Iberian Atlantic Forest Restoration: An Experiment Based in Vegetation Succession

N.A. Laskurain, I. García-Mijangos, H. Manzanedo, J. Sesma, M. Ferrari, T.G. Calvo, and Javier Loidi

Abstract Restoration of European Atlantic forest has been taking place in the Basque Country since 1994. For this study three plots were selected, each for restoration of one of the three main types of natural forest common in the area: Mesophytic Oak Forest, Eutrophic Beech Forest and Oligotrophic Beech Forest. In order to find the most appropriate method for successful restoration, the plots were planted with three different densities and three species combinations of indigenous trees and shrubs. In the species selection, mature forest and seral-stage trees and shrubs were chosen, as it was intended to investigate whether planting seral-stage species was a better option than planting mature-forest tree species directly. The results after 14 years of monitoring show that, in spite of the low overall survival rate, using seral-stages shrubs improves the biodiversity of the restored forests and accelerates succession by controlling the invasion of some shrubs, such as *Rubus* and *Ulex*, which have inhibitory effects on secondary succession in degraded lands. A selection of saplings with good root systems contributes effectively to higher survival rates and to more successful results. As a general rule, a combination of trees and shrubs is recommended for ecological restorations, and in any case, it is recommended to improve soil conditions before initiating the restoration.

Introduction

Human-induced ecosystem and habitat degradation is a widespread phenomenon throughout the world; and "Restoration Ecology", which studies all the issues of repairing, renewing and restoring ecosystems to a more natural or more sustainable situation, is an actively unfolding field in ecology. The Society for Ecological Restoration (SER) defines ecological restoration as an "intentional activity that

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initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability" (SER 2004). The practice of ecological restoration includes several activities such as: erosion control, reforestation, use of native species collected locally, removal of alien species and weeds, revegetation of disturbed areas, etc. The inexorable growth of human population worldwide, empowered by technological changes and the rise in commodity demands, causes ecosystem destruction at a pace that outraces natural recovery and current restoration activities. Our work is within the frame of the global necessity of gathering efforts to restore ecosystems for our health and well being. Ecosystems have a remarkable potential for self-repair. Given enough time, under stable conditions without human-induced severe disturbance, most degraded ecosystems can restore themselves. This self-healing capacity is an important and valuable attribute (Bradshaw 1987), but most frequently the time needed to reach a mature and complex stage is so long that active restoration can be a valuable option. Restoration, in this sense, would be a means to accelerate the natural recovery process of a degraded ecosystem.

Exact reproduction of the original community is generally impossible because some site conditions will have been altered irreversibly and some species cannot survive in them any longer or have become locally extinct (Balaguer 2002). Thus, when reflecting on the aims and intention of starting such a project, we assumed that restoration of a forest ecosystem, particularly when starting from a severely degraded stage, is not a perfect reconstruction but only an imitation of the natural forest. We can create a system that is not identical but which can be similar in essential aspects and can function in the same way (Jordan et al. 1987).

Among the different aspects of restoration, the reconstruction of natural forests is of growing importance in many areas of the world (Jordan et al. 1987) and has been considered an increasingly important activity for environmental sustainability (Miyawaki and Box 2006). In our case, we have performed a forest reconstruction experiment, i.e., an attempt to restore several types of natural forests using only woody species of the native flora. The importance and utility of acquiring knowledge for restoring natural forests is strategic in the context of the conservation policy of any country, and particularly in the European Union, where the Habitats Directive (92/43/EEC) focuses much attention in forests ecosystems (Loidi 1999).

The principles of ecological restoration are based on succession theory. This means that restoration should follow the steps accepted by the geobotanical survey for succession. Precise descriptions of vegetation succession in the past may enable us to make accurate predictions about the nature of future succession (Harper 1987). This has lead to the practice of making chronosequences (space-for-time substitutions), which have certain flaws in their predictive power (Chiarucci et al. 2010). In the absence of a better approach supported sufficiently by scientific documentation, Clementsian climax theory adapted to the concept of potential natural vegetation (PNV, Tüxen 1956) has provided the fundamental conceptual basis describing succession and the basic guidelines for restoration programs (Loidi and Fernández-González 2012). In this sense, mapping PNV types is essential for guiding the spatial aspects of restoration, and some countries have worked on this

extensively (Rivas-Martínez 1987, 2007; Miyawaki 1980–1989; Blasi 2010, etc.). PNV analysis and cartography provide the models to be tested in the practice of ecological restoration and can also be useful tools in the field of land management (Biondi 2011). Intensive research on PNV units in the Basque area has been carried out in previous years (Loidi et al. 2005, 2011; Loidi and Báscones 1995) and has described the forest types existing in the area at the moment of project design.

Forest planting in the Basque Country throughout most of the twentieth century was done almost entirely using exotic tree species: *Pinus radiata*, *Eucalyptus globulus*, *Pseudotsuga menziesii*, *Chamaecyparis lawsoniana*, *Larix kaempferi*, *Quercus rubra*, *Robinia pseudoacacia*, etc. Those plantations were extensive and nowadays cover nearly 30 % of the total area (Inventario Forestal CAE 2005). This intense planting activity has been taking place from the 1930s onwards, because before that the territory had been deforested severely by intensive land use for animal husbandry and agriculture. Such exotic tree plantations cannot be considered ecological restorations in any case, since they ignored completely the essential requirement that native species be used.

When planning the restoration project, we decided not to follow all the successive steps described by theory based on space-for-time observations. In order to ensure relative success in forest restoration we assumed that: (1) Natural forest restoration requires a minimum area and number of components; monospecific plantations are not suitable (Kirby and Patterson 1992); and (2) Some typical stages of forest development are not essential and may be bypassed (Ashby 1987). We decided to use several native species which are components of natural forests in the area. We also wanted to test whether planting mature-stage trees directly was more or less effective than planting secondary forest trees and shrubs, as representatives of earlier stages in succession. We assumed that younger-stage species may modify site conditions favoring the establishment of mature-stage species: this is the facilitation paradigm, which can be applied to forest succession and was meant to be tested in our survey.

Ecosystem restoration has become a very important issue in the Iberian Peninsula in the last years, but most of the projects have been done in the Mediterranean area, due to the urgency created by the desertification threat characterizing that environment (Benayas et al. 2003). In the Atlantic zone of the Iberian Peninsula, such experiences are scarce, particularly those focusing on restoration of natural forests. For this reason, in 1993, we started a Project entitled *Criterios de restauración de la vegetación natural en el territorio de Bizkaia mediante la utilización de especies leñosas de la flora silvestre autóctona* (Criteria for restoration of the natural vegetation in the territory of the Basque Country using woody species of the native wild flora). We established a network of plots to plant forest tree species and monitor their long-term growth. The main aim was to gain knowledge of the criteria and techniques for re-vegetation of degraded areas with natural forests. In this paper we present the results of three of those plots after 15 years of monitoring.

