

Descriptive analysis of the ‘relictual’ Mediterranean landscape in the Guadalquivir River valley (southern Spain): a baseline for scientific research and the development of conservation action plans

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Abstract Landscape fragmentation is ancient and severe in the countryside of the Guadalquivir river valley (Western Andalusia, Southern Spain). BIANDOCC is a project that aims to inventory all the forest patches embedded in this anthropogenic area to record quantitative, qualitative, and descriptive information about management, conservation status, vegetation physiognomy and floristic richness. We have characterized a ‘relictual’ landscape ($\approx 1\%$ of habitat retention) where nearly 70% of the patches ($N = 535$) are owned by private landowners who manage them to harvest pine nuts, cork, and firewood, for coal making, cattle raising, and to a lesser extent, beekeeping and agriculture. The publicly owned patches are intensively used for recreation. As a consequence, the vegetation physiognomy and conservation status in most forest stands is impoverished, with low shrub diversity and coverage and none or very low natural tree regeneration. Furthermore, patch size, connectedness and patch fractal dimension (i.e. microhabitat diversity) are all very low. However, the botanic richness is worth mentioning: 1,032 plant taxa have been identified, of which 70 are catalogued in an official red list, 39 are relevant chorological novelties, and one was newly described for science. Therefore, and interestingly, the remnant forest patches in the studied area can be regarded as relevant biodiversity reservoirs. The project reported here constitutes an important baseline for developing true conservation action plans and provides an opportunity to address the potential ecological and biological effects of fragmentation to plant genes, species, populations and communities, at the regional scale of the study, which are enhanced by the emergent landscape genetics and landscape ecology analytical tools.

Keywords Biodiversity · Connectivity · FRAGSTATS · Habitat fragmentation · Habitat loss · isolation · Mediterranean vegetation

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Introduction

From a historical perspective, intensive anthropogenic pressures on forests for cultivation, grazing, and the growing of fodder crops started to significantly clear and open the forest canopy in Europe about 6,000 years BP (Williams 2000). Nowadays, the Mediterranean forests cover only about 10% of their original areas, and just 1% of the whole forested surface in Western Europe corresponds to long-established forests (McNeely et al. 1995). The continuous management has resulted in the replacement of original forests with monospecific plantations with very low species richness and structural diversity (Godefroid and Koedam 2003). The Iberian Peninsula has witnessed the same long history of management and deforestation, since by Roman times it had already lost more than 50% of its forest canopy. Further anthropogenic management from the Middle Ages to nowadays has modelled the landscape to a scattered constellation of forested patches embedded within a highly agricultural matrix (Valladares et al. 2004).

From a biological perspective, habitat loss is a major threat to biodiversity causing the extinction of species either in the short or in the long term (Fahrig 2003), and as a dynamic element in landscape ecology, the study of habitat fragmentation has become an emergent field in ecological research (Haila 2002).

So, in the last 5 years, more than 3,000 studies (SCI database) have been published worldwide dealing with the consequences of terrestrial habitat loss and fragmentation, where precise aspects of population genetic structure and gene flow, reproductive biology and demography, population dynamics and viability, patterns of species composition and biodiversity, dispersal and migration, management of forests, among others have been addressed. Interestingly, empirical works have demonstrated that fragmentation is not always detrimental and that affects species differently (Culley and Grubb 2003), even promoting gene flow in some forest tree species (White et al. 2002). Moreover, not only habitat fragmentation per se, but the different landscape configurations that can be released by a variety of disturbances are crucial in the assessment of management and scientific research programs (McIntyre and Hobbs 1999). To sum up, Clarke and Young (2000) underlined that the proposal of conservation action plans for species and ecosystems requires not only qualitative, but also quantitative and multidisciplinary approaches, that encompass areas ranging from the monitoring and management of the genetic diversity of individuals, populations and species to more comprehensive landscape ecology perspectives.

The potential effects of habitat fragmentation in the mediterranean vegetation in the Iberian Peninsula have also attracted the researchers and many aspects have been investigated at different spatial and temporal scales and community types. For example, valuable data are available about vegetation dynamic and secondary succession after forest fragmentation and abandonment (Crespi et al. 2005; Pueyo and Alados 2007), patterns of species richness and composition in human disturbed-areas (Chust et al. 2006; Guirado et al. 2006, 2007), quantification of land-use change in time (Alados et al. 2004; Plieninger 2006), genetic structuring of populations in fragmented landscapes (López-Pujol et al. 2003; Robledo-Arnuncio et al. 2005; Jump and Peñuelas 2006), regeneration of populations (Jordano et al. 2007), disruption of plant-animal interactions in heterogeneous habitats (Fortuna and Bascompte 2006; García and Chacoff 2007), and reproductive biology of species (Lázaro and Traveset 2006).

In this paper, I describe the project BIANDOCC ('Island Forests' in Western Andalusia) that aimed to inventory and botanically and ecologically characterize the landscape and every remnant forest patch across the countryside of the Guadalquivir river valley (Western Andalusia, Southern Spain), the area being illustrative of an extreme situation of chronic

fragmentation and isolation in the Mediterranean forest. The summarized objectives in the project were: (1) to record the location, area and shape of forest patches in the studied area; (2) to categorize actual vegetation with regard to structure and floristic composition, paying special attention to endangered and endemic flora; (3) to identify current anthropogenic pressures; (4) to detect plagues or threats to forest trees; (5) to record the conservation status and the degree of natural regeneration within the patches, and (6) to detect changes in the spatial configuration of the forest patches in time (the last 50 years). The database generated in the project is unique (no comparable database seems to be available in Europe) in containing detailed spatial, botanical and ecological data at patch level.

