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Impacts of changes in land use and fragmentation patterns on Atlantic coastal forests in northern Spain

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ABSTRACT

Changes in forested landscapes may have important consequences for ecosystem services and biodiversity conservation. In northern Spain, major changes in land use occurred during the second half of the 20th century, but their impacts on forests have not been quantified. We evaluated the dynamics of landscape and forest distribution patterns between 1957 and 2003 in Fragas do Eume Natural Park (northwestern Spain). We used orthoimages and a set of standard landscape metrics to determine transitions between land cover classes and to examine forest distribution patterns. Eucalypt plantations showed the greatest increase in area (197%) over time. Furthermore, transitions to eucalypt plantations were found in all major land cover classes. Forest showed a net decline of 20% in total area and represented 30% of the landscape area in 2003. Forest losses were mainly due to eucalypt plantations and the building of a water reservoir, while forest gains were due to increases in shrubland, meadows and cultivated fields which had been recolonised. Forest patch size and core area decreased, and edge length increased over time. In turn, increases were obtained in mean distance between forest patches, and in adjacency to eucalypt plantations and to a water reservoir. These results suggest an increase in forest fragmentation from 1957 to 2003, as well as a change in the nature of the habitat surrounding forest patches. This study shows that land use changes, mostly from eucalypt plantation intensification, negatively affected forested habitats, although some regeneration was ongoing through ecological succession from land abandonment.

1. Introduction

Landscape change is often associated with increasing rates of habitat loss and fragmentation. These processes usually occur simultaneously and constitute one of the most important threats to biodiversity (Andrén, 1994; Harrison and Bruna, 1999; Brooks et al., 2002; Fahrig, 2003). Habitat loss and fragmentation affect habitat pattern by decreasing the size of habitat patches and increasing their isolation (Hanski, 1999). As a result, the probability of successful dispersal and establishment of individuals, and persistence of populations in smaller and more isolated habitat patches is reduced with negative consequences on local and regional species richness (Harrison and Bruna, 1999).

Forest habitats, which are suffering from extensive loss and fragmentation worldwide, are of extreme ecological interest from a wide range of perspectives. For instance, forest clearance affects climate by increasing land surface albedo and vegetative carbon release to the atmosphere (Bonan, 2008). Maintaining forest cover keeps water pure and reduces the magnitude and frequency of floods (Eisenbies et al., 2007). Many plant and animal species are forest specialists and the fate of their populations is deeply affected by habitat loss and fragmentation (e.g. Santos et al., 2002; Honnay et al., 2005; Cushman, 2006). Furthermore, forests conforming linear structures, such as riparian forests, are also particularly important because they maintain high species diversity and act as dispersal corridors between other forest patches (Naiman et al., 1993; Wenger, 1999; Schnitzler et al., 2005). Therefore, the analysis of landscape patterns is essential for forest conservation and should be a priority in forest management programs throughout the world.

The application of geographical information systems to ecological research has given rise to a steady increase in studies on fragmentation patterns of forests. Most of these studies provide a snapshot or assessment of temporal changes of fragmentation patterns using a wide array of metrics describing the size, shape and isolation of forest patches (e.g. Fuller, 2001; Pan et al., 2001; Staus et al., 2002; Armenteras et al., 2003; García et al., 2005; Kennedy and Spies, 2005; Echeverria et al., 2006; Gaveau et al.,

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2007). Conversely, fewer studies have reported the details of forest transitions to other land cover classes (i.e. forest loss) or viceversa (i.e. forest gain), which are crucial for understanding the temporal evolution of fragmentation patterns (e.g. Steininger et al., 2001; Plieninger, 2006; Grossman and Mladenoff, 2007), particularly of landscapes consisting of mosaics of small distinct patches. In this case, the nature of the boundary between forest and other land cover classes is also crucial because individuals are expected to approach and cross patch borders more frequently in smaller patches due to larger perimeter/area ratios (Englund and Hambäck, 2004). However, most studies concentrate on patterns and temporal changes in patch isolation and rarely consider the attributes of patch boundaries (but see Echeverria et al., 2006).

The objective of this study is to contribute to the understanding of the patterns of forest loss and fragmentation in the coastal landscapes of northern Spain. Historically, this area has been influenced by high human population density, large-scale introduction of eucalypt (*Eucalyptus* spp.) plantations (Saura and Carballal, 2004; Calvo-Iglesias et al., 2006) and small-farming practices which has resulted in highly heterogeneous land use (Manuel and Gil, 2002; Marey-Pérez et al., 2006). However, the effect of these factors on forest patterns and dynamics remains unknown. Specifically, we concentrated on changes in landscape patterns in Fragas do Eume Natural Park from 1957 to 2003, a period in which major changes in land use occurred (Calvo-Iglesias et al., 2006). This protected area was established in 1997 and contains one of the largest remaining tracts of Atlantic coastal forests in northern Spain, including well-conserved riparian forests along water courses. The specific goals of this study were (1) to quantify the changes and transitions that occurred between land cover classes from 1957 to 2003 to understand their effect on the spatial-temporal configuration of the forests; and (2) to characterise forest fragmentation patterns, using standard landscape metrics and adjacency to other land cover classes, and to determine the temporal change of these patterns.

