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RESEARCH

Use of Descriptors of Ecosystem Functioning for Monitoring a National Park Network: A Remote Sensing Approach

Domingo Alcaraz-Segura · Javier Cabello · José M. Paruelo · Miguel Delibes

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Abstract Baseline assessments and monitoring of protected areas are essential for making management decisions, evaluating the effectiveness of management practices, and tracking the effects of global changes. For these purposes, the analysis of functional attributes of ecosystems (i.e., different aspects of the exchange of matter and energy) has advantages over the traditional use of structural attributes, like a quicker response to disturbances and the fact that they are easily monitored through remote sensing. In this study, we described the spatiotemporal patterns of different aspects of the ecosystem functioning of the Spanish national parks and their response to environmental changes between 1982 and 2006. To do so, we used the NOAA/AVHRR-GIMMS dataset of the Normalized Difference Vegetation Index (NDVI), a linear estimator of the fraction of photosynthetic active radiation intercepted by vegetation, which is the main control of carbon gains. Nearly all parks have significantly changed during the last 25 years: The radiation interception has increased, the contrast between the growing and non-growing seasons has diminished, and the dates of maximum and minimum interception have advanced. Some parks concentrated more changes than others and the degree of change varied depending on their different environmental conditions, management, and conservation histories. Our approach identified reference conditions and temporal changes for different aspects of ecosystem functioning, which can be used for management purposes of protected areas in response to global changes.

Keywords Global changes · Land-surface phenology · Iberian Peninsula · Monitoring · National parks management · Normalized Difference Vegetation Index (NDVI) · Reference conditions · Seasonality · Spain

Introduction

Currently, ~13.4% of the Earth's land surface is in protected areas devoted to the preservation of biodiversity and the maintenance of ecosystem services (WDPA Consortium 2006). However, global environmental changes such as climate, atmospheric, and land-use changes, might spoil these conservation efforts (Araújo and others 2004). It is essential, then, to improve our ability to assess and monitor protected

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D. Alcaraz-Segura (✉)
Department of Environmental Sciences, University of Virginia, Clark Hall, 291, McCormick Road, Charlottesville, VA 22904, USA
e-mail: dalcaraz@ual.es; da6f@virginia.edu
URL: http://www.ual.es/personal/dalcaraz

D. Alcaraz-Segura · J. Cabello
Departamento de Biología Vegetal y Ecología, Universidad de Almería, La Cañada de San Urbano, 04120 Almeria, Spain

J. Cabello
e-mail: jcabello@ual.es

D. Alcaraz-Segura · M. Delibes
Department of Applied Biology, Estación Biológica de Doñana – CSIC, Avenida de María Luisa s/n, Pabellón del Perú, 41013 Seville, Spain

M. Delibes
e-mail: mdelibes@ebd.csic.es

J. M. Paruelo
Laboratorio de Análisis Regional y Teledetección, Facultad de Agronomía e Instituto de Investigaciones Fisiológicas y Ecológicas Vinculadas a la Agricultura (IFEVA), Universidad de Buenos Aires – CONICET, Av. San Martín 4453, 1417 Buenos Aires, Argentina
e-mail: paruelo@ifeva.edu.ar

areas in order to determine their current status and to evaluate whether they are changing and how (Barber 2004; Carabias-Lillo and others 2004). Such effort is fundamental for tracking the effects of global changes on protected area networks, for both making and evaluating management decisions (Leverington and Hockings 2004; Meffe and others 2006), and for devising early-warning systems to detect changes (Tegler and others 2001; Vos and others 2000).

To make monitoring programs feasible and effective for management, the assessments of the reference conditions and changes in ecosystems must not only cover broad areas utilizing a common, systematic, and repeatable method, but they must also be quick and inexpensive (Duro and others 2007; Ludwig and others 2004; Mildrexler and others 2007; Yaffee 1999). For these reasons, the monitored variables must meet some basic criteria (Costanza and others 1992; Grumbine 1994; Ludwig and others 2004; Zorn and others 2001): They must (1) be easily and frequently recordable at ecosystem level over large areas, (2) be comparable between local and regional scales, (3) allow the establishment of quantitative targets and baseline values, (4) capture the spatiotemporal variability caused by both natural changes and human disturbances, and, most importantly, (5) offer a short-time response that allows the early detection of impacts. In order to meet these criteria, ecosystems functional attributes (i.e., different aspects of the exchange of matter and energy between the biota and the atmosphere) have some advantages over the traditional use of structural variables. First, variables describing ecosystem functioning have a faster response to disturbances because structural inertia might delay the perception of disturbances and stress (Milchunas and Lauenroth 1995). Second, functional attributes allow the quantitative and qualitative characterization of ecosystems services (e.g., carbon sequestration, nutrient and water cycling) (Costanza and others 1997). Additionally, they can be more easily monitored than structural attributes by using remote sensing at different spatial scales, over large extents, and utilizing a common protocol (Foley and others 2007).