Material and methods

Studied area

Western Andalusia is located at the southernmost tip of the Iberian Peninsula, between the Gulf of Cádiz in the Atlantic Ocean and the Mediterranean Sea at both sides of the Strait of Gibraltar. The studied area is the Guadalquivir river valley depression, an area of 21,000 km² located between the natural boundaries of Sierra Morena in the north and the Betic Mountains in the south (Fig. 1). Mountains and legally protected areas (natural reserves, natural parks and national parks) have been explicitly excluded from the study. The Guadalquivir depression is a fertile countryside long devoted to intensive agriculture: olives, cereals, sunflower, beetroot, cotton, legumes, opium poppies, vineyards, orchards, and greenhouses, along with oranges, figs, pine trees and *Eucalyptus* plantations. The orography in the area is flat, ranging in altitude between sea level and 200 m. Lithologically, the area is made up of sediments from the Miocene to Quaternary, and its soils are derived from marls, clays, limestones, chalkstone, calcareous and siliceous sandstones and silty alluvials from the Guadalquivir and other tributary rivers (Jordán 1999). The climate is typically Mediterranean, with warm dry summers and cool humid winters. Mean annual temperatures range from 15 to 18.5°C, and annual precipitation is between 460 and 1,020 mm. Under a bioclimatic perspective, the area corresponds to the thermo-meso-mediterranean thermotype and the dry–subhumid ombrotype (Rivas-Martínez et al. 1997). Although virtually eliminated from the area, the esclerophyllous Mediterranean maquis associated with *Quercus suber* L. and *Q. ilex* subsp. *ballota* (Desf.) Samp. (accompanied by *Q. faginea* Lam. in wetter conditions) is native to the entire region and has potential for vegetation (Rivas-Martínez 1987). However, disclimatic plantations of stone pine (*Pinus pinea* L.) dating back to the eighteenth century are extensive in the area, and have become representatives of semi-natural vegetation (Granados et al. 1988).

Patch selection

We have inventoried every patch of natural or semi-natural vegetation >0.2 ha with high tree cover and a hard edge (i.e. surrounded by an anthropogenic matrix). As a first step, these elements were searched for using the Andalusian digital land cover images (1:50,000), by selecting polygons where the tree canopy was >50%. This resulted in a new coverage, including oak and pine tree woodlands and savannas, which was then superimposed on the 1999 satellite IRS Pan images (1:50,000) and the aerial digital orthophotos of Andalusia 1:5,000 (Junta de Andalucía 2004).

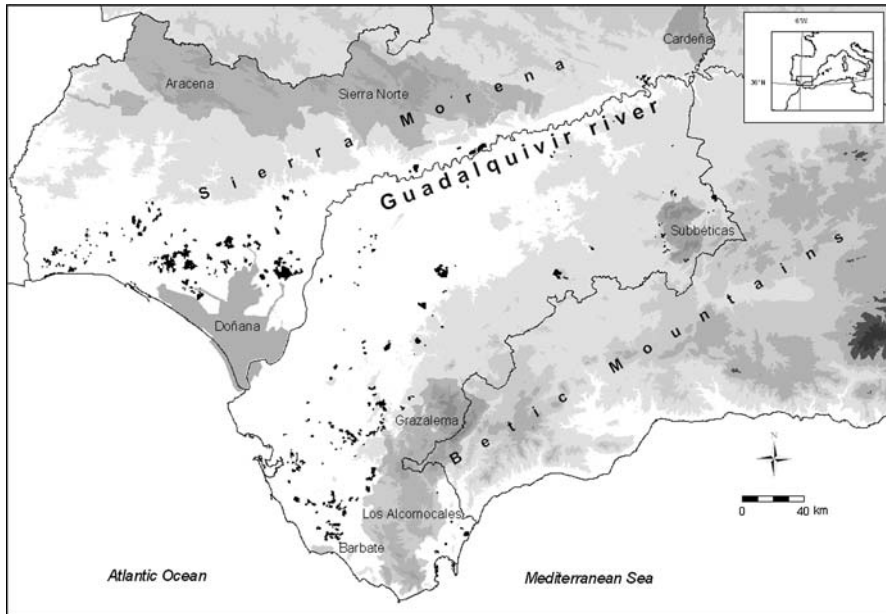


Fig. 1 Studied area in Western Andalusia (outlined). Light colour is the Guadalquivir depression (<200 m in altitude), a fertile countryside where the forest patches of BIANDOCC are embedded. Legally protected areas (national parks and natural parks) in Western Andalusia are shaded and labelled

Field work

Field work consisted of 140-day field trips with 2–4 researchers between 1999 and 2001 to locate and inventory every patch in the cartographic region, gathering quantitative, qualitative and descriptive information as depicted in Table 1 (i.e. description, management, conservation status, vegetation physiognomy and floristic composition). All patches were visited at least once, but attempts were made to visit the patches in different seasons whenever possible. Floristic composition and species richness was surveyed following an individual-based method (Gotelli and Colwell 2001) by random walks through a patch by two to three researchers, with the number of walks and time spent in a patch being proportional to its size and heterogeneity (cf. Kirby et al. 1986). Vouchers were collected and deposited in the herbarium SEV. Botanical nomenclature followed Valdés et al. (1987) and Castroviejo (1986–2005). Vegetation physiognomy was subjectively assessed by estimating tree, shrub, pasture and bare soil cover. Patches with shrub cover >25% were further sampled by randomly setting two to five (according to patch area) 20 m quantitative line transects for woody vegetation. The conservation status was estimated by a subjective consensus value (1–4) achieved between two and four investigators according to the vegetation physiognomy and the existence of cattle dung, track roads, rubbish, buildings, cartridges, barbecues, erosion, etc. Geographic coordinates of all sampling points were GPS recorded.

