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Late Holocene Forest History and Deforestation Dynamics in the Queixa Sierra, Galicia, Northwestern Iberian Peninsula

The study of the climate in the last 2700 years reflected in the palaeo record is obscured by the strong influence of human destruction of forest cover during this period. In this study 2 sites in the Queixa Sierra (northwestern Iberian Peninsula, Europe), Castelo Cerveira (1380 m) and As Aguilladas (1580 m), provide insights into high montane forest dynamics in this area since 2700 years BP. The palynological record shows regional development of vegetation associated with forest clearance. Around 2700 BP a montane Quercus–Betula *forest was destroyed, followed by an abrupt increase in grass and heather vegetation. Human impacts reached their maximum in the last 1000 years. Abundant microcharcoal particles, along with an increase in Cerealia pollen, indicate frequent fires and generally intense human impacts on the environment. Despite this deforestation, some temporary phases of* Betula *vegetation occur before the total disappearance of the natural forest and its replacement by plantations of (regional) pine forest.*

Keywords: *Vegetation history; late Holocene; pollen; charcoal; climate; human impact; Iberian Peninsula.*

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Introduction

The development of vegetation in the early Holocene, before human activity began to exert an influence, was primarily determined by autogenic processes, such as vegetation succession, soil development, and changes in climate. Human–environment relations did not have a uniform impact over the globe (Roberts 1998). This makes it difficult to evaluate the relative impacts of climate change and human activity on landscape evolution. The palaeoecological study of peat can help elucidate these impacts (Aaby and Berglund 1986). In the northwestern Iberian Peninsula, large areas of natural vegetation have been severely affected by humans, who not only lowered the timber line by grazing cattle, but also replaced native species with exotic tree species and pine (Van der Knaap and Van Leeuwen 1995). Although some records that span the Holocene have contributed to the knowledge of both vegetation and climate in the early and mid Holocene (Maldonado Ruiz 1994; Van der Knaap and Van Leeuwen 1995; Santos et al 2000), few detailed studies exist for the last 3000 years showing climatic variability (Martínez-Cortizas et al 1999).

The present study concerns 2 small-sized sites in the Queixa Sierra (Figure 1): Castelo Cerveira (1380 m asl) and As Aguilladas (1580 m asl), spanning the last 2700 years. It examines where and when human activity destroyed the original vegetation, by comparison with