Some spectral indexes derived from remote sensors are linked to functional variables of ecosystems, such as primary production, evapotranspiration, surface temperature, and albedo (e.g., di Bella and others 2000; Liang 2000; Paruelo and others 1997). One of the most frequently used indexes is the Normalized Difference Vegetation Index (NDVI). This spectral index is a linear estimator of the fraction of photosynthetically active radiation intercepted by vegetation (fAPAR) (Wang and others 2004). Radiation interception is the main control of carbon gains (Monteith 1981), and, thus, NDVI has been widely used to describe regional patterns of net primary productivity (NPP) (Paruelo and others 1997), which is the most integrative indicator of ecosystem functioning (McNaughton and others 1989; Virginia and Wall 2001). Spectral indexes related to ecosystem functions, including the NDVI, could greatly enhance the assessment and monitoring of protected areas and the implementation of management approaches, such as Adaptive Management (Walters 1986), Ecosystem Management (Grumbine 1994), Systematic Conservation Planning (Margules and Pressey 2000), and Climate Change-Integrated Strategies (Hannah and others 2002). The NDVI as a descriptor of ecosystem functions has been shown to have great value for applications in conservation biology (Turner and others 2001, 2003), in ecosystem management (Pelkey and others 2003; Sannier and others 2002), and in assessing ecological responses to global environmental changes (e.g., modifications of trophic interactions, ecological integrity, or phenology of vegetation) (Pettorelli and others 2005). Reference conditions and temporal NDVI trends in protected areas have also served as a reference for comparing the effects of land-use changes in adjacent areas (Garbulsky and Paruelo 2004; Paruelo and others 2005), allowing one to distinguish the effects of climatic and atmospheric global changes from those associated to land-use change outside the protected areas (Jenkins and Bedford 1973; Schonewaldcox 1988). In addition to changes in radiation interception, NDVI time series are particularly useful for the exploration of trends in land-surface phenology (e.g., Bradley and Mustard 2008) and seasonality [although seldom studied, but see Reed (2006)]. Indeed, many of the recent changes observed in Iberian ecosystems corresponded to phenological trends (Gordo and Sanz 2006; Peñuelas and others 2004; Wilson and others 2007).

In this study, we provide a description of the reference conditions and temporal trends of total amount, seasonality, and phenology of the radiation intercepted by the vegetation in areas included in the Spanish National Park Network. We used the seasonal and interannual dynamics of the NDVI, as an estimator of the radiation intercepted by the green canopy. We first characterized the reference conditions of the parks based on the seasonal dynamics and interannual variability of the NDVI and six NDVI-derived descriptors to evaluate ecosystem functioning patterns in the Network. Second, we calculated the temporal trends of these six descriptors of the NDVI seasonal dynamics, to identify directional changes in radiation interception, seasonality, and land-surface phenology. By characterizing both reference conditions and temporal trends, we aim to provide information that might be helpful for the management of the national parks and that might serve also as a reference situation for other nonprotected areas with similar environmental conditions.

The Spanish National Park Network and the Study Area

National parks (category II; IUCN 1998) are usually large natural or seminatural areas subjected to minimum disturbances and dedicated to biodiversity protection (Possingham and others 2006). The Spanish National Park Network aims to protect the most representative ecosystems of Spain throughout the Eurosiberian, Mediterranean and Macaronesian biogeographical regions (Plan Director de la Red de Parques Nacionales, Ley 4/1989; Cortes Generales 1989). For this study, we have selected three parks from the Eurosiberian Region [Aigüestortes i Estany de Sant Maurici (A), Ordesa y Monte Perdido (O), Picos de Europa (P)] and four parks from the Mediterranean Region [Cabañeros (C), Monfragüe (M), Sierra Nevada (S), and Doñana (D)]. We included parks that represent a wide range of environmental conditions, vegetation, species composition, and conservation histories (see Fig. 1 and Appendix 1).

Methods

Our study was based on a 25-year (1982–2006) dataset of satellite images of the NDVI, a spectral index calculated from the reflectance in the red (R) and near-infrared (NIR) wavelengths; NDVI = (NIR − R)/(NIR + R) (Tucker and Sellers 1986). We used the Global Inventory Modeling and Mapping Studies (GIMMS) NDVI dataset (Tucker and others 2005), which presents two NDVI composites per month, with a spatial resolution of 8 × 8 km. This dataset has been corrected for calibration, sensor degradation, orbital drift, view geometry, cloud cover, volcanic aerosols, and other effects not related to vegetation change (for details, see Tucker and others 2005). Those pixels corresponding to the Spanish national parks were extracted from the images of the GIMMS Eurasian subset.

