J. Range Manage.
47:498-502 November 1994

Range assessment using remote sensing in Northwest Patagonia (Argentina)

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Abstract

A methodology based on remotely sensed data (LANDSAT-MSS) was used for rapid assessment of rangelands in the grass and shrub steppes of NW Patagonia (Argentina). We calibrated Normalized Difference Vegetation Index (NDVI) data using total plant cover, grass cover, shrub cover, and floristic data. Total vegetation cover and grass cover was predicted with high accuracy from Normalized Difference Vegetation Index data. The correlation between observed and estimated cover was 0.87 and 0.82 (p<0.01) for total cover and grass cover respectively. The correlation was lower for shrub cover than for grass (r=0.45, p<0.01).

Normalized Difference Vegetation Index data was used to accurately predict cover of *Festuca pallescens* (St. Yves) Parodi (coirón blanco) and *Nassauvia glomerulosa* (Lag.) Don (colapiche), 2 species with contrasting response to grazing in the Occidental district of Patagonia, and typical of vegetation with very different grazing values. The correlation between observed and estimated from the Normalized Difference Vegetation Index cover was 0.67 and 0.53 (p<0.01) for *Festuca pallescens* (coirón blanco) and *Nassauvia glomerulosa* (colapiche) respectively.

Key Words: grass-shrub steppes, LANDSAT MSS, grass cover, shrub cover, floristic data, NDVI

Patagonia is a broad, arid, cold-temperate region of more than 600,000 km² located in the southernmost portion of Argentina and Chile, in South America. Shrub and grass steppes, and semideserts are the main physiognomic types in the region (Soriano 1956a, Paruelo et al. 1991). Most of the Patagonian region has been devoted to sheep husbandry on extensive ranches since the beginning of the century. Natural resources, particularly vegetation and soil, have been deteriorating (Soriano 1956b, Soriano and Movia 1986). A common result of the vegetation deterioration in the Patagonian steppes was the replacement of mesophytic species by species typical of more xeric environments (León and Aguiar 1985, Borelli et al. 1985, Anchorena 1985). The more dramatic changes took place in the more humid areas, dominated by *Festuca* grasslands, where deterioration was associated with a shrub encroachment process (León and Aguiar 1985). Improper management of sheep has been pointed out as a major factor in this process (Soriano and Paruelo 1990). The deterioration of the natural resources has socio-economic consequences. Since the middle of the century, and following a sustained increase, sheep numbers have declined sharply. In 1988 the number of sheep was 30% lower than in 1960 (Paruelo and Sala 1992). Because of the arid and semiarid characteristics of the region, there are few economic alternatives to sheep husbandry. Therefore, decline in sheep numbers would reflect a reduction in the carrying capacity of the system.

The consensus among technical personnel from government agencies and the scientific community is that changes in management practices in the region are needed to reverse the desertification process. The development of new management practices requires knowledge about the resources and the responses of the vegetation to grazing and other environmental factors. The first step in the design of management techniques involves the description of the major range units (vegetation units of the same forage value) and an assessment of each unit.

Traditional assessment of forage resources is not easy in Patagonia, as is the case in most developing countries. Traditional field surveys were not cost effective because of access difficulties. A quick range assessment might be based, then, on remotely sensed data (Tueller 1989). LANDSAT MSS data provides spectral information of a proper scale to assess range vegetation resources. Boyd (1986) showed the suitability of LANDSAT MSS data to monitor the brush canopy cover in Texas. The Normalized Difference Vegetation Index (NDVI), calculated from the red and infrared reflectance of a target area, was shown to be highly correlated with vegetation cover and primary production (Tucker and Sellers 1986, Box et al. 1989, Kennedy 1989). Also, the calculation of an index allows for a reduction of the dimension of the data matrix and, therefore, easier handling of large amounts of data. However, the relationship between Normalized Difference Vegetation Index and vegetation attributes changes according to spectral characteristics of the substratum and the structural characteristics of the plant cover. Consequently, calibration of the Normalized Difference Vegetation Index data is needed. Calibration of models of vegetation-spectral data relationships has been referred to as a key step in broad scale rangeland monitoring using LANDSAT data (Pech et al. 1986).