GIS and database

Inventoried patches were digitalized on-screen (ArcGis 9.0, ArcMap) on the digital aerial orthophotos (Junta de Andalucía 2004), setting the scale to 1:10 000. In the corresponding PAT table of this polygon coverage, the binary and indexed COD_POL field unequivocally

Table 1 Information recorded in the input data tables of the BIANDOCC database for the characterization of patches

Descriptive	Area	Imported from GIS
	Perimeter	Imported from GIS
	Biogeographical unit	According to Rivas-Martínez et al. (1997)
	Ombroclimate	Subhumid, humid (Rivas-Martínez et al. 1997)
	Bioclimatic belt	Thermo-mediterranean, meso-mediterranean (Rivas-Martínez et al. 1997)
	Potential vegetation	According to the phytosociological climatophilous vegetation series (Rivas-Martínez 1987)
	Photographed	No, yes
	Brief description	Including 'how to get there'
Management	Owner	Private, national government, regional government, municipality
	Current use	Cattle raising, hunting reserve, forestry, agriculture, beekeeping, property boundary, recreation
	Flammability	Grass, needles and leaves, wood piles, firewood
	Legal status	According to Nature 2000 network (Sites of Community Importance)
Conservation status	Subjective conservation status	Very low, limited, good, excellent
	Current threats	None, fires, urbanization, clearing, grazing, erosion, rubbish, roads, reservoirs, quarries, agriculture, cattle raising
	Natural tree regeneration	None, low, medium, high
	Plagues or threats	None, gypsy moth, processionary caterpillar, defoliation, drilling
Vegetation structure	Tree coverage	<25%, 26–50%, 51–75%, 76–100%
	Shrub coverage	<25%, 26–50%, 51–75%, 76–100%
	Pasture coverage	<25%, 26–50%, 51–75%, 76–100%
	Bare soil coverage	<25%, 26–50%, 51–75%, 76–100%
Floristic	Plant communities	Any, if included in the Habitat Directive 92/43/CCE
	Plant species composition	Random walks, line transects, 20 m

The information provides a comprehensive description of general ecological and biogeographic features, management, conservation status and floristic composition. Boldfaced items indicate information gathered in the field

identified and included each individual forest patch. Two further point coverages were created that included the geographic location of sampling points. Complementarily, a Microsoft™ Access 2000 database integrated with 21 input data tables and 25 dictionary tables was created, and all information (see Table 1) stored. The field COD_POL contained the primary key, and linked the database to the digital cartography. Both the database and the cartography are property of the Consejería de Medio Ambiente (Junta de Andalucía).

FRAGSTATS (v 3.3) is a spatial pattern analysis software that computes landscape metrics for categorical maps (McGarigal et al. 2002). Based on 30 m cell grids, we quantified the spatial configuration and the shape of the patches within our precise landscape by computing CONNECT and FRACT. CONNECT, or patch connectedness, measures the percentage of functional joinings between patches, where each pair of patches is either connected or not connected based on user specified threshold distances (250 and 5,000 m in this study). FRACT, or patch fractal dimension, is a log-based measure of patch shape complexity (i.e. microhabitat diversity), increasing (between 1 and 2) for highly convoluted or plane-filling perimeters (Honnay et al. 1999).

Results

After the GIS analysis and the field work, 535 forest patches were located and inventoried (Fig. 1), totalling a surface of 22931.5 ha ($\approx 1\%$ of the of the Guadalquivir river valley). Patch area oscillated to four orders of magnitude between 0.19 and 1,737 ha, but mean (\pm SD) and median values of the frequency distribution were 42.86 ± 102 and 12.3 ha, respectively (Fig. 2). The percentage of patch connectedness was low both for the 250 m ($\text{CONNECT}_{250} = 0.12\%$) and the 5,000 m ($\text{CONNECT}_{5000} = 1.79\%$) threshold distances. Patches showed low shape complexity with FRACT values ranging between 1.00 and 1.25 and an overall mean (\pm SD) value of 1.09 ± 0.04 .

The descriptive features of forest stands in BIANDOCC are listed in Table 2. It is remarkable that most patches are intensively managed by private landowners with very low conservation status and tree regeneration. Surrounding agriculture and cattle raising were the most frequently detected threats. Physiologically, stone pine (*P. pinea*), cork oak (*Q. suber*), and holm oak (*Q. ilex* subsp. *ballota*) are the predominant tree species in 412 (77%) patches, forming either pure or mixed stands (Table 3). Although patches were pre-selected in the polygon cartography by having high tree coverage ($>50\%$), field observations showed that about 25% had tree coverage between 25% and 50% (Table 4). Concordant with the overall low conservation status, nearly 45% of the patches had very scarce shrub coverage, and 38% had very high bare soil coverage (Fig. 3).