To describe the ecosystem functioning of every park pixel, we studied the seasonal dynamics of the NDVI as a surrogate of fAPAR. To obtain the mean NDVI seasonal curve of each pixel, we calculated the mean value of each bimonthly composite from the 1982–2006 period. From the NDVI seasonal curve, we derived six attributes that capture important features of ecosystem functioning (Appendix 2): the NDVI annual mean (NDVI-I), a good estimator of annual fAPAR and thus of NPP (Tucker and Sellers 1986); the annual maximum (MAX) and minimum (MIN) NDVI values, related to the maximum and minimum photosynthetic capacity of the ecosystems; the annual relative range (RREL = [MAX − MIN]/NDVI-I), a descriptor of seasonality, or the intraannual variation of light interception (Paruelo and Lauenroth 1995) and carbon fluxes (Potter and Brooks 1998); and, finally, the date of maximum (DMAX) and minimum (DMIN) NDVI values, two descriptors of the phenology of vegetation that are associated with the periods of maximum and minimum photosynthetic activity (Hoare and Frost 2004; Lloyd 1990). In the case of RREL, normalizing the annual absolute NDVI range by the NDVI-I allows the seasonality of different pixels to be comparable independently of the

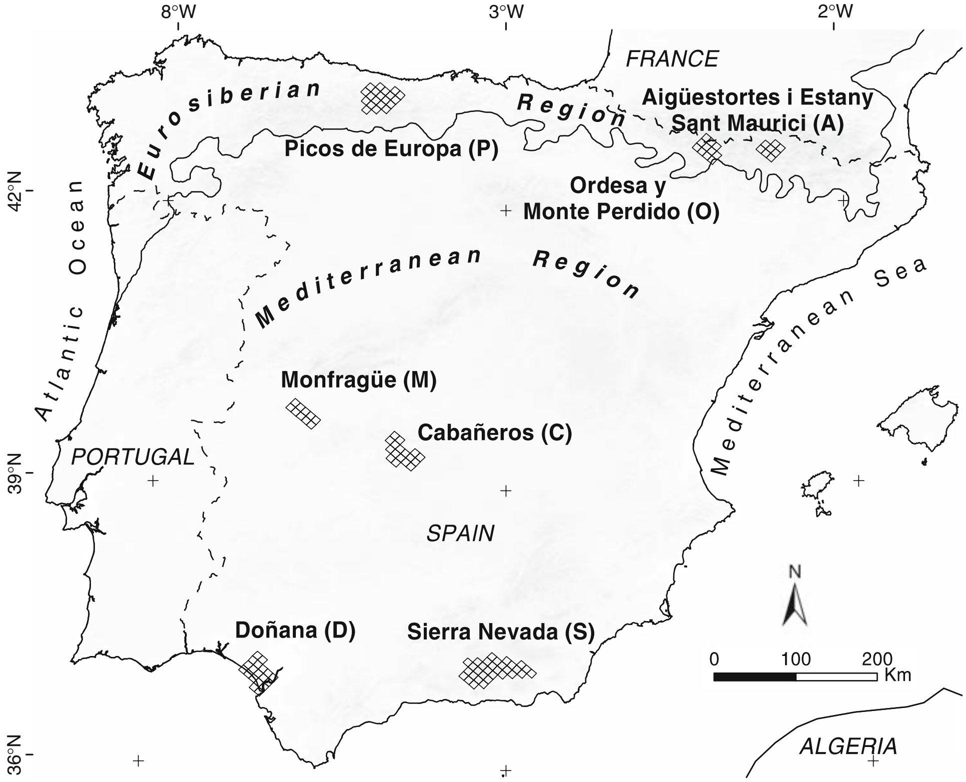

Fig. 1 Study area. National parks and biogeographical regions of continental Spain. Polygons represent the pixels of the NOAA/AVHRR-GIMMS 8 × 8-km dataset considered in this analysis for each park

different ecosystems or national parks considered. To characterize the interannual variability of ecosystem functioning, we used the interannual coefficients of variation of the NDVI seasonal dynamics and of the six selected attributes. Further explanations on the biological meaning and use of these attributes can be found in Pettorelli and others (2005).

Finally, we calculated the temporal trends of the six NDVI attributes in the 1982–2006 period. We used the Mann–Kendall trend test, a rank-based nonparametric test robust against missing values, non-normality, and temporal autocorrelation (Hirsch and Slack 1984; Van Belle and Hughes 1984). This test analyzes the existence of a monotonic temporal trend of the attribute based on Kendall's tau statistic, by summing the number of times a particular year has a higher or lower value than any previous one. The alpha level for the test was set to 0.05, and slopes with a P-value <0.05 were considered significant.