A methodology was developed to survey rangelands in NW Patagonia using remotely sensed data from LANDSAT MSS images. This methodology was designed to answer questions such as: what are the major range units on a ranch or in a region? or, what is the geographical area of each range unit?. We tested this methodology in a area of 1,500 km² of private rangelands.

This work was conducted with the economic and logistic support of the Compania a de Tierras Sud Argentino S.A., we thank to Ing. Agr. C. Vivoli, R. Petrosi and Dr. D. Perazo. D. Bran, J. Ayesa and C. Marcolín provided us useful information. J. Trlica, V.A. Deregibus and J. Fair made valuables suggestions on the manuscript. We also thank the authorities of the EERA INTA Bariloche. This work is a partial contribution of the project "Lucha contra la Desertificación en Patagonia" (LUDEPA) INTA-GTZ.
Manuscript accepted 13 Apr. 1994.

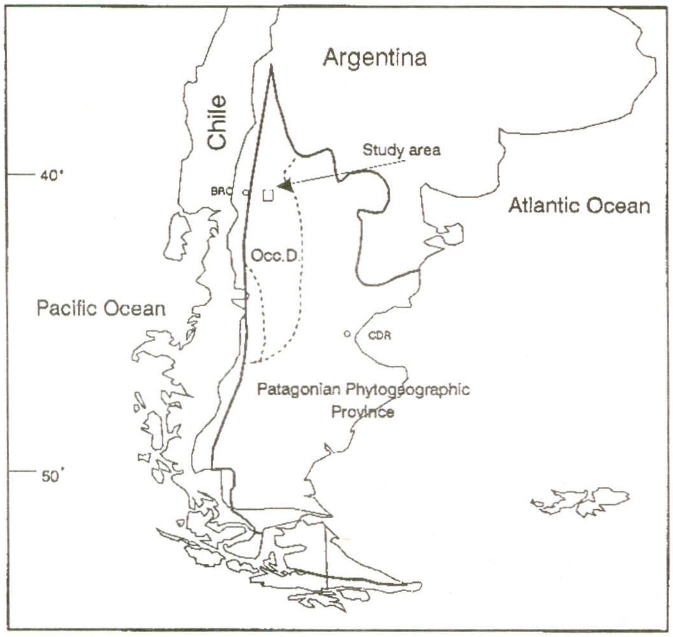

Fig 1. **Map of the southern portion of South America showing the study area. The dotted line corresponds to the boundary of the Occidental district of the Patagonian Phytogeographic Province. BRC: Bariloche city and CDR: Comodoro Rivadavia city.**

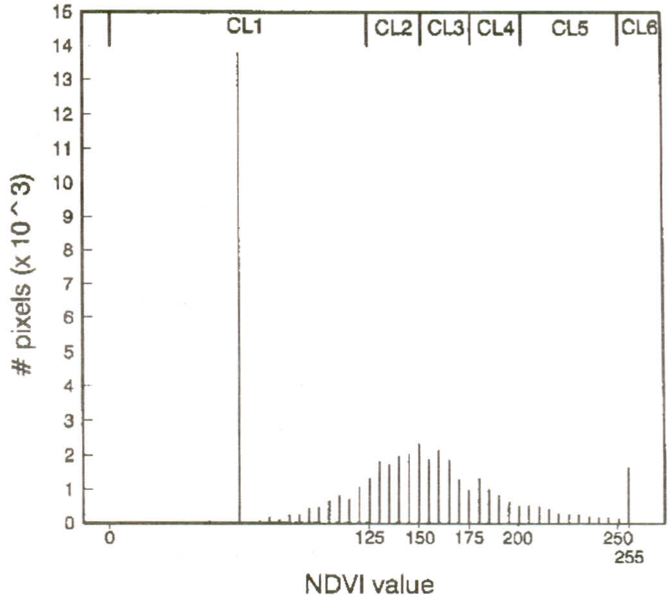

Fig 2. Histogram of the NDVI values. The NDVI intervals for each of the six NDVI classes are shown at the top of the graph. The number of pixels is displayed for intervals of 5 units of NDVI.