2. Materials and methods

2.1. Study area

Fragas do Eume Natural Park covers an area of 8962 ha in the Galician region (NW Spain). The reserve spans 43°20′-43°26′N and 7°52′-8°08′W with elevations ranging from sea level to 700 m (Fig. 1). The main water course is the Eume River which flows through a 29-km gorge. Geological substrate is dominated by acid rocks (phyllite, schist, quartzite and granite) and soils are acid with low levels of mineral nutrients and high levels of organic matter (Macías and Calvo, 1992). The climate is Atlantic-temperate, humid and mild, with an average annual precipitation of ca. 1700 mm and an average annual temperature of ca. 14 °C. There are three native forest types depending on geomorphology: (1) oak forests, located on slopes and dominated by oak (*Quercus robur*), chestnut (*Castanea sativa*) and birch (*Betula alba*) with a representative understorey of deciduous and evergreen shrubs; (2) alder forests, located on riversides with flooding sediments and dominated by alder (*Alnus glutinosa*) with ash trees (*Fraxinus angustifolia* and *Fraxinus excelsior*) and large gray willow (*Salix atrocinerea*); and (3) hazel forests, located on steep riversides with rocky river-beds dominated by hazel (*Corylus avellana*) and bay laurel (*Laurus nobilis)*. The alder forests are mainly restricted to the Eume River, whereas the hazel forests occur in its tributaries. The study area also contains an abundant herbaceous understorey of more than 150 species (for further details see Amigo and Norman, 1995). Alder and hazel forests represent the riparian forests and are listed in Appendix I of the EU Habitats Directive (EEC, 1992). These riparian forests contain a high number of threatened species, such as the Iberian endemics Gold-striped salamander (*Chioglossa lusitanica*) and the Iberian desman (*Galemys pyrenaicus)* (listed in IUCN Red List; IUCN, 2007), and the Macaronesian-European ferns *Culcita macrocarpa*, *Trichomanes speciosum* and *Woodwardia radicans* (listed in Appendix II of the EU Habitats Directive; EEC, 1992).

2.2. Aerial image processing and GIS database

Landscape fragmentation patterns were analysed using aerial photographs from American Army flights for the years 1956–1957 (hereafter 1957) and digital orthoimages from the Agrarian Plots Geographic Information System for the years 2002–2003 (hereafter 2003). The 1957 aerial photographs consisted of 28 contact copies (24×24 cm) at a scale of ca. 1:30 000. The photographs were scanned at ca. 2.55 m resolution and georeferenced with the software ERDAS IMAGINE 8.7 (Leica Geosystems, 2003) using 30–40 ground control points for each frame. The orthoimages from 2003 had a spatial resolution of 0.25 m. The imagery set was integrated into a GIS based on ArcGIS 9.1 (ESRI, 2005). Geographical information was obtained from 1:25 000 topographic maps in raster format (IGN, 2003).

2.3. Land cover classes

Land cover maps were made of Fragas do Eume Natural Park for 1957 and 2003 to analyse temporal changes in spatial configuration. Land cover was classified following the CORINE Land Cover 5th level project (IGN, 2002), obtaining the following classes (CORINE code in brackets): forests (3112 -oak forests- and 3115 -riparian forests, i.e. alder and hazel forests-), eucalypt plantations (3113), pine plantations (3121), transitional woodland (324), gorse and heathland (3221), bare rocks (332), water courses (5111), water reservoirs (5122), meadows and pastures (231), complex cultivation patterns (242), discontinuous urban fabric (112), roads (1221), construction sites (133), mineral extraction sites (131) and industrial or commercial units (121). The term “forest” is used to refer to forested areas dominated by native tree species and, therefore, does not include eucalypt or pine plantations.

We on-screen digitised land cover maps from each aerial photograph (based on texture and tone) using a minimum mapping unit of $10 \text{ m} \times 10 \text{ m}$. Woody native vegetation types (forest, transitional woodland, and gorse and heathland) were defined according to the percentage of tree cover within the patch: >75% were considered forests, 30–75% transitional woodland, and <30% gorse and heathland (IGN, 2002). Due to the difficulties imposed by shadowing, the boundaries between forests and eucalypt plantations on steep north-facing slopes were defined in the field using a hand-held GPS unit (GARMIN MAP 60CSX). As the borders between the oak and riparian forests were indistinguishable in the aerial photographs, these two land cover classes were merged into one category. In addition, the patches of riparian forests were so thin that they could not be digitised as polygons. Due to the importance of this habitat for the persistence of key red-listed and protected species, we digitised the intersection between riparian forests and river courses as polylines to generate a map of riparian forest length.

