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Original article

Potential use of pine plantations to restore native forests in a highly fragmented river basin

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Abstract

• In forests, the substitution of broadleaf species by conifers can reduce biodiversity because coniferous forests generally provide less diverse vascular understories than broadleaf forests. However, in some cases, former pine plantations might be useful for restoring native forests. We compared plant species composition on the plot scale in natural beech and mixed oak forests with that in plantations of *Pinus radiata*. Links between plant diversity and landscape parameters (patch size, fractal dimension and distance to the nearest patch of the same type) were investigated.

• The objective of this study was to evaluate the use of pine plantations for restoring native diversity in a zone where native forests are very fragmented.

• Similar to oak forests, plant diversity in pine plantations was high, mainly due to the presence of generalist species. Some species characteristic of oak forests also appeared in pine plantations, suggesting the onset of natural forest regeneration.

• These results suggest that pine plantations could be used to promote natural regeneration of original oak forests. Moreover, residual native stands should be conserved as important sources of native species and their seeds.

Mots-clés :
hêtre / diversité biologique / paysage / chêne / plantation de pins / gestion durable

Résumé – Usage possible des plantations de pins pour restaurer les forêts naturelles dans un bassin hydrographique très fragmenté.

• Dans les forêts, la substitution des espèces feuillues par des conifères peut réduire la biodiversité, car les forêts de conifères ne présentent pas généralement un sous bois aussi diversifié que les forêts feuillues. Toutefois, dans certains cas, les anciennes plantations de pins pourraient être utiles pour la restauration des forêts naturelles. Nous avons comparé la composition des espèces végétales à l'échelle de la parcelle en hêtraie naturelle et chênaie mixte de même que dans les plantations de *Pinus radiata*. Les liens entre diversité végétale et paramètres du paysage (taille des bouquets, dimension fractale, et distance du plus proche bouquet de même type) ont été étudiés.

• L'objectif de cette étude était d'évaluer le recours à des plantations de pin pour le rétablissement de la diversité naturelle dans une zone où les forêts sont très fragmentées.

• La diversité végétale des pinèdes, similaire à celle des chênaies, était élevée, principalement en raison de la présence d'espèces généralistes. Certaines espèces caractéristiques des chênaies sont aussi apparues dans les plantations de pins, ce qui suggère l'apparition d'une régénération de la forêt naturelle.

• Ces résultats suggèrent que les plantations de pins pourraient être utilisées pour promouvoir la régénération naturelle des chênaies originelles. En outre, les peuplements résiduels originels devraient être conservés comme sources importantes d'espèces naturelles et de leurs graines.

1. INTRODUCTION

During the last few centuries, natural forest areas have decreased considerably in all of Europe (Barbaro et al., 2005). Among the principal causes of this decrease are forest clearing due to an increased demand for cultivable land and the construction of infrastructures (Hanski, 2005). Tree farming is also a major cause of the decline in the size and extent of natural forests (Rescia et al., 1994).

The substitution of broadleaf species by conifers in forests can reduce biodiversity because coniferous forests generally provide less diverse vascular understories than broadleaf forests (Barbier et al., 2008). Silviculture and disturbance regimes can also effect changes in plant diversity (Roberts, 2004). Furthermore, the recent increase in the fragmentation of natural forests is one of the major threats to species diversity

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(Honnay et al., 2005). For instance, in Central Europe, human intervention has reduced the proportion of native broadleaf forests from 66% to 33% of the forested area (Kenk and Guehne, 2001). As a result, old-growth deciduous forests in Western Europe consist mostly of small tracts bearing little resemblance to the original forests (Rozas, 2006). The situation is similar in the south of Europe where, in countries such as Spain, forests have been widely subjected to communal use since the Middle Age (Pardo et al., 2004).

The aim of this study was to compare understory vegetation between two types of native species of forests (mixed oak and beech stands) and *Pinus radiata* plantations. The objective was to evaluate the use of pine plantations for restoring native diversity in a zone where native forests are very fragmented. We compared the plot-scale plant species composition of the two types of natural forests with that of plantations of *P. radiata*. Landscape context around each forest was considered in order to evaluate any potential links with forest plant diversity.

2. MATERIALS AND METHODS

2.1. Study site

The study was carried out in the Basque region in the north of Spain, at the Ibaizabal river basin (43° 07' N, 2° 51' W). Since the beginning of the twentieth century, a considerable percentage of the native deciduous woodlands in this region has been substituted by plantations of fast-growing conifer. Although a few natural forest stands remain in the region, *P. radiata* plantations comprise approximately 66% of the forested area (Ruiz de Urrestarazu, 1992; Amezaga and Onaindia, 1997).

