

TECHNICAL NOTE

An intensive tree-ring experience: Connecting education and research during the 25th European Dendroecological Fieldweek (Asturias, Spain)



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Abbreviations: AL, Alto de la Ila; CA, Castellón Alto; DAR, Dendroarchaeology; DCL, Dendroclimatology; DGM, Dendrogeomorphology; EDF, European Dendroecological Fieldweek; FD, Forest dynamic; FG, Fana de Genestaza; IF, Infiesto; OV, Oviedo Cathedral; PA, Plant anatomy; RB, Ribadeo; SE, Segovia; TI, Tineo.

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ARTICLE INFO

Article history:

Received 14 November 2016

Accepted 21 December 2016

Available online 28 January 2017

Keywords:

Dendrochronology
 Dendroarchaeology
 Dendroclimatology
 Dendroecology
 Dendrogeomorphology
 Plant anatomy

ABSTRACT

The European Dendroecological Fieldweek (EDF) provides an intensive learning experience in tree-ring research that challenges any participant to explore new multidisciplinary dendro-sciences approaches within the context of field and laboratory settings. Here we present the 25th EDF, held in Asturias, NW Spain, in summer 2014. The course, with 33 participants and 10 instructors from 18 countries included advanced training in dendrochronology skills, an overview of tree-ring broad fields and methodological basics to deal with specific research questions as well as applied advanced micro-projects in dendroarchaeology (DAR), dendroclimatology (DCL), dendrogeomorphology (DGM), forest dynamic (FD) and plant anatomy (PA). The results demonstrated the potential of tree-ring research in the Asturias region. The DAR group researched archaeological samples from different contexts (Oviedo cathedral choir stalls, Segovia cathedral roof timbers, Ribadeo shipwreck ship timbers and Bronze Age site charcoal) and explored the supply of wood in different periods. The DCL group established that the *Quercus robur* and *Castanea sativa* ring-width measurements show weak climate-growth correlations, where for many trees this is likely caused by management. The strength of the climatic signal could be enhanced using undisturbed settings. The DGM group found that *Corylus avellana* and *Salix* spp. are challenging species for dendrogeomorphological studies. Debris-flow events were detected by the presence of tension wood, growth reduction and scars, and their incidences were also supported by local meteorological data. The FD group found that tree growth decreases with increasing competition, a pattern more pronounced in *C. sativa* than in *Pinus sylvestris* forest plantations. The results indicate that wood production could be increased by applying thinning treatments on *C. sativa*. The PA group showed that xylem conduits and phloem area are organized according to the common needs for water supply to leaves and obtain photosynthetic products, regardless site growing conditions for *P. sylvestris* and *Tusilago farfara*. In conclusion, this EDF has been a model for interdisciplinary research and international collaboration that has demonstrated that high-quality research and education can be conducted within one week. The EDFs provide an important service to the dendrochronological community and demonstrate the usefulness of this educational-scientific and multi-cultural experience.

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1. History and concept of the European Dendroecological Fieldweek (EDF)

The Dendroecological Fieldweeks were designed to provide an intensive learning experience in tree-ring research that challenges participants to explore new approaches of multidisciplinary dendro-sciences within the context of a specific field and laboratory settings (Speer et al., 2006, 2017; Touchan et al., 2013). The courses have filled an important niche because they teach dendrochronology to scientists who do not have access to the few teaching tree-ring classes around the world. Dr. Fritz Schweingruber at the Swiss Federal Institute for Forest, Snow and Landscape Research WSL launched this concept in the 1980s in Europe and has organized twenty international dendroecological fieldweeks (See Table A1 Appendix A1). After his retirement, Kerstin Treydte and David Frank (both WSL) continued its organization in Europe (Fig. 1a), combining traditional and recent methods in dendrochronology together with local organizers.

The main goals of the EDF are to sharpen and broaden the dendrochronology skills of the participants, stimulate ideas for future dendrochronological research, foster collaboration and networking amongst tree-ring researchers around the world. Participants have the opportunity to achieve an overview to the broad field of tree-ring research and methodological basics to deal with specific research questions, to learn new research fields, to improve knowledge through discussion and scientific exchange and, last but not least, experience intercultural exchange and fun.

Every year the topics of the EDF try to cover an ample spectrum of dendrochronological issues and foster cross-disciplinary links. Each topic includes keynote lectures by the organizers and instructors, fieldwork, sample preparation and tree-ring data analyses in small project groups. In addition, the participants are encouraged to present their own research for discussion with organizers, instructors and colleagues. At the end of the week each group present their results, with an ample opportunity for discussion about each group project.

In this educational-scientific paper, we specifically report about the 25th EDF activities and scientific results. This event was conducted as a joint event of the WSL and CETEMAS (Andrea Hevia), IPE-CSIC (J. Julio Camarero) and UPO-IPE-WSL (Raúl Sánchez-Salguero), covering dendrochronological issues on archaeology, chemistry, climate, ecology, geomorphology and plant anatomy.

2. Structure of the 25th EDF in NW Spain

The 25th EDF was held from 31 August to 6 September 2014, in Oviedo (Asturias region, NW Spain) hosted at the Educational Foundation of Asturian Miners (FUNDOMA; www.fundoma.org) including 33 participants and 10 instructors from altogether 18 countries based on Institutions (Fig. 1b).

Participants and instructors jointly decided on five disciplines: Dendroarchaeology (DAR), dendroclimatology (DCL), dendrogeomorphology (DGM), forest dynamic (FD) and plant anatomy (PA) (Fig. 2). Each group project examined hypotheses to be addressed with dendrochronological data, keeping in mind the short time frame available for sample collection and analysis (Fig. 3). Participants received training in fundamentals of sampling techniques, equipment maintenance, site selection geared to specific objectives; and also fieldwork experience was conducted on each group (Table 1). Moreover, introductory lectures and laboratory exercises covered the fundamentals of tree-ring research, including different sample preparation methods depending on the conservation state of the wood and group material, as well as cross-dating and different tree-ring measurement systems (Stokes and Smiley, 1968; Baillie, 1982). Depending on the specific methodological needs of the group, participants had access to specific tree-ring measurement systems (Fig. 3): i) binocular microscopes and moving stage table LINTAB equipped with TSAPWin program (Rinntech, 2014), ii) scanning of high-resolution images with the free software ImageJ (<http://rsb.info.nih.gov/ij/docs/guide/index.html>), iii)

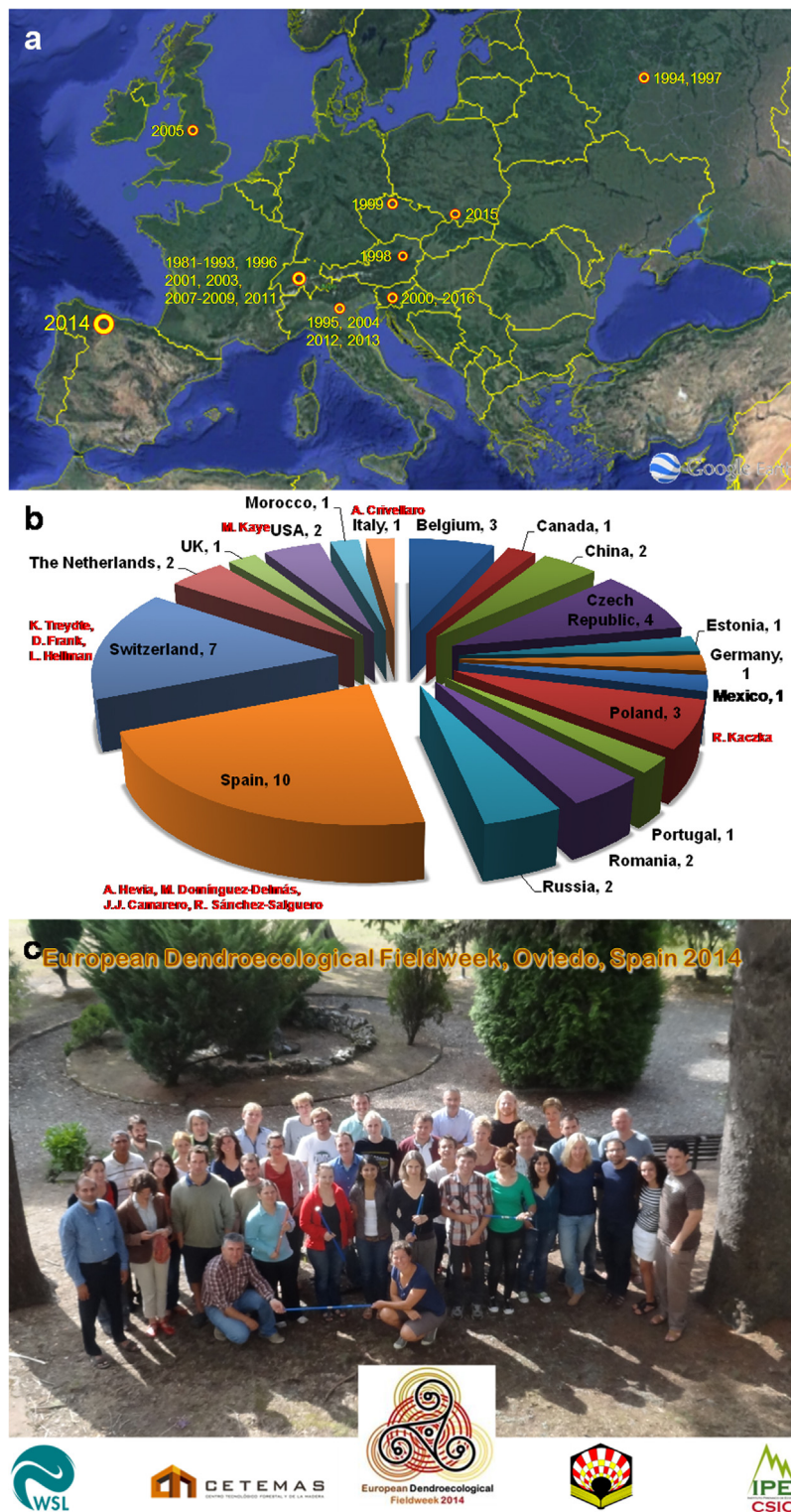


Fig. 1. (a) Locations of European Dendroecological Fieldweeks from 1981 to 2016; (b) Participants demography (Host Institutions) in red group leaders and (c) the group photo.

image analyses with the application software WinDendroTM (Regent Instruments, 2014) and iv) scanning with the software CDendro and Coorecorder (Larsson, 2013). Later lectures and laboratory exercises dealt with computer-assisted quality-control of dating and measurement with COFECHA (Holmes, 1983; Grissino-Mayer, 2001), development of site chronologies with ARSTAN (Cook and Holmes, 1999), investigation of seasonal climate signals in

tree-rings with the software Dendroclim2002 (Biondi and Waikul, 2004), treeclim (Zang and Biondi, 2015) and different R packages for statistical analyses (R Development Core Team, 2014). Additional techniques and softwares were introduced in the context of each individual group project (see details below; Fig. 3).