The hypothesis we established for this survey were that:

1. Species from seral stages have higher survival rates than long-living trees of mature stages;
2. Growth during the first years is faster in seral-stage species than in mature-stage trees.

Material and Methods

Study Area

The survey area is located in the Basque Country (northern Spain), within the area of the Urkiola Natural Park, in the southern sector of the territory of Bizkaia (Basque Country) (Fig. 1). It is a mountainous area crossed by the Duranguesado range, with its highest elevation on the Anboto peak (1330 m); most of the Natural Park area is above 600 m. The climate is temperate-oceanic with cool winters, mild summers, abundant precipitation ranging from 1400 to 2000 mm per year, and no summer drought. In the biogeographic classification of Rivas-Martínez et al. (2007), the area is included in the Basque-Cantabrian sector of the European Atlantic province of the Euro-Siberian region.

The Urkiola Natural Park is an area of high ecological diversity, and almost all the natural forest types of the Atlantic Basque Country can be found there. For this survey we have selected three of these forest types:

- Subcantabrian Mesophytic Oak Forest (*Crataego laevigatae-Querctum roboris*)
- Eutrophic Montane Beech Forest (*Carici sylvaticae-Fagetum sylvaticae*)
- Oligotrophic Montane Beech Forest (*Saxifrago hirsutae-Fagetum sylvaticae*).
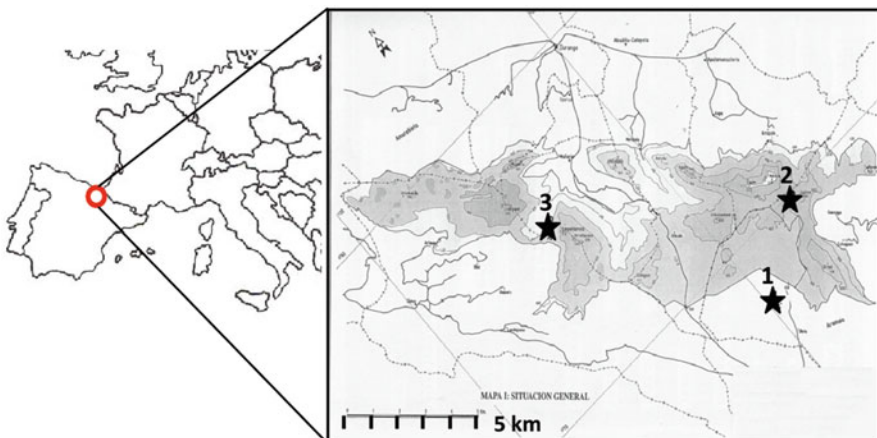

Fig. 1 Location of the three experimental plots: *1* Subcantabric Mesophytic Oak Forest; *2* Eutrophic Montane Beech Forest; *3* Oligotrophic Montane Beech Forest

Plot Design

Three plots were selected, one in each of the three forest types. The characteristics of the three plots are described in Table 1. Each plot involves two replicates of 40×40 m. Both replicates were located close to each other so that environmental conditions would be similar. Each replicate was divided into 6 subplots of 200 m^2, and different treatments (plantation density and species combination) were carried out in each subplot. There was also a control subplot for each replicate (Fig. 2).

Species Selection

Species were selected using phytosociological information about the area (Loidi et al. 1997), following the successional hypotheses of the vegetation series of the Basque Country (Loidi et al. 2011). The species are shown in Table 2.

Data Sampling

Plant survival and growth were monitored annually during the first 5 years (1994–1999) and every 5 years thereafter (1999–2008). Survival was quantified as the proportion of living saplings relative to the total number of seedlings planted in each plot. Plant growth was estimated as the absolute growth rate in height and diameter (AGRH and AGRD) and the relative growth rate in height and diameter (RGRH and RGRD) (Hunt 1982):

Absolute growth rate in height : $AGRH\,(t_n - t_0) \,=\, (ALT\,t_n - ALT\,t_0)\,/\,t_n - t_0$

Absolute growth rate in diameter : $AGRD\,(t_n - t_0) \,=\, (GROS\,t_n - GROS\,t_0)\,/\,t_n - t_0$

Relative growth rate in height : $RGRH\,(t_n - t_0) \,=\, (\ln ALT\,t_n - \ln ALT\,t_0)\,/\,t_n - t_0$

Relative growth rate in diameter : $RGRD\,(t_n - t_0) \,=\, (\ln GROS\,t_n, -\ln GROS\,t_0)\,/\,t_n - t_0$

Table 1 Description of the three plots

	Plot 1. Subcantabric Mesophytic Oak Forest type (*Crataego laevigatae-Querctum roboris*)	Plot 2. Eutrophic Montane Beech Forest type (*Carici sylvaticae-fagetum sylvaticae*)	Plot 3. Oligotrophic Montane Beech Forest type (*Saxifrago hirsutae-Fagetum sylvaticae*)
Location	Oleta area, municipality of Aramaio	Arridu area, municipality of Mañaria	Atxin area, municipality of Aramaio
UTM	30TWN2967	30TWN2575	30TWN3269
Altitude (m a.s.l.)	580	720	800
Steepness (%)	0	Between 16 and 35	Over 35
Orientation		NW	E
Precipitation (mm)	1583.7	2100.61	1774.8
Mean annual temperature (°C)	11.73	11.02	10.78
Soil type	Distric fluvisol	Orthic acrisol	Umbric regosol
Bedrock	Clayey lutites	Sandstone and clay	Sandstone
Vegetation at the beginning of the restoration	Grassland dominated by *Agrotis capillaris* accompanied by brambles and *Juncus* sp. and *Salix atrocinera* in the wettest places	Grassland dominated by *Agrostis capillaris*, with some shrubs such as willows, sloes and some disperse trees, mostly birches	Totally covered by gorses (*Ulex gallii*)
Surrounding vegetation	Artificial plantation of various species such as *Acer pseudoplatanus*, *Pinus sylvestris* and *Pinus pinaster*, with some *Quercus robur* specimens scattered in the canopy	Artificial plantation of *Pinus radiata*	Recent mixed plantation of rowan (*Sorbus aucuparia*), birch (*Betula pendula*) and beech (*Fagus sylvatica*)
Previous use of the area	Tree nursery of the forestry service		Tree plantation of *Chamaecyparis lawsoniana*

Analysis

Negative growth has been counted as null for the calculations of the growth indices. Normality analysis was performed by using the Kolmogorov-Smirnov test (Sokal and Rohlf 2012). To compare growth between species, an analysis of variance (ANOVA) was performed using the minimal-significant-differences test (DMS) when the distribution of residuals was distributed normally (Norušis 2012). In order to understand temporal changes in growth rate, relative growth in height and diameter were compared over two periods: 1994–2004 and 1994–2008. Pearson