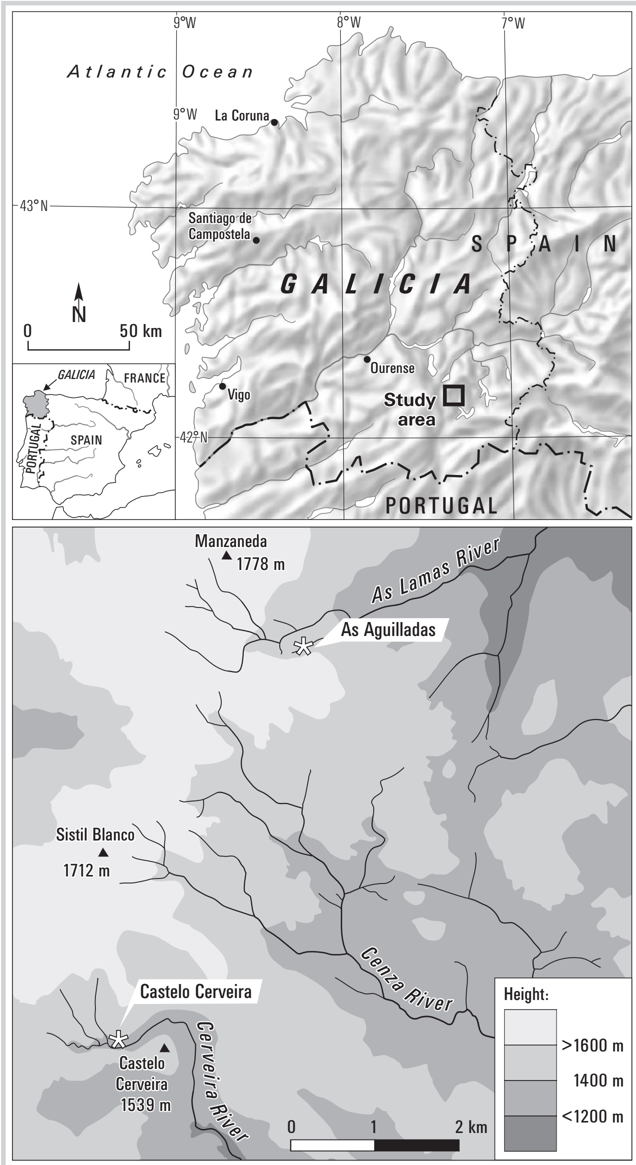

FIGURE 1 Location of the Queixa Sierra on the Iberian Peninsula, and detailed map showing the location of Castelo Cerveira and As Aguilladas. (Map of Galicia by Andreas Brodbeck, detailed map by author)

FIGURE 2 View of the Castelo Cerveira area. (Photo by Luisa Santos)

other sites at different altitudes; it also explores how strong the human impact on vegetation in the Queixa Sierra was and whether it is possible to infer climate variations in these mountainous regions from the pollen and charcoal data derived from these sequences.

Study area and methods

Environmental setting

The study area is located in the Queixa Sierra (northwestern Iberian Peninsula, Europe). The area to the south consists of sandstone and quartzite, and granite dominates in the north and northeast. Mean annual precipitation is around 2000 mm, and mean annual temperature is less than 8°C. The position of this range between the Eurosiberian and Mediterranean phytogeographical units is the reason for the existence of mixed flora, with a predominance of Eurosiberian flora.

The regional vegetation climax is an oak *Quercus pyrenaica* forest, with *Quercus robur* and *Vaccinium myrtillus* at high altitudes. Hazel, ash and birch occupy locations that are higher and cooler, or have greater precipitation, but very few natural stands remain. The repeated burning of forests in order to obtain pastureland is responsible for the dominance of scrubland.

Drillings were carried out at 4 sites in the Queixa Sierra (Fraga, H profile, Castelo Cerveira and As Aguilladas). Results from the latter 2 sites are discussed here. The sequence of Castelo Cerveira (42°11'N; 7°19'W, 1380 m) is an organic section from the Cerveira River valley. As Aguilladas (42°14'N; 7°17'W, 1580 m) is a peat bog. Both sites are small, between 0.1 and 0.2 ha. The dominant vegetation in the surrounding areas is basically scrubland and pasture (Figure 2). A few *Betula* trees are scattered on the upper slopes (Santos 1996).

Material and methods

A Russian corer was used for As Aguilladas. At Castelo Cerveira the samples were collected from a vertical section. Conventional radiocarbon dating was carried out in the Laboratório de Isótopos Ambientais (ICEN) in Sacavém (Portugal). The dates were calibrated using the Stuiver and Reimer's Calibration Program (1993, Mac Test Version #7).

The samples were processed using filtration (160 and 5μ), boiling in 10% NaOH and hot 10% HCl and 48% HF. Pollen identifications were based on Reille (1992). Three hundred to 400 pollen grains per sample were counted, as well as a minimum of 20 different taxa. Local pollen assemblage zones (LPAZs) were distinguished according to Birks and Birks (1980). The pollen sum includes pollen from trees, shrubs and herbs, except Pteridophyta. In addition, the slides were scanned thoroughly for rare pollen taxa and microcharcoal particles; for the latter, relative abundance was estimated on a 5-point scale. The diagrams were drawn using the Psimpoll computer program (Bennett 1992).

Interpretation of the pollen diagrams takes into account previous work done on recruitment of pollen in basins of different sizes. Small pollen sites between 0.1 and 0.5 ha (comparable to our study sites) recruit pollen mainly from local vegetation (eg Jacobson and Bradshaw 1981), although there is a component of the more well-dispersed and abundant regional taxa.

Results

Lithology and radiocarbon dating

The sequence of Castelo Cerveira ranges from 40 to 180 cm in depth. No material was retrieved above 40 cm because of abundant roots. Highly organic clayey silt (180–140 cm) is overlain by organic clay with some roots at the top (140–40 cm). The As Aguilladas sequence (0–180 cm) consists entirely of peat. Sediment lithology according to the Troels-Smith (1955) system is shown in Figures 3A and 3B. Four levels were radiocarbon dated (Table 1). Ages quoted are uncalibrated, but both calibrated and uncalibrated dates are listed in Table 1.