As the scientific culmination and highlight of the 25th EDF all groups presented their activities and findings to a broad audience

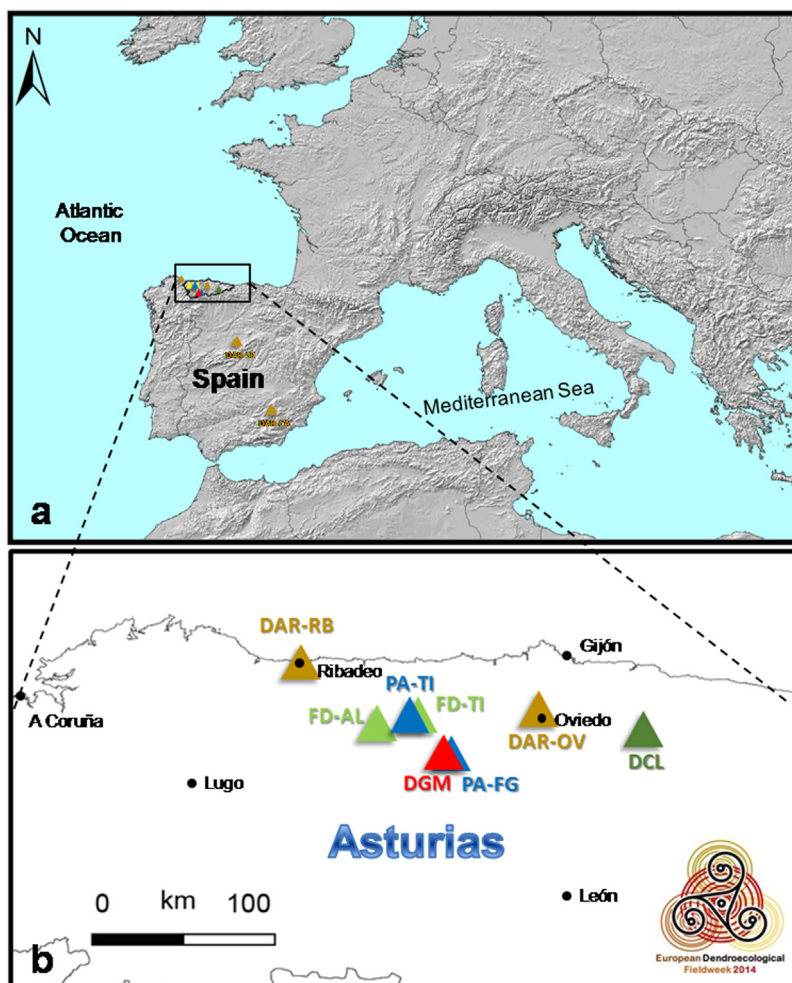


Fig. 2. (a) Overview of study sites for 25th EDF in Spain (venue was at Oviedo in Asturias region); (b) Asturias study sites for each group project (see codes in Table 1). Abbreviations: Alto de la llama (AL), Castellón Alto (CA), Dendroarchaeology (DAR), Dendroclimatology (DCL), Dendrogeomorphology (DGM), Fana de Genestaza (FG), Forest dynamic (FD), Infiesto (IF), Plant anatomy (PA), Ribadeo (RB), Segovia (SE) and Tineo (TI).

including the other participants, lecturers, local officials and forest managers, and researchers.

3. Case studies of the group projects

The study sites were located in different areas of Asturias and Spain following the specific objectives of each group (Fig. 2b). The course had access to various web-based tools and database for forest data, botanical, climatological, geological and archaeological analysis, and to historical and documentary records of environmental and urban changes archived in local libraries in Asturias.

3.1. Dendroarchaeology group (DAR)

The main objective of the DAR group was to study the supply of timber for different applications (prehistoric dwellings, art-historical objects, roof structures, and shipbuilding) in the Bronze Age and during the Early Modern Period, following a two-step approach: identifying the wood species, and carrying out tree-ring analyses afterwards to determine the date and provenance of wood. Special emphasis was given to wood preparation methods and statistical cross-dating. Selected research objects were: i) choir stalls from Oviedo Cathedral; ii) roof timbers from Segovia Cathedral; iii) timbers from the Ribadeo shipwreck; and iv) charcoal samples from the Bronze Age settlement of Castellón Alto (Galera).

3.1.1. Choir stalls at Oviedo Cathedral (DAR-OV)

The Cathedral of San Salvador (Oviedo, Asturias; Fig. 2b) was built between 1382 and 1528 (De Caso Fernández, 1981; García de Castro Valdés and Ríos González, 1996; Labra-González, 2006). The choir stalls, made between 1492–1497 C.E. (Teijeira Pablos, 1988), were partially destroyed during several events and restored in 1980 (Ara Gil, 1993). The objective was to determine the species and provenance of wood. The parts selected represented mostly carved planks corresponding to the back and sides of the stalls. The group carefully inspected the transverse ends of the different planks (Fig. 4a) in which a small portion of the transverse surface (ca. 1 mm²) was cleaned with sharp scalpel blades on inconspicuous parts (Fig. 4a) to observe the wood structure. Wood anatomical features were photographed at high-resolution. The group identified all elements as walnut (*Juglans regia*). Though this species is unsuitable for historical dendrochronology due to its prolonged history of human cultivation and its susceptibility to insect attack and fungal degradation (Miller, 1999), which hampers the development of long-span reference chronologies for dating or provenancing, walnut is particularly abundant in Asturias (MAGRAMA) and then it is very likely that wood was obtained from this region.

3.1.2. Roof structure of Segovia Cathedral (DAR-SE)

The construction began in 1525 C.E. and the central nave was completed around 1550 C.E. (Cortón de las Heras, 1997). Following

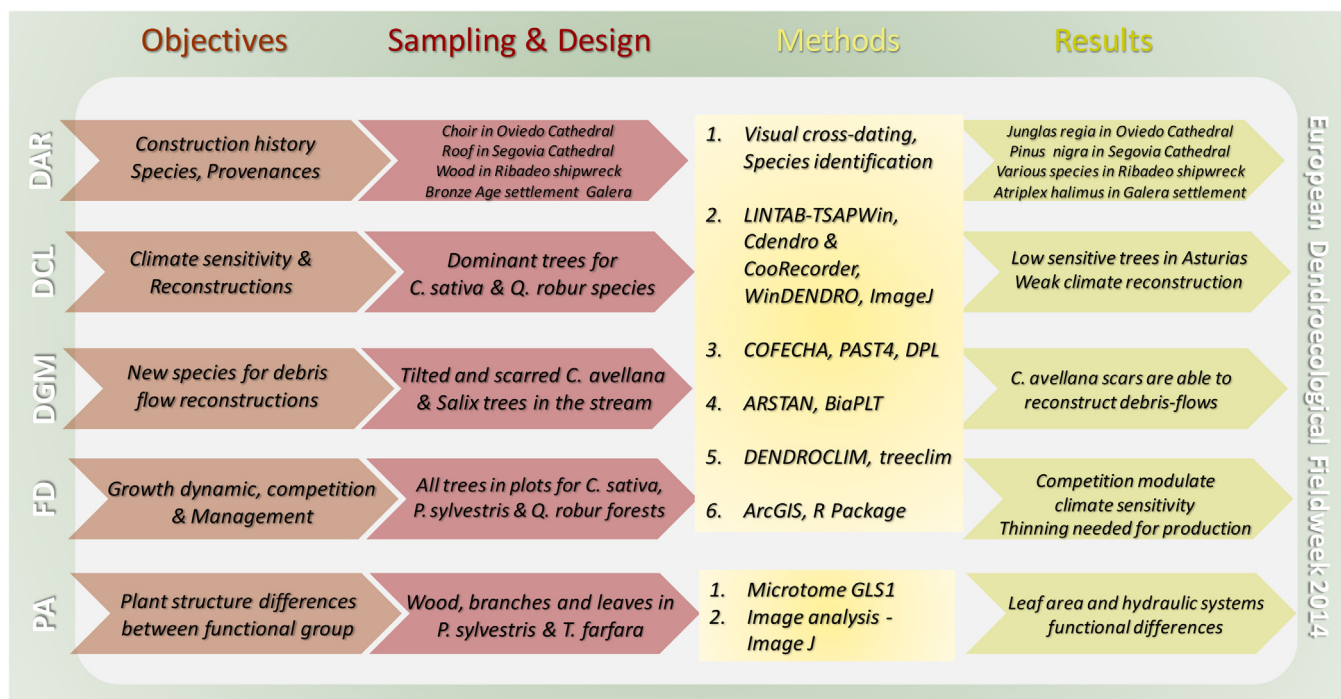


Fig. 3. Learning Flows in 25th EDF. Abbreviations: Dendroarchaeology (DAR), Dendroclimatology (DCL), Dendrogeomorphology (DGM), Forest dynamic (FD) and Plant anatomy (PA).

Lisbon's earthquake on 1 November 1755 C.E., the roof structure of the nave began to subside and had to be reinforced with supporting timbers (STs). As the date of these works was unknown, the objective was to date these STs. For this, six samples previously collected by the group leader and TRYCSA restoration company in the frame of the ForSEAdiscovery project (www.forseadiscovery.eu) were analyzed (Fig. 4b). One cross-section belonged to a tie-beam, four others were full cross-sections from STs used to reinforce the roof, and a sixth sample was half cross-section taken from a sleeper beam of the only window in the roof. All samples were identified as *Pinus sylvestris*/*Pinus nigra*, which are very similar in wood anatomical features (Schweingruber, 1990; Rodríguez-Trobajo, 2008). A wide line (2–5 mm) was cleaned from pith to bark along 2–3 radii on the transverse section using scalpel knives. Tree-ring series were measured, cross-dated internally in PAST4 version 4.3.1021 (SCIEM), and then averaged (Fig. 4b). The mean individual series were then cross-dated. These steps revealed that the four STs had been cut in the same year (Fig. 4). The presence of bark in the samples allowed establishing the cutting season of the trees: spring or early summer based of the lack or presence of latewood tracheids, respectively. This indicates that logging activities were carried out throughout the year. Those trees were likely growing in the Guadarrama forests, but cross-dating with local pine chronologies (available at the ITRDB) did not result in the absolute dating of the STs. This could be explained by a combination of the relative short length of the tree-ring series (41, 58, 59 and 82 tree-rings), the low replication of the mean curve (four series), and the possibly variable growth conditions at different elevations in the nearby mountains (Gea-Izquierdo et al., 2014) since all reference chronologies represent tree growth at the timberline. The window sleeper did not cross-date with the STs nor with the tie-beam, but an absolute date was found for this timber in the year 1771 C.E. with the reference chronologies. The latewood tracheids indicated that tree have been cut between the late summer of 1771 and the beginning of 1772 C.E. The strong match with the *P. nigra* chronology SPA1068 ($r=0.55$, Student's $t=7.56$, Percentage of parallel variation

(GI) = 65.1 for an overlap of 119 tree-rings), and the lack of significant matches with *P. sylvestris*, suggests that the window sleeper corresponds to the former species.