	20m	20m
10m	**C1**	**C2**
10m	**B1**	**B2**
10m	**A1**	**A2**
10m		**Control**
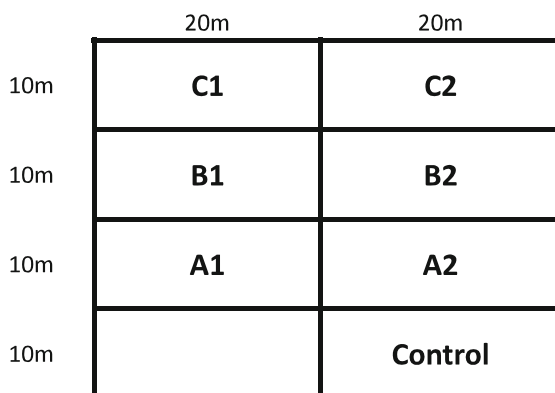
Species combinations and densities:

C: Forest trees mixed with mature forest trees

B: Pre-forest trees mixed with some shrubs and mature forest trees

A: Shrubs mixed with pre-forest trees

Control: Non-planted plot, in order to monitor natural succession of vegetation.

1: Density of 5000 trees/Ha

2: Density of 2500 trees/Ha

Fig. 2 Experimental design of the plot replicates with the spatial distribution of 6 subplots plus the control. Species combinations and densities: *C*, Pre-forest trees mixed with mature forest trees; *B*, Pre-forest trees mixed with some shrubs and mature forest trees; *A*, Shrubs mixed with pre-forest trees; *Control*, Non-planted plot, in order to monitor natural succession of vegetation. *1*, Density of 5000 trees/ha; *2*, Density of 2500 trees/ha

Table 2 Species planted in each of the three plots

Plot 1. Subcantabric Mesophytic Oak Forest type (*Crataego laevigatae-Querctum roboris*)	Plot 2. Eutrophic Montane Beech Forest type (*Carici sylvaticae-fagetum sylvaticae*)	Plot 3. Oligotrophic Montane Beech Forest type (*Saxifrago hirsutae-Fagetum sylvaticae*)
Acer campestre (ACCA)	*Crataegus monogyna* (CRMO)	*Betula celtiberica* (BECE)
Corylus avellana (COAV)	*Fagus sylvatica* (FASY)	*Crataegus monogyna* (CRMO)
Crataegus monogyna (CRMO)	*Fraxinus excelsior* (FREX)	*Fagus sylvatica* (FASY)
Euonymus europaeus (EUEU)	*Populus tremula* (POTR)	*llex aquifolium* (ILAQ)
Fraxinus excelsior (FREX)	*Prunus spinosa* (PRSP)	*Salix atrocinerea* (SAAT)
Ilex aquifolium (ILAQ)	*Rosa squarrosa* (ROSQ)	*Sorbus aucuparia* (SOAU)
Ligustrum vulgare (LIVU)	*Salix atrocinerea* (SAAT)	*Sorbus aria* (SOAR)
Prunus spinosa (PRSP)	*Sorbus aria* (SOAR)	*Salix caprea* (SACA)
Quercus robur (QURO)	*Corylus avellana* (COAV)	

correlation analysis showed high correlation between absolute and relative growth rate, indicating similar tendencies. So we present only the results for relative growth in the three plots.

Survival accumulation rate was calculated as the percentage of surviving plants in each sampling, taking the first sampling as the baseline. Cumulative survival rates were calculated by the Kaplan-Meier method, and survival curves were compared using the log-rank test (Kleinbaum 1996).

Results

Sapling Survival

In the **Subcantabrian Mesophytic Oak Forest**, the survival rate was low (25.2 %) if we consider the total number of individuals planted (Table 3). Nevertheless, some species were more successful, approaching 50 % survival, such as *Quercus robur* (QURO, 48.3 %), *Corylus avellana* (COAV, 48.3 %) and *Crataegus monogyna* (CRMO, 40 %). On the other hand, other species presented a low or very low survival rate, and *Ligustrum vulgare* and *Euonymus europaeus* did not survive at all. The survival diagram (Fig. 3) shows three separate groups. The first group involves the three species (QURO, COAV and CRMO) with over 80 % survival over the first 10 years. These species suffered high mortality during the last 5 years due mainly to routine maintenance activities, such as clipping and clearing, which eliminated some of the saplings. This group shows significant differences relative to the other species planted in the plot, except *Corylus avellana* and *Ilex aquifolium*. The second group is formed by *Acer campestre*, *Ilex aquifolium*, *Fraxinus excelsior* and *Prunus spinosa*. These had high mortality between 5 and 10 years after planting, with around 50 % survival, and then suffered high mortality again during the last 5 years. Finally, there is a third group formed by two species, *Ligustrum vulgare* and *Euonymus europaeus*, which had very low survival (less than 10 %) after the first 5 years and did not survive at all by the end of the 15 years. Average seedling life extended from 54.95 months for *Euonymus europaeus* to 167.6 months for *Crataegus monogyna* (Table 4).

A good survival rate (59.3 %) was observed in the **Eutrophic Montane Beech Forest**. Some species showed a survival rate of ca. 90 %, i.e., *Crataegus monogyna* (91 %), *Salix atrocinerea* (87.93 %) and *Corylus avellana* (86.6 %). The rest had a survival rate over 50 % except for *Sorbus aria*, with only 24.6 % (Table 5).

The survival-curve analysis (Fig. 4) showed three groups of species with significant differences among them. The first group is that with the highest survival during the monitoring time, including *Crataegus monogyna*, *Salix atrocinerea*, *Corylus avellana* and *Rosa squarrosa* (ROSQ). These species had a slight decline during the period 2004–2008, especially *Rosa*. The second group showed gradual mortality through the entire period, with over 50 % survival except for *Prunus spinosa* (36 %); it includes *Prunus spinosa*, *Populus tremula*, *Fraxinus*

Table 3 Total number of seedlings of each species planted and percentage of survival in the Subcantabric Mesophytic Oak Forest

Species	Seedling	% Seedling	Surv08	% surv08	Pos.gr	% pos.gr
QURO	236	26.50	114	48.30	111	97.4
FREX	148	16.60	20	13.50	11	55.0
LIVU	86	9.68	0	0.00	0	0.0
COAV	60	6.75	29	48.30	16	55.2
PRSP	88	10.20	9	10.20	4	44.4
ILAQ	60	6.75	13	21.60	1	7.7
CRMO	60	6.75	24	40. 00	20	83.3
ACCA	90	10.10	15	16.60	8	53.3
EUEU	60	6.75	0	0.00	0	0.0
Total	888	100 %	224	25.20 %	171	76.3