The Ibaizabal river basin covers 48 320 ha and the elevation ranges from about 50 m to approximately 1200 m (Gesplan, 2002), and includes valleys and mountains (Aizpuru et al., 1999). The area is heavily populated and industrialized (Rallo and Orive, 1998), but some zones of great ecological interest are found there, such as the Gorbea and Urkiola Natural Parks (Gesplan, 2002).

The climate of this region is Atlantic, with a mean annual precipitation of 1200–2000 mm and a mean temperature of 14 °C. The potential vegetation in virtually the entire river basin is that of mixed oak forests of *Quercus robur* and *Fraxinus excelsior* in lowland areas and the beech *Fagus sylvatica* in the higher zones. The distribution of the vegetation has been considerably altered and reduced by human activity. In the basin, many oak forests have been replaced by pine plantations, of *P. radiata* in particular (Aizpuru et al., 1999; Schmitz et al., 1998), to such an extent that native forests occupy only about 3.5% of the area of the river basin (Onaindia et al., 2004). Extensive deforestation occurred during the eighteenth and nineteenth centuries (Azkona, 1989). Later, the production of charcoal and the associated increase in logging made marked contributions to the reduction of the forested area. During the twentieth century, economic interests inspired the replanting of these forests with large pine plantations (García et al., 2004). Consequently, the native forests (mixed oak and beech forests) are now highly fragmented and surrounded by mature (more or less) pine plantations.

The mixed oak forests have a canopy dominated by *Q. robur* and *F. excelsior*. Other characteristic species are *Castanea sativa, Corylus avellana*, *Crataegus monogyna* and *Frangula alnus* (Loidi and Vascones, 1995). Beech forests are dominated by *Fagus sylvatica*; other characteristic species are *Betula celtiberica, Laurus nobilis, Oxalis acetosella* and *Vaccinium myrtillus* (Loidi and Vascones, 1995).

Sampling stand selection was based on the EUNIS habitat classification using the vegetation map on a 1:10 000 scale (Davies and Moss, 2002). Twenty-one sites representative of native forests and pine plantations were selected: seven mixed oak forests, seven beech forests and seven *P. radiata* plantations. The plots were located on sandstone soils, had similar soil conditions, and were on slopes of less than a 30% grade. Ages of forests were approximated by the Basque Forest Administration (Gesplan, 2002). The oak and beech forests were secondary forests at different stages of natural succession from previous logging. Pine plantations have a short rotation of about 40 years. Canopy cover was estimated as the percentage of surface area that was covered by overhanging vegetation (Appendix 1, available at www.afs-journal.org).

2.2. Plant species sampling

Plant species sampling took place at the selected twenty-one sites between August and September 2006. At each site, two 50 m wide transects were arranged perpendicularly, representing a total area of 90 m^2 that was divided into nine sub-plots of 5 m × 2 m (the optimum plot size was determined by the species/area curve method; Onaindia et al., 2004). In each sub-plot, the percent cover of each plant species (vascular and pteridophyte plants) was estimated at four different strata: 0–0.2 m, 0.2–2.5 m, 2.5–10 m and >10 m. Species identification was according to "Flora del Pais Vasco" (Aizpuru et al., 2007; Aseguinolaza et al., 1988). At the time of sampling, *Gramineae* had not yet flowered, making their identification difficult. Consequently, all *Gramineae* in each sampling plot were identified only at the family level, as *Poaceae*, and were quantified as a single species. Regardless, only two species of *Poaceae* (*Brachypodium sylvaticum* and*Bromus ramosus*) are usually found in the forests evaluated in this study (Aseguinolaza et al., 1988); therefore, the lack of species-level *Gramineae* identification should have little effect on diversity values.

The mean percent cover of each species was calculated according to plot and forest type. Several biodiversity indices were calculated: richness (number of different species), Shannon's diversity ($H' = -\sum p_i \log_2 p_i$, where p_i is the relative abundance of species i); and Simpson's diversity ($D = 1 - \sum p_i^2$).

2.3. Parameters at the landscape level

A GIS database was constructed and used to examine the spatial distribution patterns of species in a given area. Maps of land use based on the EUNIS habitat classification were generated from 1:5 000 scale orthophotos provided by the cartography service of the County Council of Bizkaia (year 2002). These maps were enhanced by manual digitalization and automatic scanning of the orthophotos and were prepared and saved in GIS in vector format using the ARC/INFO program.