3.1.3. Ribadeo shipwreck (DAR-RB)

In 2011, during dredging operations in the access channel to the harbor of Ribadeo (Lugo, NW Spain, Fig. 2), a shipwreck was found. Constructive features suggest that it corresponds to a 16th century ship, possibly a Spanish galleon (San Claudio Santa Cruz et al., 2014). This wreck site has high scientific and historic interest, as it is the best preserved shipwreck from that century ever found in Spain. In 2012, 29 samples were retrieved for wood identification and dendrochronological research (Fig. 4c). Fourteen samples had more than 70 tree-rings (i.e., *Quercus* subg. *Quercus*, *Picea abies*/*Larix decidua*, *P. sylvestris*/*P. nigra*, *Abies alba*). However, none of the samples could be dated since the date and provenance of the wood remains was unknown (San Claudio Santa Cruz et al., 2014). Aiming at carrying out a hands-on exercise with air-dried waterlogged samples, seven samples of different species were selected for the DAR group participants to get acquainted with i) identification of species by wood anatomical features in transverse, radial and tangential thin-sections, ii) preparation of samples using razor blades and applying chalk powder, iii) measuring of tree-ring series on digital images using CooRecorder, and iv) cross-dating using as reference the measurements taken in 2012 (Fig. 4c). Participants shared their expertise identifying wood anatomical features that led to the identification of the species, and cross-checked their on-screen measurements and with the reference tree-ring series. Research on this shipwreck is still ongoing within the ForSEAdiscovery project (Domínguez-Delmás et al., 2013).

3.1.4. Bronze Age settlement of Castellón Alto (DAR-CA)

This archaeological site has been thoroughly studied since the first excavation took place in 1918 C.E. (www.museodegalera.es). M.O. Rodríguez-Ariza, archaeobotanist and DAR group participant, has been working in the past years with wood remains of this site (Rodríguez-Ariza and Ruiz-Sánchez, 1995) (Fig. 2a) and made

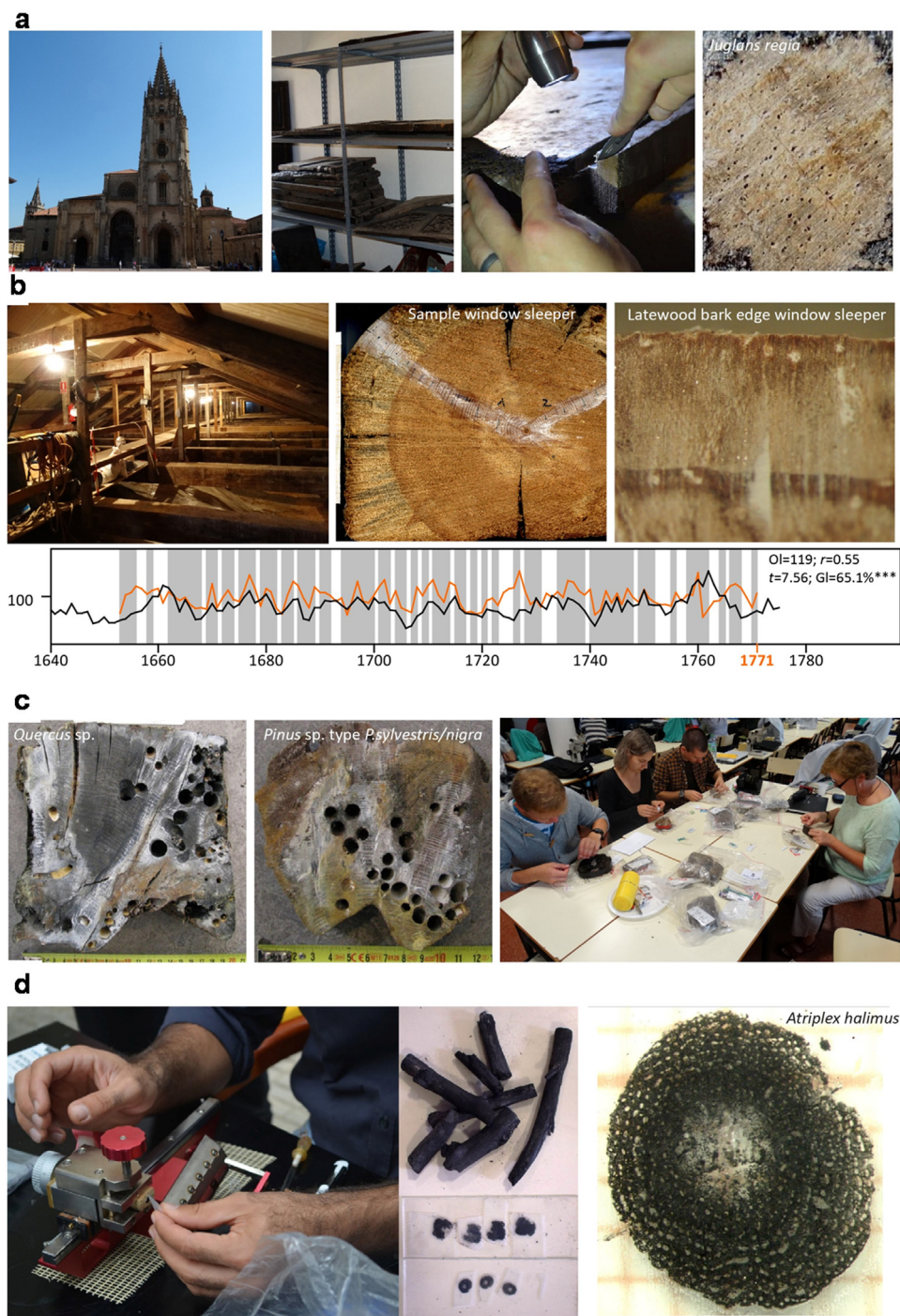


Fig. 4. DAR outcome: (a) Ovieo Cathedral sampling; (b) Segovia Cathedral and cross-dating parameters by PAST software; (c) Ribadeo shipwreck samples; (d) Charcoal samples Bronze Age site Castellón Alto.

available charcoal samples (mostly branches of small diameter) to the DAR group (Fig. 4d). The objective was to prepare the charcoal for species and tree-rings identification. In collaboration with PA group, microsections of the charcoals (transverse surface) were obtained after mounting them on small fragments on cork supports and applying an epoxy resin on the surface. Charcoal samples were identified as *Atriplex halimus* and tree-rings were absent a common feature in Mediterranean shrubs (Schweingruber et al., 2013). Given that this species is commonly found in the area of the study settlement, it is very likely that charcoals were obtained from branches of shrubs around the site.

3.2. Dendroclimatology group (DCL)

The study area was located in Infiesto (IF) (Eastern Asturias; Fig. 2), in a mixed forest dominated by oak (*Quercus robur* L.) and sweet chestnut (*Castanea sativa* Mill.), with some *Fagus* and *Betula* spp. (Table 1). Annual rainfall is about 956 mm and mean annual temperature is 10.4 °C (AEMET, 2014). The geological substrates are mainly shale and sandstone. Soils are relatively homogeneous, usually acid and predominantly humic typical dystrudept cambisol. The DCL group explored how sensitive sweet chestnut/oak forests are to climate variability in NW Spain. The research questions were: i) to which climatic parameters are *Q. robur* and *C. sativa* most sen-