Materials and Methods

Site Description

The study area was located in North-West Patagonia in a large area of more than 80,000 km^2 corresponding to the Pre-Andean region (Fig. 1). The heterogenous geology of the area has produced a highly dissected landscape. Altitudes range from 900 to 1,400 m above sea level. Thirty percent of the area has soils with rocks on the surface. Most of soils are Aridisols (Lithic Haplargids, Typic Haplargid) or Entisols (Lithic Xeropsamments, Thapto argic Xerortents) (INTA-SAGYP 1991). The area corresponds to the Occidental district of the Patagonian Phytogeographical Province (Soriano 1956a). The most characteristic physiognomic type of this phytogeographical unit is the shrub-grass steppe (Paruelo et al. 1991). A high proportion of valley bottoms are occupied by highly productive meadows, locally named "mallines".

Both the structure and function of vegetation in northwestern Patagonia are controlled by water availability (León and Facelli 1981, Paruelo et al. 1993). León and Facelli (1981) described a coenocline, in a flat area of the Occidental district of the Patagonian Phytogeographic Province, where communities changed from grass steppes to semideserts along a precipitation gradient. In our study area the complete range of plant communities described by Leon and Facelli (1981) and Golluscio et al. (1982) was found under the same precipitation regime. The heterogeneity of topographic and edaphic characteristics of the study area created important differences in water balance among stands. Stands had large differences in the amount of input water through precipitation, as a result of differences in altitude, or in run-on from upper positions. Exposure, altitude and slope also determined differences in water output through evaporation and run-off. Topographic and edaphic differences explain up to 60% of the floristic variation for an area near the study site (Jobbagy and Paruelo unpublished).

Average annual precipitation for a 27 year period was 304 millimeters. Most of the precipitation falls in winter, both as snow and rain. Mean annual temperature was 7.4 °C. Mean temperature for the warmest month (January) was 13.6 °C and for the coldest month (July) was 1.4°C (Muñoz 1981).

NDVI-Vegetation Calibration

Data for a portion (1,500 km^2) of a LANDSAT-MSS image from northwest Patagonia (January, 1986) were processed to calculate the Normalized Difference Vegetation Index (NDVI). Data processing included geometric rectification, georeferencing and projection to the Transverse Mercator coordinate system. Normalized Difference Vegetation Index was calculated as:

$$NDVI = (C4 - C2)/ [(C4 + C2) + 0.5] \quad \text{(Rouse et al. 1973)},$$

where C2 corresponds to band 2 (Red, 600-700 nm) and C4 to band 4 (Reflective Infrared, 800-1,100 nm) of the Multiple Spectral Scanner from LANDSAT. Image processing was performed in an ERDAS 7.4 system.

Because of the problems in identifying individual pixels in the field, pixels were grouped into 6 classes on the basis of their Normalized Difference Vegetation Index values. The histogram of the Normalized Difference Vegetation Index values was divided in six intervals of variable size according to the frequency of pixels in each region of the histogram (Fig. 2).

Fifty six stands larger than the pixel size of the image (79x79 m) that corresponded to different classes of Normalized Difference Vegetation Index were identified from a georeferenced image. Floristic composition, total cover, and cover-abundance of each species were recorded in the 56 stands. We performed a phytosociological census in each stand, obtaining a complete list of species and visual estimations of cover-abundance over an area of approximately 1 ha (Mueller-Dombois and Ellemberg 1974). The association of individual species to the defined values of Normalized Difference Vegetation Index was determined using Analysis of Canonical Correspondence (Ter Braak 1986). Total cover, grass cover, shrub cover and the specific cover for the more constant and abundant species were averaged for each Normalized Difference Vegetation Index class and compared using the Kruskal-Wallis test (Ott, 1993). The analysis was performed for the lowest 5 classes of Normalized Difference Vegetation Index because the highest class corresponded to a vegetation type (meadows) clearly associated with particular topographic positions and water conditions (valley bottoms with the water table near the surface).

