Applied Vegetation Science 11: 431-440, 2008
doi: 10.3170/2008-7-18522, published online 2 June 2008

Trends in the surface vegetation dynamics of the national parks of Spain as observed by satellite sensors

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Abstract
Questions: What are the current dynamics, as observed by synoptic sensors, of surface vegetation in Spanish protected areas? Are these areas and their vegetation types uniformly affected by the increase in vegetation greenness detected throughout Europe?
Location: Iberian National Parks of Spain.
Methods: We used the normalized difference vegetation index (NDVI) from global inventory modeling and mapping studies (GIMMS) advanced very high resolution radiometer (AVHRR) dataset to monitor surface vegetation. NDVI is a surrogate for the photosynthetically active radiation absorbed by vegetation (fAPAR). This functional attribute has a short-time response to disturbances, is connected to ecosystem services and can be monitored through remote sensing. First, we provide a baseline description of the NDVI dynamics in the parks and analysed its temporal trends (1981-2003). Then, we evaluated the relationships of the seasonal dynamics and interannual trends with the climate conditions, vegetation types and conservation histories of the parks.
Results: The parks showed two patterns of NDVI dynamics corresponding to Mediterranean and Eurosiberian regions. Most parks showed areas with positive NDVI trends that tended to have higher proportions of Mediterranean coniferous and mixed forests, oro-Mediterranean scrublands, heathlands, maquis and garrigues. Negative trends were scarce and associated with marshes and Alpine coniferous forests. The lack of a common response in all parks was related to their different environmental conditions, management, and conservation histories.
Conclusions: National parks are changing in the short term but not uniformly. This study represents a basis for the incorporation of functional attributes of ecosystems in the management and monitoring of protected areas in the face of global change.

Keywords: Global environmental change; Monitoring; National Park conservation; NDVI; Remote sensing.

Abbreviations: AVHRR = Advanced very high resolution radiometer; fAPAR = Fraction of photosynthetically active radiation absorbed by vegetation; GIMMS = Global inventory modelling and mapping studies; NDVI = Normalized difference vegetation index; NDVI-I = NDVI mean; RREL = Annual relative range.

Introduction

Climate change may frustrate current conservation efforts based on the present configuration of protected areas due to predicted shifts in distributions of species (e.g. Araújo et al. 2004) and even biomes (Scott et al. 2002). Thus, climate change integrated strategies are advocated for the long-term preservation of species and processes in protected areas (e.g. Araújo et al. 2004). A substantial proportion of the planet's land surface is already protected (13.4%, Anon. 2006), so it is essential to assess and monitor the areas to know how existing reserves are changing (Barber et al. 2004) before any new reserves are established. This crucial knowledge will serve to prioritize and develop adaptive management practices that mitigate the negative effects of global change on protected areas (Barber et al. 2004).

The evaluation and monitoring of protected areas based on ecosystem functioning (i.e. different aspects of the exchange of matter and energy between the ecosystem and the atmosphere) has advantages over traditional use of structural features of biodiversity (e.g, species, vegetation types) or environmental surrogates. Functional attributes have a shorter time response to disturbances than structural ones (Milchunas & Lauenroth 1995) and are tightly connected to ecosystem services (e.g. nutrient cycling, carbon gains) (Costanza et al. 1997). These attributes can be easily monitored through remote sensing (Foley et al. 2007). Ecological research based on satellite derived NDVI (Normalized Difference Vegetation Index) provides a valuable approach for biodiversity science and conservation (Turner et al. 2003), as it is useful for studying ecological responses to environmental change (Pettorelli et al. 2005) and for nature management (Sannier et al. 2002). This index is an estimator of the fraction of photosynthetically active radiation absorbed by vegetation (fAPAR) (Wang et al. 2004), the main control of carbon gains (Monteith 1981), and has been successfully used to describe regional patterns of net primary production (NPP) (Paruelo et al. 1997), the most integrative indicator of ecosystem functioning (Virginia & Wall 2001).

Thanks to strict controls on major land-use changes, protected areas provide excellent opportunities for baseline descriptions and trends of ecosystem functioning that may serve as a reference to compare the effect of environmental changes in adjacent areas (Schonewald-cox 1988). This allows the separation of the effects of management and land-use modifications from those derived from climatic and atmospheric changes. Therefore, reference situations based on NDVI can be used to evaluate the impact of global environmental change on terrestrial ecosystem functioning of national parks (Garbulsky & Paruelo 2004; Paruelo et al. 2005).