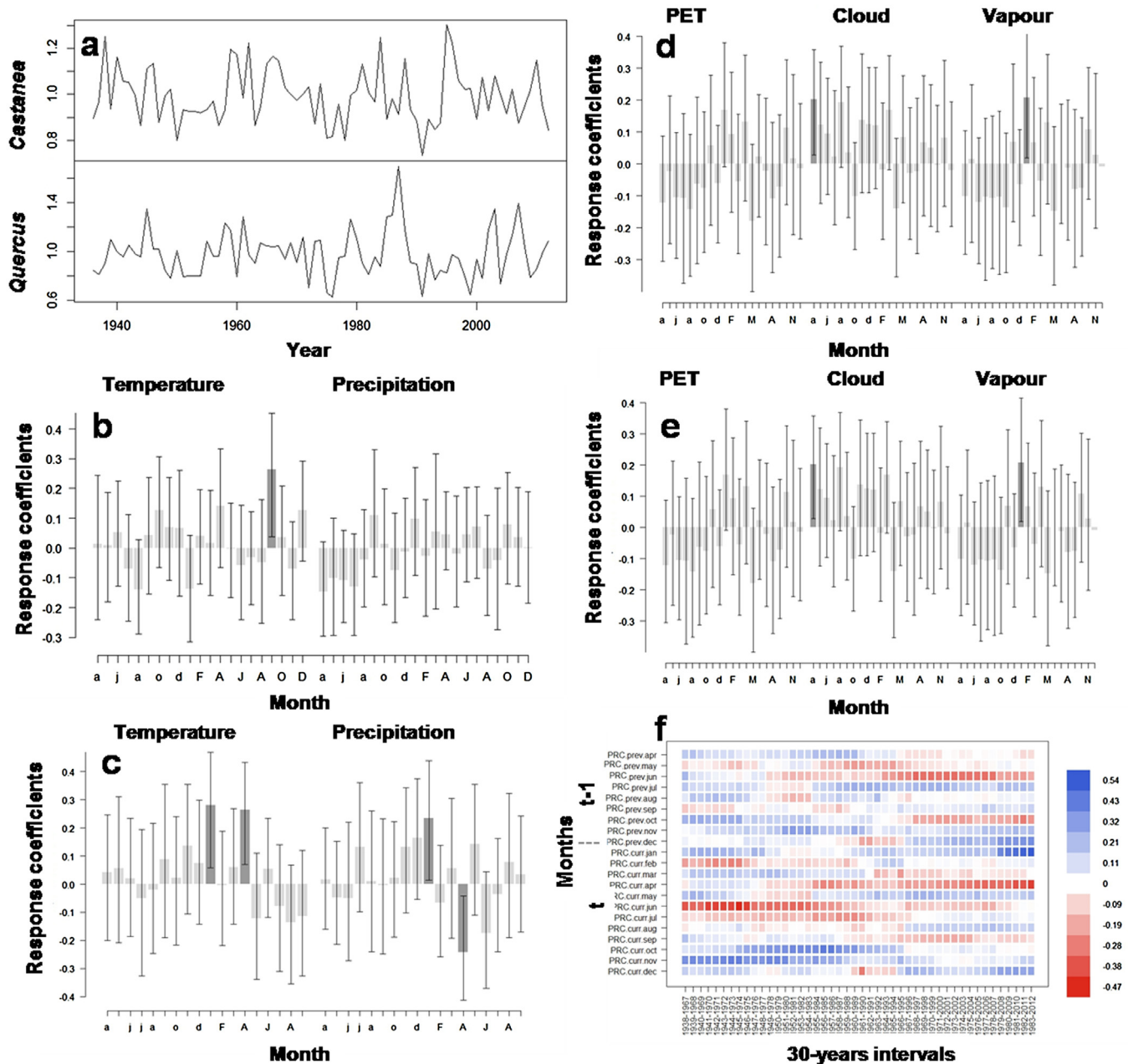


Fig. 5. DCL outcome: (a) Residual tree-ring width chronologies. Responses functions calculated between *Q. robur* (b) and *C. sativa* (c) indexed tree-ring widths and monthly climatic variables: mean temperature and precipitation. Correlation coefficients between *Q. robur* (d) and *C. sativa* (e) residual indices and potential evapotranspiration, cloud cover and vapour pressure deficit. Correlation coefficients were calculated considering months previous to (abbreviated by lower-case letters) or during the year of tree-ring formation (abbreviated by upper-case letters). Dark grey bars show significant correlations at $P < 0.01$; (f) Moving correlations (Pearson's coefficients) calculated between residual tree-ring width indices for *C. sativa* and selected monthly climate variables: months previous to (year $t-1$) or during the year of tree-ring formation (year t). The coefficients were calculated for 30-year periods lagged by 1 year for the period 1967–2012. The ticks along X-axis show the mean value of the corresponding 30-year interval.

sitive?, ii) Do *Q. robur* and *C. sativa* respond similarly to climate?, iii) Can *Q. robur* and *C. sativa* be used to reconstruct past temperature variability in NW Spain? The study design included sampling of tree cores from both dominant species in IF, *Q. robur* (37 trees) and *C. sativa* (20 trees) and development of ring-width site chronologies (Fig. 5a). The inter-series correlations were significant (*Q. robur* $r = 0.45$ for period 1879–2014 and *C. sativa* $r = 0.45$ for 1932–2014). The DCL group used the CRU TS 3.1 gridded climate data (0.5×0.5 resolution) produced by the Climate Research Unit (Mitchell and Jones, 2005) for mean monthly temperature and precipitation, cloud cover, water pressure deficit and potential evapotranspiration. The latter was calculated following Hargreaves and Samani

(1985) for the period 1901–2013. To assess the quality of tree-ring width series several dendrochronological statistics (Fritts, 2001) were calculated considering the period 1930–2014 (Table 1): first-order autocorrelation of raw ring-width data (AC), mean sensitivity (MS) of indexed growth values, mean correlation between trees (rbt), signal to noise ratio (SNR), variance accounted for by the first principal component (PC1) and the expressed population signal (EPS), which measures the statistical quality of the mean site chronology compared with a perfect infinitely replicated chronology (Wigley et al., 1984). To quantify climate-growth relationships, tree-ring widths were converted into residual indices after removing the age-related trend using the program ARSTAN (version 4.4)

Table 1
Summary of the sites and chronology characteristics for each group project.

Group	Site	Species	Latitude (North)	Longitude (West)	Elevation (meters)	N° samples	Time span	AC	MS	rbt
DAR	Oviedo (OV)	<i>Junglas regia</i>	43°21'	5°50'	-	-	-	-	-	-
	Segovia (SE)	<i>Pinus sylvestris</i>	40°57'	4°07'	-	6	-	-	-	-
	Ribadeo (RB)	<i>Quercus</i> spp., <i>Abies alba</i>	43°32'	7°02'	-	29	-	-	-	-
	Castellón Alto (CA)	<i>Artriplex halimus</i>	37°44'	2°33'	-	-	-	-	-	-
DCL	Infiesto (IF)	<i>Castanea sativa/Quercus robur</i>	43°15'	5°19'	350–450	20/37	1932/1879–2014	0.752/0.764	0.200/0.260	0.453/0.448
	Genestaza (FG)	<i>Corylus avellana/Salix</i> spp	43°35'	6°58'	900–1400	50	1972–2014	-	-	-
FD	Alto la Llama (AL)	<i>C. sativa/Q. robur</i>	43°17'	6°29'	467	57/14	1983/1987–2014	0.771/0.750	0.223/0.344	0.607/0.413
	Tineo (TI)	<i>P. sylvestris</i>	43°21'	6°24'	1014	47	1963–2014	0.726	0.230	0.433
	Genestaza (FG)	<i>Tusilago farfara</i>	43°35'	6°58'	950	6	-	-	-	-
PA	Tineo (TI)	<i>P. sylvestris</i>	43°21'	6°24'	1014	1	1963–2014	-	-	-

* Abbreviations: DAR: Dendroarchaeology, DCL: Dendroclimatology, DGM: Dendrogeomorphology, FD: Forest dynamic, PA: Plant anatomy, AC: first-order autocorrelation, MS: mean sensitivity, rbt: mean between-trees correlation of ring-width indices.

(Cook and Krusic, 2005). Tree-ring indices were obtained by dividing the observed by the expected values, which were calculated by testing linear, negative exponential, 10- and 32-year spline functions. Autoregressive modelling was then performed on these series to remove the majority of the first-order temporal autocorrelation. Finally, a biweight robust mean was computed to average the individual series and to produce mean residual chronologies of residual tree-ring width indices for each species. Analysis (program Dendroclim2002 and treeclim) of the better-replicated and least problematic of these chronologies (residual version) revealed that the chronologies have a weak and complicated seasonal climate signal: *Q. robur* growth was positively correlated with previous September temperature in the year prior to the year of tree-growth and positively correlated with current January vapour pressure deficit (Figs. 5b and 5d) (Rozas et al., 2009). In contrast, *C. sativa* growth was positively correlated with temperature and precipitation in January and contrasting positive/negative with April temperature/precipitation (Fig. 5c). The correlation with temperature increased from the late 1970s onwards, particularly in *C. sativa* (Fig. 5c). Accordingly, January to April average temperature (T) was selected as a reconstruction target only in *C. sativa*, and the DCL group proceeded to generate a temperature reconstruction for the period 1930–2014 (Fig. 5f). Despite the great uncertainty in reconstructed temperature (regression $R^2 = 0.19$), some reconstructed features were found to be consistent with documentary records of unusually cold or hot years. However, the overall conclusion of the DCL group was that there were some problems in sample replication and site selection due to the fact that the trees were not limited by a single climatic factor and the forest had been managed.

3.3. Dendrogeomorphology group (DGM)

The DGM group studied the debris-flow activity in “Fana de Genestaza” (FG) (Tineo area, Western Asturias) (Figs. 2 b, 6 a left; Table 1) (Schulz, 1858; Jiménez-Sánchez et al., 1996). The location includes an active mountain torrent representative for geomorphological processes in the Cantabrian Mountains, where frequent phenomena of debris floods are generated and transferred, and in which sediment load plays a fundamental role (Díez-Herrero et al., 2009). The catchment covers approximately 1.5 km² and extends over 650 m altitudinal distance. The average slope in the main channel is 10° (range: 8–18°). The catchment is above Cambro Ordovician quartzites stretching in NS direction and with vertical dips (Fig. 6a). The torrential debris-flow events in FG are controlled both by the rainfall regime and the volume of available material in the catchment area (Jiménez-Sánchez et al., 1996; Santos-Alonso, 2010). The main objective of the DGM group was to gain insight into the temporal dimension of these processes as well as their climatic triggers and subsequent effects on the frequency of occurrence. The group focused on these goals: i) testing the potential of the main species in riparian forests, common hazel (*Corylus avellana*) and *Salix* spp. for dendrogeomorphological studies and, ii) testing the potential for a spatio-temporal reconstruction of debris-flow activity in FG using standard dendrogeomorphological tools (Alestalo, 1971; Stoffel and Corona, 2014). The DGM group explored the following hypotheses: i) common hazel is a useful species for dendrochronological analyses, ii) debris-flow events could be detected by the presence of tension wood in bended stems, iii) coverage of the basal part of the stems by sediment should result in growth reduction, and iv) debris-flow events cause stem injuries, which persist for years as scars at the cambium. The study region is characterized by Atlantic climate with rainstorms, mild summers and long temperate winters. Average annual precipitation is 1252 mm with maximum rainfall in March, April, October, November and December (AEMET, 2014). More than 50 disturbed trees – with presence of scars, tilting, lost apical leaders or exposed

