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Evolution and structure of Artikutza, an 80-year-old beech forest in Navarra (northern Spain)

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Abstract

A structural and historical study was carried out in the beech forest of Artikutza. The aim was to analyse the natural evolution and recovery of the forest after 80 years without significant human disturbance. The current beech forest has grown on land previously covered by a woodland of pollarded oak (*Quercus robur* L.), beech (*Fagus sylvatica* L.) and chestnut (*Castanea sativa* Mill.) which were all felled. The current forest regeneration and diameter frequency distributions are not characteristic of mature forests. Future investigations should confirm whether these traits are the result of the influence of livestock grazing. The volume of dead wood accumulated is high, though it is not of large diameter (< 40 cm). Senescent trees are uncommon and hollow trees were not found. Protection and creation of pollard trees are therefore suggested as management measures for enhancing the availability of resources for forest biodiversity.

• **Key words:** Beech forest, dead wood, forest management, forest structure, history.

Resumen

Se ha estudiado la estructura forestal y la historia del hayedo de Artikutza. El objetivo ha sido analizar la evolución natural y recuperación del bosque tras 80 años sin intervenciones significativas. El bosque se ha desarrollado sobre un territorio previamente cubierto de robles (*Quercus robur* L.), hayas (*Fagus sylvatica* L.) y castaños (*Castanea sativa* Mill.) trasmochos, los cuales fueron talados. Los datos actuales de regeneración y distribución de frecuencias de clases diametrales no son típicos de bosques maduros. Investigaciones futuras son necesarias para confirmar si estas características son el resultado del efecto del ganado. El volumen de madera muerta acumulada es alto, aunque no de gran diámetro (< 40 cm). Los árboles senescentes son poco comunes y no se encontraron troncos con cavidades. Por tanto, se sugiere la protección y creación de árboles trasmochos como medida necesaria para aumentar la disponibilidad de recursos para la biodiversidad forestal.

• **Palabras clave:** Hayedo, madera muerta, gestión forestal, estructura forestal, historia.

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LABURPENA

Artikutzako pagadiaren baso-egitura eta historia aztertu dira. Helburua, berez izan duen bilakaera eta basoaren berreskuraketa analizatzea izan da, aipatzeko moduko eskuhartzerik gabe 80 urte igaro ondoren. Basoa bilakatu deneko lur-saila, lehen mugarratutako haritzez (*Quercus robur* L.), pagoez (*Fagus sylvatica* L.) eta gaztainez (*Castanea sativa* Mill.) estalita zegoen, bota zituzten arte. Birsorketa maila eta diametro-klaseek egun dituzten maiztasunen banaketak ez datoz bat baso helduak dituztenekin. Azterketa gehiago beharko dira ezaugarri hauek aziendaren eraginaren ondorioak diren ala ez jakiteko. Metaturiko hildako egur kopurua handia da, baina diametro txikikoa (< 40 cm). Zahar-itxurako zuhaitzak ez dira arruntak eta ez zen zuloak zituen enbor alerik aurkitu. Beraz, zuhaitz mugarratuen babesa eta berriak izateratzea iradokitzen da, basoaren biodibertsitaterako baliabideak emendatze bidean.

• **GAKO-HITZAK:** Pagadia, hildako egurra, baso kudeaketa, baso egitura, historia.

INTRODUCTION

Old-growth forests undisturbed by human intervention are characterized by the presence of trees of different ages, a well-developed forest stratification, abundant dead wood, and veteran and cavity trees (PETERKEN, 1996; THOMSEN, 2001), features that are considered to be of great importance for the conservation of forest biodiversity (READ, 2000; CAMPRODON & PLANA, 2001; MASON *et al.*, 2003; TAGLIAPETRIA, 2003, VALLAURI *et al.*, 2005). Most European forests, however, are deficient in or entirely lacking such high conservation-value characteristics (BUTLER *et al.*, 2002; VALLAURI *et al.*, 2002). In the Cantabrian-Pyrenean region, widespread historical exploitation of beech forests for the shipbuilding, rail, and timber industries and for grazing land, charcoal, and firewood (ASCASIBAR, 1980; RUIZ URRESTARAZU *et al.*, 1992; MEAZA, 1997) have created a shortage of forest biodiversity resources (LOIDI & BASCONES, 1995; ASEGINOLAZA *et al.*, 1996).

By studying the actual structure and periodically monitoring multi-aged forest not largely affected by human intervention we can elucidate questions on the way in which tree growth rates, veteran and dead tree densities, volumes of accumulated dead wood, cavity development in tree trunks and forest stratification have changed over time. The information gathered, integrated with previously available knowledge on the history of the particular forest, is a necessary tool for promoting the conservation, improvement and sustainable use of forest biodiversity (WATKINS & KYRBY, 1998).

Accordingly, the structure of the Artikutza beech forest was studied and compared with the available historical information, as an example of the process of natural recovery of a forest after 80 years without significant human intervention

(CATALÁN *et al.*, 1989). The objectives of this work were therefore: a) to collect data on the recent history of the beech forests of Artikutza, b) to describe the composition and size structure of seven plots of beech forests, c) to estimate the density and volume of dead wood present in these plots, and d) to assess the current and future quality of the Artikutza beech forests as faunal shelters for threatened or rare species, and as biodiversity reserves.

MATERIALS AND METHODS

Characteristics of the Area of Study: The work was carried out on the Artikutza estate, an enclave of 3700 ha situated in the municipality of Goizueta (Navarra). The highest altitude, 1054 m, lies to the south of the land, and the lowest, 250 m, in the north-westernmost point.

Annual rainfall averages about 2700 mm, and it is probably the wettest area on the Cantabrian cornice (CATALÁN *et al.*, 1989). The geologic basement contains numerous Palaeozoic elements, most of which are acidic rocks, generally granite, schist, and slate. These substrata, combined with the wet climate and the steep slopes, lead to the formation of acidic soils, principally of the ranker type (CATALÁN *et al.*, 1988).