The bare rock class included all outcrops with more than 75% rock cover. The water courses class consisted of one patch corresponding to the Eume River, since its narrow tributary streams were digitised as polylines. The meadows and pastures class included dense herbaceous vegetation and areas with hedges and non-irrigated arable lands, orchards and gardens. The complex cultivation patterns class consisted of small crop and pasture plots interspersed with scattered houses or gardens. The discontinuous

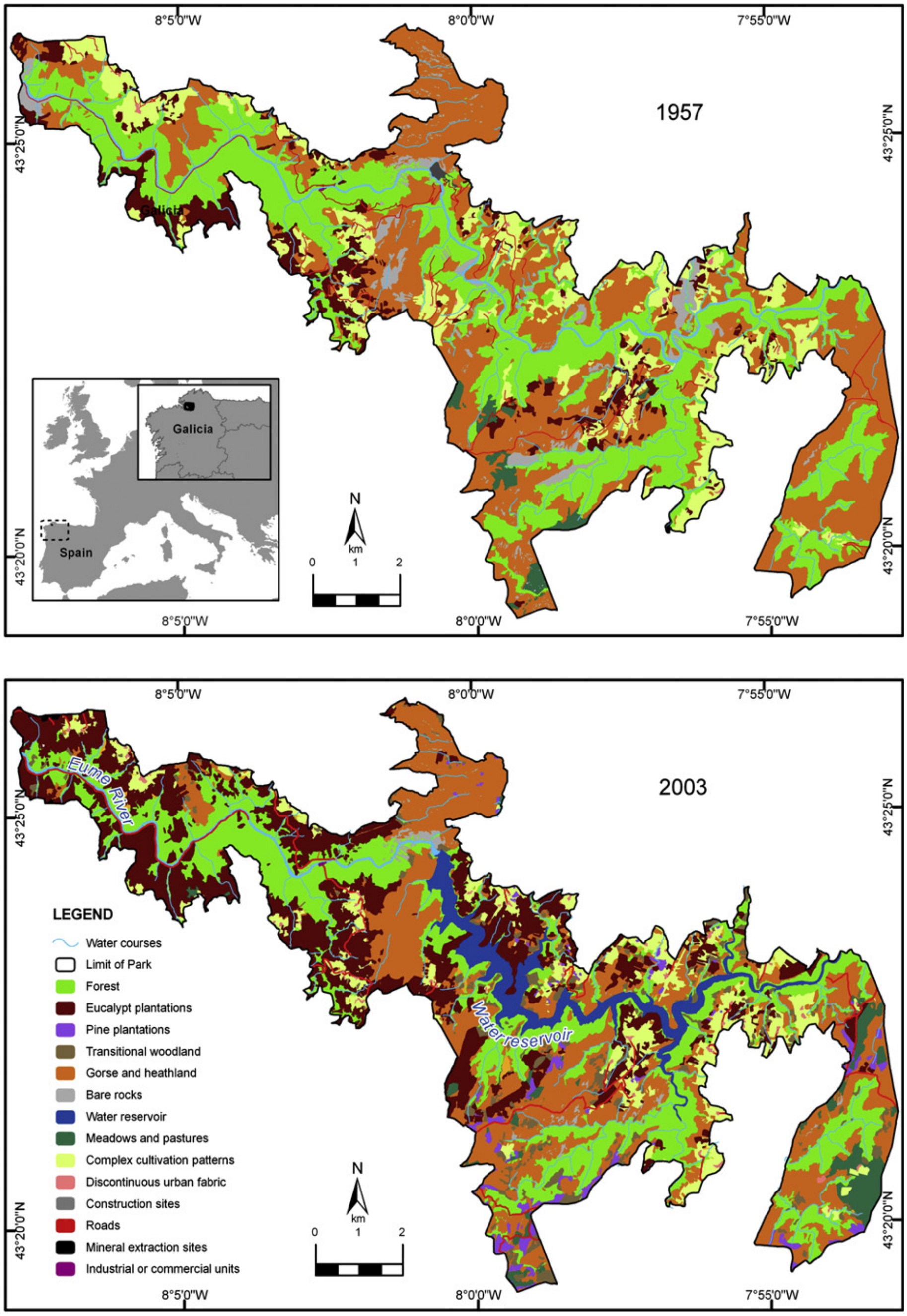

Fig. 1. Geographical location and spatial configuration of land cover classes in Fragas do Eume Natural Park in 1957 and 2003.

urban fabric class was defined as artificial surfaces with some areas of sparse vegetation. The road class included all paved ways, the mineral extraction sites class consisted of outdoor areas for extracting building material, and the industrial or commercial units class comprised all paved areas with no vegetation. The number of patches and the absolute and relative (%) area covered by each cover class was calculated directly from the polygon maps for 1957 and 2003.

2.4. Transition analysis

We mapped land cover transitions (e.g., "forest" to "eucalypt plantation") by overlaying the polygon maps for 1957 and 2003. The transition rate (p_{ij}) from class i to class j was calculated using the formula:

$$p_{ij} = A_{j\ 2003}/A_{i\ 1957}$$

where $A_{i\ 1957}$ is the area of land cover class i in 1957 and $A_{j\ 2003}$ is the area of class j in 2003. Only transitions of classes covering more than 2% of the landscape in at least one of the study years were calculated, as low cover may be associated with a greater effect of digitising errors on the estimation of transition rates.