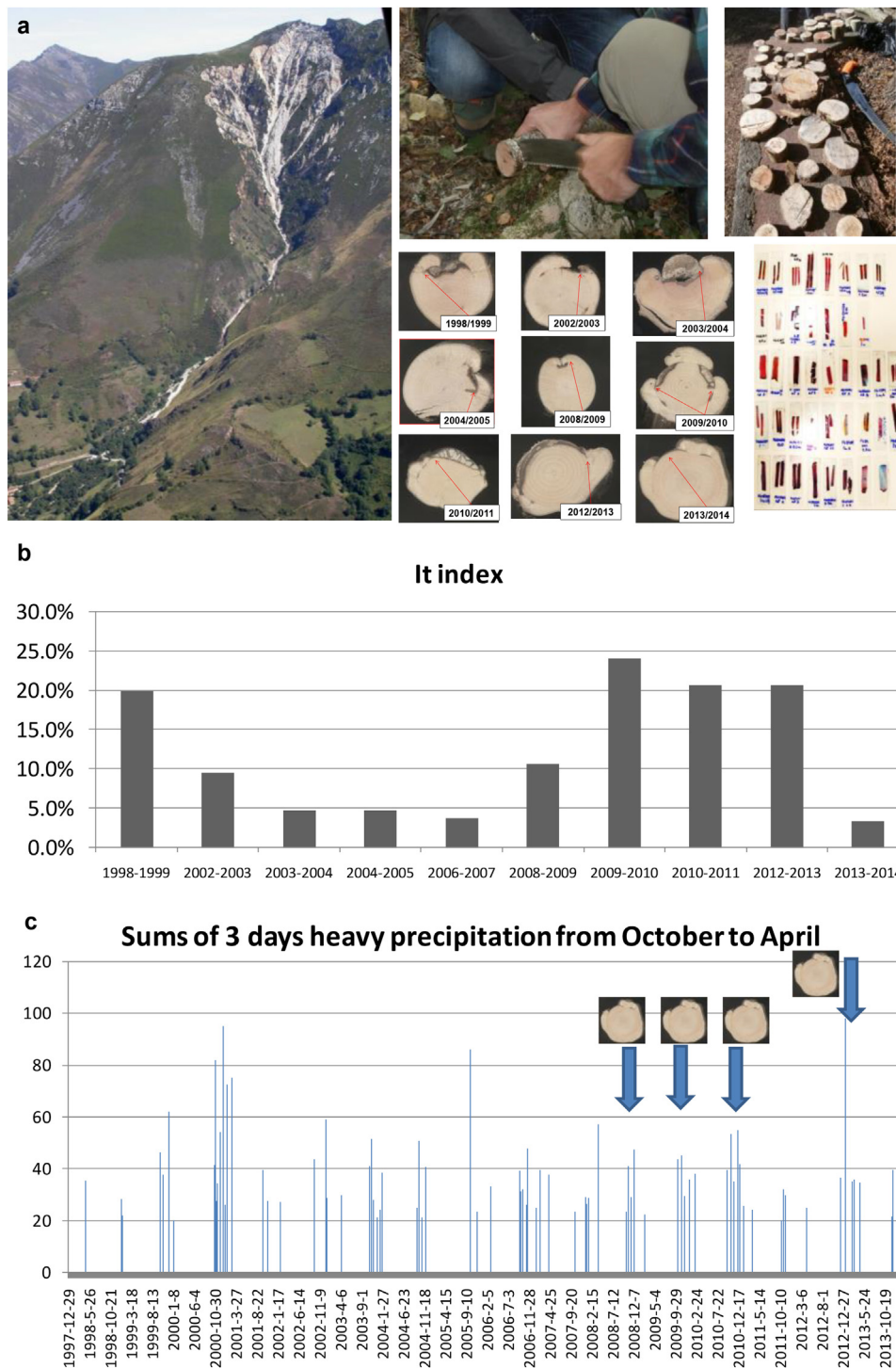


Fig. 6. DGM outcome: (a) General view of the debris-flow activity in “Fana de Genestaza” (FG) (Tineo area, Western Asturias) (left), sampling procedures, disturbed wooden sampled disks and wood anatomical preparation of scars (right); (b) Event-response histograms showing flash-flood induced growth responses from the sampled *C. avellana* trees. Bars indicate the percentage of trees responding to an event based on the Schroder (1978) index value (I_t); (c) Three-day average precipitation thresholds related to reconstructed events according to the likely seasonal correspondence from April to October. Arrows indicate average precipitation thresholds corresponding with events contrasted by historical archives.

roots in the stream banks or buried trees – located along the stream banks and/or on the fan were sampled with increment borers or collecting stem discs (Fig. 6a right) following standard procedures in dendrogeomorphology (Stoffel and Corona, 2014). In parallel, undisturbed trees were also sampled along the catchment outside the debris-flow area for building a reference chronology of the site and to identify pointer years for a reliable and precise

cross-dating with disturbed trees (Ballesteros-Cánovas et al., 2015). In addition, thin-sections from tree specimens were prepared for anatomy analysis by a sledge microtome and stained according Gärtnert and Schweingruber (2013) to identify injuries by debris-flows events (i.e., tension wood, missing and wedging rings). After sample preparation and cross-dating, a flash-floods diagnostic features were observed after 1995 when sample depth was higher than

10 disturbed trees (Fig. 6b and c). For the separation of flood signals from noise related to other external processes affecting trees, the group applied the I_t index value as defined by Schroder (1978): $I_t = (\sum_{i=1}^n R_t / \sum_{i=1}^n A_t) \times 100\%$ where (R) is the number of trees showing growth disturbances in the event year (t), and (A) is the total number of sampled trees alive in the year (t). In addition, the group also visually analyzed the spatial distribution of the affected trees along the channel and their relationship with geomorphic features. The group found that 10% of the samples had abrupt growth changes indicating geomorphologic events (i.e., decreasing growth) and competition reduction (i.e., growth release), only 8% of the samples showed tension wood due to tilting, and 70% had scars associated with local injuries. Based on the number and intensity of reactions as well as the sample depth available for each reconstructed year, the computed I_t index ranks between 3.4 and 24.1% (Fig. 6b). The resulting flash flood chronology allowed the reconstruction of four main events at the FG site in the last twenty years (Fig. 6b). The most significant events, in terms of I_t values, took place in 2009 ($I_t = 24.1\%$), 2010 and 2012 ($I_t = 20.7\%$) and 1998 ($I_t = 20.0\%$) (Santos-Alonso, 2010) (Fig. 6b). The hydrometeorological analysis of reconstructing flash floods from potential triggering situations with the highest accumulated daily rainfall precipitation recorded throughout the year, allowed a realistic calendar-dating of last flash floods (see above I_t references). Analysis of rainfall thresholds related to the likely triggers of reconstructed events showed differences in precipitation, which could be related to winter storms (Fig. 6c). The DGM group observed that autumn and winter flash floods were clearly characterized by higher total rainfall than those occurring in spring or summer. The thresholds for winter events were 40 mm for the 3-day rainfall (Fig. 6c). *C. avellana* and *Salix* spp. present in FG are a challenging species for dendrogeomorphological studies. Tension wood in *Salix* and reaction to burying were not useful to detect/reconstruct debris-flow events but it was useful in *C. avellana*. Mainly scars were found robust and efficient and enabled detecting water flow events in 2009/2010, 2010/2011 and 2012/2013, with their incidence also supported by local meteorological data.

3.4. Forest dynamic group (FD)

The group focused on two locations in the Western Asturias region (Fig. 2c): Alto de la Llama (AL), a mixed wood production forest dominated by sweet chestnut (*Castanea sativa* Mill.) and oak (*Quercus robur* L.); and Tineo (TI), a nearby Scots pine (*Pinus sylvestris* L.) plantation (Table 1). Mean annual rainfall is 1003 mm and mean annual temperature 13.5 °C (AEMET, 2014). The geological substrates are mainly shale and sandstone. Soils are relatively homogeneous, usually acid and predominantly humic typic dystrudept cambisol. The FD group explored hypotheses contrasting growth responses and competition dynamics in pine vs. mixed chestnut-oak forests. The goals were: i) to reconstruct tree growth dynamics, ii) to compare growth rates and responses to climate of *C. sativa* and *P. sylvestris*, and iii) to make recommendations for forest management. The field strategy consisted of collecting core samples from two randomly selected square plots (20 m × 20 m), one at AL and the other at TI (Table 1). All trees with diameter at 1.3 m height (Dbh) greater than 5 cm in these plots were tagged, mapped, cored and their Dbh was measured. A total of 40 and 25 trees were sampled at AL and TI, respectively. Basal Area Increments (BAI) were analyzed to explore the growth trends and climate responses. BAI is often seen as a more biologically meaningful descriptor of growth trends than only tree-ring widths (Biondi and Qeadan, 2008). The BAI was calculated from tree-ring widths as the difference between consecutive basal areas using the equation $BAI = \pi (R_t^2 - R_{t-1}^2)$, where R is the radius of the tree and t is the year of tree-ring formation. Stand struc-

ture and a distance-dependent competition index (Hegyi, 1974) were explored to understand competition-based forest dynamics (Sánchez-Salguero et al., 2015). Spatial statistic was used to characterize the spatial growth patterns and as a surrogate of spatial growth dynamics (Fig. 7a), and the mean BAI-competition relationship was calculated for the last ten years' average. Trees from the TI plot were older and had larger diameters than those located at AL (Table 1; Fig. 7b). The stand density was higher at the AL plot than at TI, despite the three sites showed contrasting stand structures with regard to species (Fig. 7a). The group found that, as expected, BAI decreases with increasing competition, higher in chestnut than in pine forests (Fig. 7c), and that a recent climate trend toward warmer and drier conditions had a negative impact on growth, particularly in September of the current year (Fig. 7d and e) (Rozas et al., 2015). The group's suggestion to local forest managers would be to modify the chestnut stand structure by thinning treatment to increase the wood production.

3.5. Plant anatomy group (PA)

The PA group worked at two study sites: 1) at Fana de Genestaza (FG), (see DGM group chapter for details) and 2) at a *P. sylvestris* plantation in Tineo (TI) (see FD group chapter) (Fig. 2; Table 1). The PA group explored the potential of stem anatomical investigations by describing the plant structure and function relationships in perennial herb (*Tusilago farfara* L.), and tree (*P. sylvestris*). The research questions were: i) What are the main differences in the anatomical structures between the two plant functional groups?, ii) Do plants adapt their xylem hydraulic diameter to environmental conditions? and iii) Can anatomical features be used to explain specific plant structures and hydraulic behavior? At the FG site the group collected the whole plants of *T. farfara* grown on sandy soil along the FG stream (Fig. 8a). Half of the collected plants were exposed to wet growing conditions. The rest was collected 2 m apart on top of a sand deposit growing in dryer conditions. Wood discs were collected from a *P. sylvestris* tree along different heights of the stem and branches were selected and cut along the trunk from the light exposed area (Fig. 8a). Microsections were prepared and image analyses were performed using ImageJ on cross-sections of the two species (Fig. 8b). Preparation of slides followed standard methods (cf. Chaffey, 2002; Gärtner and Schweingruber, 2013; Gärtner et al., 2015). The group cut 15–20 μm thin transverse sections with a GSL-1 microtome (Gärtner et al., 2014) and applied the double staining procedure. Pictures of the microsections were taken at 40–100x magnification with a light microscope (Olympus BX 51) equipped with a digital camera at the University of Oviedo. For each sample, images for the xylem of the outermost ring were taken, focused on the earlywood where the bigger conduits are found, and images of the phloem were taken as well. In addition, leaves and needles for each species were scanned to estimate leaf surface area. Images were edited to enhance the contrast and polished from staining residuals or cell contents before the analysis with ImageJ, for the estimate of the cell and leaves/needles parameters. For both the outermost xylem ring and the non-collapsed phloem region, the averaged hydraulic conduit diameter (Dh) was assessed (Kolb and Sperry, 1999). For total leaf area calculations, five methods were tested against the perimeter of the needle cross-section. The group also used properties such as the number of leaves, or the number of tracheids/vessels in stem and leaves. Besides that, tissue properties such as xylem/phloem and leaf tracheid/vessel area, leaf area, mean tracheid/vessel diameter and hydraulic diameter were investigated to provide answers to research questions. Anatomical analyses of xylem conduits, tracheids in *P. sylvestris* and vessels in *T. farfara*, and phloem sieve cells revealed that both transportation networks are organized according to the basipetal widening of conduits (Anfodillo et al., 2013; Petit and Crivellaro, 2014) (Fig. 8c).