Given Artikutza's climate and the geological substratum, oligotrophic beech forests—the target of this study—predominate, particularly the Pyreneo-Cantabrian acidophilous series, i.e. *Saxifrago hirsutae-Fageto sylvaticae Sigmetum* (LOIDI & BASCONES, 1995). Beech is the most widespread of forests throughout the estate occupying 1135 ha and 30% of the total area, followed by forest plantations (almost 30%), oak forests (21%) and heathlands (14%) (CATALÁN *et al.*, 1989). These authors calculated that without human alteration about half of the estate would naturally be occupied by beech forest, followed by oak forests (28%), currently found on the low southern slopes of Artikutza. An ecotone comprising the two types of forests would take up 17% of the surface and the rest would be shared between riparian and rocky ecosystems. At present, beech forests mostly appear in the higher areas of the estate, dropping down as far as 300m altitude on the shaded northern slopes. The interior of the beech forest is dominated almost exclusively by beech trees, with a poor under-storey and herbaceous layer, and a near continuous leaf litter on the ground.

In contrast with other European temperate forests, the observed animal community for both invertebrates (MARTÍNEZ DE MURGUÍA *et al.*, 2001, 2002, 2004; KEHLMAIER & MARTÏNEZ DE MURGUÍA, 2004) and vertebrates (CATALÁN *et al.*, 1989), in Artikutza indicates that the estate's ecosystems are relatively well conserved.

In the past, the Artikutza beech forests have suffered many alterations: they were pollarded for lumber wood, deforested for pastoral use, and substituted by exotic trees to be used in the charcoal, and rail industries (CATALÁN *et al.*, 1989). In 1919, after a period of intense forest exploitation during the late nineteenth century, the city council of San Sebastián acquired the estate with the intention of supplying water. As a result, the beech forests have remained relatively undisturbed since that time, except for the ranging of domestic livestock (based on official records by the estate wardens and personal observations). Leisure, relaxation, and environmental education activities are now also common, although access to motorized vehicles is limited (AGIRRE, 2003).

Plots of investigated beech forest: Sampling was carried out from 21st to 28th July, 2004. Altogether, seven plots of beech forest in the western part of the estate (Fig. 1), were studied. Each plot contained approximately 0.125 hectares (3 transects of 50 m arranged in a triangle) and was intended to include the greatest extension and heterogeneity of the best well-preserved stands as possible, while allowing for the best accessibility in order to avoid periodic hindrances. The characteristics of the plots are summarized in Table I.

History of the Estate: The forest history of the Artikutza estate and the plots investigated was gathered by consulting the following documentation:

Reports from the rangers of Artikutza estate provided by the land agent Iñaki Uranga.

Files kept in the Historical Archive of San Sebastián City Council:

Libro 2051: Expediente 1. 1903. Proyecto de ordenación del monte Articutza by the forester Tomás Erice.

Libro 2048: Expediente 1. 1919-1924. Expediente relativo a la administración de e inquilinato de la finca Articutza: rentas, asistencia médica, escuelas, repoblación forestal, etc.

Libro 2048: Expediente 3. 1919-1922. Expediente relativo a la repoblación forestal de la finca Articutza. Of particular interest is the report of 1918 entitled “Descripción hidrográfica y forestal de Articutza” by Benito Menéndez, then Director of Paths, Gardens and Woodlands at San Sebastián City Council.

Libro 2048: Expediente 4. 1919-1922. Expediente relativo al pastoreo en la finca Articutza.

Libro 2048: Expediente 6. 1919-1923. Expediente relativo a labores de carboneo y renta de leña de la finca Articutza.

Figure 1.- Top: Map of Spain showing the location of Artikutza Estate (red quadrant). Bottom: Map of the Artikutza Estate (modified from CATALÁN et al., 1989) indicating the seven plots (red quadrants) of beech forest investigated. From top to bottom: Iturrola, Eskas, Urdallue, Loiola, Loiola-Goizarin, Elama and Alto de Elama.

Plot	UTM coordinates X axis / Y axis	Altitude	Orientation
Elama	05977/47818	450 m	SW
Loiola	05969/47843	350 m	NE
Loiola-Goizarin	05973/47838	375 m	NW
Eskas	05974/47875	600 m	E
Alto de Elama	05974/47811	725 m	W
Urdallue	05978/47846	450 m	NE
Iturrola	05962/47880	525 m	NE

Table I.- Location and characteristics of the seven beech forests plots investigated.

Volume of fallen dead wood: The volume was calculated using the "Line Intersect Method" (LIS) described in MARSHALL *et al.* (2000). This method establishes random samples in the forest interior using transects and by recording the diameter of fallen dead trunks intercepted by the transects at the point of intersection. Afterward, a standard formula is applied to the collected data:

$$V_i = \frac{\pi^2}{8L} \sum_{j=1}^{n_{i2}} d_{ij}$$

Where V_i is the volume of dead wood from transect i (m^3 ha^{-1}), L is the longitude of transect i (m) and d_{ij} is the diameter of each piece j in transect i (cm)

For irregularly shaped and semicircular pieces, appropriate measurements and corrections were made using previously established methods (MARSHALL *et al.*, 2000). Corrections in the angle of the piece to the ground were not carried out, since almost all measurements were taken on dead wood fallen on the ground. LIS is a practical, cost-minimizing method if the aim is to estimate the volume of fallen dead wood (STAHL *et al.*, 2001).

All trunks with basal diameters of over 5 cm and a total length of more than 50 cm were measured. The measurements were taken using forest callipers. The transects were 50 m in length and 3 transects per plot were combined: one vertical, one horizontal, and one diagonal, in relation to the maximum slope.

Volume and density of stumps and snags: A border 4 m wide was established on either side of the 50 m transects. All the snags (taller than 1.3 m) and stumps (less than or equal to 1.3 m in height) within the borders were registered. To calculate the volume of dead wood, the total length and area of the trunk section at 1.3 m in the snags, and the total length and area corresponding to the average diameter (obtained by averaging the maximum and minimum diameters) in the stumps, was considered. In the case of the snags, because of the small length in the majority of cases, a dendrometric cylinder type was assumed (DIÉGUEZ *et al.*, 2003). The diameters were measured using diametric tapes.

Density of live individuals: The same method was used to calculate the densities of live individuals. Three types of individuals were distinguished: seedlings (height $\leq$ 1.5 m), saplings (height > 1.5 m and diameter > 5 cm) and trees (Diameter $\geq$ 5 cm).

Tree height: Tree height was measured using a Suunto hipsometer (DIÉGUEZ *et al.*, 2003). This apparatus presents precision errors (BARRIO *et al.*, 2002) of approximately 5% of actual measurements (AUNÓS & RODRÍGUEZ, 2002).

Tree diameter: Tree diameter was measured using diametric tapes at a height of 1.3 m from the base of the main trunk (dbh). The recommendations of DIÉGUEZ *et al.* (2003) were followed in the case of trees of thicket typology; those with irregularities and special cases. All trees were measured, while only the number of seedlings and saplings was registered.