NDVI trends at global or regional scales (e.g. Nemani et al. 2003) complicate the assessment of the particular responses that protected areas show under dissimilar management practices, land-uses, climate conditions and vegetation types. In this article, we address the important questions of how environmental changes differentially affect ecosystem functioning in protected areas, and which factors and vegetation types are involved. We first provide a reference description of the ecosystem functioning of the less disturbed areas of Spain by characterising the spatial and temporal patterns of the NDVI dynamics in the Spanish National Parks system of the Iberian Peninsula. Secondly, we analysed the temporal trends (1981-2003) of the NDVI seasonal dynamics to explore whether the NDVI increase detected throughout Europe due to global change (e.g. Julien et al. 2006) is affecting the parks uniformly. Finally, we evaluated the relationship of both the NDVI seasonal dynamics and interannual trends, with climate conditions, vegetation types and conservation histories of the parks.

Material and Methods

Our study area includes seven parks in Spain. National parks (category II; Anon. 1998) are usually large areas under a minimal disturbance regime, dedicated to biodiversity protection. The Spanish system aims to protect the best representatives of natural landscapes throughout the Eurosiberian, Mediterranean and Macaronesian biogeographical regions, by means of large natural or semi-natural areas with limited human activities and mainly devoted to conservation (Anon. 1989). Our study considered the following seven Spanish national parks of the Iberian Peninsula: Aigüestortes i Estany de Sant Maurici, Ordesa y Monte Perdido, Picos de Europa, Cabañeros, Monfragüe, Doñana and Sierra Nevada (Fig. 1). This selection covers a wide variety of environmental conditions (App. 1) and vegetation types (Fig. 2).

The NDVI is a spectral index calculated from the reflectance in the red (R) and near infrared (NIR) bands as follows (Tucker & Sellers 1986): NDVI = (NIR-R)/(NIR+R). The causal connections between fAPAR and NDVI (i.e. both depend on the amount of green leaf area in the canopy; Myneni & Williams 1994), have been demonstrated empirically for different systems (e.g. Wang et al. 2004). We based our analysis on NDVI data for the period 1981-2003. We used the 15 day composites

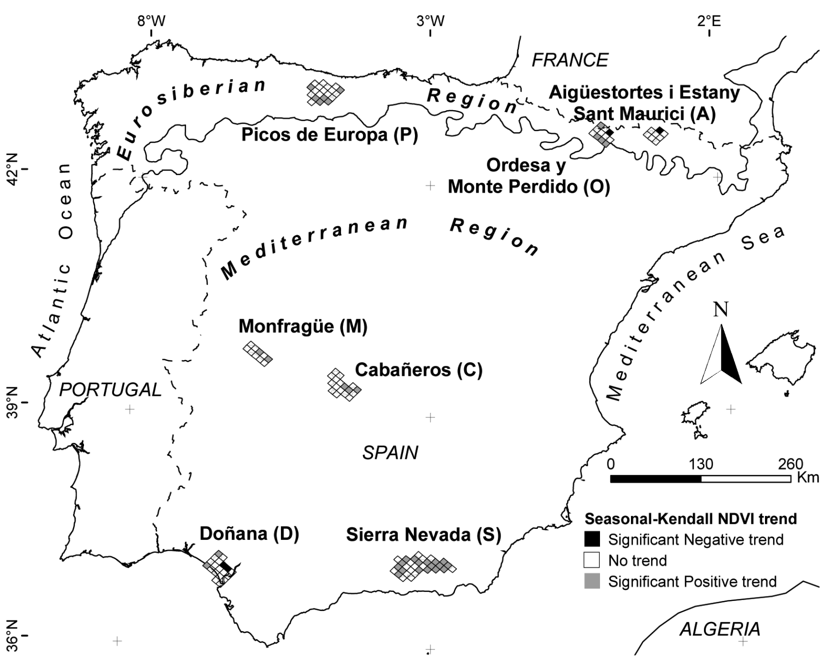

Fig. 1. Study Area. National parks and biogeographical regions of continental Spain. Pixels (AVHRR-GIMMS 8 km × 8 km) considered in the analysis are shown for each park. Pixels showing significant (p-value< 0.05) NDVI trends in the seasonal Kendall trend test during the 1981-2003 period are highlighted.