Four parameters describing patch (forest containing the plot) characteristics and landscape context were calculated for the 21 sites using the FRAGSTATS software (McGarigal et al., 2002).These parameters were total area (A), fractal dimension (FD), proximity index (Pi) and distance to the nearest patch of the same type (DNP). The FD provides information about the shape of the patch and was calculated as $FD = 2\ln P / \ln A$, where A is the surface area of each patch in m^2 and P is the perimeter in meters (McGarigal et al., 2002). The Pi measures the degree of isolation of the patch and is calculated by the

Table I. Mean values (± standard error) for diversity indices for each forest type: Richness, Shannon diversity index (H'), Simpson diversity index (D), and F and p results from ANOVA. Different superscript letters indicate significant differences between values (Fisher's test at $p < 0.05$) (means with different letters are significantly different). Pine plantations have greater species richness values and higher diversity indices than natural forests.

	Oak forest	Beech forest	Pine plantation	F	p
Richness	24.29 ± 2.25	24.29 ±7.18	24.71 ± 7.72	0.44	0.640
Diversity H'	2.93 ± 0.57[ab]	2.21 ± 1.01[a]	3.02 ± 0.16[b]	7.28	0.005
Diversity D	0.92 ± 0.19[a]	0.59 ± 0.26[b]	0.99 ± 0.09[a]	8.02	0.003

formula $Pi = \sum A_{ir}/h_{ir}^2$, where A_{ir} is the surface area of the patch (i) from one of the same type found within a radius (r), and h_{ir} is the distance to this patch. The value of Pi increases as the distance between the patches decreases. In order to determine the value of the index at different landscape levels, we calculated Pi for different radii at different vegetation-type levels (50 m, 500 m, 1 000 m and 2 000 m).

2.4. Data analysis

The mean percent cover of species, richness and diversity indices of the different forest types were compared by ANOVA using SPSS statistical software (data were normalized using the cosine function). The Levenne test was used to compare variances in homogeneity. In the ANOVA, the Games-Howell test was used for homogenous variance data and the DMS test was used for non-homogenous variance data. Fisher's test was used to compare means (Sokal and Rohlf, 1981). Cluster analysis was performed to classify plot affinities using coverage data for each species according to plot. The IndVal 2.0 method was used for grouping species that best characterized the different forest types (Dufrene and Legendre, 1997). This method is based principally on the combination of the relative abundance of each species and its relative frequency in each group.

Landscape indices of the different forests were compared using the Kruskal-Wallis non-parametric test and comparisons between two means were made using the Mann-Whitney U test. Spearman correlations were used to evaluate relationships between biodiversity indices of the different forests and the landscape parameters.

3. RESULTS

3.1. Diversity indices and affinity of sites

The plots of *P. radiata* plantations had greater mean richness values than the mixed oak and the beech forests; however, the differences were not significant. The *P. radiata* plantations also had greater indices of diversity (Shannon and Simpson) than the mixed oak and beech forests. The differences in the Shannon and Simpson diversity indices between the beech forests and the pine plantations were significant ($p < 0.05$). The differences in the Simpson diversity index values tended to be larger than the differences in the Shannon index values; the difference in the Simpson index between the mixed oak and the beech forests was significant ($p < 0.05$; Tab. I).

Cluster analysis grouped the forest plots by forest type, with the exclusion of plot number 10, a young beech forest that was grouped with a young oak forest near the pine plantation plots (Fig. 1). There was a significant positive correlation between the age of plantations and species richness, and a negative correlation between the age of plantations and the Simpson diversity index. However, there were no correlations between diversity indices and the age of plots for natural forests. There was a significant negative correlation between species richness and the cover canopy for natural oak forests (Appendix 2, available at www.afs-journal.org).

3.2. Plant species composition

One hundred and fifteen different plant species were recorded: 79 different species in the mixed oak forests, 73 in the beech forests and 61 in the pine plantations. Some species were specific to each forest type (Appendix 3).