Patches were visited once (62.6%), twice (23.1%), three (4.11%) or more times (0.37%) in different seasons according to conservation status. In all, 1,032 autochthonous taxa belonging to 90 vascular plant families were identified, out of which 70 are included in the 'Red List of the Vascular Flora of Andalusia' (Cabezudo et al. 2005) (see Appendix). These catalogued species were collected from a mean (\pm SD) number of patches of 6.0 ± 7.7 . We found a set of worth mentioning chorological novelties, and described a new plant species. With regard to woody species, mean (\pm SD) species richness at the patch level was 13.4 ± 7.1 (range 1–38), where *Asparagus* spp., *Cistus* spp., *Daphne gnidium*, *Chamaerops humilis*, *Pistacia lentiscus*, *Halimium halimifolium*, *Lavandula stoechas*, *Olea europaea*, *Myrtus communis*, *Quercus coccifera*, *Phlomis purpurea* and *Retama sphaerocarpa* were the most frequently recorded species.

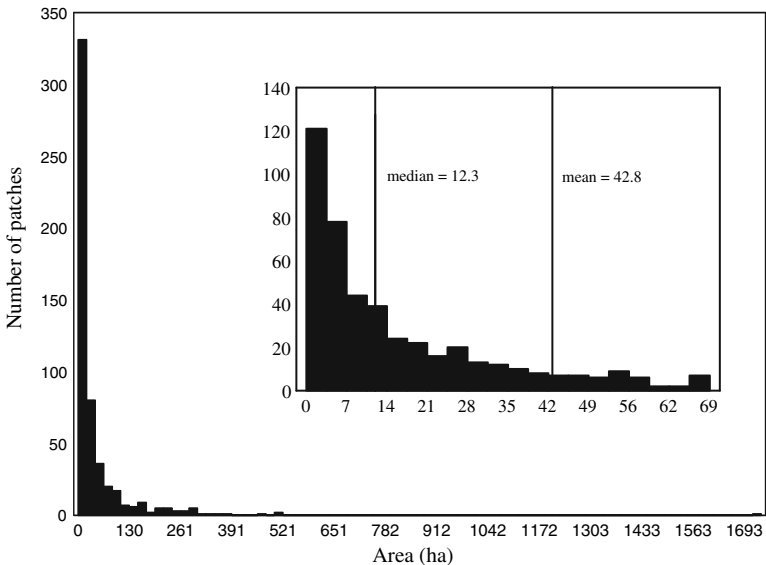


Fig. 2 Frequency distribution of patch size (80 classes) in BIANDOCC ($N = 535$). The insert shows the frequency distribution of patches (20 classes) whose area is below 70 ha ($N = 453$) with the median and mean values of the whole distribution

Discussion

Botanic enhancement

From a botanic perspective, anthropogenic areas devoted to extensive agriculture have received little attention. The present paper reports the only comprehensive ecological and botanical survey in the Guadalquivir river valley, focusing on forested patches of mediterranean vegetation that continuous and intense anthropogenic pressures have reduced to just 1% of their potential areas (Rivas-Martínez 1987).

Botanically, 1,032 non-allochthonous taxa (169 woody or climbing) belonging to 90 vascular plant families were identified during the study. This means that in $\approx 0.5\%$ of the Western Andalusia area, 35% of the species and 66% of the families in the regional flora are represented. According to the regional pattern, close to 25% of the botanical species collected within the fragments were endemic (from local to Ibero-Mauritanian distributions).

The botanical value of BIANDOCC is further qualitatively stressed (1) by the fact that 70 ($\approx 7\%$) of these taxa are in the updated ‘Red List of the Vascular Flora of Andalusia’ (Cabezudo et al. 2005), of which 37 are in IUCN (2001) CR, EN or VU categories, (2) because 39 collected taxa were important chorological novelties (Garrido et al. 2002), and (3) because one newly described species was found (Aparicio 2005). Jointly, these reports underline that despite the long history and the intensity of the past and present management of the natural vegetation in the Guadalquivir river depression, the forest patches are currently a true shelter for plant species and a valuable biodiversity reservoir.

Table 2 Characterization of the forest stands in BIANDOCC. Numbers are the percentage of patches ($N = 535$) recorded in each category. Notice that most single patches were recorded with more than one ‘current use’ and ‘current threats’

		%
Owner	Private	67.66
	Regional Government	30.28
	Public/Private	1.12
	National Government	0.93
Current use	Forestry	70.28
	Cattle raising	50.84
	Hunting	50.47
	Property boundary	22.24
	Recreation	13.27
	None	7.10
	Beekeeping	4.11
	Agriculture	3.74
	Other	0.56
Legal status	Non-categorized	86.92
	Exceptional forested landscapes	12.34
	Relevant agricultural landscapes	0.37
	‘Unique’ landscapes	0.37
Conservation status	Very low	59.63
	Limited	23.93
	Good	16.26
	Excellent	0.19
Current threats	Agriculture	70.47
	Cattle	36.26
	Rubbish	13.27
	Urbanization	12.52
	Recreation	10.84
	None	10.09
	Quarry in the proximity	5.79
	Erosion	4.86
	Grazing	2.80
	Fires	2.24
	Basic infrastructures (roads, reservoirs)	2.06
	Eucalyptus plantations	1.68
	Quarry exploitation	0.56
Golf courses	0.19	
Natural regeneration of tree species	None	37.76
	Low	26.17
	Medium	24.67
	High	11.40
Plagues or threats	None	88.04
	Processionary caterpillar	5.42
	Defoliation	3.36
	Drilling	3.18

Conservation

Within a particular landscape, the proportion of suitable habitat retention is responsible for the severity of the fragmentation effects (Andren 1994; Boutin and Herbert 2002). McIntyre and Hobbs (1999) defined four states of landscape alteration according to the

Table 3 Vegetation typology of the 535 forest stands inventoried in BIANDOCC according to the dominant tree species

