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Carpological remains from the Pliocene of Almenno and the Early Pleistocene of Leffe in the collections of the Caffi Museum of Bergamo, Italy

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ABSTRACT. The Caffi Museum of Bergamo hosts numerous fossil fruits, seeds, cones and fructifications found in the marine deposits of the Pliocene, close to the village of Almenno, and in the lacustrine deposits of the Early Pleistocene lignite-bearing basin of the historical locality Leffe. Despite the bias towards larger carpological objects, the material can be considered very relevant for the study of the history of vegetation development in Northern Italy during the late Cenozoic, because it originates from independently dated sediments and from an area that is poor in palaeocarpological assemblages. As a result of the palaeocarpological analyses, 8 carpological taxa have been determined at Almenno, and 21 at Leffe, 18 of which could be identified to a modern genus. Eventual previous determinations, often preliminary, are revised, but the occurrence of carpological remains of *Carya*, *Phellodendron* and *Magnolia* is confirmed and well-assessed in the Calabrian. Several fossil-species are reported for the first time in the studied area and permit a comparison with richer assemblages occurring in the neighbouring Piemonte region.

KEYWORDS: fruits, seeds, fossil flora, Pliocene, Early Pleistocene, Northern Italy

INTRODUCTION

The Caffi Museum of Bergamo has been carrying out the preservation and study of the palaeontological material of Bergamo province, in the Lombardy region for more than a century (e.g. Confortini et al., 2003). Its collections contain interesting fruit and seed specimens, mainly originating from a Pliocene locality, Almenno San Bartolomeo (from now on "Almenno"), and an Early Pleistocene one, Leffe (Fig. 1A). Plant remains from the Pliocene locality, Almenno were previously treated by Brambilla (1984), and partly revised by Günther and Gregor (1990).

The fossil plant remains of the Early Pleistocene Leffe lacustrine basin have been cited by Massalongo (e.g. 1852a), Sordelli (1896), Gregor (1990), Ravazzi and Rossignol Strick (1995), Ravazzi (1995), Ravazzi and Van der Burgh (1994), Ravazzi and Moscariello (1998), Ravazzi (2003), Muttoni et al. (2007) and Ravazzi et al. (2009a), who reported floristic lists including carpological remains. However, many of these fossils were never illustrated or described in detail, and the origin from a given

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site was often not indicated. The Leffe succession is rather thick and possibly spans from the Gelasian to the end of the Calabrian (Muttoni et al., 2007), therefore, any information about the stratigraphic position of individual fossil assemblages is very useful to assess their age. Thus, we tried to provide below all the available stratigraphic information for the fossil assemblages studied by us. We only anticipate here that, on the basis of palynological, palaeontological and palaeomagnetic analyses, it has been assessed that the carpoflora-bearing layers of Leffe belong to the Calabrian (~1.8–0.87 Ma; Muttoni et al., 2007).

In this paper, all the relevant carpological remains from Almenno and Leffe are reconsidered, revised and figured.

GEOLOGY AND STRATIGRAPHY

In Almenno (Northern Italy; Fig. 1A), the Pliocene sediments cropped out along a stream named Torrente Tornago, at an altitude of ~260 m a.s.l. (Fig. 1B). The Pliocene sediments were described as ~10 m thick and cropping out for a lateral extension of 100 m; they are unconformably lying over a Mesozoic