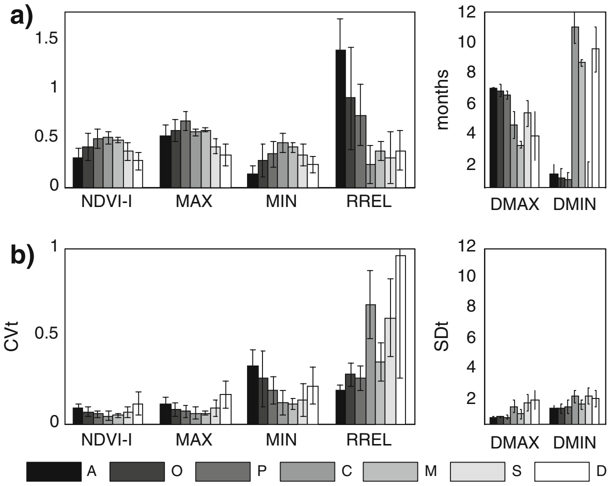

Fig. 2 Functional characterization of the national parks based on six attributes derived from the NDVI seasonal dynamics for the 1982–2006 period. (**a**) Mean values for each attribute and park; (**b**) interannual variability of the six NDVI attributes for each park calculated as the interannual coefficient of variation (CVt) for NDVI-I (NDVI annual mean), RREL (relative range), MAX and MIN (maximum and minimum NDVI), and the interannual standard deviation (SDt) for DMAX and DMIN (dates of the MAX and MIN). A: Aigüestortes i E. S. Maurici; O: Ordesa y Monte Perdido; P: Picos de Europa; C: Cabañeros; M: Monfragüe; S: Sierra Nevada; D: Doñana. Error bars indicate spatial standard deviation

Results

Characterization of the Ecosystem Functioning of the Spanish National Parks

Mean NDVI-I values for all parks varied between 0.503 (Cabañeros) and 0.271 (Doñana), whereas the pixels with the most extreme values were found in Picos de Europa and Doñana (0.639 and 0.110, respectively) (Fig. 2a). The NDVI seasonal variation (RREL) was much higher in the three Eurosiberian parks than in the Mediterranean ones; for example, Aigüestortes showed the highest RREL values, and Cabañeros the lowest. On average, the earliest date of maximum NDVI (DMAX) occurred in Monfragüe and some pixels of Doñana, whereas the three Eurosiberian parks displayed the latest NDVI peaks. The date of the minimum NDVI values (DMIN) occurred during winter in the Eurosiberian parks and most pixels of Sierra Nevada, whereas in Cabañeros, Monfragüe, Doñana, and in a few pixels of low altitude in Sierra Nevada (results not shown), it occurred during late summer and early autumn.

Two main patterns of NDVI seasonal dynamics were identified (Fig. 3a). One pattern, common to all pixels of the Eurosiberian parks, corresponded to a bell-shaped curve with high NDVI differences between the winter minima and the summer maxima, even though these differences were less marked in some parts of Ordesa and Picos de Europa. In the Eurosiberian parks, the growing season started in mid-spring, reached a peak in July, started to decline in mid to late summer, and ended by late autumn. The second pattern of NDVI seasonal dynamics, characterized by a much lower seasonal variation than the first one, corresponded to the Mediterranean parks. Instead of a NDVI curve centered in the summer, the Mediterranean parks showed the NDVI maxima from early to late spring and the minima in late summer and early autumn. Growing season in Monfragüe, Cabañeros, and Doñana started in autumn and finished in summer (Fig. 3a). However, in Sierra Nevada, the growing season started in early spring, NDVI showed a decrease in summer and eventually reached a minimum NDVI value in early winter.

Both the RREL and MIN had a greater year-to-year variability than NDVI-I and MAX (Fig. 2b). In general, the lowest interannual variation for most NDVI attributes occurred in Monfragüe and Cabañeros, whereas Doñana was the most variable national park. On average, interannual variability of seasonality (RREL) and phenology (DMAX and DMIN) were higher for the Mediterranean parks than for the Eurosiberian ones.

The interannual variability of the three Eurosiberian parks NDVI seasonal dynamics (interannual coefficient of variation in every bimonthly NDVI value) was, in general, much lower in summer than in other seasons (Fig. 3b). The Mediterranean parks generally displayed a slightly higher interannual variation in summer and autumn than in other seasons, except in the case of Sierra Nevada, which showed, as did the Eurosiberian parks, a lower interannual variability in summer. On average throughout the whole year, the highest interannual variation of the NDVI seasonal dynamics occurred in the Eurosiberian parks and

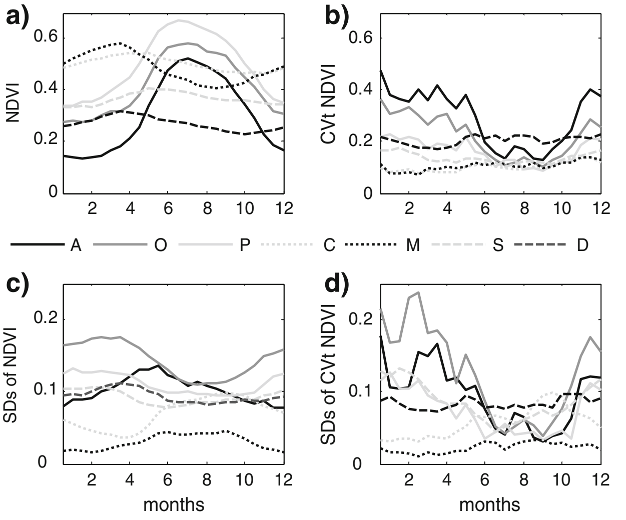

Fig. 3 (**a**) Mean seasonal dynamics of the NDVI for the 1982–2006 period for each national park. (**b**) Interannual variability of the NDVI annual curve for each park calculated as the interannual coefficient of variation (CVt) of the mean seasonal dynamics. (**c**), (**d**) The spatial standard deviation of each park for the NDVI mean seasonal dynamics (in **a**) and the interannual variability (in **b**), respectively. A: Aigüestortes i E. S. Maurici; O: Ordesa y Monte Perdido; P: Picos de Europa; C: Cabañeros; M: Monfragüe; S: Sierra Nevada; D: Doñana