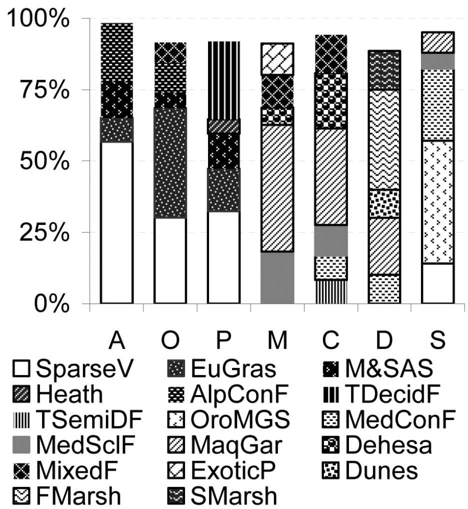

Fig. 2. Relative abundance (percentages) of different vegetation types within the Spanish National Parks, derived from the Spanish Forest Map (Ruíz de la Torre 1999) and the CORINE Land-Cover (Anon. 2000). A = Aigüestortes, O = Ordesa, P = Picos de Europa, C = Cabañeros, M = Monfragüe, D = Doñana, S = Sierra Nevada. EuGras = Eurosiberian natural and sem-natural grasslands, M&SAS = Montane and sub-alpine scrubs, AlpConF = Alpine coniferous forests, TDecidF = Temperate broad-leaved deciduous forests, TSemiDF = Temperate semi-deciduous forests, Heath = Heathlands, MixedF = Mixed forests, Dehesa = Dehesas (woody savanna), MedSclF = Mediterranean evergreen sclerophyllous forests, MedConF = Mediterranean coniferous forests, MaqGar = Maquis and garrigues, OroMGS = Oro-Mediterranean grasslands and scrubs, Dunes = Dunes and sands, DMarsh = Dried marshes, FMarsh = Freshwater marshes, SMarsh = Salt marshes, ExoticP = Exotic plantations, SparseV = Sparsely vegetated areas.

of the global inventory modelling and mapping studies (GIMMS) dataset (Tucker et al. 2005). The GIMMS data have been corrected for calibration, orbital drift, cloud cover, sensor degradation, sensor intercalibration differences, view geometry, volcanic aerosols and other effects not related to vegetation change (for details see Tucker et al. 2005). GIMMS is currently thought to be sensor-corrected, being consistent with NDVI from SPOT Vegetation and MODIS Terra satellites (Tucker et al. 2005). The approximate spatial resolution is 8 km × 8 km. We extracted the pixels corresponding to the parks from the 1981-2003 GIMMS subset of Eurasia.

To summarize the NDVI seasonal dynamics of the parks, we used the two main descriptors of the NDVI seasonal curve: the NDVI annual mean (NDVI-I) and the annual relative range (RREL = (maximum NDVI-minimum NDVI) /NDVI-I). In the Iberian Peninsula, these functional attributes have been shown to account for a great proportion of the variability in the NDVI seasonal dynamics (Alcaraz 2005; Alcaraz et al. 2006). To explore the controls on these functional attributes from both climate variables and the percentages of each vegetation type within the pixels, we used four forward stepwise multiple linear regression models: two between NDVI-I and climate and vegetation respectively; and two equivalent ones for RREL. The percentages of the different vegetation types for each pixel were derived from the Spanish forest map (Ruíz de la Torre 1999) and the CORINE land-cover database (Anon. 2000). The climatic variables were calculated from the Iberian digital climatic atlas (Ninyerola et al. 2005).

The temporal trends analysis followed the methodology proposed by de Beurs & Henebry (2005). Temporal trends were calculated using the seasonal Mann-Kendall trend test, a rank-based non-parametric test robust against seasonality, non-normality, missing values and both intra and interannual autocorrelation (Hirsch & Slack 1984; Van Belle & Hughes 1984). The test calculates the monotonic trend within each season of a year, based on Kendall's τ-statistic, by summing the number of times a particular year has a higher or lower NDVI value than any previous year. Then, it performs a heterogeneity test to see if this slope is consistent across all seasons. The α-level was 0.05 and significant slopes were considered as p-value < 0.05.

Finally, we checked if there was any linear relationship between the detected NDVI trends and the environmental conditions using a forward stepwise multiple linear regression between the slope and climatic variables and altitude. We also checked which vegetation types were associated with the NDVI trends. For this, we represented the percentage of surface that each vegetation type occupied in the sampled pixels vs the percentage of surface that it occupied in those pixels showing significant trends in the NDVI.