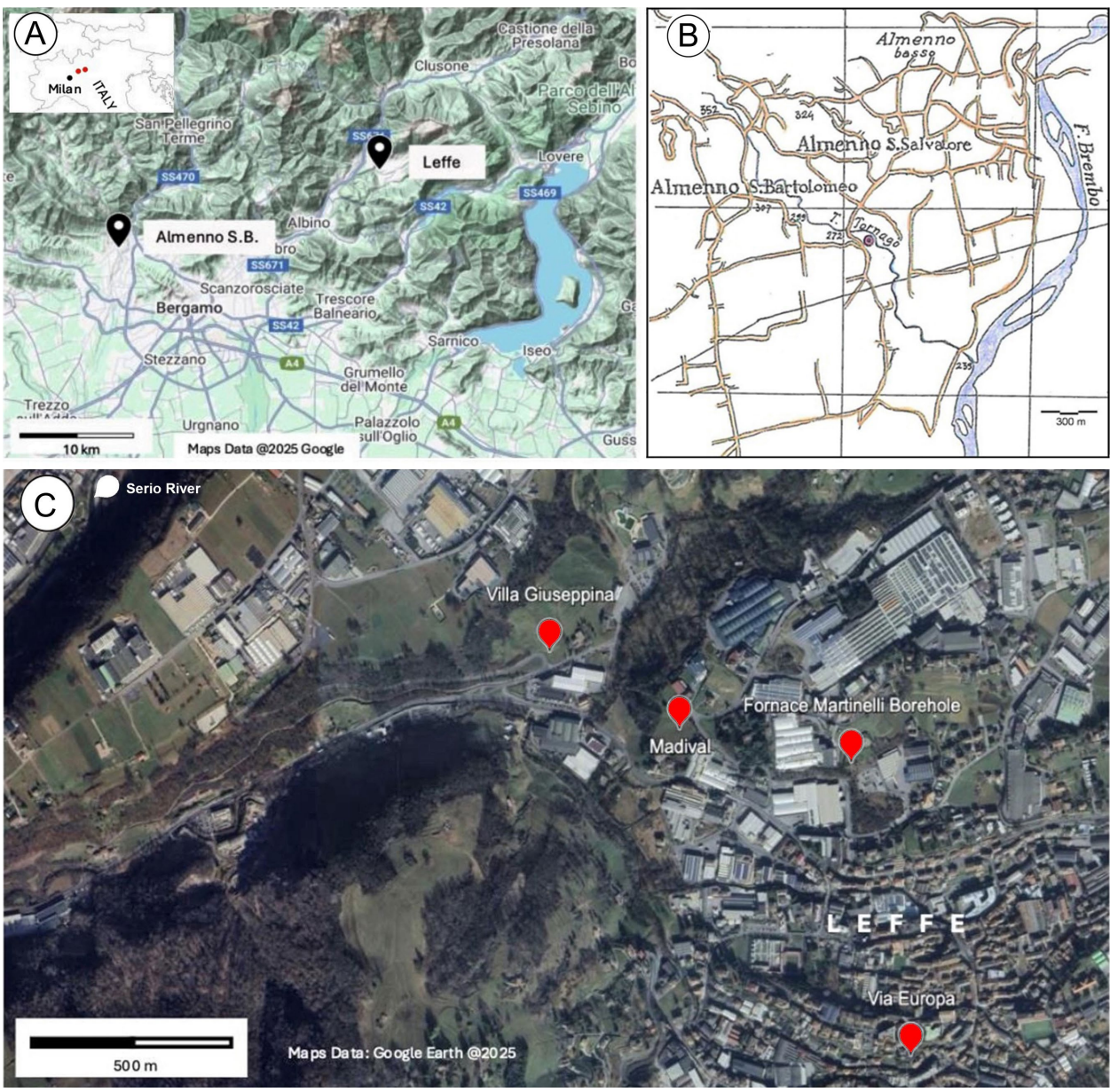

Figure 1. **A**. Map of the area of the Bergamo province comprising the sites of Almenno San Bartolomeo and Leffe. The position of the two sites in relation to the main north Italian town Milan is shown in the top left corner; **B**. Map of the Almenno San Bartolomeo site, indicated by the red circle in the centre. Drawing from Fabbricosi (1983); **C**. Satellite image of the Leffe Basin showing the location of the plant-bearing sites cited in the text. The location of the long core studied by Cremaschi and Ravazzi (1995) and Muttoni et al. (2007) is indicated as Fornace Martinelli Borehole

sedimentary succession, capped by Plio-Pleistocene fluvio-glacial conglomerates from Brembana Valley (Brambilla, 1984). Two facies were described as Pliocene in age (Brambilla, 1984): the 'argille grigie' (i.e. 'grey clays') at the bottom, and the 'sabbie gialle' (i.e. 'yellow sands'), which contain leaf impressions, on top. Sordelli (1874, 1896) described the species recovered in the 'sabbie gialle' facies, but did not mention the 'argille grigie'. From the 'argille grigie' unit, remains of marine invertebrates and plant remains like wood fragments, leaves, fruits and seeds were recovered and identified (Brambilla et al., 1983). The 'argille grigie' unit was dated to the "early-mid Pliocene" because of its foraminifera and mollusc content (Brambilla, 1984). According to the same author, the Pliocene environment was characterized by the sea, at its maximum ingression level, in which the rivers from the surrounding reliefs determined a consistent input of sediments. These rivers carried the remains of trees and shrubs from the surrounding hills and mountains to the (normally oxic) sea bottom, where they were preserved (Brambilla, 1984), probably thanks to a high sedimentation rate that permitted the transition to anoxic conditions of the buried mass of plant-bearing sediments.