The greatest mean percent cover of species per plot was found for the pine plantations (24.8 ± 2.9 species/plot), followed by the mixed oak (24 ± 0.8 species/plot) and beech forests (21.5 ± 3.3 species/plot). However, there were no significant differences in mean percent cover between forest types. The indicator species analysis (IndVal) showed that several species occurred in practically all of the plots: *Q. robur, Rubus* sp., *Hedera helix* and *C. monogyna*. There were some species more associated with the mixed oak forests, including *Smilax aspera, C. avellana, L. nobili* and *Cornus sanguinea*. The species *F. sylvatica, Viola riviniana, Geranium robertianum, Oxalis acetosella, Vaccinium myrtillus* and *Veronica officinalis* were more common in the beech forests, while *Pteridium aquilinum, Potentilla erecta, Lonicera periclymenum, Frangula alnus* and *Daboecia cantabrica* were more common in the pine plantations (Fig. 2).

Twenty species comprised more than 2% of the cover in the mixed oak forests, as did nine and 16 species in the beech forest and pine plantations, respectively. In general, species that had a higher percent cover occurred more frequently in the plots. In the oak forest plots, the dominant species was *Q. robur* with a mean percent cover of 41.7 ± 14.1%, followed by *C. avellana*, *C. sativa* and *F. excelsior*. The tree species *L. nobilis* had low percent cover but its frequency was relatively high. The percent covers of the shrubs *Ulex galii, Rubus* sp. and *Rhamnus altaernus*, and the ferns *Dryopteris affinis* and *Polystichum setiferum* were also substantial (Tab. II). There were some species characteristic of oak forests that appeared at low frequency and low cover: *Anemona nemorosa, Asplenium scolopendrium, Erica arborea, Geum urbanum, Laurus nobilis, Ligustrum vulgare, Quercus pyrenaica, R. alaternus* and *Sanicula europaea* (Appendix 3, available online at www.afs-journal.org).

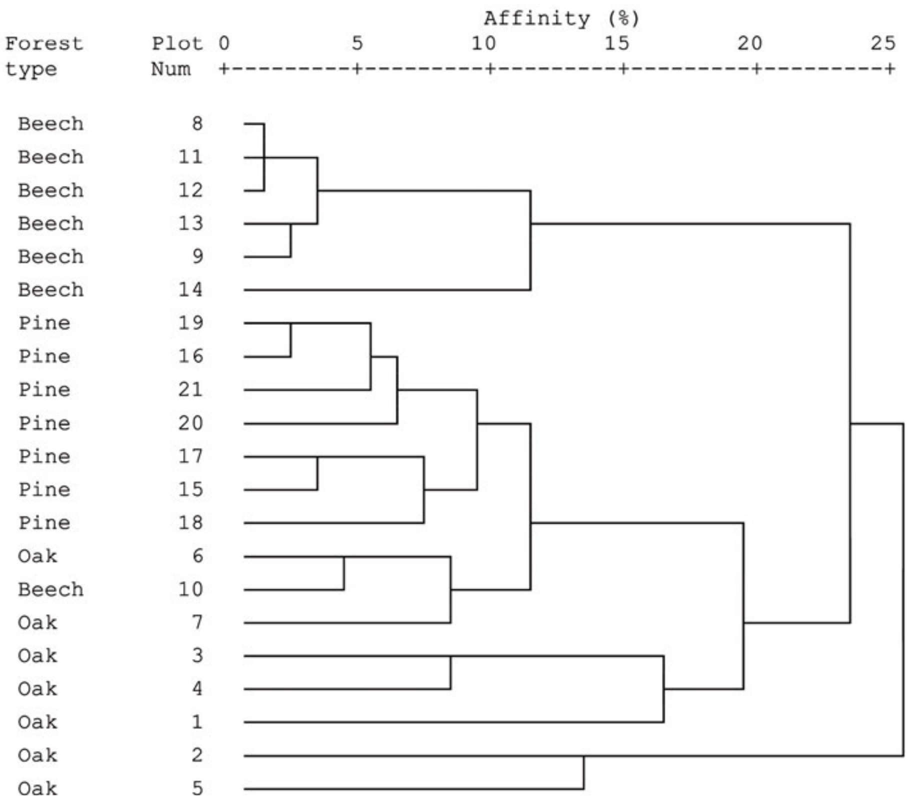

Figure 1. Affinities between plots. Oak = mixed oak forest; beech = beech forest; pine = *P. radiata* plantation. Plot numbers are as explained in Appendix 1, available online at www.afs-journal.org.