	Number of patches	Surface (ha)
Mixed stands of pine trees and oaks	141	8681.2
Cork oak (<i>Q. suber</i> L.)	91	5269.4
Holm oak (<i>Q. ilex</i> subsp. <i>ballota</i> (Desf.) Samp.)	81	3754.8
Stone pine (<i>P. pinea</i> L.)	99	1943.5
Wild olive (<i>Olea europaea</i> var. <i>sylvestris</i> Brot.)	48	1307.8
Swamp pine (<i>P. halepensis</i> Miller)	28	987.0
Abandoned olive (<i>Olea europaea</i> L. var. <i>europaea</i>) cultivations	19	517.8
Mixed stands of pine trees	26	436.9
Muricated oak (<i>Q. faginea</i> Lam.)	1	30.0
Maritime pine (<i>P. pinaster</i> Aiton)	1	2.7

Table 4 Vegetation physiognomy of the 535 forest stands inventoried in BIANDOCC

Coverage (%)	Tree	Shrub	Pasture	Bare soil
Absent	0	1.50	0.75	0.37
<25	1.50	42.80	29.35	59.81
26–50	23.74	22.80	22.99	27.48
51–75	46.36	24.30	19.07	8.60
>76	28.41	8.60	27.85	3.74

Numbers are the percentage of patches recorded in each category of coverage and vegetation layer

degree of habitat destruction that varied from ‘intact’ to ‘relictual’. In intact landscapes, more than 90% of the original habitat remains, with high connectivity among patches, whereas in relictual landscapes, not only is the degree of destruction of the habitat extreme (remaining <10%), but there is low or null connectivity among patches, and the remaining habitats are highly modified. Relictual landscapes are the most vulnerable, since they are associated with urban and intensive agricultural regions where economic pressures recurrently destroy the habitat. Our data show that BIANDOCC is a neat ‘relictual’ landscape where both overall patch area (median area = 12.3 ha) and shape complexity (FRAC = 1.09) are very low, and where the spatial connectivity among such patches is mostly lacking, even when taking large distances into account (CONNECT₅₀₀₀ = 1.79%).

We found that as a consequence of intensive anthropogenic management the vegetation in most forest stands is impoverished and in a poor conservation status, with low shrub diversity and coverage and none or very low natural tree regeneration. Given the small patch size and low connectedness in our study area, the surrounding agriculture, urbanization pressure, and rubbish deposition are imminent threats if action plans are not urgently developed and adequately implemented. Although even small patches can persist in these ‘relictual’ conditions, biodiversity components and ecological interactions are seriously at risk (McIntyre and Hobbs 1999).

Scientific research

The basic axiom in biological conservation is that the biology of the species or systems targeted for conservation has to be understood, taking into account the different scales at which biodiversity can be measured and the genetic processes that determine the performance



Fig. 3 Individual features in the ‘relictual’ landscape of BIANDOCC, where patches are small, isolated, and representative of a highly modified habitat. Cork oak and holm oak forests are native and have potential for vegetation in this territory, which is currently devoted to extensive agriculture, but where semi-natural instances of disclimatic plantations of stone pine (*P. pinea*) are very common

of populations (Picó and van Groenendael 2007). In this regard, the database described in the present study constitutes an important baseline to address habitat fragmentation of mediterranea forests under the emerging landscape genetics and landscape ecology perspectives.

Population and landscape genetics are of interest in describing and understanding micro-evolutionary processes that generate genetic structure across space, such as gene flow and local adaptation. This is crucial not only for scientific knowledge, but for practitioners as well (Manel et al. 2003). The detailed spatial information contained in BIANDOCC is valuable to compare the patterns of genetic diversity and structure within and among populations in selected ecologically ‘keystone species’ (Mills et al. 1993) or between common and rare species (Whiteley et al. 2006), and to assess the relative importance of genetic drift and gene flow in a historical time scale. On the other hand, the use of highly variable genetic markers (AFLP and nSSR) and the statistical power of Assignment Tests (Manel et al. 2005), Twogener (Smouse et al. 2001), and Kinship Coefficients (Hardy et al. 2004) allows the gauging of the fine spatial genetic structure of populations and the gene flow rates (pollen and seed mediated) at an ecological time scale.

Landscape ecology deals with the spatial extent and configuration at which ecological patterns and processes take place (Turner 2005). One of the most outstanding ecological patterns is the species–area relationship (Lomolino 2000), which has been frequently used as a conceptual framework in biological conservation, and maximizing the species number in patchy landscapes (e.g. the SLOSS approach) became an objective in itself (Honnay et al. 1999). However, both theoretical and empirical works have shown that the extinction of species in mosaic landscapes becomes more and more frequent as habitats continue to disappear due to the existence of ‘fragmentation thresholds’ (Bascompte and Solé 1996; Fahrig 2002). The data in BIANDOCC are suited to explore the patterns of variation of species richness and composition, by using a Model Selection approach based on Information Theory procedures (Johnson and Omland 2004), and the existence of fragmentation thresholds, both at patch and landscape levels, working out the linearity of the relationship. Furthermore, it is possible to study the spatial modularity in the landscape by identifying modules, or groups of patches, trying to decipher the functional role of every single patch as a function of its structural situation in the spatial network

(Fortuna et al. 2006). Functional traits of plants (life-form, mating system, dispersal ability) are also key elements in all these approaches.