The Early Pleistocene Leffe Basin occupies a tributary valley of the Serio River (Northern Italy; Figs 1 and 3) and was filled by a lake that endured a long succession of climatic oscillations (e.g. Ravazzi and Rossignol Strick, 1995; Ravazzi and Moscariello, 1998; Muttoni et al., 2007). Starting from the second half of the 19th century, the palaeolake area became a mining site and sediments were excavated to extract brown coal (or lignite). During the mining activities, many Mammal remains were discovered and described (see overview in Breda and Marchetti, 2007, for a comprehensive revision of the mammals from Leffe). Together with the animal remains, a few palaeobotanical remains were also extracted and studied (e.g. Massalongo, 1852a, b; Sordelli, 1874). More recently, palaeovegetation reconstructions based on pollen analysis were published (e.g. Ravazzi and Rossignol Strick, 1995; Ravazzi et al., 2009b). In 1991, a 189 m long core was recovered (Cremaschi and Ravazzi, 1995) and enabled the analysis of the entire lacustrine sedimentary succession. A combination of magnetostratigraphy and mammal biostratigraphy allowed dating the palaeolake succession, and all the included remains, to a time interval from 1.94–1.78 Ma ago to 0.87 Ma ago (Muttoni et al., 2007). The more detailed magnetobiostratigraphic framing of the three "lignite banks" and of the layers with mammal assemblages (Breda and Marchetti, 2007; Muttoni et al., 2007) allows us to constrain the age of the plant macrofossil assemblages described by us in the range between 1.5 and 0.9 Ma.

MATERIAL AND METHODS OF PALAEOBOTANICAL INVESTIGATIONS

This work is mainly based on the morphological analysis of carpological material larger than 5 mm, stored at the Caffi Museum of Bergamo. Several photographs were acquired by Franco Valoti with a Nikon D810 Full Frame digital camera, others were obtained by the authors with a Nikon Coolpix P7100 camera. In addition, a very small sediment sample from Leffe (Via Europa site, 0.06 dm^3 of blackish, poorly sorted medium-fine sand, label LF11 C7F) was sieved with the usual palaeocarpological method described by Martinetto (1994a) and Basilici et al. (1997). In this case, we picked out from the residue also the small carpological objects (less than 5 mm), and we observed and photographed them with a Wild M3 microscope, mounting a Leica Flexacam c3 with a phototube.

For the identification of the carpological material, we mainly used the extensive literature listed by Martinetto (2015). Direct comparison with reference fossil specimens of the CENOFITA collection (Martinetto and Vassio, 2010; Martinetto, 2015), managed by the Regional Museum of Natural Sciences of Turin (from now on indicated with the acronym MRSN-P/345-CCN), was also performed. This collection and the associated database were also used to analyze the geographic and stratigraphic distribution of the taxa occurring at Almenno and Leffe.

ORIGIN OF THE CARPOLOGICAL MATERIAL OF ALMENNO

The material was accessed by the Caffi Museum during the second part of the 20th century by a few persons (e.g. Carlo Barbero, Mario Gervasutti) who checked the bed of the Tornago river (Fig. 1B) and recovered naturally exposed plant fossils, bringing them to the museum and indicating the location of the finding. All the carpological material treated by us was already studied in a thesis (Fabbricosi, 1983). The carpological remains were indicated (Brambilla, 1984) as originating from the deposit of "gray clays". These were marine sediments and contained a lot of molluscs and foraminifera. The plant macroremains were quite rare; their conservation state ranges between fair and good; the larger macroremains are often squeezed because of the successive sediment load.

ORIGIN OF THE CARPOLOGICAL MATERIAL OF LEFFE

The Leffe lignite-bearing basin (Fig. 1C) has been extensively excavated in the 19th century, when large outcrops were available, but scarce attention was devoted to the recovery of plant remains, in particular those smaller than 5 mm. Partial exceptions are the reports of Balsamo Crivelli (1840), Massalongo (1852a, b, 1856) and Sordelli (1874, 1896). These authors only described a few cm-sized fossil fruits (two species of "*Castanea*", *Juglans bergomensis*: Fig. 2) and female cones (Figs 3, 4) from the Leffe excavations, with the exception of mm-sized seeds of *Vitis* described by Sordelli (1896).

During the second half of the 20th century, the Museo Caffi's staff visited sites where sediment blocks were exhumed during the construction of buildings at Leffe. These were opened in the field and in the museum to extract the visible fruits and seeds. Two main places were investigated at Leffe, following the excavations in the rare construction sites: Via Europa (year 1982) and Madival (year 1983). Further carpological remains from the Leffe Basin were recovered during the research activities of the CNR and Caffi Museum in the localities Casnigo (Ravazzi, 1995: p. 436) and Villa Giuseppina (Ravazzi, 2003), but these have not yet been published, except for some data about the distribution of carpological taxa reported by Martinetto (1999, 2001a).