Results

Ordination of the Spanish National Parks based on NDVI seasonal dynamics

The distribution of the parks in the NDVI-I (a surrogate for fAPAR and NPP) vs RREL (descriptor of seasonality) space (Fig. 3) illustrates their function in terms of the dynamics of radiation interception. The pixels of the parks were widely spread along the NDVI-I gradient (Fig. 3). Doñana, Sierra Nevada and Picos de Europa occupied the widest range. Picos de Europa, Cabañeros and Monfragüe showed the highest values of NDVI-I, while Doñana and Aigüestortes were the lowest. In general, within a given range of NDVI-I, Eurosiberian parks showed higher seasonality of radiation

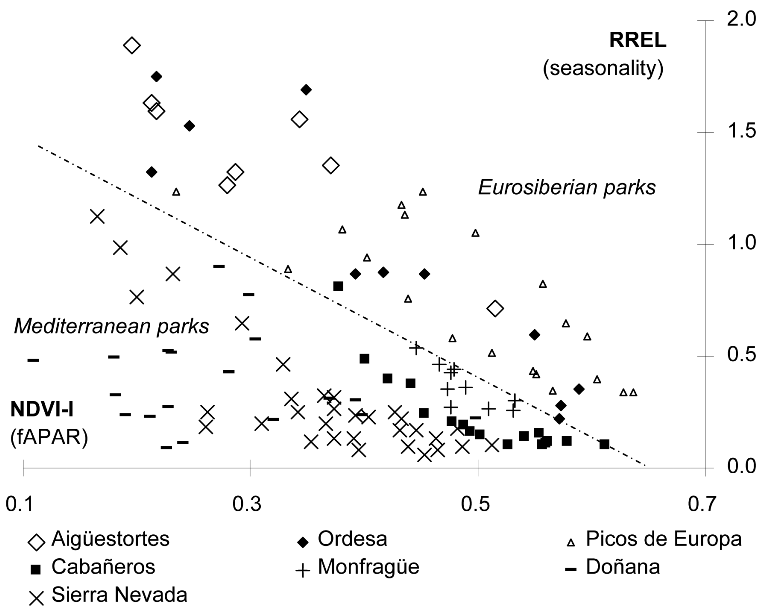

Fig. 3. Functional space of the continental Spanish National Parks in terms of NDVI-I (NDVI annual mean, a surrogate of fAPAR and NPP) and RREL (annual relative range of NDVI, a descriptor of the intra-annual variation or seasonality).

interception (RREL) than the Mediterranean parks (Fig. 3). Within the Mediterranean parks, only the summits of Sierra Nevada showed very high values for RREL (with summer maxima). Monfragüe was constrained to the smallest gradient for both attributes.

The NDVI-I showed a significant positive relationship with both mean annual precipitation and maximum temperatures in the multiple linear regression (Table 1). However, they only explained up to 11% (cumulated determination coefficient r^2=0.11) of the variability of NDVI-I (Table 1). The determination coefficient increased to 0.71 when the analysis was performed on vegetation types (Table 1). The NDVI-I tended to be higher in pixels with more mixed, deciduous, sclerophyllous and semi-deciduous forests, and lower where sparsely vegetated areas, dunes, freshwater marshes and cultivations occupied high percentages of the pixels. Seasonality (RREL) was negatively related to mean annual temperature but positively related to precipitation. These two climatic variables explained up to 54% of the variability of RREL. The vegetation types that showed a stronger positive relationship with seasonality were sparsely vegetated areas, heathlands and Alpine coniferous forests. In contrast, pixels with high presence of Mediterranean coniferous forests, maquis and garrigues showed low seasonality. Vegetation types explained 82% of the variation in RREL.

Temporal trends of NDVI in the Spanish national parks system

The parks showed significant trends in the NDVI between 1981 and 2003 (Fig. 4). Nevertheless, in Aigüestortes, only very small portions of the parks borders were included in pixels that showed significant NDVI trends. In general, positive trends were more frequent than negative ones (Fig. 4). Doñana was the park containing the highest absolute area displaying negative NDVI trends (Figs. 1 and 4). Parks including high mountains, such as Sierra Nevada, Picos de Europa and Ordesa, experienced positive trends in the highest number of pixels (from 30% to 55%; Fig. 4), although in Ordesa they occurred in pixels located in the park border (Fig. 1). NDVI positive trends also tended to be higher in these parks and in Doñana (Fig. 4), although in Doñana, NDVI positive trends occurred mainly in pixels located at the park border (Fig. 1).