Surv08, Number of specimens surviving in 2008; *% surv08*, Survival percentage in 2008; *Pos.gr*, Number of specimens with positive growth in 2008; *% pos.gr*, Percentage of specimens with positive growth with respect to the surviving specimens in 2008 for each of these species
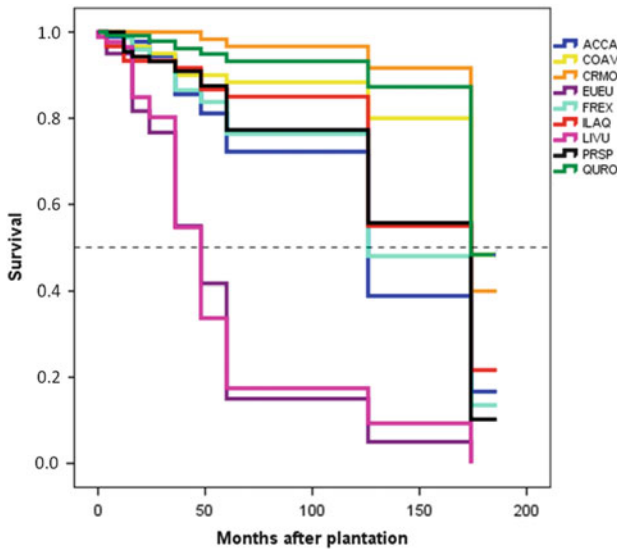

Fig. 3 Accumulated survival curves for each of the species planted in the Subcantabric Mesophytic Oak Forest, the *dotted line* indicates 50 % survival

excelsior and *Fagus sylvatica*. The third group involves only *Sorbus aria*, which suffered high mortality during the second year after planting. Average seedling life extended from 83.36 months for *Sorbus aria* to 172.4 months for *Rosa squarrosa* (Table 6).

The **Oligotrophic Montane Beech Forest** showed very low survival in general (17.5 %), and only one species, *Sorbus aucuparia* (77 %), had over 50 % survival. The next highest survival rate was that of *Sorbus aria* at 35.7 %. Other species, such as *Betula celtiberica* (17.9 %), *Ilex aquifolium* (15 %), *Fagus sylvatica* (8.60 %)

Table 4 Mean survival times (months) and log rank test results for the planted species in the Subcantabric Mesophytic Oak Forest

|	Survival means (S.E.)	ACCA	COAV	CRMO	EUEU	FREX	ILAQ	LIVU	PRSP
ACCA	121.36 (5.71)								
COAV	153.43 (6.03)	22.29***							
CRMO	167.6 (3.09)	28.02***	0.02						
EUEU	54.95 (5.43)	51.47***	79.79***	105.25***					
FREX	128.61 (4.47)	0.25	26.74***	31.64***	76.21***				
ILAQ	133.03 (6.61)	2.8	10.59**	13.46***	57.77***	2.22			
LIVU	58.63 (5.01)	52.88***	84.27***	106.53***	0.063	79.83***	58.10***		
PRSP	133.68 (5.73)	0.59	23.16***	28.75***	65.73***	0.12	1.3	66.99***	
QURO	161.93 (2.33)	66.46***	0.2	0.48	245.03***	81.22***	27.81***	255.67***	60.32***

S.E. = Standard error
**P < 0.01
***P < 0.001

Table 5 Total number of seedlings of each species planted and percentage of survival in the Eutrophic Montane *Beech Forest* type

Species	Seedling	% Seedling	Surv08	% surv08	Pos.gr	% pos.gr
FASY	236	26.50	140	59.30	84	60.0
POTR	148	16.60	86	58.10	75	87.2
PRSP	30	3.37	11	36.60	1	0.09
FREX	90	10.13	45	50.00	21	46.7
SOAR	150	16.89	37	24.60	0	0.0
ROSQ	30	3.37	22	73.30	1	0.05
CRMO	116	13.06	105	91.00	48	45.7
COAV	30	3.37	26	86.60	17	65.4
SAAT	58	6.50	51	87.93	41	80.4
Total	888	100	527	59.30	286	54.3

Surv08, Number of specimens surviving in 2008; *% surv08*, Survival percentage in 2008; *Pos.gr*, Number of specimens with positive growth in 2008; *% pos.gr*, Percentage of specimens with positive growth with respect to the surviving individuals in 2008 for each of these species

Fig. 4 Accumulated survival curves for the species planted in the Eutrophic Montane Beech Forest type, the *dotted line* indicates 50 % survival
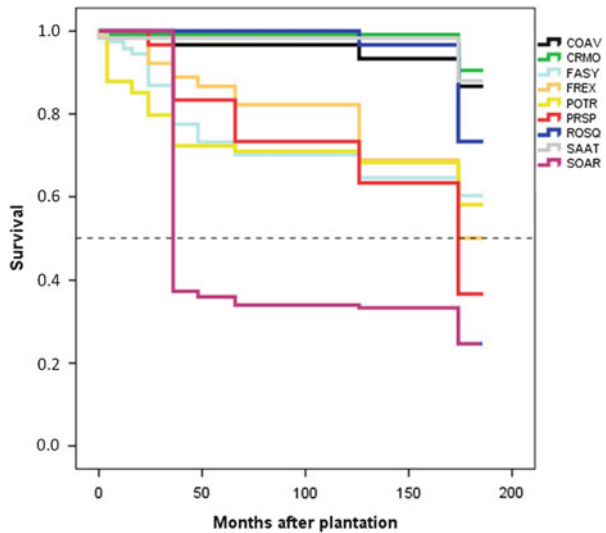
and *Salix atrocinerea* (1.90 %) presented very low survival rates. *Crataegus monogyna* and *Salix caprea* did not survive at all (Table 7).