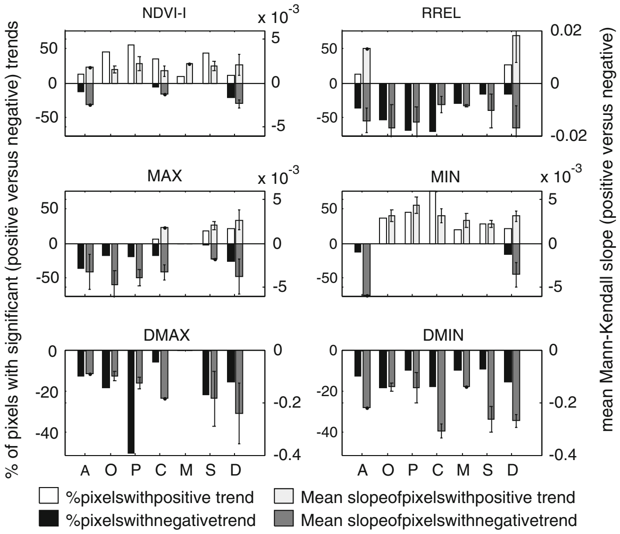

Fig. 4 Temporal trends in the Spanish national parks between 1982 and 2006 for six descriptors of ecosystem functioning derived from the NDVI dynamics: NDVI-I, MAX, and MIN represent the annual mean, maximum, and minimum NDVI values, respectively (estimators of radiation interception), RREL is the NDVI annual relative range (indicator of seasonality), and DMAX and DMIN correspond to the dates of the MAX and MIN values, respectively (descriptors of land-surface phenology). 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 Mann–Kendall trend test. A: Aigüestortes i E. S. Maurici; O: Ordesa y Monte Perdido; P: Picos de Europa; C: Cabañeros; M: Monfragüe; S: Sierra Nevada; D: Doñana. Error bars indicate spatial standard deviation of temporal trends

Doñana, whereas the lowest occurred in Cabañeros and Monfragüe.

Trends of the Ecosystem Functioning During the Last 25 Years

The six descriptors of ecosystem functioning derived from the NDVI seasonal dynamics displayed significant trends between 1982 and 2006 in most of the Spanish national parks (Figs. 4 and 5). The trends with the highest statistical significance were positive for NDVI-I and MIN but negative for MAX and RREL. Regarding the dates of the maximum (DMAX) and minimum (DMIN) NDVI values, the significant trends were negative in all parks; so both dates tended to occur earlier in the year. Among all functional attributes, RREL showed the greatest significant trends (both in percentage of pixels and slope of the trend), whereas MAX showed the lowest trends. Among all parks (Fig. 5), Monfragüe showed the lowest trends, whereas Picos de Europa and Doñana the greatest.

Discussion

The assessment and monitoring of protected areas are essential to establish priorities in decision-making, to evaluate the effectiveness of management, and to track the effects of global changes on protected areas (Barber and others 2004; Leverington and Hockings 2004; Meffe and others 2006). They also allow one to separate the effects of climate and atmospheric change from human land-use changes outside protected areas (Jenkins and Bedford 1973; Schonewaldcox 1988). In this study, we used the same satellite-based approach across parks and biogeographical regions to characterize the reference conditions and to detect the temporal trends of ecosystem functioning in the Spanish National Park Network. We assume that our study is not biased by atmospheric oscillation cycles because it considers a 25-year period with both extremely wet and dry weather conditions (de Castro and others 2005).

Reference Conditions

The seasonal dynamics of radiation interception of the parks was rather similar to those of the biogeographical regions that they represent: the Eurosiberian and the Mediterranean regions (Alcaraz-Segura 2005). In the Eurosiberian parks, the growing season was centered in the early summer. In these parks, fAPAR (NDVI) is severely constrained by temperature during the winter, but water