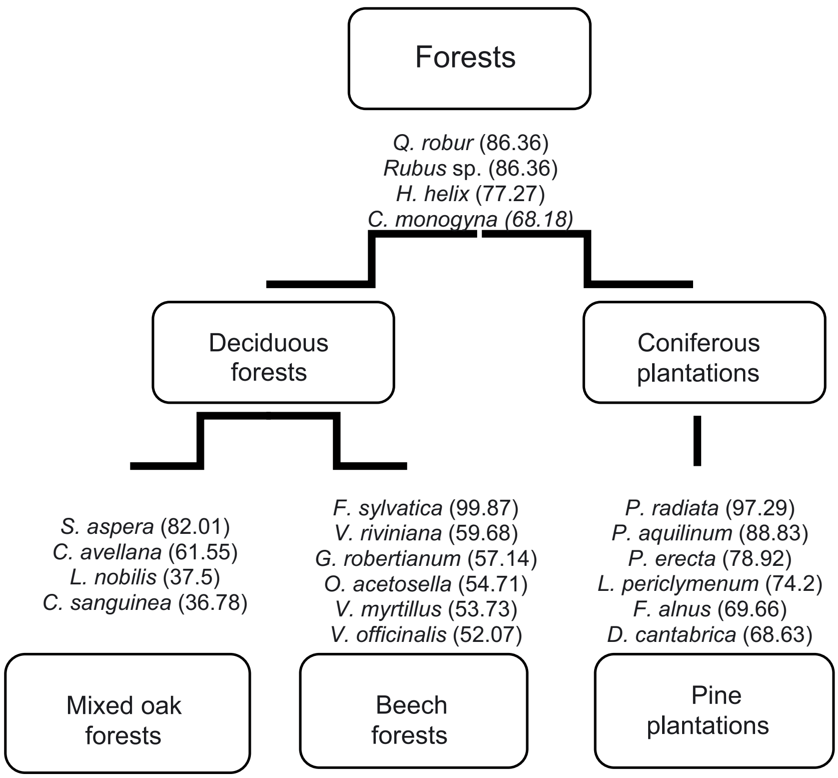

Figure 2. Distribution of plant species according to its affinity (%) with each forest type (results from IndVal 2.0 method).

Table II. Mean percent cover (± standard error [SEM]) of plant species in the mixed oak forests for which the percent cover exceeded 2%. *Laurus nobilis* was included because of its high frequency.

Plant species	Cover % (mean ± SEM)	Frequency
Trees		
Alnus glutinosa (L.) Gaertner	3.3 ± 3.3	1
Betula celtibericaa L.	5.0 ± 3.2	2
Castanea sativa Miller	9.1 ± 4.6	3
Fraxinus excelsior L.	5.0 ± 3.5	3
Laurus nobilis L.	0.8 ± 0.1	3
Quercus pyrenaica Willd.	3.7 ± 3.7	1
Quercus robur L.	41.7 ± 14.1	7
Robinia pseudoacacia L.	4.0 ± 1.7	3
Salix atrocinerea Brot.	5.3 ± 3.5	2
Shrubs		
Cornus sanguinea L.	3.0 ± 0.8	3
Corylus avellana L.	31.0 ± 11.9	5
Crataegus monogyna Jacq.	4.1 ± 3.9	5
Frangula alnus Miller	3.1 ± 1.5	3
Rhamnus alaternus L.	6.5 ± 6.0	2
Rubus sp.	8.8 ± 2.2	7
Ulex gallii Planchon	8.9 ± 7.1	5
Climbers		
Hedera helix L.	15.4 ± 9.7	6
Ferns		
Dryopteris affinis (Lowe) Fraser- Jenkins	5.1 ± 3.6	3
Polystichum setiferum (Forsskål) Woynar	5.5 ± 4.1	2
Pteridium aquilinum (L.) Kuhn	3.3 ± 1.7	4
Herbs		
Poaceae	17.6 ± 6.5	7
Smilax aspera L.	10.2 ± 6.6	6

In beech forests, the dominant species was *F. sylvatica*, with a mean percent cover of 94.9 ±12.3%, much higher than any other tree species including *Q. robur, C. sativa* and *B. celtiberica*. There were also some natural forest-typical species that were present in high frequency but with low coverage, such as *V. myrtillus, O. acetosella, G. robertianum* and *V. officinalis* (Tab. III). Some other species had a low frequency and low cover, such as *Anemona nemorosa, Athyrium filix-foemina, Helleborus viridis, Saxifraga hirsuta, Sibthtorpia europaea, Sorbus aria* and *Stellaria alsine* (Appendix 3).