Survival curves (Fig. 5) showed that all the planted species suffered high, gradual mortality throughout the monitoring period and that most seedlings, except *Sorbus aucuparia*, died during the first 5 years. Three groups with significant differences between them can be distinguished. The first group was formed by only *Sorbus aucuparia*, with the highest survival scores and significant differences from all the other taxa. The second group was formed by *Sorbus aria* (SOAR),

Table 6 Mean survival times (months) and log rank test results for the planted species in the Eutrophic Montane Beech Forest type

|	Survival means (S.E.)	COAV	CRMO	FASY	FREX	POTR	PRSP	ROSQ	SAAT
COAV	167.8 (5.47)								
CRMO	170.36 (2.18)	0.14							
FASY	117.87 (4.52)	11.44**	45.26***						
FREX	141.13 (5.63)	12.65***	45.17***	0.10					
POTR	127.88 (5.82)	8.40**	32.57***	0.87	0.62				
PRSP	135 (10.55)	15.82***	47.38***	0.47	0.89	2.08			
ROSQ	172.4 (1.68)	1.36	4.41*	6.10*	7.33**	3.59	10.62**		
SAAT	163.41 (4.16)	0.01	0.25	20.66***	22.41***	14.88***	25.80***	2.01	
SOAR	83.36 (5.30)	36.32***	116.20***	17.19***	18.31***	20.94***	3.67	27.00***	60.94***

S.E. = Standard error
*P < 0.05
**P < 0.01
***P < 0.001

Table 7 Total number of seedlings of each species planted and percentage of survival in the Oligotrophic Montane Beech Forest type

Species	Seedling	% Seedling	Surv08	% surv08	Pos.gr	% pos.gr
FASY	256	25.90	22	8.60	12	54.5
ILAQ	100	10.12	15	15	1	6.7
CRMO	100	10.12	0	0.0	0	0.0
SAAT	154	15.58	3	1.90	1	33.3
SOAU	122	12.36	94	77.0	68	72.3
SACA	30	3.03	0	0.0	0	0.0
SOAR	14	1.41	5	35.7	0	0.0
BECE	212	21.40	38	17.90	38	100.0
TOTAL	988	100	177	17.50	120	67.8

Surv08, Number of specimens surviving in 2008; *% surv08*, Survival percentage in 2008; *Pos.gr*, Number of specimens with positive growth in 2008; *% pos.gr*, Percentage of specimens with positive growth with respect to the surviving individuals in 2008 for each of these species

Fig. 5 Accumulated survival curves for the species planted in the Oligotrophic Montane Beech Forest type, the *dotted line* indicates 50 % survival
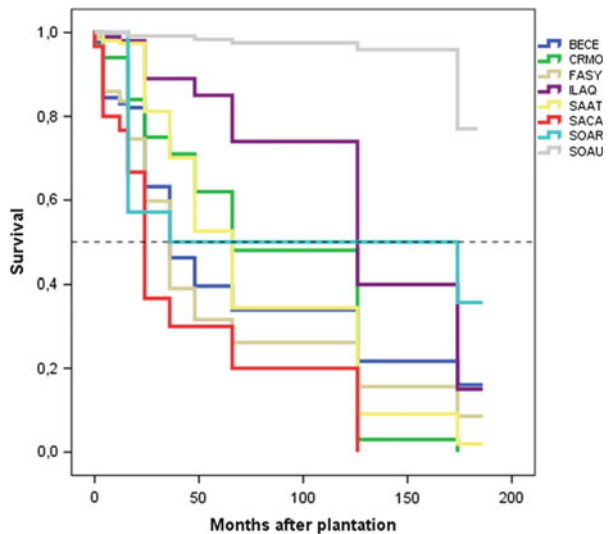
Betula celtiberica, *llex aquifolium*, *Fagus sylvatica* and *Salix atrocinerea*; in this group, *llex aquifolium* deviates slightly because it is the only species presenting significant differences from all the other taxa. The third group was formed by *Crataegus monogyna* and *Salix caprea*, with no survival. Average seedling life extended from 44.07 months for *Salix caprea* to 170 months for *Sorbus aucuparia* (Table 8).

Table 8 Mean survival times (months) and log rank test results for the planted species in the Oligotrophic Montane Beech Forest type

	Survival means (S.E.)	BECE	CRMO	FASY	ILAQ	SAAT	SACA	SOAR
BECE	71.61 (4.42)							
CRMO	80.8 (5.00)	0.09						
FASY	60.9 (3.70)	5.14*	2.75					
ILAQ	123.94 (5.30)	16.27***	40.43***	40.51***				
SAAT	76.17 (3.96)	0.17	0.21	4.17*	46.50***			
SACA	44.07 (8.22)	9.22**	13.65***	4.53*	53.62***	15.68***		
SOAR	96.43 (22.03)	1.49	6.62*	4.58*	0.13	6.15*	7.71**	
SO AU	170 (1.96)	145.91***	208.52***	200.22***	107.23***	222.91***	195.60***	22.18***

S.E. = Standard error
*P < 0.05
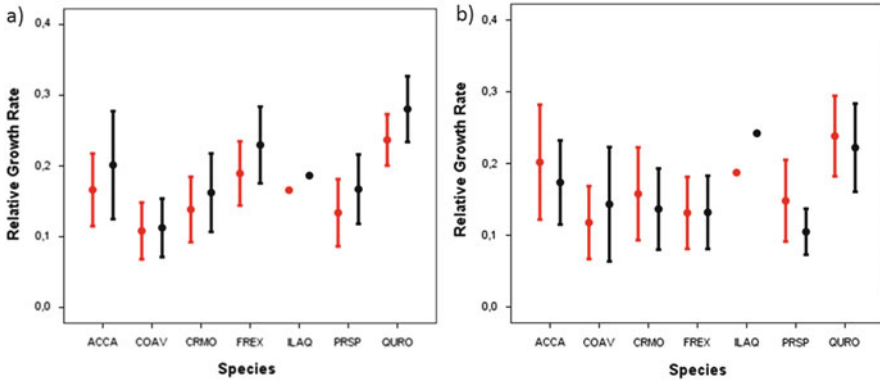**P < 0.01
***P <0.001

Fig. 6 Mean and standard deviation for (**a**) relative growth rate in height and (**b**) relative growth rate in diameter in Subcantabric Mesophytic Oak Forest type. *Red bars*: 1994–2004 and *black bars*: 1994–2008
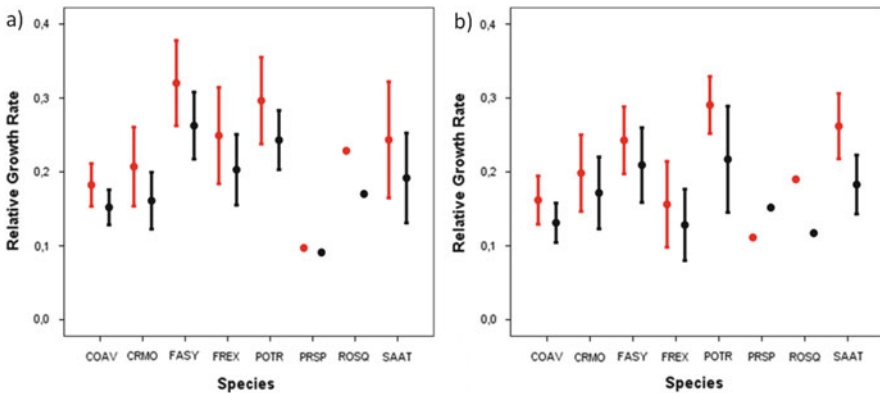

Fig. 7 Mean and standard deviation for (**a**) relative growth rate in height and (**b**) relative growth rate in diameter in Eutrophic Montane Beech Forest type. *Red bars*: 1994–2004 and *black bars*: 1994–2008