Tree species present: All live trees were identified to species level, while dead trees and fallen dead wood were identified as best as possible by morphological and anatomical traits. The following species were found: ash (*Fraxinus excelsior* L.), beech (*Fagus sylvatica* L.), birch (*Betula pubescens* Ehrh.), cherry (*Prunus avium* L.), chestnut (*Castanea sativa* Mill.), crab apple or pear (doubtful identification: *Malus* sp. or *Pyrus* sp.), field maple (*Acer campestre* L.), hawthorn (*Crataegus monogyna* Jacq.), hazel (*Corylus avellana* L.), holly (*Ilex aquifolium* L.), pedunculate oak (*Quercus robur* L.) , sessile or white oak (*Quercus petraea* (Mattuschka) Liebl.), Scots pine (*Pinus sylvestris* L.) and an unknown species.

Dead chestnuts and oaks were not distinguished. Data for these species are therefore shown together. Unknown species are indicated with question marks in tables and figures.

Structural tree typology: Each tree was assigned to a structural type:

- Coppice: tree that presents various trunks from the base.
- Pollard: tree with a short trunk and large limbs from a height of 1.5 m or above.
- Maiden tree: tree with one trunk from the base.

Presence of tree cavities of interest: Cavities visible from the ground, with humus in their interior, with openings of a diameter greater than or equal to 5 cm, which are free from water and plants are of interest for their potential as havens for uncommon invertebrate species. The presence of such cavities in the trees was also registered.

State of tree decay: Each tree measured was assigned a state of decay. The classification is as follows (taken from CAREY & HEALY, 1981): State 1: Tree with a regular crown and with no dead branches of diameters greater than 10 cm; State 2: Tree with 1 or 2 large dead branches of diameters greater than 10 cm; State 3: Tree with 3 or more dead branches of diameters greater than 10 cm and a large portion of the crown (>1/3) is dead or has disappeared; State 4: Tree with a partially dead trunk; State 5: The entire tree is dead, although it remains standing.

State of wood decomposition: Each fallen log, trunk, or branch measured to calculate the volume of dead wood was assigned a decomposition level, following the basic criteria proposed by the USDA (United States Agricultural Department): 1: Log intact, firm, and recently fallen; 2: Log partially intact, and partially soft sapwood that cannot be separated by hand, but has begun to decompose; 3: Sapwood is absent or can be separated by hand into large pieces; 4: Rotted, soft heartwood, that can easily be pierced with a sewing needle; 5: The log does not keep its shape and spreads out soft and powdery on the ground; 2Y: Rotted and decaying heartwood that retains a hard exterior, leaving hollow pieces.

Results

Forest History of the Artikutza Estate: In 1903, the engineer Tomás Erice inventoried all trees in the estate with diameters exceeding 20 cm (when measured at chest height). The territory was divided into 35 stands of pollard and maiden trees and into 9 stands of coppice trees. The predominant trees were (in this order), pedunculate oak, beech, and chestnut. Ash, lime, and maple trees were found in the coolest and most fertile places, while willow and alder trees were found along rivers and streams.

The area of the estate was calculated at 3726 ha; pollard and maiden tree woodland occupied 2073 ha, coppice 938 ha, and cleared areas 715 ha.

Within the 35 stands a total of 302154 trees were registered, distributed as follows: 23069 maiden oaks, 151764 pollard oaks, 2010 maiden beeches, 114364 pollard beeches, 1174 maiden chestnuts, and 9503 pollard chestnuts.

Each of the plots examined in this work was included in Tomás Erice's stands as follows (Table II): Elama: characterized by the presence of oaks (69%) and pollard trees (94%), Loiola: oaks (74%) and pollard trees (98 %), Loiola-Goizarin: oaks (82%) and pollard trees (94%), Eskas: oaks (76%) and pollard trees (75%), Urdallue: beeches (63%) and pollard trees (99%), and Iturrola: oaks (48 %), beeches (42%) and pollard trees (100%). The connection to Alto de Elama is uncertain; it may correspond to Stand 31; however, this is not certain.

Plot	Stand	Area (ha)	Maiden Oaks	Pollard Oaks	Maiden Beeches	Pollard Beeches	Maiden Chesnuts	Pollard Chesnuts	Total
Elama	31	23	20	238	2	76	0.1	24	360
Loiola	15	141	4	123	0.01	44	-	1	172
Loiola-Goizarin	34	61	4	68	0.3	7	1	8	88
Eskas	2	26	115	249	1	102	2	12	481
Alto de Elama	Data not available								
Urdallue	11	162	2	56	0.4	97	-	0.01	155
Iturrola	1	121	-	49	-	43	-	11	103

Table II.- Density (individuals ha^{-1}) of trees in the stands found within the sampled plots in 1903 (inventory created by Tomás Erice).

Plot	Maiden Oaks	Coppice Oaks	Maiden Beeches	Pollard/Copicce Beeches	Maiden Chesnuts	Maiden Other species	Total
Elama	8	-	142	-	8	108	266
Loiola	-	-	250	-	8	8	266
Loiola-Goizarin	75	-	92	17/8	58	92	342
Eskas	-	-	300	8/-	8	-	316
Alto de Elama	92	-	358	-	-	192	642
Urdallue	-	-	283	-	-	-	283
Iturrola	-	8	450	-/17	75	-	550

Table III.- Current density of trees (individuals ha^{-1}) in the same stands identified by Tomás Erice in 1903 (see Table II), extrapolated from the plots investigated in 2004.

Since the access to the woodland available at that time did not allow for very intensive exploitation, the arboreal masses presented vigorous appearance and good state, despite—according to Tomás Erice—the anarchic grazing and senseless usage systems employed. A plan of use for the inventoried woodland over the following 15 years was consequently drawn up, with the intention of obtaining railway sleepers, poles, and charcoal. In addition, rapid-growing species such as poplars were introduced in response to the social demands of the period.

In 1903 and 1908 the Artikutza Forest and Exploitation companies were formed. With the idea of gathering firewood and allowing intense forest exploitation, the companies extended the 1898 narrow-gauge railway all the way to Elama (DEL BARRIO, 1989).