Pollen diagrams

Both pollen diagrams show a dominance of herb pollen (Figures 3A and 3B). Two local pollen assemblage zones (LPAZs) were established in Castelo Cerveira (described in Table 2), and 4 zones with 2 subzones in As Aguilladas (described in Table 3).

The 2 sites are only 5 km apart, with an altitudinal difference of 200 m. The dominant pollen curves have generally similar trends; differences can be explained mainly in terms of pollen recruitment. As Aguilladas records higher regional pollen diversity, whereas Caste-

FIGURES 3A AND 3B
3A: Pollen diagram from Castelo Cerveira (selected taxa). AP: Arboreal pollen; NAP: Non-arboreal pollen. Dots indicate percentages of less than 0.5%. Lithostratigraphic symbols follow Troels-Smith (1955).
3B: Pollen diagram from As Aguilladas (selected taxa). AP: Arboreal pollen; NAP: Non-arboreal pollen. Dots indicate percentages of less than 0.5%. Lithostratigraphic symbols follow Troels-Smith (1955). Estimated ages of the sequence were calculated by linear interpolation between each date.

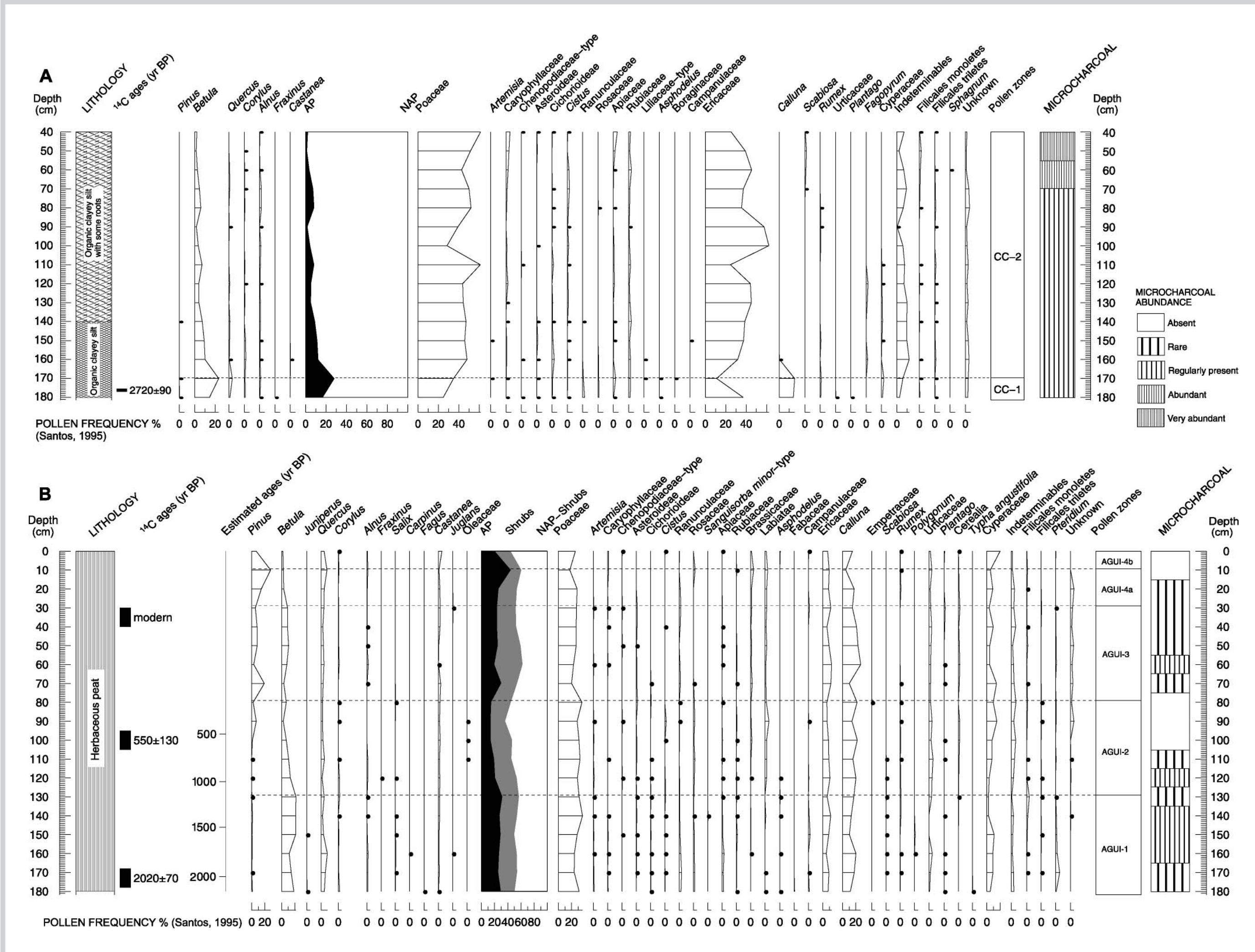

TABLE 1 Radiocarbon dates of the pollen sequences (Santos et al 2000). The calibrated age range (Stuiver and Reimer 1993) was calculated with a probability of 95.4% (two sigma). AGUI: As Aguilladas; CC: Castelo Cerveira.

Site	Depth (cm)	Material dated	Laboratory reference	Age in years (BP)	Calibrated age (BP)	Calibrated age [AD(+); BC (–)]	δ^{13}C (‰)
AGUI	30–40	Peat	ICEN-1026	Modern	< 0	After AD 1950	–25.80
AGUI	95–105	Peat	ICEN-1025	550±130	717–304	+1233 to +1646	–25
AGUI	168–178	Peat	ICEN-1024	2020±70	2141–1818	–191 to +132	–26.69
CC	175	Clayey silt	ICEN-1043	2720±90	3075–2710	–1125 to –760	–26.30

TABLE 2 Description of the local pollen assemblage zones (LPAZs) in the Castelo Cerveira sequence. CC: Castelo Cerveira; AP: Arboreal pollen.