Sapling Growth

Plant growth was analyzed by combining all the data for height and diameter increases by the different species for the two periods monitored (1994–2008 and 1994–2004). The standard deviation was very high, due to the high variation in growth rate among individuals (Figs. 6, 7 and 8).
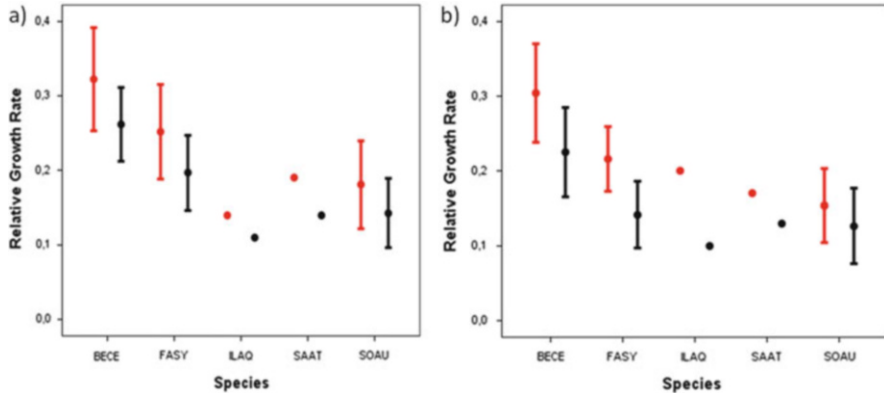
Fig. 8 Mean and standard deviation for (**a**) relative growth rate in height and (**b**) relative growth rate in diameter in Oligotrophic Montane Beech Forest type. *Red bars*: 1994–2004 and *black bars*: 1994–2008

Subcantabrian Mesophytic Oak Forest Type (*Crataego laevigatae-Querctum roboris*)

In all, more than 75 % of the surviving plants had positive growth. *Quercus robur* had the best result, with almost all surviving seedlings showing positive growth (97.4 %); this was followed by *Crataegus monogyna* (83.3 %). The relative rate of height growth was greater for the 15 years than for the first period in all species, but the opposite was true for diameter growth, except for *Corylus avellana*.

Over the 15 years of monitoring, the species with the highest growth rate in height was *Quercus robur* ($RGRH_{1994–2004} = 0.24$ and $RGRH_{1994–2008} = 0.28$) and *Acer campestre* had the second fastest growth per year. On the other hand, the lowest rates of height growth were by *Corylus avellana* ($RGRH_{1994–2004} = 0.11$ and $RGRH_{1994–2008} = 0.11$), followed by *Crataegus monogyna* and *Prunus spinosa* (Fig. 5a). *Quercus robur* ($RGRD_{1994–2004} = 0.24$ and $RGRD_{1994–2008} = 0.22$) and *Acer campestre* were the two species with the fastest relative rates of diameter growth, while *Prunus spinosa* ($RGRD_{1994–2004} = 0.15$ and $RGRD_{1994–2008} = 0.10$) was the slowest, followed by *Fraxinus excelsior* (Table 9, Fig. 6b).

Eutrophic Montane Beech Forest (*Carici sylvaticae-Fagetum sylvaticae*)

In spite of having the highest survival rates (59.3 %), only 54 % of the surviving seedlings in this forest type had positive growth. The highest growth percentages were by *Populus tremula* (87.21 %) and *Salix atrocinerea* (80.39 %).

Relative rates of height and diameter growth were higher in all species during 1994–2004 than during 1994–2008. This suggests a tendency for growth to slow down during later years.

Table 9 Results of Fisher LSD post-hoc tests for ANOVA between relative growth rate for planted species in Subcantabric Mesophytic Oak Forest type

		1994–2004					1994–2008				
		ACCA	COAV	CRMO	FREX	PRSP	ACCA	COAV	CRMO	FREX	PRSP
RGRH	COAV	0.06**					0.09***				
	CRMO	0.03	0.03**				0.04	0.05**			
	FREX	0.02	0.08****	0.05**			0.03	0.12***	0.07***		
	PRSP	0.03	0.03	0.01	0.06*		0.03	0.05*	0.01	0.06*	
	QURO	0.07***	0.13***	0.10***	0.05***	0.10***	0.08***	0.18***	0.12***	0.05**	0.11***
RGRD	COAV	0.08**					0.03				
	CRMO	0.04	0.04*				0.04	0.01			
	FREX	0.07**	0.01	0.03			0.04	0.01	0.01		
	PRSP	0.05	0.03	0.01	0.02		0.07	0.04	0.04	0.03	
	QURO	0.04	0.12***	0.08***	0.11 ***	0.09**	0.05*	0.08****	0.09***	0.09***	0.12***

*P < 0.05
**P < 0.01
***P < 0.001

Table 10 Results of Fisher LSD post-hoc tests for ANOVA between relative growth rate for planted species in Eutrophic Montane Beech Forest type

		1994–2004					1994–2008				
		COAV	CRMO	FASY	FREX	POTR	COAV	CRMO	FASY	FREX	POTR
RGRH	CRMO	0.02					0.01				
	FASY	0.14***	0.11***				0.10***	0.10***			
	FREX	0.07**	0.04**	0.07***			0.05**	0.04***	0.06 ***		
	POTR	0.11 ***	0.09***	0.02*	0.05**		0.09***	0.08***	0.02**	0.04***	
	SAAT	0.06 ***	0.04**	0.08***	0.01	0.05***	0.04**	0.03**	0.07 ***	0.01	0.05***
RGRD	CRMO	0.04**					0.04**	0.04***			
	FASY	0.08***	0.04***				0.08***	0.04**	0.08 ***		
	FREX	0.01	0.04**	0.09***			0.01	0.05***	0.01	0.09***	
	POTR	0.13***	0.09***	0.05***	0.13***		0.09***	0.01	0.01	0.09***	
	SAAT	0.10***	0.06***	0.02*	0.11***	0.03**	0.05**	0.01	0.03*	0.05***	0.03**

*P < 0.05
**P < 0.01
***P < 0.001

Table 11 Results of Fisher LSD post-hoc tests for ANOVA between relative growth rate for planted species in Oligotrophic Montane Beech Forest type

		1994–2004		1994–2008	
		BECE	FASY	BECE	FASY
RGRH	FASY	0.07**		0.06***	
	SOAU	0.14***	0.07**	0.12***	0.05***
RGRD	FASY	0.09***		0.08**	
	SOAU	0.15***	0.06***	0.10***	0.02

**$P < 0.01$
***$P < 0.001$

The highest rate of height growth over the whole 15 years of monitoring was by *Fagus sylvatica* ($RGRH_{1994–2004} = 0.32$ and $RGRH_{1994–2008} = 0.26$), followed by *Populus tremula* and *Salix atrocinerea*; the lowest rate corresponded was by *Corylus avellana* ($RGRH_{1994–2004} = 0.18$ and $RGRH_{1994–2008} = 0.15$) (Fig. 7a).