According to a report written by the Director of Paths, Gardens, and Woodlands, Benito Menéndez, in 1918 — after 15 years of exploitation — the oak-dominated pollard plantations continued to be Artikutza's principal forest mass. The wooded area was estimated at around 1350 ha, 55% less than in the earlier inventory. While the Artikutza, Añarbe, and Iturrola river basin was fully wooded, the Erroiarri, Enobieta, and Urdallué basin was only partially wooded and in the Elama basin only about 30% of total surface was wooded. There were various ash, American oak, walnut, chestnut, Lombardy poplar, acacia, and elm nurseries as well as Scots pine, radiata pine, and poplar plantations. Pollards and coppices were also felled for charcoal and lumber at a frequency varying between 1 and 8 years. The report recommended halting forest exploitation for lumber and charcoal, and planting new trees in the mountain. Maiden beech trees were preferred because oak had been seriously affected by the *Oidium* disease. The substitution of indigenous oak with American oak was also considered a preferable alternative.

Later documents (1919-1924) from the city council and the estate manager Martin Alberdi made reference to a prohibition on livestock ranging and the cessation of exploitation for lumber and charcoal. Yet in actual fact, between 1919 and 1923 loads of lumber were still being sold on the estate. The forest landscape was described as a pasture-woodland composed of pollards and coppice. Martin Alberdi favoured the increase of maiden trees by experimenting with exotic species and eliminating all coppice, old, and pollard trees. Exploitation plans with fixed felling rotations were also established and new tree nurseries were created. Between 1921 and 1924, 495,800 Scots pines, more than 35,000 radiata pines, and about 3,300 trees comprising American oak, false acacia, and spruce were planted.

Martin Alberdi also promoted fencing of the estate to prevent livestock getting in. This concern arose out of an annual count of head of livestock apprehended: 60 in 1919, 5070 in 1920, and 10882 in 1921. By 1923, some boundaries were fenced in and by 1924 the entire estate was fenced in, except for a few dilapidated sections in Oiartzun. Nonetheless, there continued to be complaints regarding incursions of livestock that same year.

Neither the date of termination of felling for charcoal and lumber nor verification of whether beech was planted in certain stands (as Martin Alberdi claims) have been found in the publicly-available Municipal Historical Archive.

Since this time some of the exotic plantations have been subject to removal and felling, particularly those in the northern part of the estate (estate wardens, personal communication). According to the records of forest wardens, the beech forests located in the north-western zone (corresponding to the Iturrola plot in this work) were exploited between 1950 and 1960. During this decade, the beech forest—bounded by the Iturrola and Añarbe rivers and the highway running down from the Eskas caretaker's office—was felled and inhabited. Most recently, in 2001, new interventions created some bald patches on the northern and north-eastern sides of Mendarrieta Mountain (Iñaki Uranga, personal communication).

Over the last 15 years, numerous forest warden's reports have documented the presence of livestock within the estate, estimating around one thousand head in total (Iñaki Uranga, personal communication).

By the late 1980s, Artikutza's indigenous forest mass covered a total of 1935 ha (CATALÁN et. al., 1989).

Beech forest structure: According to the data registered in this work, over one century, the Artikutza forest has gone from a predominance of oak species and pollard trees to being dominated by beech and maiden trees (see Tables II and III).

A summary of the structural data is shown in Table IV. In all plots studied, beech was the dominant living tree species (see also Fig. 2), and was the only species in the Urdallué plot. However, in Elama, Loiola-Goizarin and Alto de Elama the understorey was typical of a beech forest, with a practically absent herbaceous layer and a litter cover composed almost entirely of dead beech leaves. In Elama, the other tree species were typical of the understorey (hawthorn berry, holly, and hazelnut) and generally did not reach the main forest canopy. In Loiola-Goizarin, apart from these species, pedunculate oak was abundant as a canopy tree, accounting for

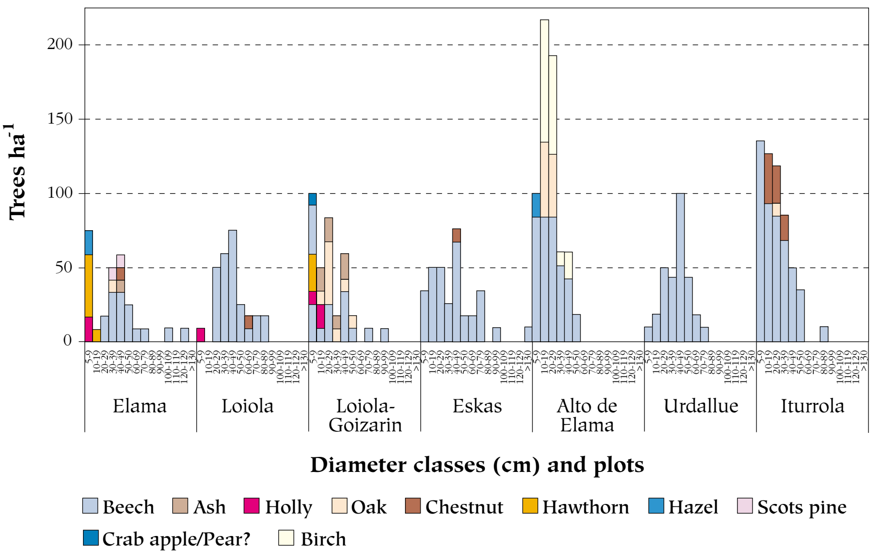

Figure 2. Densities of trees for each class of diameter obtained at the plots.

21.95% of the live trees in the plot, followed by chestnut (17.08%). In Alto de Elama, birch and sessile oak were also frequent (27.28% and 14.29% respectively).

In general, there was a low density of live trees in states of decay 3 or 4 (Table IV). The Eskas and Alto de Elama plots were the exception, containing 75 and 200 trees ha^{-1} respectively.

The distributions of diametric classes (Fig. 2) indicate that beech was more abundant at diameters between 40 and 49 cm, with the exception of the Alto de Elama and Iturrola plots, where beech was more frequent in the 20-29 and 5-9 cm diameter classes, respectively.

All trees measured had a maiden typology, with the exception of two pollard beech trees and one coppice beech in Loiola-Goizarin; one pollard beech in Eskas, and two coppice beeches and one coppice oak in Iturrola. No live or dead trees with cavities of interest were noted.

On the whole, trees between 20 and 29 m tall (Fig. 3) predominated. Alto de Elama and Iturrola were the exceptions to this pattern, showing a predominance of trees between 10 and 19 m tall, while in Loiola-Goizarin almost the same density of trees was found in the 10-19 and 20-29 m height classes. Only two trees over 30 m in height were measured in the Urdallue plot.