Normalized Difference Vegetation Index Calibration test

To test the accuracy and reliability of the calibration of Normalized Difference Vegetation Index against the vegetation data we performed an evaluation of the models adjusted in their predictive operation (Wegener and Malone 1983). We randomly chose 3 field observations for each Normalized Difference Vegetation Index class. Calibration was recalculated, without these field observations, and then used to obtain new estimates of total plant cover, shrub cover, grass cover, *Festuca pallescens* (St. Yves) Parodi (coirón blanco) cover, and *Nassuavia glomerulosa* (Lag.) Don (colapiche) cover for each Normalized Difference Vegetation Index class. These estimates were compared with the average values of the 3 selected censi. We chose *Festuca pallescens* (coirón blanco) and *Nassauvia glomerulosa* (colapiche) as test species because they showed high constancy and a contrasting association to Normalized Difference Vegetation Index classes.

Random partitioning of data allowed for a test with data independent of that used in the calibration. We performed 5 random partitioning of the data. Comparison of predicted and observed values of the variables (total cover, grass cover, shrub cover, *Festuca* and *Nassauvia* cover) was performed using regression analysis.

Results and Discussion

Total plant cover showed significant differences among Normalized Difference Vegetation Index (NDVI) classes (Fig.3). This variable increased consistently from NDVI class 1 (low NDVI) to NDVI class 5 (high NDVI) (Fig. 3). This increase largely resulted from a 6-fold rise in grass cover. Shrub cover declined slightly as Normalized Difference Vegetation Index class increased (Fig. 3).