2.5. Forest fragmentation analysis

Quantification and temporal comparison of the spatial configuration of forest patches were conducted following a set of standard landscape metrics reported in recent forest fragmentation studies (e.g. Armenteras et al., 2003; Kennedy and Spies, 2005; Echeverria et al., 2006): (1) largest patch index (% of landscape comprising the largest patch) and (2) mean patch size (ha), to quantify the incidence and changes in patch size; (3) total edge length (km), (4) total core area (total patch size remaining after removing a specific buffer edge, ha) and (5) largest patch core area (ha), to evaluate the incidence and changes in edge effect; (6) mean patch distance (average of the nearest distance between the edges of all patches, m) and (7) adjacency index (total km and relative % length of the edge between native forest and other land cover classes), to estimate the degree and changes in patch isolation considering Euclidean distances and the nature of the surrounding matrix. To calculate core area, the interior forest was defined at a distance of 50 m to the edge, as suggested for temperate forests (Murcia, 1995; Yates et al., 2004; Honnay et al., 2005).

Quantification and temporal comparison of the spatial configuration of riparian forests was based on linear segments rather than areas, as they were digitised as polylines. For 1957 and 2003, the number of segments and the absolute and relative length (% relative to total water course length) of riparian forests were calculated from the polyline maps. All absolute changes in land cover area and length were quantified by calculating the difference between the values in 1957 and 2003 and relative changes (R_i) using the formula:

$$R_i = [(A_{i\,2003} - A_{i\,1957}) \cdot 100]/A_{i\,1957}$$

where $A_{i\,1957}$ and $A_{i\,2003}$ are the area or length of land cover class *i* in 1957 and 2003, respectively.

3. Results

3.1. Land cover patterns and changes

Twelve and fourteen land cover classes were identified in 1957 and 2003, respectively (Table 1, Fig. 1). In 1957, forest, gorse and heathland, and complex cultivation patterns, accounted for approximately 88% of the area. In 2003, forest and gorse and heathland were still dominant in the landscape, accounting for 77% of the area, but eucalypt plantations were also important. From 1957 to 2003 forest cover decreased by approximately 20% and the number of forest patches increased more than two-fold. Gorse and heathland decreased by over 30% and the number of patches increased. A similar pattern was found for complex cultivation patterns. In contrast, eucalypt plantations increased in area by approximately 200% from 1957 to 2003, while the number of patches experienced a moderate increase. Pine plantations, transitional woodland, water reservoir, meadows and pastures, discontinuous urban fabric, roads, mineral extraction sites and industrial or commercial units showed a gain in area from 1957 to 2003, while bare rocks, water courses and construction sites showed a decline in area (Table 1). The number of patches of all land cover classes increased over time with the exception of bare rocks, water courses and construction sites. It should be noted that the 1957 aerial photographs were taken during dam building prior to water filling. Thus, dam construction and forest clear-cutting in the reservoir basin generated a large construction site patch and several bare rock patches, respectively (Fig. 1).

3.2. Transition analysis

Of the 8 major land cover classes, forest had the highest rate of retention (i.e. forest to forest), followed by eucalypt plantations, complex cultivation patterns, gorse and heathland, bare rocks and meadows and pastures (Table 2). As transitional woodland and water reservoir were absent in 1957, no transitions were calculated from those classes. Regarding transitions to different land cover classes, approximately 12% of forest in 1957 became eucalypt plantations and 9% became water reservoir in 2003. 12% of eucalypt plantations changed to gorse and heathland and 13% to complex cultivation patterns. Gorse and heathland primarily changed to eucalypt plantations and to meadows and pastures. Bare rocks mostly transitioned to gorse and heathland and also to eucalypt plantations. Meadows and pastures mainly became gorse and heathland, transitional woodland and eucalypt plantations. Complex cultivation patterns mostly changed to eucalypt plantations and to gorse and heathland. In summary, all main land cover classes present in 1957 underwent transitions to eucalypt plantations in 2003 with relatively high values (>0.1), whereas all transitions to forest had values under 0.1.

3.3. Forest fragmentation analysis

In 1957, 86% of total forest area was comprised by a large patch of 2848 ha located along the Eume river gorge (this patch was

Table 1
Number of patches, absolute (ha) and relative (%) areas for each land cover class in Fragas do Eume Natural Park in 1957 and 2003. Net change (absolute and relative) in number of patches and area is also shown. Change values greater than 0 indicate gains, and those less than 0 indicate losses. * indicates that relative change was not calculated because that land cover class was absent in 1957.