For relative rate of diameter growth, *Populus tremula* ($RGRD_{1994–2004} = 0.29$ and $RGRD_{1994–2008} = 0.22$) had the highest values, followed by *Fagus sylvatica* and *Salix atrocinerea* (Fig. 6b); *Corylus avellana* ($RGRD_{1994–2004} = 0.16$ and $RGRD_{1994–2008} = 0.13$) had the slowest growth. Differences in growth between most of the species pairs declined over time, not only for relative height growth but also for relative diameter growth (Table 10).

Oligotrophic Montane Beech Forest Type (*Saxifrago hirsutae-Fagetum sylvaticae*)

Although survival was very low (17.5 %), the proportion of seedlings with positive growth reached 67.8 % and *Betula celtiberica* stood out with 100 % survival, followed by *Sorbus aucuparia* with 72.3 % (Table 7).

Relative rates of height and diameter growth were higher in the period 1994–2004 in all the species, indicating a slowing-down in their growth rate.

Over the 15 years of monitoring, the species with the highest rates of height and diameter growth was *Betula celtiberica* ($RGRH_{1994–2004} = 0.32$; $RGRH_{1994–2008} = 0.26$; $RGRD_{1994–2004} = 0.30$ and $RGRD_{1994–2008} = 0.23$), followed by *Fagus sylvatica*; lower rates were showed by *Sorbus aucuparia* ($RGRH_{1994–2004} = 0.18$; $RGRH_{1994–2008} = 0.14$; $RGRD_{1994–2004} = 0.15$ and $RGRD_{1994–2008} = 0.13$) (Fig. 8a, b). Differences in growth between all the species pairs declined with time, not only for relative height growth but also for relative diameter growth (Table 11).

Discussion

Seeding survival can be attributed to the combined effects of human disturbance and microclimatic conditions (Ramírez-Marcial 2003) and also to the quality of the seedlings, in terms of their survival capacity (Grossnickle 2012). The high survival

(almost 60 %) among seedlings in the Eutrophic Montane Beech Forest (EMBF), as compared to the Oligotrophic Montane Beech Forest (OMBF, less than 20 %), is related to soil and climatic conditions where the plots are located. The Oligotrophic beech forest, besides having poorer nutrient availability, is located on a steeper slope that experiences high runoff, thus captures less water, and consequently is drier. In addition, the sandstone substrate facilitates water loss and the southeast orientation confers greater summer drought. The better soil conditions in the Eutrophic beech plot and its northwest orientation, which promotes higher humidity especially in summer, has led to better plant survival. On the other hand, the poor quality of the seedlings of several species, such as *Sorbus aria*, *Ligustrum vulgare*, *Euonymus europaeus* and *Prunus spinosa*, caused high mortality during the first years (Grossnickle 2012). Another factor was the action of herbivores that affected some species, such as *Ilex aquifolium*.

Already in 2004 it was observed that a high proportion of the trees showed very little growth; by 2008 high mortality was recorded. Root-system size is proportional to the diameters of the above-ground main stem (Mexal and Landis 1990), and the ability to grow roots has a significant effect on survival (Grossnickle 2012). Thus, the low growth rate could indicate a small root system that leads to plant death. Moreover, the routine maintenance work conducted in the plots increased the mortality, especially in the Subcantabrian Mesophytic Oak Forest, where about 30 % of the seedlings were cut.

There was some variation in survival between different functional groups. In general, shrubby species showed better survival than species of mature stages in later succession. Thus, the hypothesis that species of seral stages (secondary forests and shrubland) have higher survival rate than mature-stage species seems to be confirmed. This is to be expected for beech, since it is well known that it has lower survival rates under high light intensity (Petritan et al. 2007; Jarcuska 2009). This was not the case with oak (*Quercus robur*), however, which had a survival rate similar to that of *Corylus avellana* or *Crataegus monogyna*.

Relative rate of height growth has been greater in the last 5 years than in the previous period in mesic oak forest (SMOF), but in the beech forest plots growth in the first 10 years was greater than in the last period. Even the species planted in both the mesic oak forest and eutrophic beech forest, such as *Corylus avellana*, *Crataegus monogyna* and *Fraxinus excelsior*, showed this tendency. This suggests that greater water availability in deeper soil layers of the flat ground, where the plots are located, could induce more growth in the last period, once the tree roots had reached these more moist levels. The different relative growth rates of *Fagus sylvatica* in the eutrophic versus oligotrophic beech forest can be explained by the worse soil and microclimatic conditions at the Oligotrophic Montane Beech Forest plot.

There are also some other differences between the functional groups of plants. Trees of mature and secondary stages (*Quercus robur*, *Fagus sylvatica*, *Populus tremula* and *Acer campestre*) tend to show greater rates of height and diameter growth than do shrubs of successional stages (*Crataegus monogyna*, *Prunus spinosa* and *Corylus avellana*). The higher growth rate of the mature-forest species

is a phenomenon that has also been observed in tropical forests by Shono et al. (2006), where a number of primary forest species had better growth rates than did secondary-forest species.

In summary, the results have proved that the initial topographic and soil conditions of the plots determine the afforestation success to a great extent, which was already evident and reported by the second year of monitoring (Sesma et al. 1997). The Eutrophic Montane Beech Forest plot, with more structured soil and humid conditions, especially in summer, had better survival and growth rates, probably due to the orientation of the plot. On the other hand, the steeper slope and sandy soil of the Oligotrophic Montane Beech Forest plot, together with its SW orientation, resulted in worse conditions for seedling establishment, increasing mortality and reducing growth rates. In fact, water stress related to high temperatures and lower moisture availability in pastures was reported as one of the main factors causing mortality in several reforestation attempts (Hooper et al. 2002, Doñobeytia et al. 2007). Finally, in the Mesic Oak Forest plot, there were some areas with very compacted soil due to the presence of paths; this resulted in high plant mortality in the first years. Another factor that caused a remarkable decline in the survival of all species was the weeding and clearing work carried out in the plots, especially in the oak forest. Although weeding has been documented to have a strong positive effect on seedling and sapling growth (Löf and Welander 2004), it must be done by hand or very carefully, in order to avoid cutting the plants.

Despite low overall survival, the general growth rate of the surviving seedlings allows us to conclude that the study results were positive, accelerating the natural forest successional processes and controlling invasion by shrub species like *Rubus* and *Ulex*, which limit natural succession in degraded lands (cf Shono et al. 2006). Tree-planting strategies should include improving the soil conditions before afforestation and selecting seedlings with good root systems that contribute to better survival. With regards to species selection, even though growth rates were higher in trees than in shrubs, we recommend using shrubs also in order to improve the biodiversity of the restored forests.