Finally, Simulated Annealing (Dupanlup et al. 2002) and Population Graph (Dyer and Nason 2004) are emerging approaches to integrate genetic and landscape data to create complex spatial topologies resulting from the interaction of genetic processes within and among populations, both at historical and ecological time scales. Hypotheses related to vicariance, isolation by distance, genetic connectivity, or complex phylogeographic patterns (Dyer and Nason 2004) can be evaluated, and landscape genetics and landscape ecology approaches integrated (Storfer et al. 2007) in the BIANDOCC project.

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Appendix

Plant taxa collected from the remnant forest patches of Western Andalusia included in the Red List of the Vascular Flora of Andalusia (Cabezudo et al. 2005), and the number of patches in which they were collected

	No. of patches
Critically endangered (CR)	
<i>Limonium silvestrei</i> Aparicio	1
<i>Fumana juniperina</i> (Dunal) Pau	2
<i>Ononis azcaratei</i> Devesa	1
<i>Adenocarpus gibbsianus</i> Castroviejo and Talavera	1
<i>Genista ancistrocarpa</i> Spach	2
<i>Thymelaea lythroides</i> Barratte and Murb.	1
<i>Thymus albicans</i> Hoffm. and Link	9
<i>Allium pruinatum</i> Link ex Sprengel	9
Mean \pm SD	3.6 \pm 4.0
Endangered (EN)	
<i>Juniperus oxycedrus</i> subsp. <i>macrocarpa</i> (Sibth. and Sm.) Ball	1
<i>Dianthus broteri</i> Boiss. and Reuter	8
<i>Iberis ciliata</i> subsp. <i>welwitschii</i> (Boiss.) Moreno	4
<i>Pistorinia breviflora</i> Boiss.	13
<i>Lathyrus nudicaulis</i> (Wilk.) Amo	1
<i>Ononis leucotricha</i> Cosson	5
<i>Plantago algarbiensis</i> Samp.	4
<i>Galium concatenatum</i> Cosson	3
<i>Klasea monardii</i> (Dufour) J. Holub	2
<i>Centaurea aspera</i> subsp. <i>scorpiurifolia</i> (Dufour) Nyman	7
<i>Anthemis bourgaei</i> Boiss. and Reuter	1
Mean \pm SD	4.4 \pm 3.7

		No. of patches
Vulnerable (VU)	<i>Juniperus phoenicea</i> subsp. <i>turbinata</i> (Guss.) Nyman	10
	<i>Armeria macrophylla</i> Boiss. and Reuter	8
	<i>Armeria gaditana</i> Boiss.	10
	<i>Erica lusitanica</i> Rudolphi	1
	<i>Erica andevalensis</i> Cabezudo and Rivera	1
	<i>Erica ciliaris</i> L.	1
	<i>Mercurialis elliptica</i> Lam.	23
	<i>Euphorbia baetica</i> Boiss.	10
	<i>Eryngium corniculatum</i> Lam.	2
	<i>Eryngium galioides</i> Lam.	1
	<i>Triguera osbeckii</i> (L.) Willk.	1
	<i>Echium gaditanum</i> Boiss.	6
	<i>Linaria munbyana</i> (Boiss.) Boiss. and Reuter	1
	<i>Centaurea exarata</i> Cosson	7
	<i>Cynara algarbiensis</i> Cosson ex Mariz	3
	<i>Heteranthemis viscidhirta</i> Schott	3
	<i>Hymenostemma pseudoanthesis</i> (G. Kuntze) Willk.	10
<i>Gaudinia hispanica</i> Stace and Tutin	8	
Mean \pm SD		5.7 \pm 5.9
Nearly threatened (NT)	<i>Asplenium billotii</i> F. Schultz	4
	<i>Juniperus phoenicea</i> L. subsp. <i>Phoenicea</i>	9
	<i>Quercus lusitanica</i> Lam.	1
	<i>Silene mariana</i> Pau	2
	<i>Loeflingia baetica</i> Lag.	32
	<i>Armeria velutina</i> Boiss. and Reuter	34
	<i>Celtis australis</i> L.	1
	<i>Drosophyllum lusitanicum</i> (L.) Link.	1
	<i>Ulex minor</i> Roth	16
	<i>Oenanthe pimpinelloides</i> L.	1
	<i>Sideritis perezlarae</i> (Borja) Obón and Rivera	4
	<i>Antirrhinum graniticum</i> subsp. <i>Onubensis</i> (F. Casas) Valdés	3
	<i>Verbascum barnadesii</i> Vahl	1
	<i>Pancreatium maritimum</i> L.	3
Mean \pm SD		8.0 \pm 11.3
Deficient data (DD)	<i>Isoetes velatum</i> A. Braun subsp. <i>Velatum</i>	2
	<i>Silene scabriflora</i> subsp. <i>tuberculata</i> (Ball) Talavera	3
	<i>Arenaria algarbiensis</i> Welw. ex Willk.	12
	<i>Armeria hirta</i> Willd.	13
	<i>Limonium ovalifolium</i> (Poiret) O. Kuntze	1
	<i>Armeria hispalensis</i> Pau	4
	<i>Armeria linkiana</i> Nieto Feliner	1
	<i>Tuberaria brevipes</i> Boiss. and Reuter	17
	<i>Tuberaria conmutata</i> Gallego	37
	<i>Tuberaria echioides</i> (Lam.) Willk.	18
	<i>Ononis cintrana</i> Brot.	3
	<i>Thymelaea pubescens</i> subsp. <i>elliptica</i> (Boiss.) Kit Tan	1
	<i>Anchusa calcarea</i> Boiss.	3
	<i>Verbascum masguindali</i> (Pau) Benedí and JM Montserrat	1
	<i>Centaurea cordubensis</i> Font Quer	4
	<i>Centaurea alba</i> subsp. <i>macrocephala</i> (Pau) Talavera	1
	<i>Triglochin laxiflora</i> Guss.	1
	<i>Juncus emmanuelis</i> A. Fernandes and García	3
	<i>Bromus macrantherus</i> Enriques	1
Mean \pm SD		6.6 \pm 9.2