Only altitude showed a slightly positive relationship with the NDVI trends, but explained a very small percentage (5%) of the variability (n = 117, β = 0.23, r^2 = 0.05, p = 0.01; p-value < 0.05). None of the climatic variables showed any significant relationship with the NDVI trends, nor did we find any significant relationships between the NDVI trends and the year when the parks were established.

In general, positive NDVI trends occurred in pixels with a relatively higher percentage of surface occupied by Mediterranean coniferous forests, heathlands, maquis, garrigues, oro-Mediterranean grasslands and scrubs and mixed forests (points above the 1:1 line in Fig. 5a), but

Table 1. Results of the four stepwise multiple linear regressions between NDVI-I and RREL and the climatic variables and vegetation types. The table shows the order in which each variable was introduced into the model, the adjusted slope (Beta), its *p*-value and the cumulated determination coefficient r^2 after including each variable. See Fig. 2 for vegetation type abbreviations.

	NDVI-I (productivity)				RREL (seasonality)			
	Order	Beta	*p*-value	r^2	Order	Beta	*p*-value	r^2
MAP	1	0.44	<0.01	0.04	2	0.28	<0.01	0.54
MAT					1	–0.52	<0.01	0.50
TMAX	2	0.35	<0.01	0.11				
TMIN								
MixedF	1	0.21	<0.01	0.19	6	–0.11	0.01	0.81
TDecidF	2	0.24	<0.01	0.33				
MedScIF	3	0.16	<0.01	0.48				
SparseV	4	–0.43	<0.01	0.54	1	0.51	<0.01	0.55
Dunes	5	–0.32	<0.01	0.60				
FMarsh	6	–0.24	<0.01	0.63				
Cultive	7	–0.24	<0.01	0.68				
TSemiDF	8	0.13	0.02	0.69				
OroMGS	9	-0.12	0.03	0.71				
Heath					2	0.29	<0.01	0.65
AlpConF					3	0.29	<0.01	0.75
MedConF					4	-0.20	<0.01	0.77
MaqGar					5	-0.20	<0.01	0.79
SMarsh					7	0.09	0.03	0.82

Abbreviations: MAP = Mean annual precipitation, MAT = Mean annual temperature, TMAX = Maximum temperature, TMIN = Minimum temperature**.**

relatively low percentage of sparse vegetation and dehesas (points below the 1:1 line in Fig. 5a). Pixels showing significant negative trends were relatively dominated by freshwater and dried marshes and Alpine coniferous forests (points above the 1:1 line in Fig. 5b).