Land cover class (abbreviation)	1957			2003			Change 1957–2003		
	Patches	Area		Patches	Area		Patches	Area	
		(ha)	(%)		(ha)	(%)		Absolute	Relative (%)
Forest (Forest)	64	3306.5	36.9	137	2659.5	29.7	+73	−647.0	−19.6
Eucalypt plantations (Eucal)	162	615.3	6.9	200	1829.7	20.4	+38	+1214.4	+197.4
Pine plantations	0	0.0	0.0	96	144.9	1.6	+96	+144.9	*
Transitional woodland (Trans)	0	0.0	0.0	267	302.9	3.4	+267	+302.9	*
Gorse and heathland (Gorse)	169	3483.0	38.9	213	2386.2	26.6	+44	−1096.8	−31.5
Bare rocks (Bare)	356	254.6	2.8	255	94.2	1.1	−101	−160.4	−63.0
Water courses	1	59.5	0.7	1	24.5	0.3	0	−35.0	−58.8
Water reservoir (Water)	0	0.0	0.0	1	400.1	4.4	+1	+400.1	*
Meadows and pastures (Mead)	23	121.2	1.4	30	268.0	3.0	+7	+156.8	+129.4
Complex cultivation patterns (Comp)	89	1080.0	12.0	139	799.8	8.9	+50	−280.2	−25.9
Discontinuous urban fabric	69	17.7	0.2	72	26.0	0.3	+3	+8.3	+46.9
Roads	51	11.1	0.1	60	17.9	0.2	+9	+6.8	+61.3
Construction sites	1	10.8	0.1	0	0.0	0.0	−1	−10.8	−100.0
Mineral extraction sites	1	1.6	0.0	4	7.4	0.1	+3	+5.8	+362.5
Industrial or commercial units	1	0.5	0.0	1	0.7	0.0	0	+0.2	+40.0
Total	928	8961.8	100.0	1476	8961.8	100.0	+489	0.0	0.0

Table 2
Transitions between land cover classes in Fragas do Eume Natural Park from 1957 to 2003. Each column indicates the proportion (values between 0 and 1) of area with a given land cover class in 1957 that belonged to each class in 2003. Only transitions for land cover classes covering more than 2% of landscape in at least one of the study years are shown. Land cover class abbreviations are as in Table 1. Transitions over 0.1 are in bold. *indicates that transition was not calculated because that land cover class was absent in 1957.

2003	1957							
	Forest	Eucal	Trans	Gorse	Bare	Water	Mead	Comp
Forest	**0.726**	0.021	*	0.063	0.000	*	0.090	0.044
Eucal	**0.115**	**0.677**	*	**0.150**	**0.198**	*	**0.149**	**0.211**
Trans	0.017	0.044	*	0.056	0.015	*	**0.176**	0.047
Gorse	0.044	**0.115**	*	**0.534**	**0.447**	*	**0.439**	**0.115**
Bare	0.002	0.001	*	0.007	**0.223**	*	0.002	0.000
Water	0.085	0.000	*	0.016	0.069	*	0.000	0.001
Mead	0.002	0.014	*	**0.127**	0.004	*	0.054	0.000
Comp	0.007	**0.125**	*	0.040	0.041	*	0.080	**0.572**

larger than total forest area in 2003, Fig. 1). The remaining forest area occurred in patches under 1000 ha with about 4% in patches under 100 ha (Fig. 2). In 2003 the 2848 ha patch had decreased by 28% and had fragmented into three patches of 273, 751 and 1003 ha. The 1003 ha patch was located along the low Eume River gorge (Fig. 1). The area covered by patches under 100 ha increased from 1957 to 2003. The number of patches under 10 ha, and particularly those under 1 ha, also increased from 1957 to 2003, representing a higher proportion of total number of patches (Fig. 2). Subsequently, largest patch index and mean patch size decreased from 1957 to 2003 (Table 3).

As seen in Table 3, total edge length increased between the studied years and total core area decreased from 62% of total forest area in 1957 to only 44% in 2003. There was also a decline in largest patch core area. Mean distance between patch edges increased by approximately 31% from 1957 to 2003. Because of the increase in total edge length, forest patches showed an increase of 32% in the total adjacency index from 1957 to 2003 (Table 4). In 1957, forest

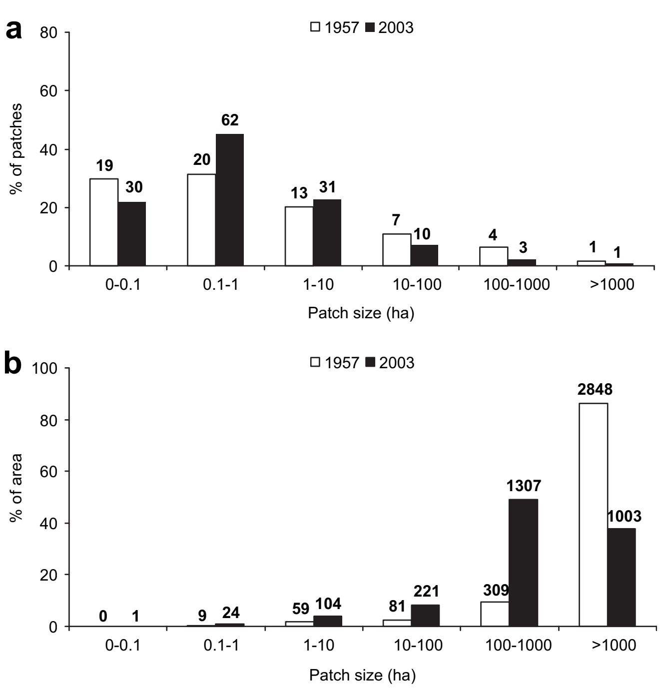

Fig. 2. Percentage of (a) patches and (b) total area of different forest patches in Fragas do Eume Natural Park. Absolute (a) number of patches and (b) area shown above each bar.