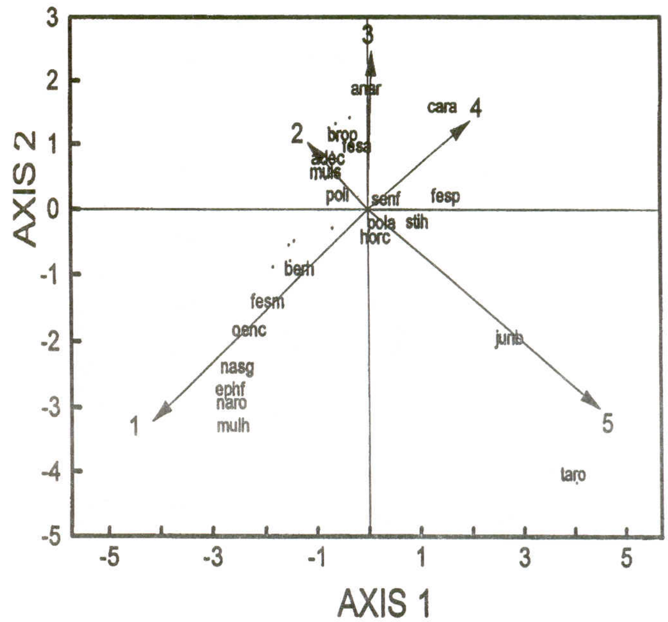

Fig 4. Plot of the first 2 axes of the Analysis of Canonical Correspondence of the floristic data in the space of NDVI data. Each arrow corresponds to the direction of each NDVI class. The first axis explains 47% of the total variation and it had a high correlation with NDVI class. The second axis explains 37% of the total variation. ephf: *Ephedra frustillata* Miers, naro: *Nardophyllum obtusifolium* H. et A., mulh: *Mulinum haleii* Skottsb., nasg: *Nassauvia glomerulosa* (Lag.) Don, oenc: *Oenothera contorta* Dougl., fesm: *Festuca magellanica* Lam., berh: *Berberis heterophylla* Juss., muls: *Mulinum spinosum* (Cav.) Pers., adec: *Adesmia campestris* (Rendle) Skottsb., poli: *Poa ligularis* Ness ap. Steud., brop: *Bromus pictus* Hook., fesa: *Festuca argentina* (Speg.) Parodi, anar: *Anartrophyllum rigidum* (Gill. ex H. et A.) Hier., horc: *Hordeum comosum* Presl., pola: *Poa lanuginosa* Poir., senf: *Senecio filaginoides* DC., stih: *Stipa humilis* Cav., cara: *Carex argentina* Barros, fesp: *Festuca pallescens* (St. Yves) Parodi, junb: *Juncus balticus* Willd., taro: *Taraxacum officinallis* Weber.

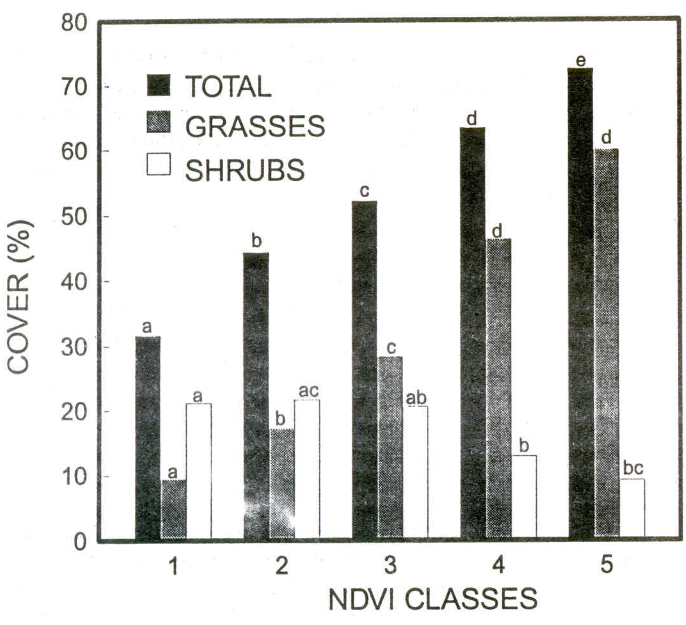

Fig 3. Total, grass and shrub cover (%) for each NDVI class. Different letters indicates significant differences from Kruskal-Wallis test (p<0.05) among NDVI classes.

Forty-nine percent of the total floristic variation was associated with the Normalized Difference Vegetation Index classes. The first axis of the Analysis of Canonical Correspondence (ACC) (Fig. 4) was strongly correlated with Normalized Difference Vegetation Index values (r=0.84, $p<0.01$). Four shrub species were associated in the ACC with the lowest Normalized Difference Vegetation Index class: *Mulinum halei* Skottsb., *Nardophyllum obtusifolium* H. et A., *Ephedra frustillata* Miers and *Nassauvia glomerulosa* (colapiche). *Taraxacum officinale* Weber (diente de león) and *Juncus balticus* Willd. (junco), typical species of meadow edges, were associated with the highest Normalized Difference Vegetation Index classes. *Festuca pallescens* (coirón blanco), a highly preferred bunchgrass, was the steppe species most closely associated with high Normalized Difference Vegetation Index classes (high rank scores in axis 1).

Significant differences among classes of Normalized Difference Vegetation Index were noted for dominant species (Fig. 5a). *Festuca pallescens* (coirón blanco) had low cover values in the first 2 classes of Normalized Difference Vegetation Index and significantly higher values in the highest classes. *Stipa speciosa* Trin. et Rupr. (coirón amargo) was a frequent and highly variable component of all the Normalized Difference Vegetation Index units. The more frequent