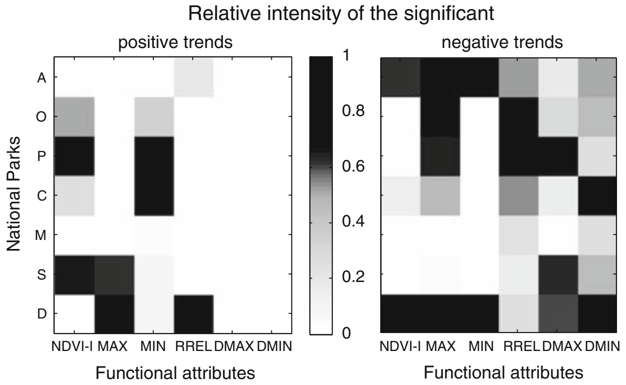

Fig. 5 Comparison across national parks (*Y*-axis) and functional attributes (*X*-axis) of the relative intensity of the significant Mann–Kendall temporal trends of the 1982–2006 period. To allow a quick comparability among the slopes of the different attributes, the relative intensity of the trends was calculated, first, by multiplying the percentage of pixels with significant trends by their slope and, second, by normalizing these products between 0 and 1 (for each attribute, each product was divided by the maximum product of that attribute). NDVI-I, MAX, and MIN: annual mean, maximum, and minimum NDVI values, respectively, estimators of radiation interception; RREL: NDVI annual relative range, indicator of seasonality; and DMAX and DMIN: dates of the MAX and MIN values, respectively, descriptors of land-surface phenology. A: Aigüestortes i E. S. Maurici; O: Ordesa y Monte Perdido; P: Picos de Europa; C: Cabañeros; M: Monfragüe; S: Sierra Nevada; D: Doñana

availability and warmth during the summer allows the annual radiation interception (NDVI-I) to be relatively high in the Iberian context (Alcaraz-Segura and others 2006). Nevertheless, after radiation interception peaked (DMAX) in June–July, it decreased in July–August, probably due to water limitation on productivity under the highest temperatures. On the contrary, the Mediterranean parks were characterized by a low seasonality (RREL) with moderate to high NDVI values throughout the year, particularly in Monfragüe, which is the park with the highest percentage of evergreen vegetation (Appendix 1). The growing period in the Mediterranean parks started in middle to late autumn, an increase of vegetation activity that is locally referred to as “otoñada” (autumn growth). As reported by Alcaraz-Segura and others (2006), a high radiation interception in late autumn is the general pattern in low Mediterranean mountains of the Iberian Peninsula. Nevertheless, in Sierra Nevada, a high Mediterranean mountain ranging from 1200 to 3480 m of altitude, winter cold did not allow any increase in intercepted radiation until spring.

The Eurosiberian parks showed the lowest variability in radiation interception during summer. The summer weather in this area is especially constant, with high temperatures and available water (Rodó and Comín 2001). Winter severity is more variable (Rodó and Comín 2001) and had a greater effect on the interannual variability of the Eurosiberian than of the Mediterranean parks. The relatively high NDVI interannual variation in March–April must be particularly considered in monitoring programs in Aigüestortes and Ordesa, because the interannual variability of temperatures in these months affects treeline patterns in the Central Pyrenees (Camarero and Gutiérrez 2004).

The Mediterranean parks, especially Monfragüe and Cabañeros, are dominated by evergreen vegetation, which contribute to maintain a constant interannual variability throughout the year. However, because the Mediterranean climate is highly unpredictable (Rodó and Comín 2001), all parks in this region showed higher interannual variation in phenology (DMAX and DMIN) and seasonality (RREL) than the Eurosiberian ones. Doñana showed the highest interannual variance for the six attributes analyzed here. This park protects an environmentally heterogeneous area, which includes marshlands, shrublands, and pine forests. The park is affected by high year-to-year changes in precipitation, freshwater inflows, agricultural groundwater use, and human-controlled flooding of the marshland (Fernández-Delgado 2006).

Trends in Ecosystem Functioning

The observed trends in ecosystem attributes in protected areas clearly shows that in a global change context, conservation is a moving target (Harris and others 2006). Management schemes in protected areas need to incorporate the ecosystem functioning changes to anticipate consequences and to handle inevitable transitions among alternative states. The results presented also stress the need for monitoring protected area networks considering different dimensions of ecosystem functioning.

We found that trends might differ both in sign and magnitude among national parks pertaining to the same biogeographical region. For instance, different trends occurred between Aigüestortes and Ordesa (Eurosiberian Region) and between Cabañeros and Monfragüe (Mediterranean Region), despite their proximity and similarity in vegetation types and in environmental controls of ecosystem functioning (Alcaraz-Segura 2005). On the contrary, despite the differences between Eurosiberian and Mediterranean parks in the reference seasonal and interannual dynamics of radiation interception, the trends in the six studied attributes did not differ between the two regions (although positive trends in the MAX only occurred in the Mediterranean parks). We also found that the mean NDVI trend of individual parks might differ from the observed regional trends (see also Alcaraz-Segura and others 2008). Such differences suggest that the drivers operating at regional scales would differ from those acting at the park level. Conservation policies and management should, then, be different for the protected area than for the surrounding areas.