Regeneration, measured as the seedling and sapling densities, was greatest in Elama, with almost 9600 individuals ha^{-1}, and was lowest in Eskas, where it barely exceeded 150 individuals ha^{-1} (Tab. IV). In the remaining plots, density values oscillated between 700 and 2350 individuals ha^{-1}.

Volume and density of dead wood: The volume of dead wood, including both standing and fallen stems, exceeded 30 m^3 ha^{-1} in all plots except Iturrola where the volume was 5.72 m^3 ha^{-1}. In the Elama, Loiola-Goizarin, and Iturrola, the volume of fallen dead wood exceeded that of dead standing trees, in contrast to the other plots (Tab. IV). Loiola-Goizarin, Alto de Elama, and Urdallue were the only plots where the greatest part of dead wood came from species other than beech (Fig. 4). With regard to the state of decomposition, Loiola and Urdallue stood out as being the only plots where advanced decomposition states predominated over recent ones (Tab. IV).

Beech stump density only exceeded that of other species in the Eskas plot (Fig. 5). In the Loiola-Goizarin plot all registered stumps were of either oak or chestnut. In all plots, with the exception of Alto de Elama, the majority of the stumps showed signs of felling, with smooth upper surfaces. In general, oak or chestnut stumps were discovered in all plots; however, Alto de Elama differed from the others due to the high density of birch stumps. With the exception of Urdallue and Iturrola, the greatest snag densities were discovered in the diametric class 10-19 cm.

	Elama	Loiola	Loiola-Goizarin	Eskas	Alto de Elama	Urdallue	Iturrola	Mean
PB	53.12	93.75	34.14	93.37	55.84	100	84.85	73.58
PB20	88.23	96.77	71.43	64.86	18.60	88.23	25.00	64.73
DT	267	267	342	317	642	283	550	381
DT30	167	208	108	183	133	208	175	169
DT40	117	150	92	158	75	167	92	122
DT70	25	33	17	50	0	8	8	20
DT12	267	258	308	242	442	283	533	333
DT34	0	8	33	75	200	0	17	48
DS	75	42	92	142	167	33	125	97
DS30	0	0	8	17	0	25	8	8
DS40	0	0	0	8	0	8	0	2
VS	12.14	21.38	32.53	41.20	20.97	57.92	2.31	26.92
VL	24.99	14.42	44.33	12.36	9.82	9.63	3.41	16.99
VL30	12.54	0	9.79	0	0	0	0	3.19
VL12	19.61	4.90	25.39	11.99	8.91	3.00	3.01	10.97
VL34	5.38	9.52	18.94	0.37	0.91	6.63	0.40	6.02
VS+VL	37.13	35.8	76.86	53.56	30.79	67.55	5.72	43.92
DST	50	125	125	125	242	258	117	149
VST	2.48	5.62	13.45	28.81	4.91	20.96	19.38	13.66
VS+VL+VST	39.61	41.42	90,31	82.37	35.7	88.51	25.1	57.57
DSE	9555	1882	2266	125	816	691	1807	2449
DSA	8	0	83	41	16	17	117	40
DSE+DSA	9563	1882	2349	166	832	708	1924	2489
DBSE	642	700	775	42	25	483	25	385
DBSA	0	0	25	33	8	0	117	26
DBSE+DBSA	642	700	800	75	33	483	142	411

Table IV.- Summary of the forest structural data: PB = percentage of beeches, PB20 = percentage of beeches >= 20 m height, DT = density of living trees, DT30 = density of living trees > 30 cm DBH, DT40 = density of living trees > 40 cm DBH, DT70 = density of living trees > 70 cm DBH, DT12 = density of living trees of 1-2 decay classes, DT34 = density of living trees of 3-4 decay classes, DS = density of snags, DS30 = density of snags > 30 cm diameter, DS40 = density of snags > 40 cm diameter, VS = volume of snags, VL = volume of logs, VL30 = volume of logs > 30 cm diameter, VL12 = volume of logs of 1-2 decay classes, VL34 = volume of logs of 3-4 decay classes, DST = density of stumps, VST = volume of stumps, DSE = density of seedlings, DSA = density of saplings, DBSE = density of beech seedlings, DBSA = density of beech saplings. Density units: trees ha-1, volume units: m^3 ha^{-1}.

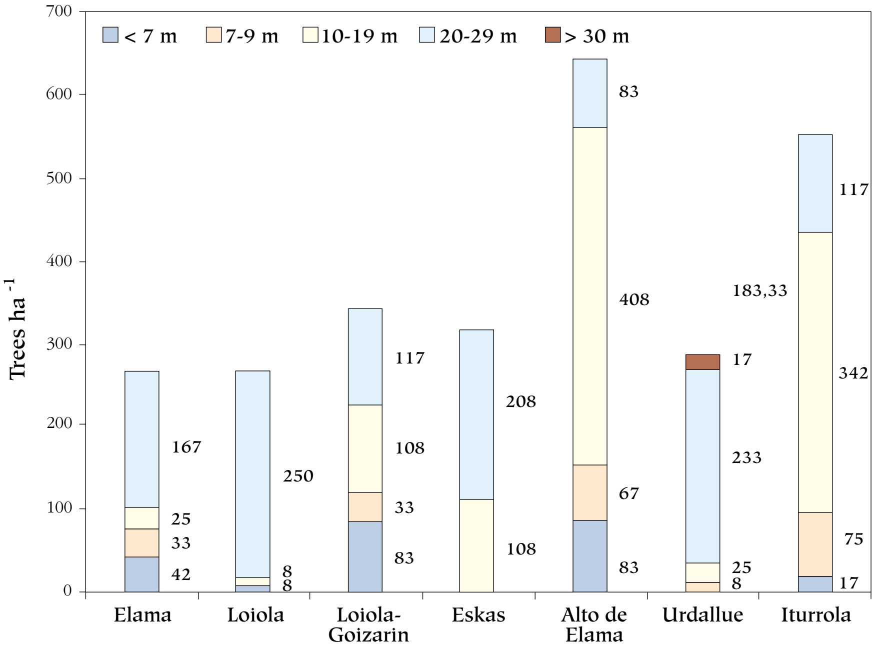

Figure 3.- Tree height-class distribution for each plot analysed.

