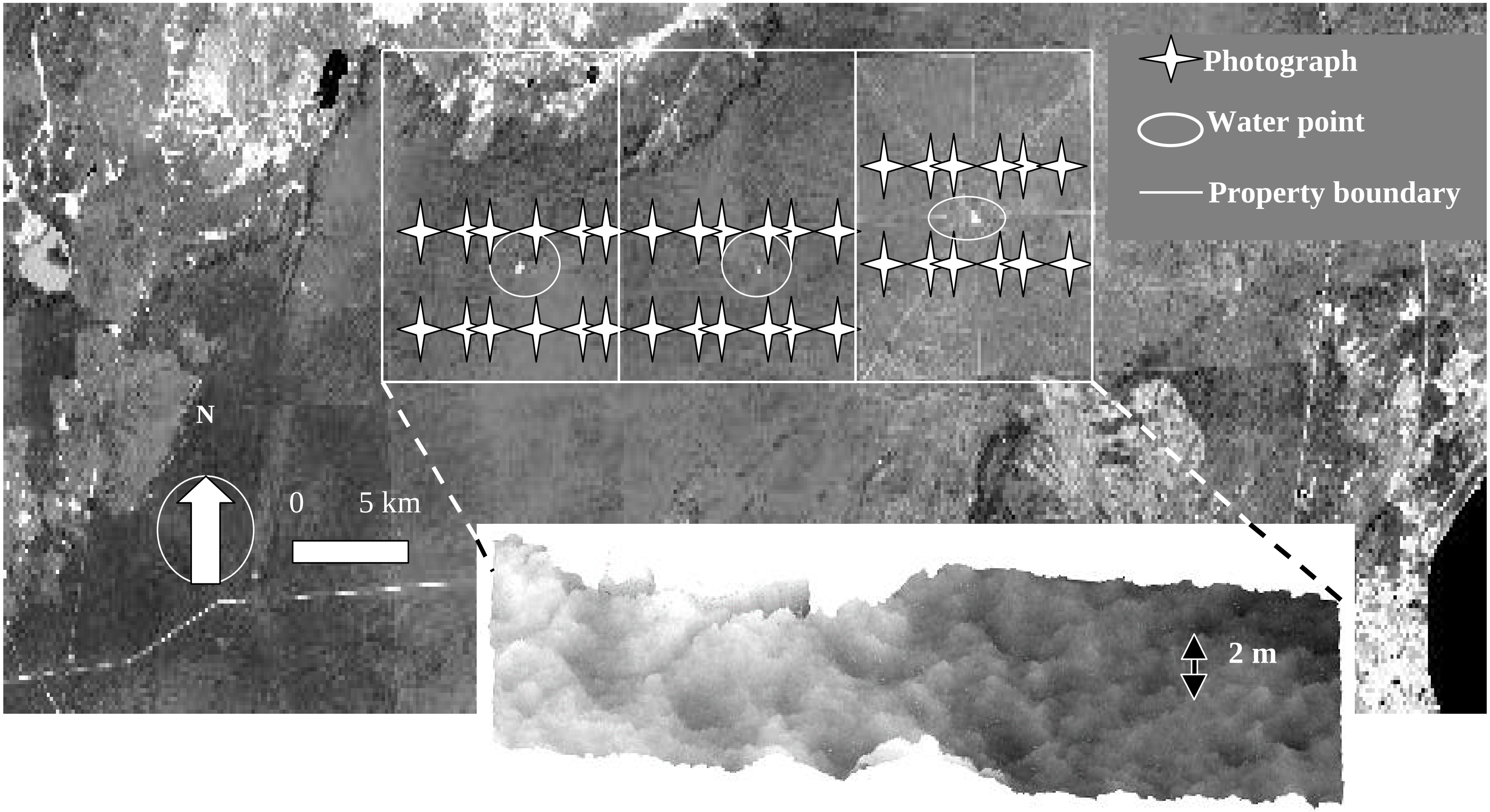
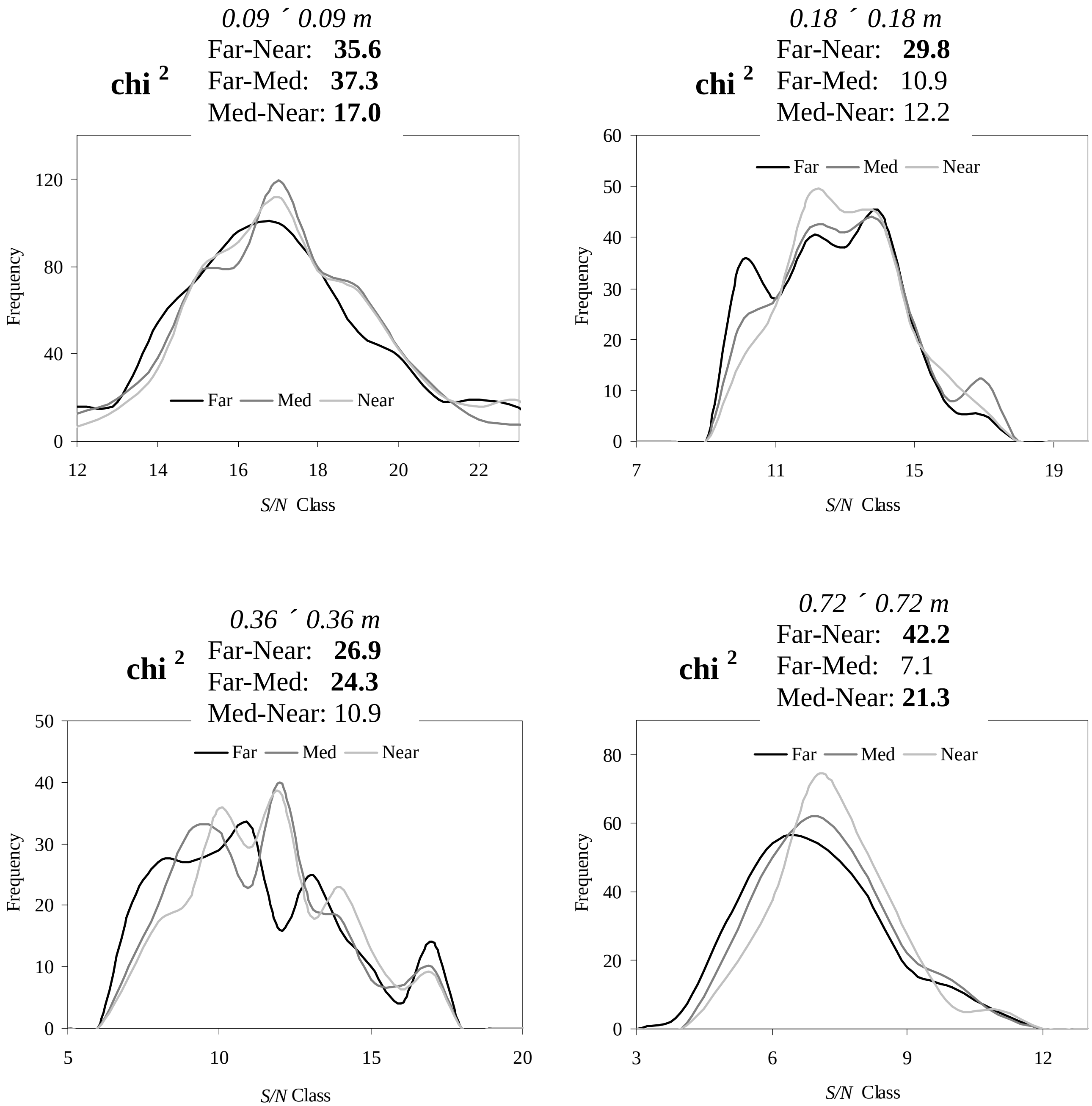

Photograph
Water point
Property boundary
N
0
5 km
2 m

Figure 3


0.09 ´ 0.09 m
chi 2
Far-Near: 35.6
Far-Med: 37.3
Med-Near: 17.0
Frequency
S/N Class
Far
Med
Near
0.18 ´ 0.18 m
chi 2
Far-Near: 29.8
Far-Med: 10.9
Med-Near: 12.2
Frequency
S/N Class
Far
Med
Near
0.36 ´ 0.36 m
chi 2
Far-Near: 26.9
Far-Med: 24.3
Med-Near: 10.9
Frequency
S/N Class
Far
Med
Near
0.72 ´ 0.72 m
chi 2
Far-Near: 42.2
Far-Med: 7.1
Med-Near: 21.3
Frequency
S/N Class
Far
Med
Near