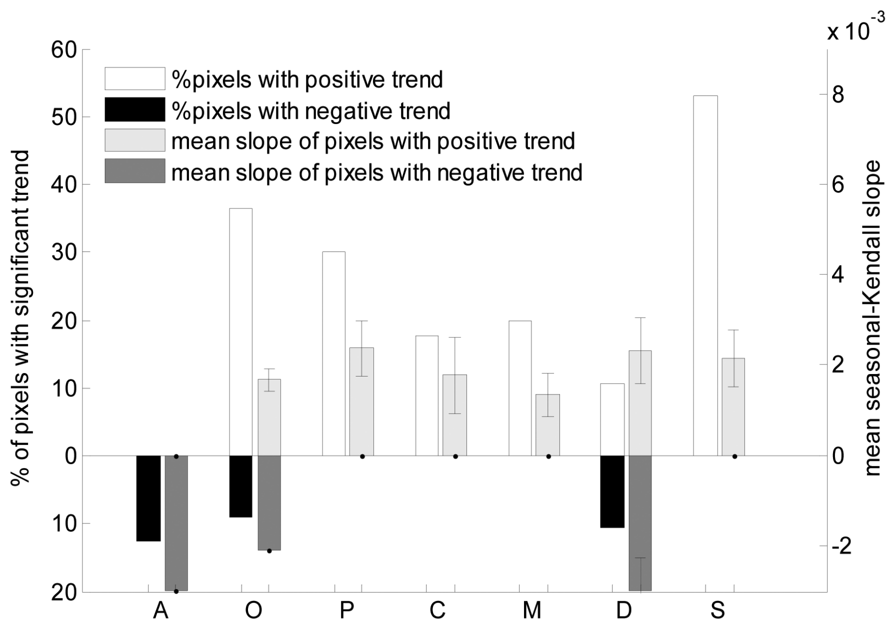

Fig. 4. Trends in the NDVI (a surrogate of fAPAR and NPP) in the Spanish National Parks between 1981 and 2003. Bars represent the percentage (left y axis) and mean slope (right y axis) of the pixels that showed significant (*p*-value < 0.05) positive (upper bars) and negative (lower bars) trends for each park. Trends were obtained using the seasonal Kendall trend test. A = Aigüestortes, O = Ordesa, P = Picos de Europa, C = Cabañeros, M = Monfragüe, D = Doñana, S = Sierra Nevada.

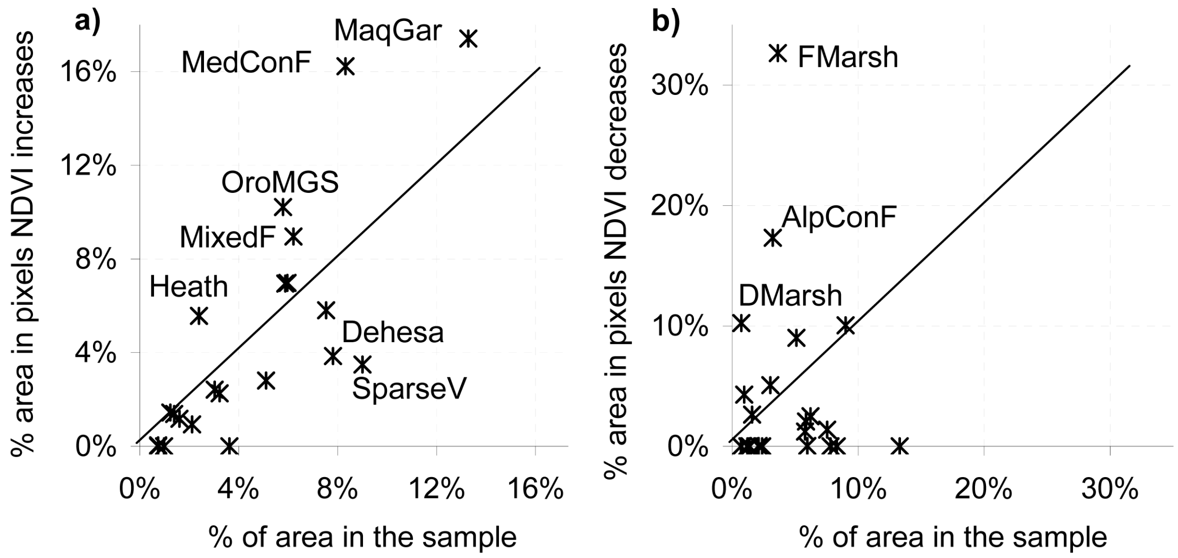

Fig. 5. Vegetation types associated with the NDVI (**a**) positive and (**b**) negative trends. The percentage of surface that each vegetation type occupied in the sampled pixels (x axes) is represented vs. the percentage of surface that it occupied in those pixels showing significant trends in the NDVI (y axes). Only vegetation types distant from the 1:1 line are labelled. See Fig. 2 for vegetation types abbreviations.

Discussion

Baseline description of ecosystem functioning of the Spanish National Parks

The ordination of the parks based on the two main descriptors of the NDVI seasonal dynamics, NDVI-I and RREL, agreed with the two main patterns of ecosystem functioning observed for the Iberian natural vegetation, the Eurosiberian and the Mediterranean (Alcaraz 2005). The same values of radiation interception (NDVI-I) were reached under higher seasonal differences (higher RREL) in the Eurosiberian parks than in the Mediterranean parks. Summits of Sierra Nevada have NDVI dynamics that contrast with its Mediterranean context (highest RREL values and lowest NDVI-I), which agrees with their very high number of Alpine disjunctions and endemisms (Blanca et al. 1998).