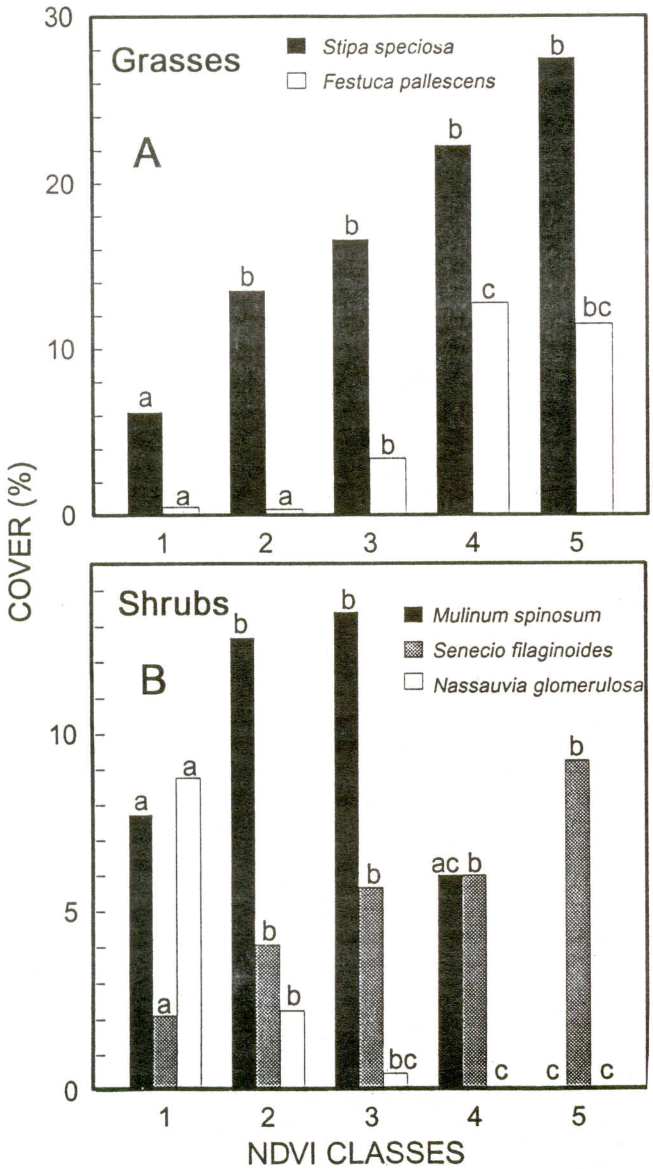

Fig 5. Mean cover by NDVI classes for dominant grasses (A) and shrubs (B). Different letters indicate significant differences from Kruskal-Wallis test (*p*<0.05) among NDVI classes.

species of shrubs in the censi showed different patterns along with the Normalized Difference Vegetation Index increase: *Nassauvia glomerulosa* (colapiche) declined exponentially, *Senecio filaginoides* DC. (charcao) increased and *Mulinum spinosum* (Cav.) Pers. (neneo) showed a peak at intermediate values (Fig. 5b).

Estimated and observed values for censi not used in the generation of estimates showed a high correlation for total cover, grass and shrub cover, and cover of *Festuca pallescens* (coirón blanco) and *Nassauvia glomerulosa* (colapiche) (Table 1). Correlation coefficients were statistically significant ($p<0.01$) for all cases, and both y-intercept and slope did not differ from 0 and 1 respectively ($p<0.01$). The prediction accuracy was higher for total cover and grass cover than for shrub cover (Table 1).

At the species level, the cover of *Festuca pallescens* (coirón blanco) and *Nassauvia glomerulosa* (colapiche) was predicted with good accuracy from Normalized Difference Vegetation Index data. These 2 species are typical of the Occidental district of Patagonia, and have very different range values and responses to the desertification process. A set of highly valuable forage grasses and forbs species were associated with *Festuca pallescens* (coirón blanco) (León and Facelli 1981, Golluscio et al. 1982, León and Aguiar 1985). On the contrary, *Nassauvia glomerulosa* (colapiche) represents a floristic group of xerophytic and spiny shrubs (León and Facelli 1981, Golluscio et al. 1982), almost never browsed by sheep (Bonvisutto et al. 1983).