Site	Depth (cm)	Pollens	Main features of LPAZs
CC-2	**40–170**	Poaceae–Ericaceae–*Betula*	Decrease in AP. Presence of *Castanea*. Poaceae and Ericaceae dominate.
CC-1	**170–180**	Poaceae–Ericaceae–*Betula*–*Calluna*	Low AP values represented by *Betula*. Regular presence of *Quercus* and sporadic presence of *Alnus* and *Corylus*. Ericaceae, *Calluna* and Poaceae dominate the herbaceous strata. *Upper limit:* Decrease in *Betula*, *Calluna* and *Quercus*. Increase in Ericaceae and Poaceae.

TABLE 3 Description of the local pollen assemblage zones (LPAZs) in the As Aguilladas sequence. AGUI: As Aguilladas; AP: Arboreal pollen.

Site	Depth (cm)	Pollens	Main features of LPAZs
AGUI-4b	**0–10**	Poaceae–*Calluna*–Cyperaceae–*Pinus*	Decrease in *Pinus*, *Quercus* and *Corylus* and increase in *Castanea*, Poaceae, *Calluna* and Cyperaceae.
AGUI-4a	**10–30**	Poaceae–*Pinus*–*Calluna*	Small increase in *Pinus* and *Quercus* and slight decrease in *Betula*. Decrease in Poaceae and *Calluna*. *Upper limit:* Decrease in AP except *Castanea* and increase in Poaceae and *Calluna*.
AGUI-3	**30–80**	Poaceae–*Calluna*–Ericaceae–*Pinus*	Moderate increase in *Pinus*, *Betula* and *Quercus*. Decrease in Poaceae. *Upper limit:* Increase in *Pinus* and decrease in *Betula*.
AGUI-2	**80–130**	Poaceae–*Calluna*–Cyperaceae	Substantial decrease in *Betula* and slight increase in *Pinus* and *Castanea*. Poaceae, *Calluna*, Ericaceae and Cyperaceae dominate. *Upper limit:* Increase in *Pinus* and decrease in Poaceae.
AGUI-1	**130–180**	Poaceae–*Betula*–*Calluna*	Low AP values represented mainly by *Betula* and *Quercus*. Presence of *Corylus, Alnus, Castanea, Fagus* and *Pinus*. *Calluna,* Ericaceae and Poaceae dominate the herbaceous strata. *Upper limit:* Decrease in AP and increase in *Calluna* and Cerealia.