Table 3
Landscape metrics of forest in Fragas do Eume Natural Park in 1957 and 2003. The absolute and relative change of each landscape metric is also shown. Change values greater than 0 indicate gains, and those less than 0 indicate losses.

Landscape metric	1957	2003	Change 1957–2003	
			Absolute	Relative (%)
Largest patch index (%)	32	11	−22	−34.4
Mean patch size ± SD (ha)	52 ± 344	19 ± 110	−33	−63.5
Total edge length (km)	367	484	+118	+32.1
Total core area (ha)	2054	1178	−876	−42.6
Largest patch core area (ha)	1842	530	−1312	−71.2
Mean distance ± SD (m)	489 ± 315	641 ± 546	+152	+31.1

was mostly adjacent to gorse and heathlands, complex cultivation patterns, and to a lesser extent, to exotic (eucalypt and pine) plantations. In 2003, although gorse and heathland was still the major land cover class adjacent to forest, there was a substantial increase in adjacency to eucalypt and pine plantations and also to the new water reservoir (Table 4).

In 1957, a high percentage (89%) of total water course length was covered by riparian forests, including the whole length of the Eume River (Table 5, Fig. 3). In 2003, riparian forest length decreased by 34% from 142 to 94 km due to the building of the water reservoir (23%) and eucalypt plantations (11%). The water reservoir accounted for a 16 km (54%) decline in riparian forest length along the Eume River (alder forest, see Study area). However, most riparian forest destruction occurred along the Eume River tributaries (hazel forests), which experienced a 32 km decrease in length and an increase in the number of segments between 1957 and 2003 (Table 5, Fig. 3).

4. Discussion

4.1. Changes in land cover classes

Our results showed extremely high spatial heterogeneity in land cover over the whole area in both study periods, with most land cover classes consisting of a large number of patches interspersed with other classes (Fig. 1). This was related to the sparsely distributed human population, the subdivision of land in small holdings and traditional forest management in northern Spain consisting of clear-cutting for wood extraction and farming (Marey-Pérez et al., 2006).

Table 4
Absolute (km) and relative (%) adjacency index between forest and the other land cover classes in Fragas do Eume Natural Park in 1957 and 2003. The absolute and relative change of the adjacency index is also shown. Change values greater than 0 indicate gains, and those less than 0 indicate losses. * indicates that relative change (%) was not calculated because that adjacency class was absent in 1957.

Adjacent class	Adjacency index				Change 1957–2003	
	1957		2003		Absolute	Relative (%)
	(km)	(%)	(km)	(%)		
Eucalypt plantations	42.7	11.6	161.7	33.4	+119.0	+278.7
Pine plantations	0.0	0.0	8.9	1.9	+8.9	*
Transitional woodland	0.0	0.0	44.0	9.1	+44.0	*
Gorse and heathland	227.5	62.1	175.1	36.2	−52.4	−23.0
Bare rocks	31.4	8.5	0.0	0.0	−31.4	−100.0
Water reservoir	0.0	0.0	53.1	10.9	+53.1	*
Meadows and pastures	5.1	1.4	10.2	2.1	+5.1	+100.0
Complex cultivation patterns	51.3	14.0	30.5	6.3	−20.8	−40.5
Discontinuous urban fabric	0.3	0.1	0.4	0.1	+0.1	+33.3
Roads	7.0	1.9	0.0	0.0	−7.0	−100.0
Mineral extraction sites	0.6	0.2	0.0	0.0	−0.6	−100.0
Industrial units	0.6	0.2	0.0	0.0	−0.6	−100.0
Total	366.5	100.0	483.9	100.0	+117.4	+32.0

Table 5
Number of segments, absolute and relative segment length for riparian forest and deforested river courses in Fragas do Eume Natural Park in 1957 and 2003. The net change (absolute and relative) in number of segments and length is also shown. Change values greater than 0 indicate gains, and those less than 0 indicate losses.