In the pine plantations, the dominant species was *P. radiata* (mean percent cover = 51.5 ± 6.3%), followed by *P. aquilinum, Rubus* sp., *Robinia pseudoacacia*, *U. galii*, *D. cantabrica* and *C. avellana* (Tab. IV). Pine plantations also contained other species characteristic of natural forests such as *Arbutus unedo, A. filix-foemina, C. sanguinea, F. excelsior, Ilex aquifolium, Polystichum setiferum, Q. ilex, Q. pyrenaica* and *Vaccinium myrtillus* (Appendix 3).

There were no significant correlations between species cover and forest age or the percent cover of canopy.

Table III. Mean percent cover (± standard error [SEM]) of plant species in the beech forests for which the percent cover exceeded 2%.

Plant species	Cover % (mean ± SEM)	Frequency
Trees		
Betula celtiberica L.	3.3 ± 3.3	2
Castanea sativa Miller	3.6 ± 3.6	1
Fagus sylvatica L.	94.9 ± 12.3	7
Quercus robur L.	7.0 ± 3.9	4
Shrubs		
Corylus avellana L.	2.1 ± 1.9	3
Crataegus monogyna Jacq.	2.3 ± 1.2	5
Ilex aquifolium L.	2.3 ± 1.2	4
Rubus sp.	3.9 ± 1.9	4
Vaccinium myrtillus L.*	1.4 ± 0.5	4
Ferns		
Pteridium aquilinum (L.) Kuhn	2.6 ± 1.5	4
Herbs		
Geranium robertianum L.*	0.6 ± 0.2	4
Oxalis acetosella L.*	0.8 ± 0.3	4
Poaceae	17.6 ± 10.1	7
Veronica officinalis L.*	0.2 ± 0.1	4

* Indicates a species that was included because of its high frequency.

3.3. Landscape-level characteristics

There were significant differences in patch size among the different types of forests ($p < 0.05$). Mixed oak forests had the smallest mean patch size (8.6 ± 4.6 ha), followed by beech forests (64.2 ± 17.5 ha). The mean patch size for *P. radiata* plantations was much greater (364.8 ± 124.1 ha). There were no significant differences in FD among the different types of forests. However, there were significant differences in the DNP among the different forest types ($p < 0.05$). The beech forests had the largest DNP (94 ± 69.7 m), whereas the *P. radiata* plantations had the smallest DNP (16 ± 0.1 m). Interestingly, the Pi showed that mixed oak forests were most isolated (65 ± 31.4) as compared with beech forests (343 ± 275.1) and *P. radiata* plantations (8 829 ± 3 477.5; $p < 0.05$; Tab. V).

No correlations between plant diversity indices and landscape parameters were found for oak forests or for beech forests. However, there was a significant negative relationship between the Shannon diversity index and the FD for pine plantations ($r = -0.761$; $p \leq 0.05$; Appendix 2). Analysis of relationships between species (percent cover) and landscape parameters revealed only a negative correlation between *Q. robur* and the patch size ($r = -0.52$, $p < 0.01$), and the DNP ($r = -0.48$, $p < 0.05$). There was also a negative correlation between *C. sanguinea* and the patch size ($r = -0.47$, $p < 0.05$), and between *S. aspera* and the patch size ($r = -0.50$, $p < 0.05$).

Table IV. Mean percent cover (± standard error [SEM]) of plant species in the *P. radiata* plantations for which the percent cover exceeded 2%.

Plant species	Cover % (mean ± SEM)	Frequency
Trees		
Castanea sativa Miller	2.5 ± 1.4	4
Pinus radiata D. Don.	51.5 ± 6.3	7
Quercus robur L.	4.7 ± 1.7	7
Robinia pseudoacacia L.	7.8 ± 6.6	2
Salix atrocinerea Brot.	3.2 ± 2.2	4
Shrubs		
Calluna vulgaris (L.) Hull	2.0 ± 0.9	5
Corylus avellana L.	4.6 ± 1.4	3
Crataegus monogyna Jacq.	3.2 ± 1.5	5
Daboecia cantabrica (Hudson) C. Koch	5.4 ± 2.7	6
Erica cinerea L.*	2.0 ± 0.5	5
Frangula alnus Miller	7.3 ± 4.8	6
Hypericum androsaemum L.	2.5 ± 1.8	4
Rubus sp.	22.0 ± 8.1	7
Ulex gallii Planchon	7.6 ± 3.4	5
Climbers		
Hedera helix L.	4.5 ± 2.9	5
Lonicera periclymenum L.*	1.7 ± 0.6	6
Ferns		
Dryopteris affinis (Lowe) Fraser- Jenkins	4.8 ± 4.8	1
Pteridium aquilinum (L.) Kuhn	23.9 ± 3.8	7
Herbs		
Poaceae	27.6 ± 10.5	7
Potentilla erecta (L.) Raeuschel*	1.6 ± 0.8	6

* Indicates a species that was included because of its high frequency.