lo Cerveira has higher pollen concentrations (not shown here; see Santos 1996). The local vegetation (Poaceae, Ericaceae and *Calluna*) is strongly represented in both diagrams. Microcharcoal particles are rare or regularly present in most of As Aguilladas, but always present and even very abundant in Castelo Cerveira.

Interpretation and discussion

The Castelo Cerveira and As Aguilladas sequences together cover a 2700-year record of vegetation history in the Queixa Sierra (northwestern Iberian Peninsula). Previous studies from this area can help to understand its vegetation dynamics before 2700 BP. As generally accepted for southern Europe (Huntley and Birks 1983), the substitution of montane pine during the Lateglacial by a postglacial *Quercus* expansion also characterizes the early Holocene in the Queixa Sierra (Maldonado Ruiz 1994; Santos et al 2000).

After 5000 BP the mixed oak forest in the Queixa Sierra diminished, as indicated by the pollen diagrams of As Lamas (Maldonado Ruiz 1994) and Fraga (Santos

TABLE 4 Late Holocene pollen associations in Galicia. (Source: Van Mourik 1999)

Association	Chronozone	Vegetation type
L	Subatlantic	Pine plantation
K	Subatlantic	Chestnut plantation
J	Subatlantic	Heath, dominated by Ericaceae
H	Subatlantic	Cultivated land, dominated by Gramineae and Cerealia
G	Subatlantic	Deforestation; increase in *Castanea* and Cerealia
F	Subboreal/ Subatlantic	First signs of deforestation; decrease in *Quercus*

et al 2000). Widespread deforestation took place in the Queixa Sierra during the last 4000 years, associated with the arrival of cultivation at low altitudes (Santos et al 2000). The transition of forest to shrubland is more evident in the last 3000 years. In both the Castelo Cerveira and As Aguilladas sequences, expansion of open areas is evident (Figures 3A and 3B). According to Van Mourik (1999), the Subboreal/Subatlantic transition of pollen assemblages in Galicia is characterized by the first signs of deforestation and a decrease in *Quercus* (Table 4). Nevertheless, whereas in Castelo Cerveira the values of *Quercus* pollen decrease at the Subboreal/Subatlantic transition (after 170 cm), the first signs of deforestation are not recorded because the low AP values at the base of Castelo Cerveira indicate that deforestation had already taken place prior to the start of the diagram, in contrast to Van Mourik's statement. In the As Aguilladas sequence, after 2000 BP, the decline in deciduous forests seems to have favored the expansion of *Betula*. The non-arboreal vegetation that occupies the free spaces left by the oak is mostly grassland and moorland.

At c2700 BP, the Castelo Cerveira sequence shows scant arboreal cover, in the form of *Betula*, and dominance of grasses and Ericaceae. The spread of moorland in the Queixa Sierra has been dated at between 2000 BP (Prada, 1100 m asl) and 2550 BP (As Lamas, 1360 m) (Maldonado Ruiz 1994) (Figure 4). The values of Ericaceae at the beginning of the Castelo Cerveira diagram (1380 m) suggest an earlier origin of the heath area in the higher reaches of these mountains. In the Courel Sierra (Figure 4; Santos et al 2000) the clearing of the forest resulted in an increase in *Betula* vegetation, although sites left by clearing of oak were mostly occupied by grasses and moorland plants.

Widespread forest clearance has also been recognized in other Sierras south and east of the Queixa Sierra (Figure 4), such as Sanabria Marsh at c1000 BP (1085 m, Allen et al 1996), Lago de Ajo at c2000 BP (1570 m, Allen et al 1996), and La Baña at c1779 BP (1450 m, Janssen 1996). However, in Sanabria Marsh, oak woodland is still dominant, with stands of *Pinus* at higher elevations. Oak maintains its dominance in Lago de Ajo, with a decline in the values of *Corylus* and *Ulmus* and an increase in grass and moorland.