Table 1. Results of comparisons between estimated (from NDVI) and observed values of 5 vegetation attributes (total cover, grass cover, shrub cover, *Festuca pallescens* and *Nassauvia Glomerulosa* cover). r: correlation coefficient, a: Y-intercept, b: slope, df: degrees of freedom and F: calculated F-Snedecor statistics. $F_{0.01}$ = 7.15

Cover Class	r	a	b	d.f.	F
Total	0.87	3.01	0.954	53	167
Grasses	0.82	2.3	0.983	53	108
Shrubs	0.45	0.43	0.98	53	13
F. pallescens	0.67	-0.11	0.80	53	45
N. glomerulosa	0.53	0.59	0.86	53	21

Remotely sensed data allowed for adequate estimations of the area of each Normalized Difference Vegetation Index class. In the study area, 47% corresponded to class 1, and 17 to class 2 (Fig. 2). The calibration of the Normalized Difference Vegetation Index against vegetation data presented in figures 3 and 5 showed that these classes corresponded to 2 shrub steppe vegetation units, one dominated by *Nassauvia glomerulosa*, and the other by *Mulinum spinosum*. Sixteen percent of the area corresponds to the Normalized Difference Vegetation Index class 3, nine percent to class 4, six percent to class 5 and four percent to class 6 (Fig. 2). Class 3 was a transitional steppe between those with a high cover of *Festuca pallescens* (classes 4 and 5) and those with a low cover of this grass (classes 1 and 2) (Fig. 3 and 5). Class 6 corresponded to meadows ("mallines").

Conclusions

The use of remote sensing provided a valuable tool for a quick assessment of the distribution of vegetation units in Patagonia. The methodology presented helped us to define rangeland units based on the cover of the main functional types (grass and shrubs), and of the dominant species. It also allowed to quantify the area cover for each of those units.

Normalized Difference Vegetation Index values derived from LANDSAT MSS allowed a good discrimination of units differing in total cover, grass cover, and shrub cover. This is very important in areas with a high topographic and edaphic heterogeneity. In those areas the vegetation units have a patchy distribution. Consequently, it is difficult to get a good estimation of the spatial extent of each unit. In the study area, and in a great part of western Patagonia, meadows, grass steppes, and shrub steppes form a spatial mosaic where each unit has a very different range value. A field estimation of their proportions is almost impossible given the modal size of paddocks in most of the ranches of the region (2,500 ha).

In Patagonia, since the introduction of sheep at the end of the XIX century, stocking rates in an individual paddock has been decided by ranchers through trial and error, which is expensive and inefficient (Soriano and Paruelo 1990, Paruelo et al. 1992). The knowledge of the relative proportion of shrub steppes, grass steppes, and meadows is critical in the assignment of stocking rates. For the study area, the average stocking rates of a paddock over a 20 years period, showed a highly significant correlation with the proportion of meadows (NDVI class 6) in the paddock ($Sheep.ha^{-1}.year^{-1}$ in the $paddock_i$ = 0.47 + 3.97 * Prop. of meadows in the $paddock_i$, r = 0.66, F=10.4, n=15, p<0.01).

The characterization of the vegetation units in terms of primary production, forage availability through the year, forage quality, etc., and the assessment of its spatial coverage, will allow for a more accurate estimation of the range value of each management unit (paddock, ranch, etc.). An efficient survey methodology, together with an increasing knowledge of the structure and function of the Patagonian ecosystem will give us better information for land-use planning so that the process of deterioration of the natural resources in Patagonia can be reduced.

The proposed methodology could be extrapolated to large area of the Patagonian region. However, it should require an on site validation of the relationship between the Normalized Difference Vegetation Index and vegetation as described here. The method could have some problems in areas where different vegetation units has similar spectral responses, i.e. the forest-steppe ecotone, grass steppes and/or dense evergreen scrubs.

Note: A copy of the map produced using the Normalized Difference Vegetation Index data is available on request.

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