Categories correspond with IUCN (2001)

References

- Alados CL, Pueyo Y, Barrantes O, Escos J, Giner L, Robles AB (2004) Variations in landscape patterns and vegetation cover between 1957 and 1994 in a semiarid Mediterranean ecosystem. *Landsc Ecol* 19: 543–559
- Andren H (1994) Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat, A review. *Oikos* 71:355–366
- Aparicio A (2005) *Limonium silvestrei* (Plumbaginaceae), a new agamospecies from southern Spain. *Annales Botanici Fennici* 42:371–377
- Bascompte J, Solé RV (1996) Habitat fragmentation and extinction thresholds in spatially explicit models. *J Anim Ecol* 65:465–473
- Boutin S, Hebert D (2002) Landscape ecology and forest management, developing an effective partnership. *Ecol Appl* 12:390–397
- Cabezudo B, Talavera S, Blanca G, Salazar C, Cueto M, Valdés B, Hernández-Bermejo E, Herrera CM, Rodríguez Hiraldo C, Navas D (2005) Lista Roja de la flora vascular de Andalucía. Junta de Andalucía, Sevilla
- Castroviejo S (1986–2005) Flora Iberica, vols I–XXI. Departamento de publicaciones del CSIC, Madrid
- Chust G, Perez-Haase A, Chave J, Pretus JL (2006) Floristic patterns and plant traits of Mediterranean communities in fragmented habitats. *J Biogeogr* 33:1235–1245
- Clarke GM, Young AG (2000) Introduction: genetics, demography and the conservation of fragmented populations. In: Young AG, Clarke GM (eds) Genetics, demography and viability of fragmented populations. Cambridge University Press, Cambridge
- Crespi A, Bernardos S, Castro A, Fernandes CP, Amich F (2005) Phytostructural characterization of several vegetation types in northern Portugal. II. The structural expressivity and the resistance of the vegetation. *Plant Biosyst* 139:387–398
- Culley TM, Grubb TC (2003) Genetic effects of habitat fragmentation in *Viola pubescens* (Violaceae), a perennial herb with chasmogamous and cleistogamous flowers. *Mol Ecol* 12:2919–2930
- Dupanloup I, Schneider S, Excoffier L (2002) A simulated annealing approach to define the genetic structure of populations. *Mol Ecol* 11:2571–2581
- Dyer RJ, Nason JD (2004) Population Graphs, the graph theoretic shape of genetic structure. *Mol Ecol* 13:1713–1727
- Fahrig L (2002) Effect of habitat fragmentation on the extinction thresholds, a synthesis. *Ecol Appl* 12:346–353
- Fahrig L (2003) Effects of habitat fragmentation on biodiversity. *Annu Rev Ecol Syst Evol* 34:478–515
- Fortuna MA, Bascompte J (2006) Habitat loss and the structure of plant–animal mutualistic networks. *Ecol Lett* 9:278–283
- Fortuna MA, Gómez-Rodríguez C, Bascompte J (2006) Spatial network structure and amphibian persistence in stochastic environments. *Proc R Soc B* 273:1429–1434
- García D, Chacoff NP (2007) Scale-dependent effects of habitat fragmentation on hawthorn pollination, frugivory, and seed predation. *Conserv Biol* 21:400–411
- Garrido B, Aparicio A, Pérez Porras C, Aparicio J, García Martín F, Fernández Carrillo L, Carrasco MA (2002) Flora de interés en los bosques-isla de Andalucía Occidental. *Acta Botanica Malacitana* 27:295–332
- Godefroid S, Koedam N (2003) How important are large vs. Small forest fragment for the conservation of the woodland flora in a suburban context? *Glob Ecol Biogeogr* 12:287–298
- Gotelli NJ, Colwell RK (2001) Quantifying biodiversity, procedures and pitfalls in the measurement and comparison of species richness. *Ecol Lett* 4:379–391
- Granados M, Martín A, García Novo F (1988) Long-term vegetation changes on the stabilized dunes of Doñana National Park (SW Spain). *Plant Ecol* 75:73–80
- Guirado M, Pino J, Roda F (2006) Understorey plant species richness and composition in metropolitan forest archipelagos: effects of forest size, adjacent land use and distance to the edge. *Glob Ecol Biogeogr* 15:50–62
- Guirado M, Pino J, Roda F (2007) Comparing the role of site disturbance and landscape properties on understorey species richness in fragmented periurban Mediterranean forests. *Landsc Ecol* 22:117–129
- Haila Y (2002) A conceptual genealogy of fragmentation research, from island biogeography to landscape ecology. *Ecol Appl* 12:321–334
- Hardy OJ, González-Martínez SC, Fréville H, Boquien G, Mignot A, Colas B, Olivieri I (2004) Fine-scale genetic structure and gene dispersal in *Centaurea corymbosa* (Asteraceae) I. Pattern of pollen dispersal. *J Evol Biol* 17:795–806
- Honnay O, Hermy M, Coppin P (1999) Impact of habitat quality on forest plant species colonization. *For Ecol Manage* 115:157–170