Climatic conditions explained part of the variation in the seasonal dynamics of the NDVI in the parks. Although the percentage of the variation explained was low, we found a positive relationship between the mean NDVI (NDVI-I) and precipitation and temperature, as in previous studies (Paruelo & Lauenroth 1995). The linear response of NDVI-I to precipitation reveals the restriction of water availability, which is most critical in the Mediterranean vegetation (Blondel & Aronson 1999). On the other hand, the positive relationship with temperature shows the restriction that low temperatures impose on plant growth, particularly in high mountains and in the Eurosiberian region (Chabot & Hicks 1982). In the case of seasonality (RREL), it was lower under warmer conditions but tended to increase with precipitation due to the much higher precipitation of the Eurosiberian parks.

The vegetation type composition accounted for more variation of the seasonal variability of NDVI than climate in the Spanish national parks. The presence of mixed and broad-leaved forests tended to significantly increase the NDVI annual mean (NDVI-I) while marginal cultivations and scattered vegetation decreased it. For example, in the Eurosiberian parks, the NDVI mean increases (Figs. 3 and 6) with the proportion (Fig. 2) of deciduous forests (mainly *Fagus*), from Aigüestortes (mainly *Abies* and *Pinus sylvestris* forests) to Ordesa (coniferous, mixed and deciduous forests) and Picos de Europa (mainly *Fagus* forests). In the Mediterranean parks, the NDVI mean increases with the abundance of sclerophyllous trees (i.e. *Quercus rotundifolia* and *Q. suber*). Seasonality (RREL) was significantly higher in pixels dominated by Alpine forests, heathlands and, mainly, high mountain sparse vegetation. Seasonality was significantly lower under the presence of evergreen sclerophyllous shrublands (i.e. maquis and garrigues) and Mediterranean evergreen conifers.

Temporal trends of the NDVI in the Spanish National Parks System

Protected areas may not follow the regional trends observed at global or continental scales. For example, from the regional NDVI trends reported in the Iberian Peninsula (e.g. González-Alonso et al. 2004; Vicente-Serrano & Heredia-Laclaustra 2004) the northern mountains, where the Eurosiberian parks are located, would be expected to undergo large increases. However, in Aigüestortes and Ordesa (NE Spain), the majority of the parks did not show any significant positive NDVI trends, and some negative trends were found at some borders. Using the same rationale, NDVI decreases would be expected to occur in southwestern valleys but, in Doñana national park, both positive and negative trends occurred.

Several factors might be involved in the NDVI trends that different parks experienced. In the Pyrenees Cordillera of NE Spain, in spite of regional decreases in precipitation (Abaurrea et al. 2002), positive trends in temperature during recent decades (Brunet et al. 2001b) have led to positive NDVI trends throughout the Pyrenees (González-Alonso et al. 2004). These trends agree with the intensification in the regeneration of the sub-alpine forest found in the Central Pyrenees (Camarero & Gutiérrez 1999). However, the majority of the area in Aigüestortes did not experience significant NDVI trends. Several reasons may be implicated in this absence of trends within the parks: (1) grazing pressure fell in the area in the 1950s, which led to a drastic modification in the structure of the ecosystems at that time (García-Ruiz & Lasanta-Martínez 1990); (2) as a consequence of their land-use history (App. 1), the removal of harmful land-uses would have produced the secondary succession many years before our study period; (3) higher interannual variability of temperature (Tardif et al. 2003) has limited the treeline ascent expected from higher temperatures in the last decades (Camarero & Gutiérrez 2004) and (4) as sparse vegetation and grasses dominate this park (> 60% area, Fig. 2), they impose a structural constraint on the degree of primary production, due to canopy stature and heterogeneity (Fig. 5a).

Sierra Nevada was the national park most affected by the positive trends in the NDVI, followed by Picos de Europa. In both parks, pixels that included transitions from high-mountain vegetation (heathlands and oro-Mediterranean scrublands) to mixed and coniferous forests tended to show NDVI increases. These vegetation types were relatively abundant in pixels with positive trends in the parks system (Fig. 5a). In Sierra Nevada, previous studies have already proved the effects of warming (Hódar & Zamora 2004), where protection and restoration measures introduced in the 1980s and 1990s may also have promoted positive NDVI trends. In Picos de Europa, the increases in temperature (Oñate & Pou 1996) and precipitation (de Castro et al. 2005) and the protection measures introduced in the 1990s may have elevated NDVI. Here, trends occurred in the southernmost pixels under Mediterranean influence. This might be an early indicator of biome shifts as reported in a similar biogeographical transition in NE Spain (Peñuelas & Boada 2003), where heathlands migrating to higher altitudes are being replaced by deciduous forests and the latter by evergreen *Quercus ilex* in the last century.