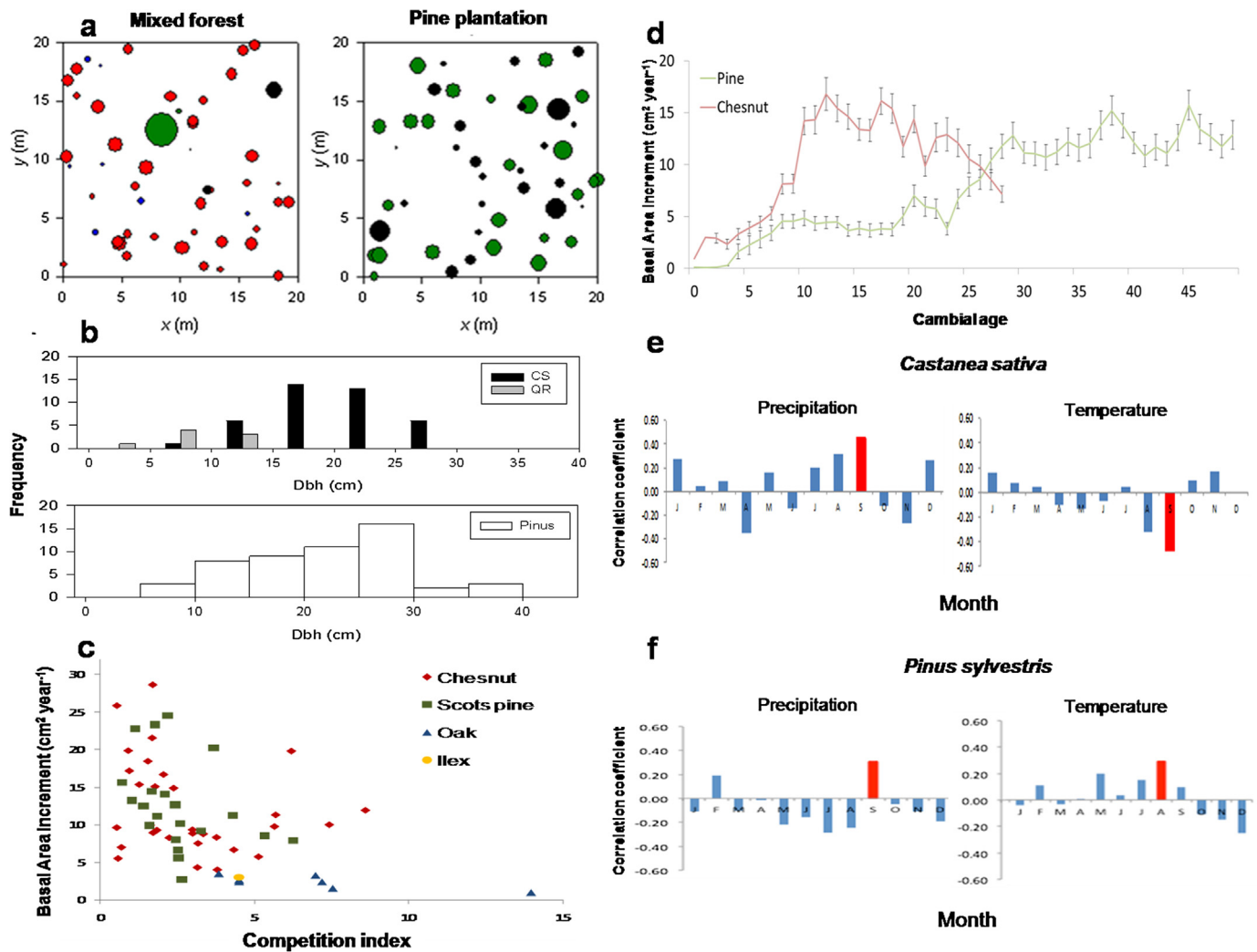


Fig. 7. FD outcome: (a) Spatial patterns for each plot: Tineo forest (TI) (red-*C. sativa*; black-*Q. robur*; green-*P. radiata*; blue-*Ilex aquifolium*) and Alto de la Llama (AL) (green-*P. sylvestris*; black-*Quercus* spp.); (b) Frequency of tree size data structure (Dbh, diameter at breast height) of sampled plots; (c) Relationships between the competition index and the Basal Area Increment (BAI) of trees in the four study species present in the plots considering the time period 1990–2013; (d) Average Basal Area Increment trends and cambial age for the main species in each plot; Correlation coefficients calculated between *C. sativa*; (e) and *P. sylvestris*; (f): Basal Area Increment and monthly climatic variables: precipitation (left graph) and mean temperature (right) calculated considering the year of tree-ring formation (from January to December). Red bars shown significant correlations at $P < 0.01$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The tissue properties analyses showed that pith area proportional to the distance of the sampling point to plant apex was significantly larger for the herb in contrast to phloem and xylem areas that were larger in trees (Fig. 8d). Dh increased with total leaf area continuously from the stem base to the apex (Fig. 8e) following a power trajectory also with the length of the stem apex (L) in both xylem and phloem (Olsen et al., 2014). The increase in Dh of xylem conduits with L varied, however, between the analyzed individuals (Petit et al., 2011). It must nevertheless be highlighted that Dh estimates for both functional groups increased with the number and area of the needles of leaves (Fig. 8f) irrespectively of the differences of the numbers of vessels and tracheids analyzed per image (Petit et al., 2011). The results show the potential to use the hydraulic diameter for leaf area estimations without using simplified procedures that introduce biases (Lin et al., 2002). Additionally due to the strong relationship with stem height, anatomy could be useful in reconstructing tree height throughout its life-time.

4. Conclusions

The 25th EDF demonstrated the potential of tree-ring data from tree species and sites in NW Spain for studying archaeology, climate, forest dynamic, geomorphology and plant anatomy aspects (Fig. 3). To dendrochronologically establish the date and provenance of historical timbers of oak and pine in Spain, a denser network of multi-century long chronologies is required. However, despite the lack of absolute dates, tree-rings can reveal coeval groups of timbers, different building phases, and in the presence of bark, the seasons when logging activities were carried out. Additionally, the identification of species used in art-historical objects and built structures from different periods can provide insights into the geographical origin of the wood and the use of local timber resources. Although the climate signal in tree-ring widths of the sampled trees is weak, and for many trees likely distorted by effects of management, stronger climate reconstructions may

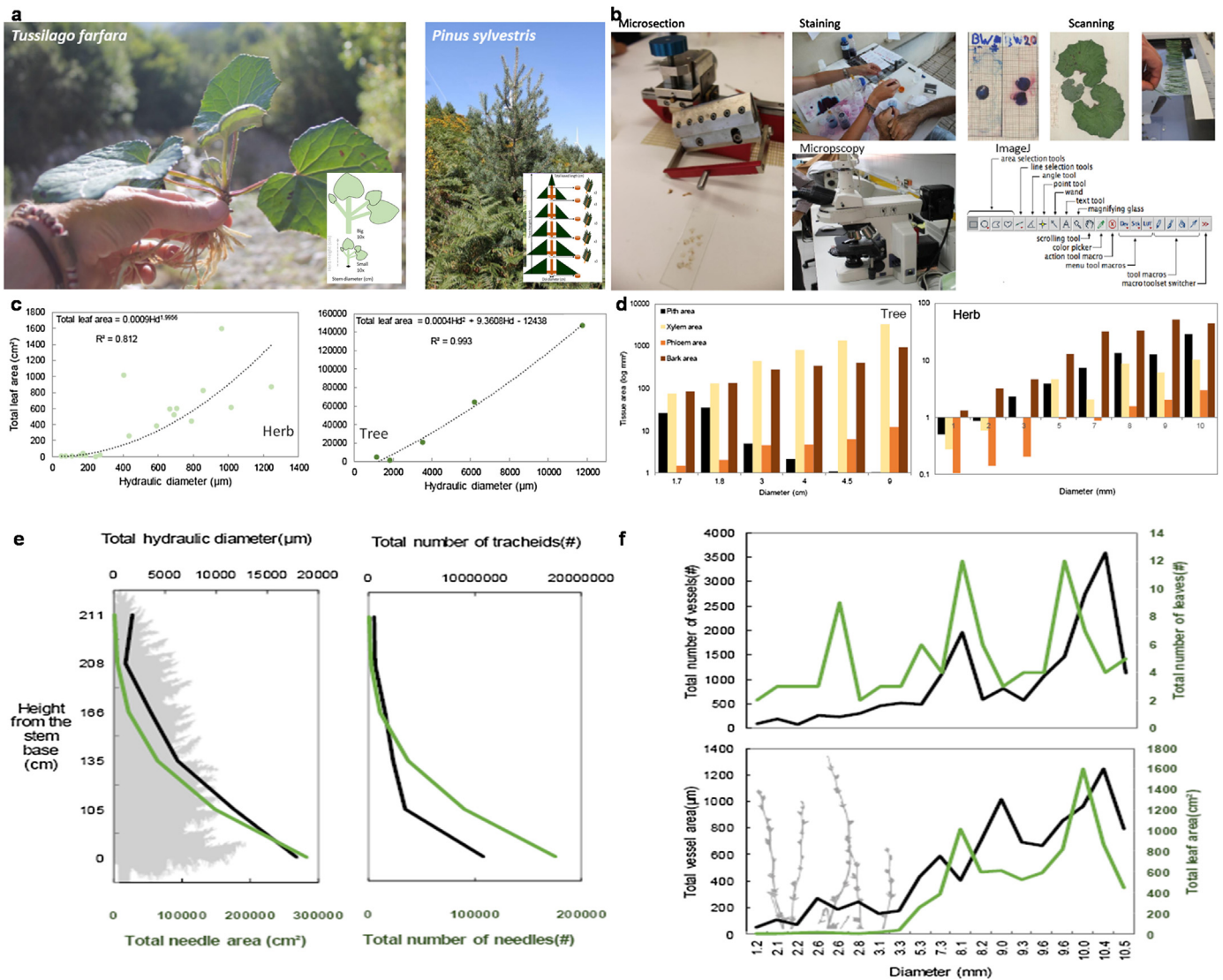


Fig. 8. PA outcome: (a) Sampling design for each species; (b) wood and leaf anatomical laboratory preparation procedures; (c) anatomy against plant structure; (d) tissue properties; (e) relationship between *P. sylvestris* height, needle area and estimated hydraulic diameter; (f) variations of *T. farfara* vessel and leaf areas along the stem diameter.