Whereas previous works have mainly focused on trends of the NDVI annual mean or maximum (e.g., Alcaraz-Segura and others 2008; Jia and others 2006), we found significant trends in six ecosystem functioning attributes. Our results suggest that the seasonality and phenology of radiation interception has experienced important changes (e.g., see trends for MAX in Monfragüe; Fig. 4) between 1982 and 2006. Across the parks, radiation interception tended to increase, the contrast between the growing and nongrowing seasons (seasonality) tended to diminish, and the date of maximum and minimum interception (phenology) tended to occur earlier in the year. Some of the trends described can be linked to changes at community or population levels. For example, the uniform trends across parks toward an earlier occurrence of DMAX and DMIN match the phenological changes observed in migratory birds' and insects' life cycle during the last three decades throughout different locations in the Iberian Peninsula (Gordo and Sanz 2006; Peñuelas and others 2004; Wilson and others 2007).

Analyses of Individual Parks

In the Eurosiberian parks of Picos de Europa and Ordesa, the important increase in radiation interception [consistent with the regional mean NDVI trends (Vicente-Serrano and Heredia-Laclaustra 2004)] and the decrease in seasonality might be an early indicator of biome shifts. The growth of the deciduous vegetation in these parks is highly seasonal and is constrained by winter minima, whereas Mediterranean sclerophyllous vegetation has low seasonality and moderate NDVI values in winter (Alcaraz-Segura 2005). Indeed, the replacement of Eurosiberian deciduous forests and subalpine vegetation caused by the ascend of Mediterranean evergreen vegetation has been reported in a similar biogeographical transition in NE Spain (Peñuelas and Boada 2003). The intensification of the subalpine forest regeneration in the Central Pyrenees (Camarero and Gutiérrez 1999) (in Ordesa) and the regional increases in temperature (Brunet and others 2001b; Serra and others 2001) and precipitation (de Castro and others 2005) (in Picos de Europa and Ordesa) might have contributed to the positive NDVI-I and MIN and negative RREL trends.

In the Mediterranean parks of Sierra Nevada, Cabañeros, and Monfragüe, we also observed positive NDVI-I and MIN and negative RREL trends. In Sierra Nevada, where warming is causing an altitudinal ascent of species (Hódar and Zamora 2004), we observed a significant increase in radiation interception despite the absence of significant precipitation trends (Galán and others 1999). In Monfragüe and, especially, in Cabañeros, the large increase in winter minimum temperatures (Brunet and others 2001a; Cañada and others 2001; Galán and others 2001) favored a large increase in the minimum radiation interception. In contrast, the slight increases in spring–summer maximum temperatures (Staudt 2004) led to both increases and decreases of the maximum radiation interception. Aside from the temperature trends, in these three Mediterranean parks, protection removed harmful land uses favoring the encroachment of evergreen matorral (Valladares and others 2004). This fact might also explain the observed decrease in seasonality and the increase in minimum and mean NDVI.

Doñana and Aigüestortes, from the Mediterranean and the Eurosiberian regions, respectively, showed different trends than the rest of the parks; they are the only ones containing areas that experienced positive RREL trends and negative trends in NDVI-I, MAX and MIN. Despite of the high interannual variability observed in Doñana, part of the park showed a reduction in radiation interception (negative trends in MIN, MAX, and NDVI-I). This reduction was consistent with regional NDVI trends associated with lower precipitation and higher temperatures due to the winter NAO course (Vicente-Serrano and Heredia-Laclaustra 2004) and with the earlier withering of the marshland in the summer, and the greater herbivory since the 1980s (see Fernández-Delgado 2006). However, another part of Doñana displayed unexpected trends from the regional studies but in a similar direction to the rest of the Mediterranean parks (increase in radiation interception and decrease of seasonality). Such areas corresponded to Mediterranean evergreen forests and scrublands.

In the case of Aigüestortes, part of the park also showed trends consistent with the regional NDVI and climatic trends (Vicente-Serrano and Heredia-Laclaustra 2004) toward a higher radiation interception and a lower seasonality, which were also similar to the other Eurosiberian parks, like Ordesa, although not associated with increases in the minimum but to decreases in the maximum NDVI. However, another part of Aigüestortes displayed unexpected trends from the regional studies: negative for NDVI-I and MIN but positive for RREL. In such areas, preliminary studies have found a decline in the successful establishment of tree seedlings at the treeline (E. Gutiérrez, personal communication) probably associated to an increase in the interannual variability of temperature (Camarero and Gutiérrez 2004). In our reference characterization, the interannual variability of radiation interception in Aigüestortes was indeed the greatest of the Network, especially for MIN.

Concluding Remarks

The approach presented allowed us to detect changes in nearly all parks of the Spanish National Parks Network: Radiation interception is increasing, seasonality is decreasing, and the phenology of the maximum and minimum radiation interception is occurring earlier in the year. These findings provide a new perspective in the evaluation of conservation policies by showing the variability and trends of ecosystem attributes of the protected areas. Our results highlight the risks of a static view of conservation actions. A monitoring system based on ecosystem functional attributes complements programs based on structural features and on other levels of organization. The analyses performed showed, for example, that some parks (such as Picos de Europa, Ordesa, or Doñana) are experiencing more changes in ecosystem functioning than others (such as Monfragüe). Such information provides elements for the definition and prioritization of policies and management actions at the scale of the network of protected areas.