In Cabañeros and Monfragüe, the NDVI positive trends could be related to both climatic and management changes since their initial protection (Appendix). On one hand, positive trends would have followed the lengthening of the growing period due to temperature increases (Galán et al. 2001), stronger in winter (Brunet et al. 2001a) than in summer (Staudt 2004), despite the fact that precipitation did not change significantly in central Iberia during the recent decades (although interannual variability slightly increased) (Galán et al. 1999). On the other hand, pixels experiencing positive trends had a higher proportion of maquis and garrigues (Fig. 5a), the dominant vegetation in these parks (Fig. 2). These NDVI trends agree with the observed general densification in evergreen woody vegetation in the recent decades in the Iberian matorral as a consequence of land-use abandonment (Blondel & Aronson 1999; Valladares et al. 2004).

Finally, in Doñana, marshes (unique to this park, Fig. 2) showed a significant decrease in NDVI (Fig. 5b). Two reasons can be related to their NDVI decline: an increase in herbivory by wild herbivores (e.g. deer, geese) and free-living stock (cows, horses) (see Fernández-Delgado 2006) and, certainly, an earlier senescence of vegetation related to management practices (i.e. artificial early summer drying of the wetland after the mid 1980s to avoid avian botulism). Furthermore, Vicente-Serrano & Heredia-Laclaustra (2004) relate the NDVI decreases in SW Spain to higher temperatures and lower precipitation associated with the trends in the winter north Atlantic oscillation (NAO). Nevertheless, the borders of Doñana national park (integrated by coniferous forests, maquis and garrigues) did not follow this regional pattern, showing positive NDVI trends instead.

Overall, the vegetation greenness of the parks has changed in the last two decades and some of the vegetation types under protection were more affected by NDVI trends than others. Positive trends tended to occur in pixels with high proportions of maquis and garrigues, and also those that included transitions from high mountain vegetation to mixed and Mediterranean coniferous forests. Negative trends occurred in pixels dominated by marshes and also in Alpine coniferous forests, where mortality of seedlings has increased from the 1980s in the region of Aigüestortes (E. Gutiérrez pers. comm.).

Conclusions

Our study addresses important questions of how global environmental change affects vegetation functioning in protected areas and how we can measure it. It describes a simple, but effective, approach based on satellite data, providing reference estimates and changes of vegetation functioning that can be useful for the assessment of conservation strategies of national parks in response to environmental changes. The study system, despite being focused on a specific geographic area (the Spanish system of national parks), offers a unique opportunity to answer our questions because of the broad biogeographical and environmental gradients that it includes. We used the NDVI seasonal dynamics to give a baseline ('state of the parks') description of the spatiotemporal variability of vegetation greenness of the Iberian vegetation types protected under these parks. This approach allows a fast assessment, monitoring and comparison of protected areas with uniform methodology. In addition, the analyses performed highlighted an important point in evaluating conservation policies: protected areas are changing in the short term and, at least in terms of vegetation greenness, they are changing in a directional way. In our case, a large part of the Spanish National Parks is intercepting more photosynthetically active radiation than in the past. Differential responses of particular parks and the vegetation types they protect depend on their environmental conditions, management practices and conservation histories.

Acknowledgements. The authors are very grateful to Dr. G. Henebry and two anonymous referees for their useful comments that significantly improved this paper. Some ideas were developed while the first author held a fellowship at the University of Buenos Aires (thanks to M. Garbulsky, G. Piñeiro, J.P. Guerschman) and University of Oxford (thanks to R.J. Whittaker, I. Parmentier). University of Virginia Research Computing Laboratory (K. Gerber, E. Hall, K. Holcomb) helped with the analysis. Junta de Andalucía (FPDI2000-BOJA140/2000- and projects RNM1288 and RNM1280), Postdoctoral program of Ministerio de Educación y Ciencia, OAPN 066/2007, Ecología de Zonas Áridas Group, University of Almería, University of Buenos Aires, CONICET and FONCYT gave financial support. Source for the satellite data was the Global Land Cover Facility, www.landcover.org. The CORINE land-cover-1990 map was supplied by the EIONET - European Environmental Agency.

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Received 2 February 2007;
Accepted 26 February 2008;
Co-ordinating Editor: J. Ohmann.

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