be possible through the increase of replication by adding more trees from relatively undisturbed settings, and chronology extension back in time may be possible with tree-rings from remnant wood. Future dendroclimatology work should also exploit the climate signal in tree-ring parameters other than total ring-width – for example, stable isotopes, maximum latewood density or quantitative wood anatomical features. From a forest ecology point of view, results suggest that the growth of *C. sativa* and *Q. robur* in Asturias forests is particularly sensitive to previous autumn climate conditions and that the influence of temperature and precipitation is especially dependent on the species and modulated by competition. Future dendroecological studies should address how the detected growth changes are associated with thinning treatments in the study area, and should explore in more detail how the wood production response is modulated by species composition and stand structure. Extending analysis would provide valuable recommendations for planning future forest management in NW Spain. The dendrogeomorphological findings from the FG stream with an abundance of flood-damaged trees show great potential. Our limited study barely taps the potential for flash-flood reconstruction from this resource, and stresses the need to take more samples in order to isolate the correct geomorphic signal. The plant

anatomy group showed that anatomical analysis on xylem conduits and phloem area in *P. sylvestris* and *T. farfara* showed that the hydraulic transportation network of both species is organized according to the common needs for water supply to leaves and to get photosynthetic products, regardless of site conditions. Altogether, the participants of the 25th EDF learned how much quality research a dedicated team of researchers can complete in one week. The 25th EDF has been a model for interdisciplinary research and collaborative investigation that has contributed to the education of the participants and the expansion of research collaborations of the group leaders; become in most cases the research network of the participants after fieldweek. We hope that this intensive learning experience in the broad field of tree-ring research will help to demonstrate the usefulness of this type of experiential learning also for the fieldweeks in upcoming years.

Acknowledgements

This 25th EDF was carried out as joint event of the Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf-Switzerland, CETEMAS (Forest and Wood Technology Research Centre) in Asturias, University of Córdoba (UCO) and

IPE-CISC (Instituto Pirenaico de Ecología – Consejo Superior de Investigaciones Científicas)–Zaragoza, from Spain. The organizers sincerely thank the FUNDOMA, Consejería de Desarrollo Rural y Recursos Naturales–Principado de Asturias, UniOvi (Universidad de Oviedo), Tineo and Oviedo Councils and the Oviedo Cathedral bishopric for the support and facilities to organize this course. We thank Dr. J. Mañada, Mrs. P. Barrero, Mr. E. Álvarez and Mrs. L. González (CETEMAS), as well as Drs. T.E. Diaz and A. Casares (UniOvi) for their contribution and support during this EDF. Special thanks to Mr. Miguel A. García (CETEMAS). We thank the ATR (Association for Tree-Ring Research) and ABET (Asociación Española de Ecología Terrestre) for generous grants provided to students. We thank the course sponsors: Cox Analytical Systems, Geonatura, GISIBERICA, Haglöf Sweden, Regents Instruments and RinnTech. R. Sánchez-Salguero is grateful for the postdoctoral fellowship of UCO–Campus de Excelencia CIA3 and FEDER–Programa de Fortalecimiento de las capacidades en I + D + i de las Universidades 2014–2015 de la Junta de Andalucía (Univ. Pablo de Olavide). M. Domínguez-Delmás was supported by a Marie Skłodowska Curie Innovative Training Networks Fellowship (ForSEADiscovery project, PITN-2013-GA-607545). This course was partially supported by the projects CoMo-ReAdapt (CG12013-48843-C2-1-R) and FORRISK (Interreg IV B SUDOE, SOE3/P2/FS23). We thank useful comments provided by Dr. P. Cherubini and one anonymous reviewer.

Appendix A

See [Table A1](#)

Table A1

Prof. Dr. Fritz Schweingruber kindly compiled his recollections and some details for all fieldweeks from 1986 to 2001. We include this table as received recognizing that this valuable contribution does not list the same information consistently throughout all years (e.g. not all instructors are listed by name). We thank Fritz Schweingruber for providing this table, and more so far the legacy which he has firmly established for subsequent generations of dendrochronologists.

Year	Topics	Organizers and team leaders*	N° participants	City/Region/Country
1986	Dendroecology	F. Schweingruber and others	16	Alpine farmhouse, Hasliberg, Switzerland
1987	Dendroecology	F. Schweingruber and others	16	Hut, Doro above Lavorgo, Ticino, Switzerland
1988	Dendroecology	F. Schweingruber	18	Forest house, Suaiza above Lavorgo, Ticino, Switzerland
	Dendroentomology	D. Eckstein, H.C. Fritts		
	Dendroclimatology	H. C. Fritts		
1989	Alpine Dendroecology	F. Schweingruber and others	31	University house of Geneva, Bourg St Pierre, Gr. St. Bernhard, Switzerland
1990	Alpine Dendroecology	F. Schweingruber, H.C. Fritts and L. Ydun	40	Old hotel, Brienzerthorn, Switzerland
1991	Mountain Dendroecology	F. Schweingruber, E. Vaganov, S. Shyiatov and others	45	Skihous Brambruesch, Chur, Switzerland
1992	Alpine Dendroecology	F. Schweingruber and others	65	Old house of an electrical company, Saas Almagell, Switzerland
1993a	Alpine Dendroecology	F. Schweingruber and others	40	Holiday house, Tschier, Switzerland
	Technology, Forestry	C. Mattheck, P. Piussi and others		
1993b	Alpine Dendroecology	F. Schweingruber and others	35	Holiday house, Tschier, Switzerland
	Technology, Forestry	C Mattheck, P. Piussi and others		
1994	Dendroecology	D. Katz, F. Schweingruber and others	100	Boat and military caserne, Tapjorne Kirilov, Vologad, Russia
1995a	Mountain Dendroecology	C. Urbinati, F. Schweingruber and others	65	Reserach Center, Monte Bondone, Trento, Italy
1995b	Alpine Dendroecology	C. Urbinati, F. Schweingruber and others	65	Reserach Center, Monte Bondone, Trento, Italy
1996a	Mountain Dendroecology	F. Schweingruber and others	60	Holiday house, Selma, Calacatal, Ticino, Switzerland
1996b	Mountain Dendroecology	F. Schweingruber and others	60	Holiday house, Selma, Calacatal, Ticino, Switzerland
1997	Mountain Dendroecology	F. Schweingruber, E. Vaganov, J. Banks and others	40	Sport training camp, Semiski Pass Altai, Russia
1998a	Dendroecology	R. Wimmer, F. Schweingruber and others	50	University lecture house, Rosalia Mts, Vienna, Austria
1998b	Dendroecology	R. Wimmer, F. Schweingruber and others	50	University lecture house, Rosalia Mts, Vienna, Austria
1999	Dendroecology	M. Kroupov, F. Schweingruber and others	50	University lecture house, Babunek, Vimprek, Tschechoslovakia
2000	Dendroecology	T. Levanic, H. Bugmann, F. Schweingruber and others	45	Hotel Masun, Ljubliana, Slovenia
2001	Dendroecology	F. Schweingruber and others	49	Holiday house, Lantsch, near Davos, Switzerland

*Information about 1986–2001 Fieldweeks provided by Fritz Schweingruber and the anonymous reviewer. Group leaders were always PhD Students of Prof. Dr. Fritz Schweingruber as Veronika Stöckli, Stefan Berli, Marco Isel, Jan Esper, Felix Kienast and many others. All fieldweeks from 1986 to 2001 were supported by the Univ. of Basel and the Swiss Academy of Science. Werner Schoche was mostly the cook.