Discussion

Evolution of the beech forest: Any extrapolation of the data obtained from the 7 plots should be undertaken with caution, since they only represent an area of 0.84 ha out of a total beech forest of 1135 ha. However, structural parameters from the plots concur with historical data in indicating the main changes that have occurred in the forest of Artikutza:

Former predominance of pollarded trees: At present, all plots are almost entirely made up of maiden trees. Moreover, similar stump densities (117-125 ha^{-1}) coincide in four plots (Loiola, Loiola-Goizarin, Eskas, Iturrola), suggesting a regular arrangement of pollarded trees, characteristic of managed forests. This confirms that the survey by the then administrator of the estate, Martin Alberdi, was carried out on the old and pollarded trees. Although no historical information was encountered to support this conclusion, it is logical to presume that by that time exploitation for lumber and charcoal would have definitively finished.

Former predominance of oak trees: According to LOIDI & BASCONES (1995), the potential vegetation in the plots studied is beech forest. This suggests that the former presence of oaks is a result of the practice of favouring the plantation of pollard oaks to meet the demand for charcoal and wood, common in the surrounding lands between the fifteenth and nineteenth centuries (ARAGÓN, 2001).

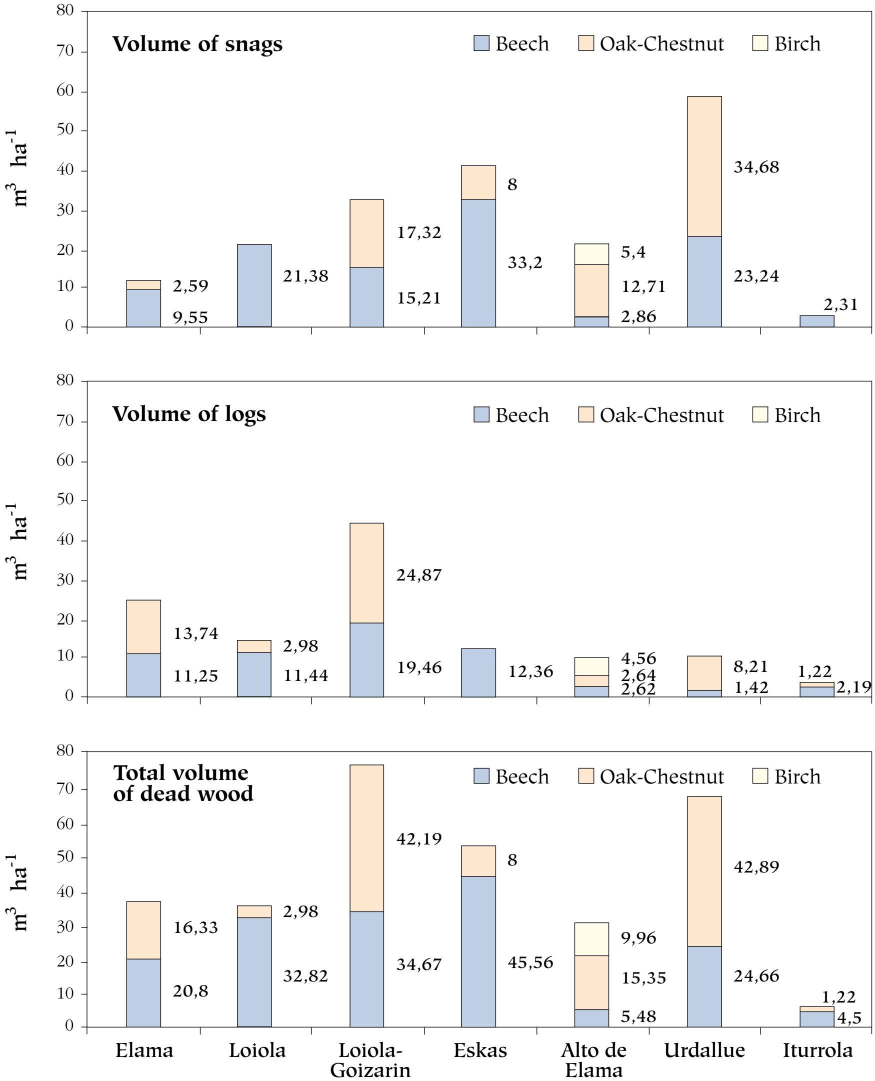

Figure 4. - Volume of dead wood and distribution by species; snags; logs; and combined standing and fallen coarse woody material.

The data shows the predominance of oak and chestnut stumps over those of beech in all plots sampled (with the exception of Eskas). The data for Eskas do not coincide with the Tomás Erice's report in 1903 (Tab. I), which indicates that oak predominated in Stand 2. Nonetheless, the stand covered 26 ha and it is probable that in this area alone beech predominated. Alto de Elama seems to be another exception to the pattern. In 1918, Benito Menéndez wrote that 70% of the Elama valley, to which Alto de Elama belongs, was plains, particularly in the higher zones, indicating that the plot was pasture land, as is the case about 100 m higher up on the hillside. The large density of birch trunks, dead trees—many of which are birch and white oak—and total trees suggests that beech still continues to exercise some hegemony over the birch forest that would have set in after the pasture was abandoned. The pioneering and heliophyl character of the birch, which dies when the beech canopy closes over has already been registered in the beech-birch forest of the Urkiola Natural Park (HERRERA *et al.*, 2002). Although a higher density of germinating birch seedlings is observed than beech, the birch seedlings are very small (most are less than 15 cm in height) and probably do not survive more than a few months, as the aforementioned authors suggest.

<u>Establishment of an 80-year-old forest</u>: With the recorded enclosure of the estate against livestock in 1924 and the fact that sales of timber ended around 1923, much of the Artikutza beech forest started to regenerate 80 years ago. Depending on the age of the forest, the diametric class of the most frequent live beeches ranges from 40 to 49 cm. The fact that average annual radial growth for beech is 0.28 cm, based on data from the Urkiola (Bizkaia) beech-birch forest (HERRERA et al., 2002), supports the hypothesis that the Artikutza beech forest is 80 years old. Furthermore, it implies an average diameter of 44.8 cm. This is a good approximation, although should be treated with caution, since the same authors and other researchers (ROZAS, 2004) indicate that growth varies considerably depending on environmental conditions and competition with other individuals surrounding the tree. Most of the trees that actually exceed this diametric class are probably surplus not withdrawn after the last pollard fellings because of the Estate Administration's early-1920s plan favouring maiden trees. Most plots would thus contain trees from two coexisting generations: one made up of trees with diameters ≥ 60 cm (which could be close to 200 years old), and another with diameters < 50-60 cm, which would have been established throughout the twentieth century. Future studies of tree ring slices will be necessary to test this hypothesis. These surpluses indicate that the Artikutza beech forests have a thick tree (>47.5 cm) density (72 ha^{-1}), greater than that of the beech forest of Aztaparreta (Western Pyrenees) (58 ha^{-1}), which is considered virgin or at least without intervention over the last 400 years (GIL PELEGRÍN *et al.*, 1989). The observed density of large trees (dbh > 70 cm) of 27 ha^{-1}, is also greater than the densities of 10-20 ha^{-1} found in the old-growth temperate and boreal forests of Europe (NILSSON *et al.*, 2003). These differences could also be the result of the faster growth of the beech in the warmer and more moderate climate of Artikutza.