4. DISCUSSION

4.1. Contribution of each stand type to diversity conservation

Beech forests tend to be less diverse forests because the *F. sylvatica* canopy creates a heavy shade that inhibits the growth of many species. There tend to be few types of species per plot, comprising a small percent of the cover as compared with the dominant *F. sylvatica* (Coroi et al., 2004). Although we might expect natural forests to be more diverse than plantations (Coroi et al, 2004; Wulf, 2002), in this study, the pine plantations tended to be more diverse than the natural forests. The *P. radiata* plantations had greater mean richness and higher diversity values than the mixed oak and beech forests. This might have been due to the presence of generalist colonizer species in addition to some species characteristic of mixed oak forests. However, the total number of species found was higher in natural forests than in the pine plantations.

There was a significant positive correlation between the age of the plantation and species richness, which suggests that forest age can be an important parameter in explaining the species composition of forests. Coniferous plantations should become slightly more similar in plant species to the natural stands with increasing age, as has been reported for Canadian plantations (Roberts, 2002) and Belgium forests (Godefroid et al., 2005). There were no correlations between the age of plots and species richness for natural forests, possibly due to the low number of plots and the small age range of the natural forests. This could also be due to an interaction between time and patch size, because plantations had greater patch sizes and were younger than the natural forests. The effects of time on species richness could not be separated from patch area, and patch area and time clearly interacted (Jacquemyn et al., 2001).

The negative correlation between species richness and the cover canopy for oak natural forests was probably due to the limited amount of light available for forest succession, which can cause a decline in plant species richness (Howard and Lee, 2003; Gondard and Romane, 2005).

4.2. Use of pine plantations to restore native forests

Despite the fact that the Ibaizabal river basin is a degraded and fragmented area, it has a relatively high floristic richness. One hundred and fifteen different species of vascular plants were identified. The largest number of plant species was found in the mixed oak forests (79 different species). Many species were present in each of the different forest types studied, such as the hawthorn *Rubus* sp. Previous studies have shown that the conditions in *P. radiata* plantations favor the growth of *Rubus* sp. (Amezaga and Onaindia 1997).

We found slightly more pioneer species in the plantations than in the natural forests (Zerbe, 2002), including *D. cantabrica, Calluna vulgaris* and *P. aquilinum* (Aizpuru et al., 1999). Mixed oak forests and plantations had many species in common, such as the pioneer species *B. celtiberica* (Onaindia and Amezaga, 2000), *C. sativa* and *P. aquilinum*. In contrast, the beech forests had a canopy dominated by *F. sylvatica*, which is usually the only tree species in beech masses in the region. Most of the species identified by IndVal analysis as characteristic of pine plantations, such as *P. aquilinum, P. erecta, L. periclymenum, F. alnus* and *D. cantabrica*, are broad-ranged generalist species (Aizpuru et al., 2007). Also, the presence of the fern *D. affinis* subsp. *Affinis*, a species typical of mature forests (Bossuyt et al., 1999; Honnay et al., 1999; Onaindia et al., 2004), is an indicator of the advanced restoration level of the pine plantations. Moreover, the high percent cover of *C. avellana* and *C. sativa* and the presence of some species representative of natural forests, such as *A. unedo, A. filix-foemina, C. sanguinea, C. monogyna, F. alnus, F. excelsior, I. aquifolium, P. setiferum, Q. ilex, Q. pyrenaica, Q. robur* and *V. myrtillus*, suggest a considerable degree of maturity in the plantations.

Some species characteristic of natural forests, such as *A. nemorosa, S. europae* and *S. hirsuta*, did not appear in plantations, possibly because the plantations were too young. This finding indicates that more succession time is needed to restore the species composition to that of the natural forests. Considering that forest restoration is an important objective for sustainable forest management in Europe (Zerbe, 2002),

Table V. Landscape parameters for mixed oak forests, beech forests and pine plantations. *FD* = Fractal dimension; *P*i 500 = proximity index in a radius of 500 m; *NND* = nearest neighbor distance; Min = minimum value; Max = maximum value; Mean ± SE = mean ± standard error. *p*-Values were derived from the Kruskall-Wallis test. Different superscript letters indicate significant differences between values (Mann-Whitney U test at $p < 0.05$) (means with different letters are significantly different).