References

Ashby WC (1987) Forests. In: Jordan WR et al (eds) Restoration ecology: a synthetic approach to ecological research. Cambridge University Press, Cambridge, pp 89–108

Balaguer L (2002) Las limitaciones de la restauración de la cubierta vegetal. Ecosistemas 11:72–82

Benayas JM, Espigares T, Nicolau JM (eds) (2003) Restauración de ecosistemas mediterráneos. Universidad de Alcalá. Alcalá de Henares

Biondi E (2011) Phytosociology today: methodological and conceptual evolution. Plant Biosyst 145:19–29

Blasi C (ed) (2010) La vegetazione d'Italia, con carta delle serie de vegetazione in scala 1:500.000 edn. Palombi, Roma.

Bradshaw AD (1987) Restoration: an acid test for ecology. In: Jordan WR et al (eds) Restoration ecology: a synthetic approach to ecological research. Cambridge University Press, Cambridge, pp 23–29

Chiarucci A, Araújo MB, Decocq G, Beierkuhnlein C, Fernández-Palacios JM (2010) The concept of potential natural vegetation: an epitaph? J Veg Sci 21:1172–1178

Doñobeytia FR, Tacher SL, Perales H, Ramires N, López S (2007) Establecimiento de seis especies arbóreas nativas en un pastizal degradado en la selva La Candona, Chiapas, México. Departamento académico de biología, Universidad Nacional Agraria La Molina, Lima-Perú

Grossnickle SC (2012) Why seedlings survive: influence of plant attributes. New For 43:711–738

Harper JL (1987) The heuristic value of ecological succession. In: Jordan WR et al (eds) Restoration ecology, a synthetic approach to ecological research. Cambridge University Press, Cambridge, pp 35–45

Hooper E, Condit R, Legendre P (2002) Responses of 20 native tree species to reforestation strategies for abandoned farmland in Panama. Ecol Appl 12(6):1626–1641

Hunt R (1982) Plant growth curves—the functional approach to plant growth. Edward Arnold, London, 248 pp

Inventario Forestal CAE (2005) http://www.nasdap.ejgv.euskadi.net/r50-15135/es/contenidos/informacion/if_aprox_bosque/es_dapa/if_aprox_bosque.html

Jarcuska B (2009) Growth, survival, density, biomas partitioning and morphological adaptations of natural regeneration in *Fagus sylvatica*: A review. Dendrobiology 61:3–11

Jordan WR, Gilpin ME, Aber JD (eds) (1987) Restoration ecology. A synthetic approach to ecological research. Cambridge University Press, Cambridge

Kirby KJ, Patterson G (1992) Ecology and management of semi-natural tree species mixtures. In: Cannell MGR et al (eds) The ecology of mixed-species stands of trees. Blackwell, Oxford, pp 189–209

Kleinbaum DG (1996) Survival analysis. A self learning text. Springer, New York

Löf M, Welander NT (2004) Influence of herbaceous competitors on early growth in direct seeded *Fagus sylvatica* L. and *Quercus robur* L. Ann For Sci 61(8):781–788

Loidi J (1999) Preserving biodiversity in the European Union: the habitats directive and its application in Spain. Plant Biosyst 133(2):99–106

Loidi J, Báscones JC (1995) Memoria y mapa de series de vegetación de Navarra. Ed. Gobierno de Navarra, Pamplona, 99 pp

Loidi J, Biurrun I, Herrera M (1997) La vegetación del centro-septentrional de España. Itinera Geobotanica 9:161–618

Loidi J, Biurrun I, Campos JA, García-Mijangos I, Herrera M (2011) La vegetación de la Comunidad Autónoma del País Vasco. Leyenda del mapa de series de vegetación a escala 1:50.000. Ed. Universidad del País Vasco (electronic edition). ISBN: 978-84-694-4731-4

Loidi J, Fernández-González F (2012) Potential natural vegetation: reburying or reboring? J Veg Sci 23:596–604

Loidi J, Herrera M, Salcedo I, Galarza A, Iturrondobeitia JC (2005). Bizkaiko Basoak/Los Bosques de Bizkaia. Diputación Foral de Bizkaia, 383 pp

Mexal JG, Landis TD (1990) Target seedling concepts: height and diameter. In: Rose R et al (eds) Target seedling symposium: proceedings of the western forest nursery associations (Forest Service Gen. Tech. Rep. RM-200:17–36). USDA, Washington, DC

Miyawaki A (ed) (1980–1989) Nihon Shokusei-shi [Vegetation of Japan], 10 vols. Shibundō, Tokyo

Miyawaki A, Box EO (2006) The healing power of forests: the philosophy behind restoring earth's balance with native trees. Kōsei Publishing, Tokyo

Norušis MJ (2012) IBM SPSS statistics 19.0 statistical procedures companion. Prentice Hall

Petritan AM, Von Lüpke B, Petritan IC (2007) Effects of shade on growth and mortality of maple (*Acer pseudoplatanus*), ash (*Fraxinus excelsior*) and beech (*Fagus sylvatica*) saplings. Forestry 80(4):397–412

SER (2004) The SER primer on ecological restoration, version 2. Society for Ecological Restoration Science and Policy Working Group

Ramírez-Marcial N (2003) Survival and growth of tree seedlings in anthropogenically disturbed Mexican montane rainforests. J Veg Sci 14:881–890

Rivas-Martínez S (1987) Memoria del mapa de series de vegetación de España 1:400.000. ICONA. Minist. Agricultura Pesca y Alimentación, Madrid, 208 pp

Rivas-Martínez S (2007) Mapa de series, geoseries y geopermaseries de vegetación de España [Memoria del mapa de vegetación potencial de España]. Itinera Geobotanica 17:5–435

Sesma J, Laskurain NA, Garcia-Mijangos I, Manzanedo H, Loidi J (1997) Establecimiento de árboles y arbustos en la restauración de la vegetación potencial en el parque natural de Urkiola: supervivencia y crecimiento de los plantones. Proceedings del I Congreso Forestal Hispano-Luso/II Congreso Español 2:617–622

Shono K, Davies SJ, Khen CY (2006) Regeneration of native plant species in restored forests on degraded lands in Singapore. For Ecol Manage 237:574–582

Sokal RR, Rohlf FJ (2012) Biometry: the principles and practice of statistics in biological research, 4th edn. W. H. Freeman & Co., New York, 937 pp

Tüxen R (1956) Die heutige potentielle natürliche Vegetation als Gegenstand der Vegetationskartierung. Angew Pflanzensoziologie 13:5–55