Water courses	1957			2003			Change 1957–2003		
	Segments	Length		Segments	Length		Segments	Length	
		(km)	(%)		(km)	(%)		Absolute	Relative (%)
Deforested	82	17.0	10.7	106	29.0	23.7	+24	+12	+41.4
Riparian forest	50	141.7	89.3	74	93.6	76.3	+24	−48.1	−33.9
Eume River	1	29.6	18.7	1	13.6	11.1	0	−16	−54.1
Eume tributaries	49	112.1	70.6	73	80.0	65.2	+24	−32.1	−28.6
Total	132	158.7	100.0	180	122.6	100.0	+48	−36.1	−22.7

Land cover area comparisons and detailed transition analyses showed that the landscape was highly dynamic over the 50-year period, mostly due to the establishment of exotic species plantations (especially eucalypt), farming abandonment and the building of a water reservoir. Eucalypt plantations were mostly introduced in northern Spain during the second half of the 20th century in order to produce pulp (Manuel and Gil, 2002; Nuñez-Regueira et al., 2002). This activity is still maintained at present and represents one of the major landscape impacts on rural lowlands in northern Spain (Loidi, 1994). In fact, our results showed that all major land cover classes present in 1957, especially those of complex cultivation patterns, had been partly replaced by eucalypt plantations in 2003. Farming abandonment also represented large landscape changes due to the depopulation of these rural lowlands during the second half of the 20th century (Calvo-Iglesias et al., 2006; Marey-Pérez et al., 2006). The abandoned cultivated areas were replaced by shrubby vegetation represented by gorse and heathland associated with ecological succession. Gorse shrub and heathland mainly changed to eucalypt plantations. However, it should be noted that gorse (*Ulex* spp.) and heath (*Erica* spp. and *Calluna vulgaris*) species frequently persist in the understory of eucalypt plantations (Basanta et al., 1989). Meadows and pastures followed a similar pattern. Most of the meadow and pasture areas present in 1957 were also converted into eucalypt plantations, shrubs and even transitional forest. However, in 2003 meadows and pastures experienced a net increase in area, as a relatively large proportion of the gorse and heathland present in 1957 converted into meadows and pastures, probably due to increased fire frequency (Moreira et al., 2001).

4.2. Changes in forest pattern

Forest area decreased by approximately 20% in Fragas do Eume Natural Park from 1957 to 2003. This change represents an annual deforestation rate of −0.47% (r calculated according to Puyravaud, 2003) which is comparable to that estimated for other temperate forests (e.g. Staus et al., 2002; Kennedy and Spies, 2005). Because the 20% decline is a net change, it resulted from both losses and gains in area. Forest loss in the study area was mainly due to an increase in exotic plantations (mostly eucalypt), as shown for other regions in northern Spain (Loidi, 1994) and, to a lesser degree, the building of a water reservoir. This contrasts with the high forest losses reported over the last few decades due to logging and agriculture, particularly in tropical areas (e.g. Steininger et al., 2001; Gaveau et al., 2007). These factors were also important in European forests, but prior to the study period (Grashof-Bokdam, 1997; Santos et al., 2002). Forest gains were mainly due to transitions from meadows and pastures, gorse and heathland, and complex cultivation patterns, suggesting some regeneration through ecological succession from land abandonment. Some regeneration can also be inferred from the increase in transitional woodland from 0% in 1957 to 3.4% of landscape in 2003.

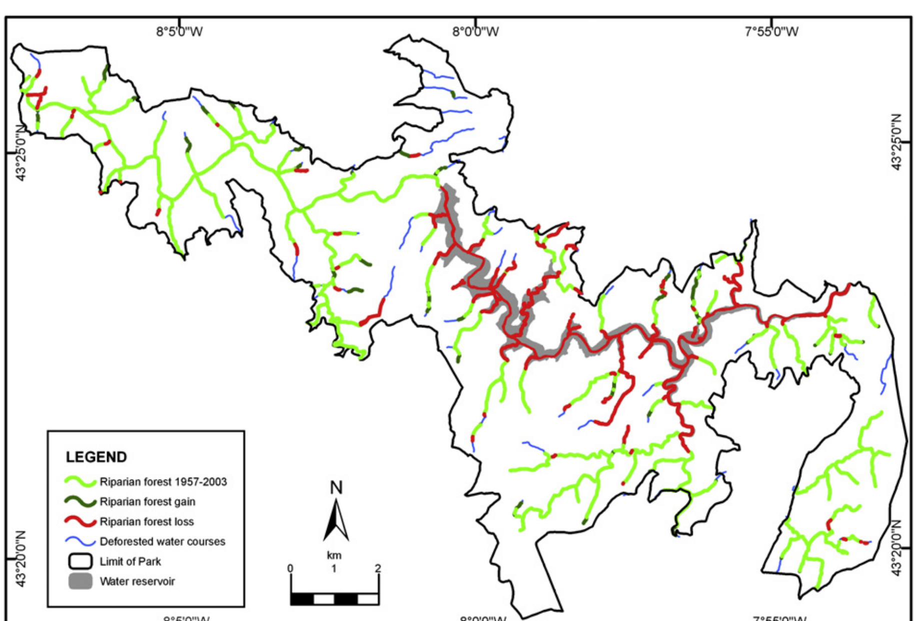

Fig. 3. Changes in the spatial distribution of riparian forest in Fragas do Eume Natural Park.