The Alto de Elama plot shows a greater frequency of low-diameter trees because the steep slope and barely developed soil hinders tree growth (CARCELLER *et al.*, 1992, SEBASTIA, 1992); here most trees therefore have heights of less than 20m and diameters less than 30 cm.

Unlike the other plots, according to the records of the estate wardens, who register a period of beech tree felling and repopulation between 1950 and 1960, Iturrola has a younger beech forest of the following characteristics: 1) dominated by trees with small diameters (the diametric class 5-10 cm pervades), 2) large live tree density, 3) highest abundance of saplings, 4) lowest volume of dead wood, and 5) and most of the dead wood (88%) is in a barely advanced state of decomposition.

Intermittent disturbance of livestock: Despite the enclosure of 1924, there are numerous records of the presence of livestock registered by the estate warden. The regeneration observed is scarce when compared with figures obtained from the nearby beech forest in Marumendi in the Aralar Sierra, which was protected against livestock (AUNÓS *et al.*, 1992). The majority of cases in Artikutza shows densities of less than 2,000 seedlings ha^{-1}, while in Marumendi density oscillates between 11800-12800 seedlings ha^{-1}.

The difference may be due to the presence of livestock— ovine, bovine and equine—observed on an everyday basis and in practically every part of the estate. However, the different microclimatic, climatic, and structural conditions of the two beech forests as well as the masting character of beech (PIOVESAN & ADAMS, 2001) might also influence this disparity. It also seems that the impact of the livestock has varied depending on the site, as trunk diameter classes distributions suggest: Elama, Loiola-Goizarin, Eskas and Iturrola show a downward curve, indicating continuous tree regeneration; while Loiola, Urdallue and Alto de Elama show unimodal distribution, probably caused by greater livestock impact. That downward distribution, and greater density of the diametric classes > 40-50 cm, can also be observed in the forest of Aztaparreta in stands not affected by livestock (GIL PELEGRÍN *et al.*, 1989).

Moreover, livestock has historically damaged forest regeneration severely in some European oak and beech forests (MOUNTFORD *et al.*, 1999; ROZAS, 2003). Despite this, GARRIGUE & MAGDALOU (2000) found the impact of cattle in the forest of La Massane (southeast France) to be insignificant. The estate warden estimates that between cow, sheep, and horses there are approximately 1000 head of livestock in Artikutza (Iñaki Uranga, personal communication). Accordingly, livestock density comes close to 2.7 heads ha^{-1}, while the proposed threshold to avoid excessive pressure on natural regeneration is 10 cows ha^{-1} (CAMPRODON, 2001). However—as the last author states—since damage done to regeneration depends on multiple environmental and anthropic variables, the burdens caused by herbivores cannot be generalized. It would be necessary to make a study to quantify the combined effect of livestock and indigenous hoofed animals in the estate, such as roe deer and wild boar, which can also affect natural regeneration (ROSELL, 2001).

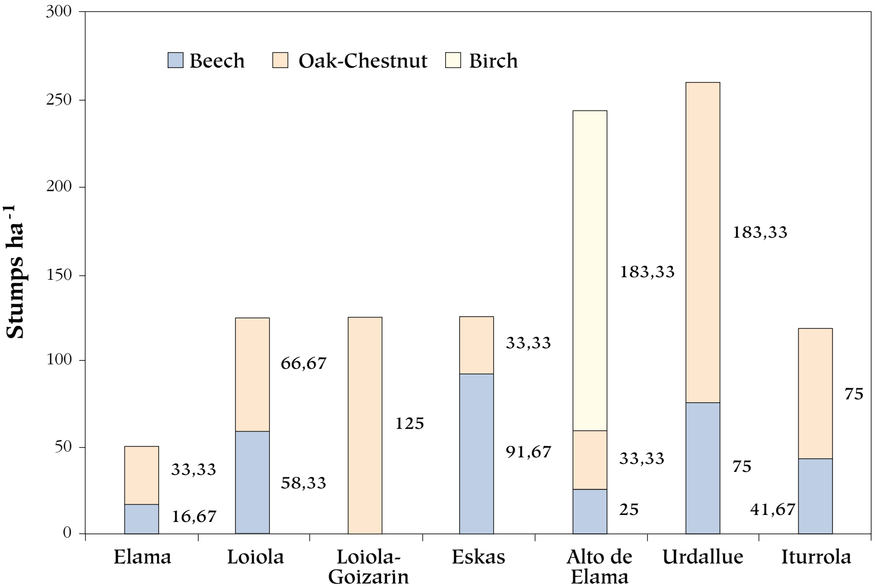

Figure 5. Density of stumps registered for each plot.

Evolution of the amounts of dead wood and cavity trees**:** If we remove the Iturrola plot from the analysis, since it was affected by more recent intervention, total density of snags and volumes of dead wood show values corresponding to mature European forests without human intervention for over 80 years (VALLAURI *et al.*, 2002). However, the average volume of dead wood (snags and logs) in Artikutza ranks (50.28 ± 7.7 m^3 h^{-1}) far below that found in other lowland beech forests reserves in Europe (132 ± 70 m^3 h^{-1}) after more than 50 years without exploitation, better matching the amounts registered (99 ± 98 m^3 h^{-1}) in more recent protected woods (CHRISTENSEN *et al.*, 2005). The lack of snags with diameters greater than 40 cm, which normally show densities in excess of 10 ha^{-1} (NILSSON *et al.*, 2003; PIOVESAN *et al.*, 2005), and the lack of cavity trees, the densities of which in mature forests vary between 10 and 20 trees ha^{-1} (VALLAURI *et al.*, 2002), are further indicators separating Artikutza from the usual parameters of a forest that has been unexploited for more than several decades.