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Appendix 1

Vegetation types, climatic characteristics, and conservation histories of the seven studied Spanish national parks

	Eurosiberian parks			Mediterranean parks			
	A	O	P	C	M	S	D
Vegetation types (% of Area of each park)							
SparseV	57	30	32			14	
EuGrass	8	38	15				
M&SAS	13	6	12				
Heath			5				
AlpConF	20	10					
TDecidF		5	27				
TSemiDF		1	1	8		1	
OroMGS						43	
MedConF		1		8	1	25	10
MedSclF		1		11	18	6	
MaqGar				34	44	7	20
MedGras				5			1
Dehesa				19	6		
MixedF	2	7	4	13	11	3	
ExoticF						11	3
Dunes							10
FMarsh							35
SMarsh							14
WaterS						7	7
Pasture			3				
Area (ha)	14,119	15,608	64,660	40,856	18,118	86,208	54,252
Buffer (ha)	26,733	19,678	–	–	116,160	85,750	7,450
Creation and expansions, Year (% Area)	1955 (70) 1988 (72) 1996 (100)	1918 (13) 1982 (100)	1918 (26) 1995 (100)	1995 (95) 2005 (100)	2007 (100)	1999 (100)	1969 (70) 1978 (93) 2004 (100)
Previous protections, Year (% Area)	–	–	–	Natural park 1988 (66)	Natural park 1979 (104)	Natural park 1989 (163)	Biologic reserve 1964 (13%)
Altitude (m)	2,368	2,087	1,299	788	384	2,137	7
Max/Min	1,406/2,979	662/3,288	75/2,646	521/1,428	270/511	1,200/3,482	0/47

Appendix continued

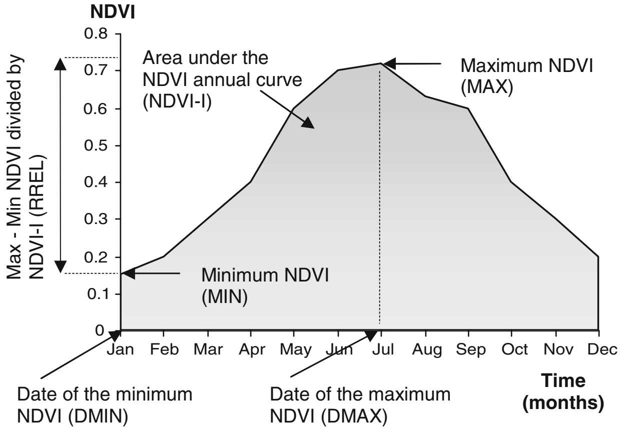
	Eurosiberian parks			Mediterranean parks			
	A	O	P	C	M	S	D
MAP (mm)	1,368	1,377	1,829	642	696	899	572
Max/Min	700/1,400	1,200/2,000	700/2,000	520/910	637/780	450/1,200	530/600
MAT (°C)	3.5	4.9	7.5	13.9	16.5	10.2	17.5
Max/Min	2/8	2/10	4/13	11/15	16/17	8/16	17/18
TMIN (°C)	−6.5	−5.2	−2.7	0.8	10.3	0.3	5.6
Max/Min	−7/−4	−6/−3	−5/3	0/2	10/11	−1/5	5/6
TMAX (°C)	13.5	16.9	19.9	32.4	22.7	26.3	33.7
Max/Min	10/24	10/27	16/25	27/34	22/23	23/32	33/34

A: Aigüestortes i E. S. Maurici; O: Ordesa y Monte Perdido; P: Picos de Europa; C: Cabañeros; M: Monfragüe; S: Sierra Nevada; D: Doñana

Vegetation types were derived from the Spanish Forest Map (Ruíz de la Torre 1999) and the CORINE Land-Cover (EEA 2000). SparseV = sparsely vegetated areas, EuGras = Eurosiberian natural and seminatural grasslands, M&SAS = Montane and subalpine scrubs, Heath = heathlands, AlpConF = Alpine coniferous forests, TDecidF = temperate broadleaf deciduous forests, TSemiDF = temperate semideciduous forests, Oro-MGS = Oro-Mediterranean grasslands and scrubs, MedConF = Mediterranean coniferous forests, MedSclF = Mediterranean evergreen sclerophyllous forests, MaqGar = Maquis and garrigues, MedGrass = Mediterranean natural and seminatural grasslands, Dehesa = dehesas (woody savanna), MixedF = mixed forests, ExoticF = exotic forests, Dunes = dunes, sands and plains, FMarsh = freshwater marshes, SMarsh = salt marshes, WaterS = water surfaces, Pasture = pastures. MAP = mean annual precipitation, MAT = mean annual temperature, TMIN = mean of the minimum temperatures of the coldest month, TMAX = mean of the maximum temperatures of the warmest month

Appendix 2

The figure shows the six attributes derived from the seasonal curve of NDVI that were used in the functional characterization and the detection of trends in the national parks (NDVI-I, MAX, MIN, RREL, DMAX, and DMIN).



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