Parameters		Min	Max	Mean ± SE	*p*
Area (Ha)	Oak forest	1.2	39.5	8.6 ± 4.6^{a}	0.06
	Beech forest	1.0	131.4	64.2 ± 17.5^{b}	
	Pine plantation	12.5	810.0	364.8 ± 124.1^{c}	
FD	Oak forest	1.315	1.402	1.370 ± 0.01	0.16
	Beech forest	1.307	1.426	1.356 ± 0.01	
	Pine plantation	1.294	1.473	1.402 ± 0.02	
NND (m)	Oak forest	12	143	57 ± 16.9^{a}	0.42
	Beech forest	6	513	94 ± 69.7^{b}	
	Pine plantation	0	69	16 ± 9.1^{c}	
*P*i 500	Oak forest	4	270	65 ± 31.4^{a}	0.009
	Beech forest	0	1 984	343 ± 275^{b}	
	Pine plantation	18	24 517	$8\,829 \pm 3\,477.5^{c}$	

P. radiata plantations might serve as useful tools for restoring the original forest biodiversity in the region.

4.3. Importance of landscape structure

At landscape level, the oak forests were very small and isolated with a high degree of fragmentation. Their mean size was 8.6 ha and there was no substantially large area of mixed oak in the entire river basin. Moreover, these forests were confined to marginal zones.

The distribution of the beech forests did not appear to be altered as much as that of the mixed oak forests, possibly because beech trees grow at higher elevations that are less suitable for *P. radiata* plantations. Consequently, the isolation of the beech forest plots is due less to forestry than to natural causes (Rodríguez et al., 2006).

Fragmentation implies an exclusion of specialist species (Barbaro et al., 2005) and reduces the structural complexity of mature forests. However, in this study there were no significant relationships between landscape parameters and plant diversity. No direct effect of forest fragmentation on stand diversity for native forests was evident, possibly due to the small size of the natural forests and the larger size of the plantations. The negative correlations between the species *Q. robur, C. sanguinea* and *S. aspera* and patch size probably result from the fact that these species have a high percentage of cover in natural oak forests, which are the smallest forests in the area.

Some characteristic understory species (*A. nemorosa, S. europae* and *S. hirsuta*) did not appear in the plantations. This could also be due to the young age of the plantations. It may be necessary to preserve remnant old stands in order to maintain some residual native plants (Hanski, 1998; Hanski, 2005; Moola and Vasseur, 2004). These residual stands would serve as important seed sources for the dispersal of native species and promoting biodiversity in the regenerating forests. It has been demonstrated that woody species are able to establish under closed canopy in fragmented coppice forests and form a seedling bank, which may be used for natural regeneration (Gonzalez et al., 2008).

The process of fragmentation affects the forest plant richness and diversity not only by reducing patch size, but also by increasing the degree of isolation. More than a century after the onset of forest fragmentation, an extinction debt persists for species with low rates of population turnover (Vellend et al., 2006). The greatest positive effect is obtained if forests located close to remnants of biologically diverse forests are restored; this facilitates the migration of target species to the restored forests (Hanski, 2000). The regional variation in ancient forest plant species suggests that regional lists are more appropriate for assessing the conservation value of forests than global, pan-European lists (Hermy et al., 1999).

The landscape structure around the pine plantations might determine their suitability for forest restoration in the studied area. It is important to preserve the patches of natural forest between plantations to maintain a source of plant species; if plantations are too isolated from the surrounding native forests, colonization of native species will be difficult.

5. CONCLUSION

These data indicate that the pine plantations are as diverse as the mixed oak forests and much more diverse than the beech forests. Plantations contain an important community of typical natural forest species and their evolution might be considered as a natural phase in forest development. However, some characteristic understory species did not appear in plantations. Therefore, for sustainable forest management, it is necessary to maintain the plots of natural forest among the remaining plantations to promote the colonization of indigenous species.

The high degrees of fragmentation and isolation of the oak forests could be factors in their continuing degradation, and could lead to progressive colonization by generalist species and a reduction in diversity. To conserve and promote biodiversity, attempts should be made to increase the area of natural forests by regenerating the existing pine stands and connecting small patch forests to one other. The forests and plantations should be monitored to detect species characteristic of natural forests and to evaluate the diversity and landscape indices, thereby increasing our understanding of the evolution of forests.

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