The Castelo Cerveira diagram records increased fire frequency associated with an abrupt increase in grasses at the top of the sequence. The As Aguilladas sequence records layers containing charcoal particles that could indicate the destruction of the local forest by burning. Furthermore, the As Aguilladas sequence records a rise in fire-adapted *Pteridium* from c2000 BP. Two phases of temporary regeneration of *Betula*, probably favored by the decline of oak, followed by 2 phases of deforestation, are recorded. After 2700 BP, the Castelo Cerveira sequence records a brief increase in *Betula*, followed by deforestation. After this date, the As Aguilladas sequence records a *Betula* maximum at c2000–1200 BP, followed by deforestation (from c1200 BP) before the appearance of *Pinus*. This last deforestation coincides with maximum regional development of agriculture (continuous cereal-type curve). Both the temporary *Betula* regeneration dated approximately

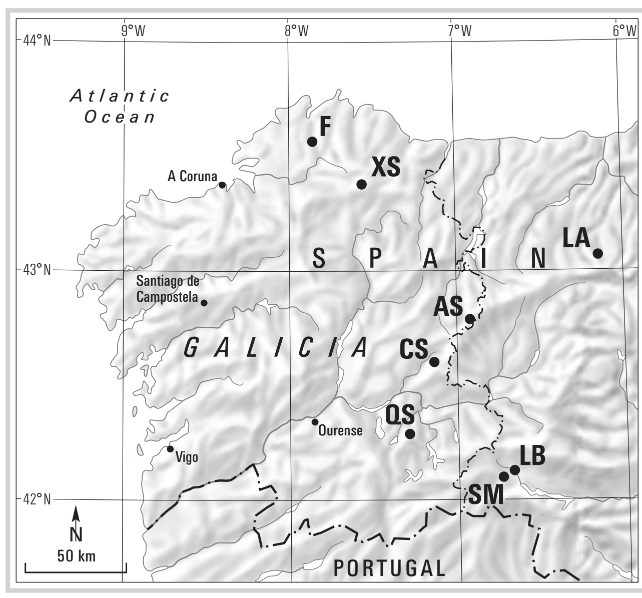

FIGURE 4 Location of additional pollen sequences mentioned in the text. **QS**: Queixa Sierra (As Lamas, 1360 m asl and Prada, 1100 m asl; Maldonado Ruiz 1994; Fraga, 1360 m asl and H profile, 1310 m asl; Santos et al 2000); **CS**: Courel Sierra (Laguna Lucenza, 1420 m asl; Santos et al 2000); **XS**: Xistral Sierra (Tremoal da Pena Veira, 620 m asl; Ramil Rego 1992); **SM**: Sanabria Marsh (1050 m asl; Allen et al 1996); **F**: Ferreira (680 m asl; Van Mourik 1986); **LA**: Lago de Ajo (1570 m asl; Allen et al 1996); **AS**: Ancares Sierra (Muñoz Sobrino et al 1997); **LB**: La Baña (1450 m asl; Janssen 1996).

2000–1200 BP and the subsequent deforestation are also recorded in pollen diagrams at high altitude in the nearby Ancares Sierra (Figure 4; Muñoz Sobrino et al 1997). On the other hand, if local pollen recruitment is assumed, the short-lived *Betula* regeneration phase recorded at 170 cm in Castelo Cerveira may have taken place close to the site. Similarly, the absence of a clear *Betula* regeneration phase in Castelo Cerveira at c2000–1200 BP may reflect the vegetation close to the site rather than regional vegetation. An alternative explanation for the absence of this *Betula* phase might be that sediment layers of that age are missing due to a sedimentological hiatus. Nevertheless, Muñoz Sobrino et al (1997) detected 3 regional phases in the last third of the Holocene in the Ancares mountains, before the increase in *Pinus* values: deforestation in 3000–2000 BP, forest regeneration in 2000–1200 BP, and deforestation after 1200 BP.