These differences are due to the particular history of the beech forest at Artikutza, where most trees from the former forest where felled, while in most of the European reserves cited, forests existed continuously over time. As a result, most of the bigger trees are relatively young (several 300 year-old beeches have been registered displaying a resumption of growth in the Irati forest, close to Artikutza [BOURQUIN-MIGNOT & GIRARDCLOS, 1998]), and they do not show branches exceeding 40 cm in diameter. Live trees that exceed this diameter and that are in advanced states of decay (3-4) are rare (5.65% of the total of live trees). as a result, a relatively small amount of dead wood has been observed, few snags and no logs > 40 cm in diameter have been generated.

The lack of snags > 40 cm in diameter due to the lack of felling for around a century concurs with the findings of KIRBY *et al.* (1998) in Great Britain. Likewise, the volumes of dead wood in the Lady Park Wood in the United Kingdom (GREEN & PETERKEN, 1997)—which have a similar history to Artikutza—are higher in the 90-year-old (87.93 ± 12.11 m^3 ha^{-1}) and lower in the 50-year-old stands (24.26 ± 2.92 m^3 ha^{-1}). Because most pieces of logs and snags measure less than 20 cm in diameter, it appears that competitive exclusion is the regular factor behind the generation of dead wood, as GREEN & PETERKEN (1997) have found. This shelf-thinning process certainly happens in Loiola-Goizarin and in Alto de Elama. The former plot is located practically at the end of a valley, where beech and mixed forests frequently overlap (CATALÁN *et al.* 1989). In this enclave both types of forests overlap. Since a large tree mortality can be observed, the two appear to be competing. Perhaps because of this, the plot has the greatest volume of dead wood (75 m^3 ha^{-1}), obviously due to the large snags and logs present. This plot offers better conditions for the establishment of oak and chestnut, which put up a stronger resistance to beech, than the other plots (such as the nearest one, Loiola): 34.15% of live trees are beech while 39.03% are oak and chestnut and their regeneration is approximately 34.14% for the beech and 21.28% for the other two species. Between the two groups of species, dead wood volume also presents similar proportions. In the case of the Alto de Elama plot, the high density of birch trunks and snags —many of which are birch and white oak—and trees in total, indicate that the beech has not yet finished exercising its hegemony over the birch and white oaks. Further specific studies would be required to determine how much other variables, such as windstorms, contribute to the input of dead wood.

With regard to the availability of cavities, tree species influences cavity generation, while thicker trees (>30 cm) and more advanced stages of decay favour its development (FAN *et al.*, 2003). Although the snag density in Artikutza is typical of mature forests, individuals with diameters of over 30 cm are scarce. Indeed, only 6.67 trees ha^{-1} with diameters greater than 30 cm and states of decay greater than 4 have been found. Due to their size, these trees would be more likely to produce cavities and to have a partially dead trunk. Furthermore, all of these individuals have been recorded in only one plot (Eskas). However, it should be borne in mind that FAN et al. (2003) carried out their research in a forest dominated by another tree species, a factor that also influences the generation of cavities. The same authors also point out that in some forests larger diameters are required (> 60 cm).

Implications for the conservation of biodiversity: well-structured and high-interest communities of vertebrates (CATALÁN et al., 1989) and invertebrates (MARTÍNEZ DE MURGUÍA *et al.*, 2001, 2002, 2004; KEHLMAIER & MARTÍNEZ DE MURGUÍA, 2004) have been registered in Artikutza, reflecting its well-preserved condition compared to other beech forests in the region. One fly species from the Pipunculidae family, *Chalarus leticiae* (KEHLMAIER, 2003), has even been found to be endemic to Artikutza.

More specifically, the forest fauna studied hereto in Artikutza indicates the presence of dead wood as one of the most important biodiversity resources for invertebrates: the high interest communities of present Hymenoptera (MARTÍNEZ DE MURGUÍA *et al.*, 2002) rely on dead wood as an essential habitat resource, since the structure of the forest floor does not provide appropriate sites for nesting. Thus the disappearance of dead wood would cause the local extinction of 14 wasp species currently found in this natural environment (MARTÍNEZ DE MURGUÍA *et al.*, 2001). The community of Syrphidae (Diptera) contains 4 species (all of which present saproxylophagous larvae) which are useful in identifying forests of international importance for nature conservation (KEHLMAIER & MARTÍNEZ DE MURGUÍA, 2004). Furthermore, the community of saproxylic Coleoptera indicates availability of dead wood in all states of decomposition (MARTÍNEZ DE MURGUÍA *et al.*, 2004), which concurs with the data in this study.

As already discussed, beech growth is faster in Artikutza than in the virgin forest of Aztaparreta. It is therefore worth pointing out that the conservation of mature forests should not be limited to the steepest and highest slopes of the hills and mountains. In more favourable conditions, the development of large trees, and as a consequence, the generation of more dead wood and cavity trees will be quicker in lower and flatter lands, creating more biodiversity resources at a faster rate.

However, the beech forest of Artikutza has not generated another important biodiversity resource: cavity trees. This lack of cavity trees is a consequence of the removal of pollard trees in the 1920s, and the fact that the beech forest is not old enough to have generated trees with holes. Since pollard trees are mainly confined to the northern part of Artikutza´s estate and are more prone to developing cavities than maiden trees, they must be preserved. Besides, it would be advisable to promote the occurrence of pollard trees by applying carefully thought-out pollarding techniques (READ, 1996, 2000), and plan their location to allow connectivity between them.

As the presence of livestock seems to be unavoidable and constant and pollard trees develop better in open woodlands, they should be promoted in low tree-density stands with the highest livestock impact. Because vulnerable tree-dwelling species have different habitat requirements, such as exposure to sunlight, and different preferences for tree species (CAMPRODON, 2001; BOUGET & GOSSELIN, 2005), it would be worthwhile considering transforming some of the forest stands into woodland-pasture landscapes, in order to enhance biodiversity resources and allow the development of other tree species currently in regression in Artikutza, such as oaks and chestnuts. Some fenced regeneration areas may possibly be needed to allow replacement of consecutive generations of trees over time

It is clear that the protection of the forest, and the restrictions on exploitation of the land and access by car, due to the preservation of a drinking water reservoir, have allowed the establishment of a largely natural beech forest. If this land use persists, Artikutza could potentially be an important field laboratory for monitoring the natural evolution of the forest and experiment with the proposed conservation techniques (and others if required), whose results could be useful for managing temperate forests with a similar history.

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