References

- AEMET, 2014. Agencia Estatal de Meteorología. Ministerio de Agricultura, Alimentación y Medio Ambiente. Gobierno de España.
- Alestalo, J., 1971. Dendrochronological Interpretation of Geomorphic Processes. *Fennia* 105. Societa Geographica Fennia, 140 pp.
- Anfodillo, T., Petit, G., Crivellaro, A., 2013. Axial conduit widening in woody species: a still neglected anatomical pattern. *IAWA J.* 34 (4), 352–364.
- Ara Gil, C.J., 1993. La intervención del escultor Alejo de Vahía en la sillería de coro de la catedral de Oviedo. *Anales de la Historia del Arte*. 4. Ed. Complutense Madrid.
- Baillie, M.G.L., 1982. *Tree-Ring Dating and Archaeology*. University of Chicago Press, Chicago.
- Ballesteros-Cánovas, J.A., Rodríguez-Morata, C., Garófano-Gómez, V., Rubiales, J.M., Sánchez-Salguero, R., Stoffel, M., 2015. Unravelling past flash flood activity in a forested mountain catchment of the Spanish Central System. *J. Hydrol.* 529 (2), 468–479.
- Biondi, F., Qeadan, F., 2008. A theory-driven approach to tree-ring standardization: defining the biological trend from expected basal area increment. *Tree-Ring Bull.* 64, 81–96.
- Biondi, F., Waikul, K., 2004. DENDROCLIM2002: A C++ program for statistical calibration of climate signals in tree-ring chronologies. *Comput. Geosci.* 30, 303–311.
- Chaffey, N., 2002. *Wood Formation in Trees*. Cell and Molecular Biology Techniques. Taylor and Francis, London.
- Cook, E.R., Holmes, R.L., 1999. Program ARSTAN – Chronology Development with Statistical Analysis (user's Manual for Program ARSTAN). Laboratory of Tree-Ring Research, University of Arizona, 18 pp.
- Cook, E.R., Krusic, P.J., 2005. Program ARSTAN- A Tree-Ring Standardization Program Based on Detrending and Autoregressive Time Series Modeling, with Interactive Graphics, Tree-Ring Laboratory. Lamont Doherty Earth Observatory of Columbia University, Palisades, NY <http://www.ldeo.columbia.edu/tree-ring-laboratory/resources/software>.
- Cortón de las Heras, M.T., 1997. La Construcción De La Catedral De Segovia (1525–1607). Caja de Ahorros y Monte de Piedad, Segovia, 292 pp.
- Diez-Herrero, A., Laín-Huerta, L., Llorente-Isidro, M., 2009. *A Handbook on Flood Hazard Mapping Methodologies Geological Hazards/Geotechnics 2*. Madrid. Spanish Geological Survey, 190 pp.
- De Caso Fernández, F., 1981. La Construcción De La Catedral De Oviedo (1293–1587). Oviedo.
- Domínguez-Delmás, M., Nayling, N., Wazny, T., Loureiro, V., Lavie, C., 2013. Dendrochronological dating and provenancing of timbers from the Arade 1 shipwreck. *Portugal. Int. J. Naut. Archaeol.* 42 (1), 118–136.
- Fritts, H.C., 2001. *Tree Rings and Climate*. Blackburn Press, Caldwell.
- Gärtner, H., Schweingruber, F.H., 2013. *Microscopic Preparation Techniques for Plant Stem Analysis*. Verlag Dr. Kessel, Remagen, 78 pp.
- Gärtner, H., Lucchinetti, S., Schweingruber, F.H., 2014. New perspectives for wood anatomical analysis in dendrosciences: the GSL1-microtome. *Dendrochronologia* 32, 47–51.
- Gärtner, H., Cherubini, P., Fonti, P., von Arx, G., Schneider, L., Nievergelt, D., Verstege, A., Bast, A., Schweingruber, F.H., Büntgen, U., 2015. Technical challenges in tree-ring research including wood anatomy and dendroecology. *J. Vis. Exp.* 97, 1–10, e52337.
- García de Castro Valdés, C., Ríos González, S., 1996. Introducción a La Arquitectura En Asturias En Los Siglos VIII-IX. Gijón.
- Gea-Izquierdo, G., Viguera, B., Cabrera, M., Cañellas, I., 2014. Drought induced decline could portend widespread pine mortality at the xeric ecotone in managed Mediterranean pine-oak woodlands. *For. Ecol. Manage.* 320, 70–82.
- Grissino-Mayer, H.D., 2001. Evaluating crossdating accuracy: a manual and tutorial for the computer program COFECHA. *Tree-Ring Bull.* 57 (2), 205–221.
- Hargreaves, G.H., Samani, Z.A., 1985. Reference crop evapotranspiration from temperature. *Appl. Eng. Agric.* 1, 96–99.
- Hegyí, F., 1974. A simulation model for managing jack-pine stands. In: Fries, J. (Ed.), *Growth Models for Tree and Stand Simulation*. Royal Collage of Forestry, Stockholm, Sweden, pp. 74–90.
- Holmes, R.L., 1983. Computer-assisted quality control in tree-ring dating and measurement. *Tree-Ring Bull.* 43, 68–78.
- Jiménez-Sánchez, M., Menéndez Duarte, R., Fariás Arquer, P., Fernández Menéndez, S., 1996. La Fana de Genestaza: un ejemplo de un sistema torrencial activo en la Cordillera Cantábrica. *Geogaceta* 20 (5), 1109–1111.
- Kolb, K.J., Sperry, J.S., 1999. Differences in drought adaptation between subspecies of sagebrush (*Artemisia tridentata*). *Ecology* 80, 2373–2384.
- Labra-González, C.M., 2006. El impulso constructivo de la Catedral de Oviedo durante el reinado de Isabel la Católica: el pórtico y obras contemporáneas. *De Arte: revista de historia del arte* 5, 107–123.
- Larsson, L., 2013. CooRecorder and Cdendro Programs of the CooRecorder/Cdendro Package Version 7.6. <http://www.cybis.se/forfun/dendro>.
- Lin, J.X., He, X.Q., Hu, Y.X., Kuang, T.G., Ceulemans, R., 2002. Lignification and lignin heterogeneity for various age classes of bamboo (*Phyllostachys pubescens*) stems. *Physiol. Plant* 114, 296–302.
- Miller, R.B., 1999. Characteristics and Availability of Commercially Important Woods. Forest Products Laboratory. 1999. Wood Handbook – Wood as an Engineering Material. Gen. Tech. Rep. FPL-GTR-113. Madison. Department of Agriculture, Forest Service, Forest Products Laboratory, WI: U.S., 463 pp.
- Mitchell, T., Jones, P., 2005. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *Int. J. Climatol.* 25, 693–712.
- Olsen, M.E., Anfodillo, T., Rosell, J.A., Petit, G., Crivellaro, A., Isnard, S., León-Gómez, C., Alvarado-Cárdenas, L.O., Castorena, M., 2014. Universal hydraulics of the flowering plants: vessel diameter scales with stem length across angiosperm lineages, habits and climates. *Ecol. Lett.* 17 (8), 988–997.
- Petit, G., Crivellaro, A., 2014. Comparative axial widening of phloem and xylem conduits in small woody plants. *Trees-Struct. Funct.* 28 (3), 915–921.
- Petit, G., Anfodillo, T., Carraro, V., Grani, F., Carrer, M., 2011. Hydraulic constraints limit height growth in trees at high altitude. *New Phytol.* 189, 241–252.
- R Development Core Team, 2014. R: a language and environment for statistical computing R Foundation for Statistical Computing, Vienna, Austria Available at: <http://www.R-project.org/>.
- Regent Instruments, 2014. WinDendro. An Image Analysis System For Tree-Rings Analysis. <http://www.regent.qc.ca/products/dendro/DENDRO.html>.
- Rinntech, 2014. LINTAB. Precision ring by ring. <http://www.rinntech.com/Products/Lintab.htm>.
- Rodríguez-Ariza, M.O., Ruiz-Sánchez, V., 1995. *Antracología Y Palinología Del Yacimiento Argárico De Castellón Alto (Galera, Granada)*. Anuario Arqueológico De Andalucía 1992 II., pp. 169–176.
- Rodríguez-Trobajo, E., 2008. Procedencia y uso de la madera de pino silvestre y pino laricio en edificios históricos de Castilla y Andalucía. *Arqueología de la Arquitectura* 5, 33–53.
- Rozas, V., Lamas, S., García-González, I., 2009. Differential tree-growth responses to local and large-scale climatic variation in two *Pinus* and two *Quercus* species in northwest Spain. *Ecoscience* 16 (3), 299–310.
- Rozas, V., Camarero, J.J., Sangüesa-Barreda, G., Souto, M., García-González, I., 2015. Summer drought and ENSO-related cloudiness distinctly drive *Fagus sylvatica* growth near the species rear-edge in northern Spain. *Agric. For. Meteorol.* 201, 153–164.
- Sánchez-Salguero, R., Linares, J.C., Camarero, J.J., Madrigal-González, J., Hevia, A., Sánchez-Miranda, A., Ballesteros-Cánovas, J.A., Alfaro-Sánchez, R., García-Cervigón, A.I., Bigler, C., Rigling, A., 2015. Disentangling the effects of competition and climate on individual tree growth: a retrospective and dynamic approach in Scots pine. *For. Ecol. Manage.* 358, 12–25.
- San Claudio Santa Cruz, M., González Gallero, R., Casabán Banaclocha, J.L., Castro, F., Domínguez-Delmás, M., 2014. El pecio de Ribadeo, un excepcionalmente bien conservado pecio español del siglo XVI. In: Nieto Prieto, X., Ramírez Pernía, A., Recio Sánchez, P. (Eds.), *Actas Del I Congreso De Arqueología Náutica Y Subacuática Española*. Ministerio de Educación, Cultura y Deporte, pp. 169–178.
- Santos-Alonso, R., 2010. *Flujos De Derrubios En La Cornisa Cantábrica: Evidencias, Modelo De Susceptibilidad Y Relevancia Geomorfológica* PhD Thesis. Universidad de Oviedo.
- Schroder, J.F., 1978. Dendrogeomorphological analysis of mass movement on table cliffs plateau, Utah. *Quart. Res.* 9, 168–185.
- Schulz, G., 1858. Descripción Geológica De La Provincial De Oviedo Imprenta Y Librería De Don José González, Madrid, 138 pp.
- Schweingruber, F.H., Börner, A., Schulze, E.-D., 2013. *Atlas of Stem Anatomy in Herbs Shrubs and Trees*, vol. 2. Springer-Verlag, Berlin, Heidelberg.
- Schweingruber, F.H., 1990. *Anatomy of European Woods*. Haupt Verlag, Bern, Stuttgart.
- Speer, J.H., Brown, P.B., Krusic, P., Grissino-Mayer, H., 2006. Professional fieldweeks as an educational experience and a venue for explorative research: case study of the North American Dendroecological Fieldweek. In: Speer, J.H. (Ed.), *Experiential Learning and Exploratory Research. The 13th Annual North American Dendroecological Fieldweek (NADEF)*. Indiana State University, Department of Geography, Geology, and Anthropology, Professional Paper Series No. 23, pp. 3–14.
- Speer, J.H., Bräuning, A., Zhang, Q.-B., Pourtahmasi, K., Gaire, N.P., Dawadi, B., Rana, Yub Raj, Dhakal, P., Acharya, R.H., Adhikari, D.L., Adhikari, S., Aryal, P.C., Bagale, D., Baniya, B., Bhandari, S., Dahal, N., Dahal, S., Ganbaatar, N., Giri, A., Gurgung, D.B., Khandu, Y., Maharjan, B., Maharjan, R., Malik, R.A., Nath, C.D., Nepal, B., Ngoma, J., Pant, R., Pathak, M.L., Paudel, H., Sharma, B., Hossain, M. Sd., Soronzonbold, B., Swe, T., Thapa, I., Tiwari, A., 2017. *Pinus roxburghii* stand dynamics at a heavily impacted site in Nepal: research through an educational fieldweek. *Dendrochronologia* 41, 2–9, <http://dx.doi.org/10.1016/j.dendro.2016.01.005>.
- Stoffel, M., Corona, C., 2014. Dendroecological dating of geomorphic disturbance in trees. *Tree-Ring Bull.* 70, 3–20.
- Stokes, M.A., Smiley, T.L., 1968. *An Introduction to Tree-Ring Dating*. University of Arizona Press Tucson.
- Teijeira Pablos, M.D., 1988. La sillería de coro de la catedral de Oviedo. *Boletín del Seminario de Estudios de Arte y Arqueología* 64, 467–468.
- Touchan, R., Meko, D.M., Ballesteros, J.A., Sánchez-Salguero, R., Camarero, J.J., Kerchouche, D., Muntan, E., Khabeche, M., Blanco, J.A., Rodríguez-Morata, C., Garófano-Gómez, V., Martín, L.A., Alfaro-Sánchez, R., Garah, K., Hevia, A., Madrigal-González, J., Sánchez-Miranda, A., Shestakova, T.A., Tabakova, M., 2013. Dendrochronology course in Valsain forest, Segovia Spain. *Tree-Ring Bull.* 69, 93–100.
- Wigley, T., Briffa, K., Jones, P., 1984. On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology. *J. Clim. Appl. Meteorol.* 23, 201–213.
- Zang, C., Biondi, F., 2015. treeclim: an R package for the numerical calibration of proxy-climate relationships. *Ecography* 38, 431–436.