- IUCN (2001) IUCN Red List Categories version 3.1. Available at http://www.redlist.org/info/categories_criteria2001.html
- Johnson JB, Omland KS (2004) Model selection in ecology and evolution. *Trends Ecol Evol* 19:101–108
- Jordán A (1999) Mapa litológico de Andalucía. Informe Técnico 926/98/P/00. Consejería de Medio Ambiente, Junta de Andalucía, Sevilla
- Jordano P, García C, Godoy JA, García-Castaño JL (2007) Differential contribution of frugivores to complex seed dispersal patterns. *Proc Natl Acad Sci USA* 104:3278–3282
- Jump AS, Peñuelas J (2006) Genetic effects of chronic habitat fragmentation in a wind-pollinated tree. *Proc Natl Acad Sci USA* 103:8096–8100
- Junta de Andalucía (2004) Ortofotografía digital de Andalucía. Consejería de Obras Públicas y Transportes, Consejería de Agricultura y Pesca. Consejería de Medioambiente, Sevilla
- Kirby KJ, Bines T, Burn A, Mackintosh J, Pitkin P, Smith I (1986) Seasonal and observer differences in vascular plant records from British woodlands. *J Ecol* 74:123–131
- Lázaro A, Traveset A (2006) Reproductive success of the endangered shrub *Buxus balearica* Lam. (Buxaceae): pollen limitation, and inbreeding and outbreeding depression. *Plant Syst Evol* 261:117–128
- Lomolino MV (2000) Ecology's most general, yet protean pattern, the species-area relationship. *J Biogeogr* 27:17–26
- López-Pujol J, Orellana MR, Bosch M, Simon J, Blanche C (2003) Effects of habitat fragmentation on allozyme diversity and conservation status of the coastal sand dune plant *Stachys maritima* (Lamiaceae) in the Iberian Peninsula. *Plant Biol* 5:504–512
- Manel S, Gaggiotti OE, Waples RS (2005) Assignment methods, matching biological questions with appropriate techniques. *Trends Ecol Evol* 20:136–142
- Manel S, Schwartz MK, Luikart G, Taberlet P (2003) Landscape genetics, combining landscape ecology and population genetics. *Trends Ecol Evol* 18:189–197
- McGarigal K, Marks BJ, Holmes C, Ene E (2002) FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at the following web site: <http://www.umass.edu/landeco/research/fragstats/fragstats.html>
- McIntyre S, Hobbs R (1999) A framework for conceptualising human effects on landscapes and its relevance to management and research models. *Conserv Biol* 13:1282–1292
- McNeely JA, Gadgil M, Leveque C, Padich C, Redford K (1995) Human influence on biodiversity. In: Heywood VH (ed) *Global biodiversity assessment*. Cambridge University Press, Cambridge
- Mills LS, Soule ME, Doak DF (1993) The keystone-species concept in ecology and conservation. *BioScience* 43:219–224
- Picó FX, van Groenendael J (2007) Large-scale conservation in European semi-natural grasslands: a population genetic perspective. *Divers Distrib* 13:920–926
- Plieninger T (2006) Habitat loss, fragmentation, and alteration - Quantifying the impact of land-use changes on a Spanish dehesa landscape by use of aerial photography and GIS. *Landsc Ecol* 21:91–105
- Pueyo Y, Alados CL (2007) Effects of fragmentation, abiotic factors and land use on vegetation recovery in a semi-arid Mediterranean area. *Basic Appl Ecol* 8:158–170
- Rivas-Martínez S (1987) Memoria del Mapa de Series de Vegetación de España. Instituto Nacional para la Conservación de la Naturaleza (ICONA), Madrid
- Rivas-Martínez S, Asensi A, Diez-Garretas B, Molero J (1997) Biogeographical synthesis of Andalusia (southern Spain). *J Biogeogr* 24:915–928
- Robledo-Arnuncio JJ, Collada C, Alia R, Gil L (2005) Genetic structure of montane isolates of *Pinus sylvestris* L. in a Mediterranean refugial area. *J Biogeogr* 32:595–605
- Smouse PE, Dyer RJ, Westfall RD, Sork VL (2001) Two-generation analysis of pollen flow across a landscape. I. Male gamete heterogeneity among females. *Evolution* 55:260–271
- Storfer A, Murphy MA, Evans JS, Goldberg CS, Robinson S, Spear SF, Dezzani, R, Delmelle E, Vierling L, Eaits LP (2007) Putting the 'landscape' in landscape genetics. *Heredity* 98:128–142
- Turner MG (2005) Landscape Ecology, What Is the State of the Science? *Annu Rev Ecol Evol Syst* 36:319–344
- Valdés B, Talavera S, Fernández-Galiano E (1987) Flora Vasculare de Andalucía Occidental. Ketres Editores, Barcelona
- Valladares F, Camarero JJ, Pulido F, Gil-Pelegrín E (2004) El Bosque Mediterráneo, un sistema humanizado y dinámico. In: Valladares F (ed) *Ecología del bosque mediterráneo en un mundo cambiante*. Ministerio de Medio Ambiente, EGRAF S.A., Madrid
- White GM, Boshier DH, Powell W (2002) Increased pollen flow counteracts fragmentation in a tropical dry forest: an example from *Swietenia humilis* Zuccarini. *Proc Natl Acad Sci USA* 99:2038–2042
- Whiteley AR, Spruell P, Allendorf PW (2006) Can common species provide valuable information for conservation? *Mol Ecol* 15:2767–2786
- Williams M (2000) Dark ages and dark area, global deforestation in the deep past. *J Hist Geogr* 26:28–46