Forest covered about 30% of landscape in 2003, which is similar to other fragmented temperate forests (e.g. Fuller, 2001; Pan et al., 2001; García et al., 2005; but see Santos et al., 2002). However, this figure is higher than the estimated 20% for the Atlantic forests of Galicia (Ministerio de Medio Ambiente, 2002). This may be due to the complex relief of Fragas do Eume Natural Park, which may have favoured large forest areas on less accessible slopes (Saura and Carballal, 2004).

In addition to the general decline in total forest area, our results showed substantial changes in forest spatial patterns (Table 3), which suggests an increase in forest fragmentation over time. These changes are qualitatively similar to those reported in other forest studies (e.g. Fuller, 2001; Echeverria et al., 2006). The fine resolution (0.01 ha) used to map patches in this study, compared to the larger resolutions applied in some forest studies (e.g. Echeverria et al., 2006; Plieninger, 2006), allowed us to determine that over 20% of patches were smaller than 0.1 ha and over 60% were smaller than 1 ha in both of the study years (Fig. 2).

The temporal changes in forest patterns also implied changes in the nature of the adjacent land cover classes. The most relevant changes were the great increase in adjacency to eucalypt plantations and the water reservoir. Exotic eucalypts are known to spread easily around and into native forest patches due to their high growth rate and ability to alter forest floor quality (Fabião et al., 2002; Fernández et al., 2004). The water reservoir may also have led to structural changes in forest edges by facilitating the establishment of eucalypts and shrubs at reservoir shores (Harper and MacDonald, 2001).

Changes in forest patterns (reductions in patch size and core area, and increases in edge length and isolation) may have negative ecological implications on forest specialists over time. However, studies relating fragmentation and ecological diversity are still scarce in the Atlantic forests of northern Spain and most evidence comes from other areas or different forest types in nearby regions (e.g. Porej et al., 2004; García et al., 2005; Pardini et al., 2005; Quevedo et al., 2006).

Changes in adjacency may also have negative implications on forest specialists. In particular, the marked increase in forest edge length adjacent to eucalypt plantations probably increased forest species' isolation. Eucalypt plantations are known to generate ecological disturbances, such as increases in soil dryness and erosion, which may result in declines in plant species diversity (Fabião et al., 2002; Carneiro et al., 2008) and density of some animals such as the northern-Iberian endemic amphibian *C. lusitanica* (Vences, 1993).

4.3. Changes in riparian forest patterns

Although the analyses of changes in riparian forest patterns were more limited than for the whole forest class, they deserve special attention due to their ecological importance. Our results suggest an increase in fragmentation over time (Table 5). In principle, this habitat appeared to be relatively well-conserved, because 76% of total river course length was still covered by riparian forest in 2003. However, this land cover class experienced one of the greatest declines over the study period (34%; cf. Tables 1 and 5). The major causes were the building of the water reservoir, which mostly affected the alder forest of the Eume River, and the impact of eucalypt plantations, which mainly altered the hazel forests of tributaries. Thus, evaluation of habitat conservation status based solely on a snapshot of the landscape could lead to misleading conclusions.

Riparian forests have a range of ecological properties which make them particularly important landscape components. Firstly, riparian forests act as dispersal corridors, facilitating individual exchange between natural habitat patches (e.g. Naiman et al., 1993; Mech and Hallett, 2001; Haddad et al., 2003). Specifically, this has been found for some threatened ferns (Quintanilla et al., 2007) and for the amphibian *C. lusitanica* (Alexandrino et al., 2000) in Atlantic regions. Secondly, riparian forests may act as buffers for some forest specialists in fragmented landscapes, as for instance mitigating the impacts derived from forest harvesting and exotic plantations (Cockle and Richardson, 2003; Boothroyd et al., 2004; Homyack and Haas, 2009).

5. Conclusions

The marked changes in landscape composition found in Fragas do Eume Natural Park between 1957 and 2003 were mainly driven by anthropogenic factors such as the intensification of eucalypt plantations, farming abandonment and the building of a water reservoir. Anthropogenic factors also modified forest spatial patterns, as a more fragmented distribution was found in 2003 than in 1957. The temporal changes in spatial patterns were accompanied by substantial modifications in the nature of the habitats adjacent to forest patches (e.g. eucalypt plantations). Riparian forest was one of the land cover classes that suffered major declines over the study period due to the building of a water reservoir and the impact of eucalypt plantations. It should be noted that Natural Park regulations (Consellería de Agricultura, Ganadería y Montes, 1996) have virtually stopped forest loss during the last few years (personal observation). These regulations also establish that meadow, pasture, gorse and heathland areas can be restored into forest, although this has not yet been put into practice. We think that restoration efforts should focus on connecting the largest forest patches. However, more research is needed to determine the effects of forest patch size, isolation and adjacency as well as of riparian forests on both species richness and the distribution and abundance of forest specialists, particularly of those endangered species inhabiting the Atlantic forests in northern Spain.

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