In As Aguilladas, deforestation after 1200 BP (estimated age) was progressive and accompanied by *Castanea* and the development of Cerealia, in accordance with Van Mourik's Subatlantic association G (1999; Table 4). The history of *Castanea* in the Iberian Peninsula during glacial and interglacial periods of the Pleistocene is still a matter of discussion (Uzquiano 1992; Sánchez Goñi 1993; Santos et al 2000). In particular, several authors associated *Castanea* with the Roman period (Torras Troncoso et al 1980; Peñalba 1989; Janssen 1994), assuming that the Romans introduced this tree to the Iberian Peninsula. The As Lamas diagram (Queixa Sierra; Maldonado Ruiz 1994), however, records isolated pollen grains of *Castanea* as early as 7000 BP. Continuous presence of this pollen is recorded from 4000 BP in Prada (Queixa Sierra; Maldonado Ruiz 1994) and c1500 BP in As Aguilladas. In all cases maximum representation is attained from c1000 BP onwards, when human pressure was greatest in the Queixa Sierra (Maldonado Ruiz 1994). *Castanea* also colonized the neighboring Courel Sierra after 4000 BP (4075±75 years BP; Santos et al 2000), although maximum representation was attained only in the last 2000 years. Santos et al (2000) refute the idea that its appearance in Galicia is linked to Romanization, although this taxon became widespread as a result of Roman cultivation.

Although isolated pollen grains of Cerealia have been recorded in As Aguilladas (1580 m) from c1400 BP (140 cm) until very recently, agricultural activities have not been recorded in the higher mountain regions of the northwestern Iberian Peninsula (Allen et al 1996). In Prada (Maldonado Ruiz 1994), a significant presence of cereal pollen at lower altitudes in the Queixa Sierra (1100 m asl) was detected from 4000 BP. In other Galician lower-altitude sequences, the first appearances of Cerealia pollen occur earlier: from 5490±90 BP onward in Tremoal da Pena Veira (620 m, Xistral Sierra; Figure 4) (Ramil Rego 1992), and before 4740±40 BP in Ferreira (680 m, Montes del Buio) (Van Mourik 1986).

The continuous presence of *Castanea* pollen in As Aguilladas from c1500 BP contrasts with its scanty record in Castelo Cerveira. Also, Castelo Cerveira (1380 m) does not record any cereal cultivation. Despite the small size of the 2 pollen sites, the more local (versus regional) pollen recruitment of Castelo Cerveira seems to be the main explanation for the differences in pollen and charcoal between the 2 sites, without discarding other explanations such as a sedimentological hiatus. The record of clear anthropogenic pollen indicators and the presence of some layers with charcoal in As Aguilladas indicate the use of fire, which could be agriculturally driven. In contrast, the abundance of charcoal in Castelo Cerveira and the absence of anthropogenic indicators could indicate that an increase in fire frequency took place in areas inaccessible for agricultural fields. This charcoal dust may be a result of pastoral fires.

The increase of *Pinus* in As Aguilladas agrees with modern reforestation, which began in the northwestern Iberian Peninsula 200 years ago (Torras Troncoso et al 1980; Tornqvist et al 1989). Alternatively, the earlier *Pinus* increase (in As Aguilladas) dated c500 BP could reflect more southern regional populations. The Lateglacial *Pinus* forest disappeared with the onset of the Holocene and was replaced by an Atlantic deciduous forest. The relatively low altitude of the Galician mountain ranges could have allowed the general expansion of oak forest, leaving no space for *Pinus* until recent afforestation (Santos et al 2000).

Conclusions

The present study was undertaken to identify late Holocene environmental changes using pollen and charcoal analyses in 2 sediment profiles from the Queixa Sierra (northwestern Iberian Peninsula) spanning the last 2700 years. The palynological record shows forest clearance, interrupted by temporary phases of *Betula* vegetation, followed by the development of grasses and moorland, and ending with pine expansion. The impact of human activities, especially cereal cultivation, reached its maximum in these mountain areas in the last 1000 years. Abundant microcharcoal particles may be regarded as an indicator of human activity, indicating forest clearance by fire around the sites. Late Holocene climate changes are difficult to identify because of the intense human impact upon the environment. The obvious consequence of this human impact is the removal of the original continuous tree cover, but widespread expansion of cultivated plants is evident only from c1000 BP. *Pinus* development at c500 BP could indicate the record of regional forests.

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