Figure 2. Historical collection of fossil fruits of *Juglans bergomensis* stored at the Caffi Museum of Bergamo (MCSNB1224). Scale = 4.5 cm

Figure 3. Leffe Via Europa site. **1**. Original image of the excavation in the year 1982; **2**. Situation of the site in the year 2024, the plant-bearing deposit is buried by the ground level of the building (image courtesy GoogleMaps)

We report here the available information about each sampling site:

Leffe Via Europa. The precise site of the excavation, carried out in the years 1982 to build a house, was located at the present civic number 16 of Via Europa, at 446 m a.s.l., as documented in the pictures (Fig. 3). The research and recovery of fossil plant material was carried out by Anna Paganoni and Mario Pandolfi of Caffi Museum. For the assessment of the stratigraphic position of the short succession it can be useful to mention the presence of a thick deposit of brown coal rich in siliciclastic sediments and a conglomerate (Peia-Gandino unit; Muttoni et al., 2007) at the top of the excavated wall, at an elevation of 465 m a.s.l., which is in outcrop still today behind the house. The most probable correlation of this short section is with the "first lignite bank" of the Leffe basin depocentre (Cremaschi and Ravazzi, 1995: fig. 4), in which such a seam is located between 432 m and 429 m a.s.l. The age of this seam is constrained between 1.10 and 0.99 Ma (Muttoni et al., 2007, Fig. 4). However, if we want to be very cautious and argue that the "second" and not the "first lignite bank" cropped out at the Via Europa site, the age of the plant-bearing deposit can be considered not older than 1.5 Ma and not younger than 0.99 Ma (Muttoni et al., 2007: p. 166).

Madival. The site was represented by an excavation for building purposes, at 430 m a.s.l., close to a still existing factory named Madival and just 200 m apart from the site Villa Giuseppina, well described by Ravazzi and Van der Burgh (1994), where the "main brown coal layer" (i.e. the "second lignite bank" of Muttoni et al., 2007) cropped out in the 1990s. Anna Paganoni and Mario Pandolfi of Museo Caffi recovered a few plant fossils in emergency conditions in 1983. The age of this plant-bearing deposit, close to the "second lignite bank", must be approximately 1.5 Ma (Muttoni et al., 2007: p. 166).

Villa Giuseppina road curve at elevation 424 m a.s.l. (in synthesis, **VG424**) This site yielded material in danger of destruction, probably recovered in 1978 by Bortolo Mottinelli, who delivered the specimens to the Caffi Museum and indicated the precise location of the finding. The carpological fossils included some of the better-preserved specimens of *Juglans bergomensis* (MCSNB7916, MCSNB7917).

The same place of Villa Giuseppina (VG424) was indicated by other people as a collection site of nut specimens delivered to the Caffi Museum (e.g. *Carya*, MCSNB7921a, MCSNB7943-45) with the indication of the precise location of the findings, also visited by personnel of the Caffi Museum. These plant-bearing sediments must be not too much above the "second lignite bank" (age approximately 1.5 Ma: Muttoni et al., 2007: p. 166). However, due to the imperfect method of recovery of the fossils, their age is cautiously considered between 1.5 and 1.3 Ma.

"Leffe" generic. A few specimens of female conifer cones (Figs 3, 4) and several nuts of *Juglans bergomensis*, considered part of the 19th-century Caffi collection (MCSNB1224, Fig. 2), are just labeled "Leffe", without further information. The same uninformative indication is reported in Caffi Museum's database for a few 20th-century accessions, probably delivered to the museum by someone who noticed these fossils in the field. According to the experience of the Caffi Museum staff, most, if not all, of these fossils should originate from the landfills of still accessible mining activities and from ephemeral outcrops around the aforementioned locality, Villa Giuseppina. This fossil plant material is not very relevant for stratigraphic considerations. However, its age must fall in the range of the "biogenic unit", i.e. between 1.5 and 0.9 Ma (Muttoni et al., 2007).

RESULTS

The analysis of the collection of the fossil carpological material from Almenno enabled the identification of eight taxa (Table 1), most of which were already reported (Table 2) from other Pliocene sites of Northern Italy (Martinetto, 2015).

The collection of carpological material from Leffe contained interesting taxa that were described and illustrated in more detail than it was done in previous preliminary papers (Gregor, 1990; Günther and Gregor, 1990;

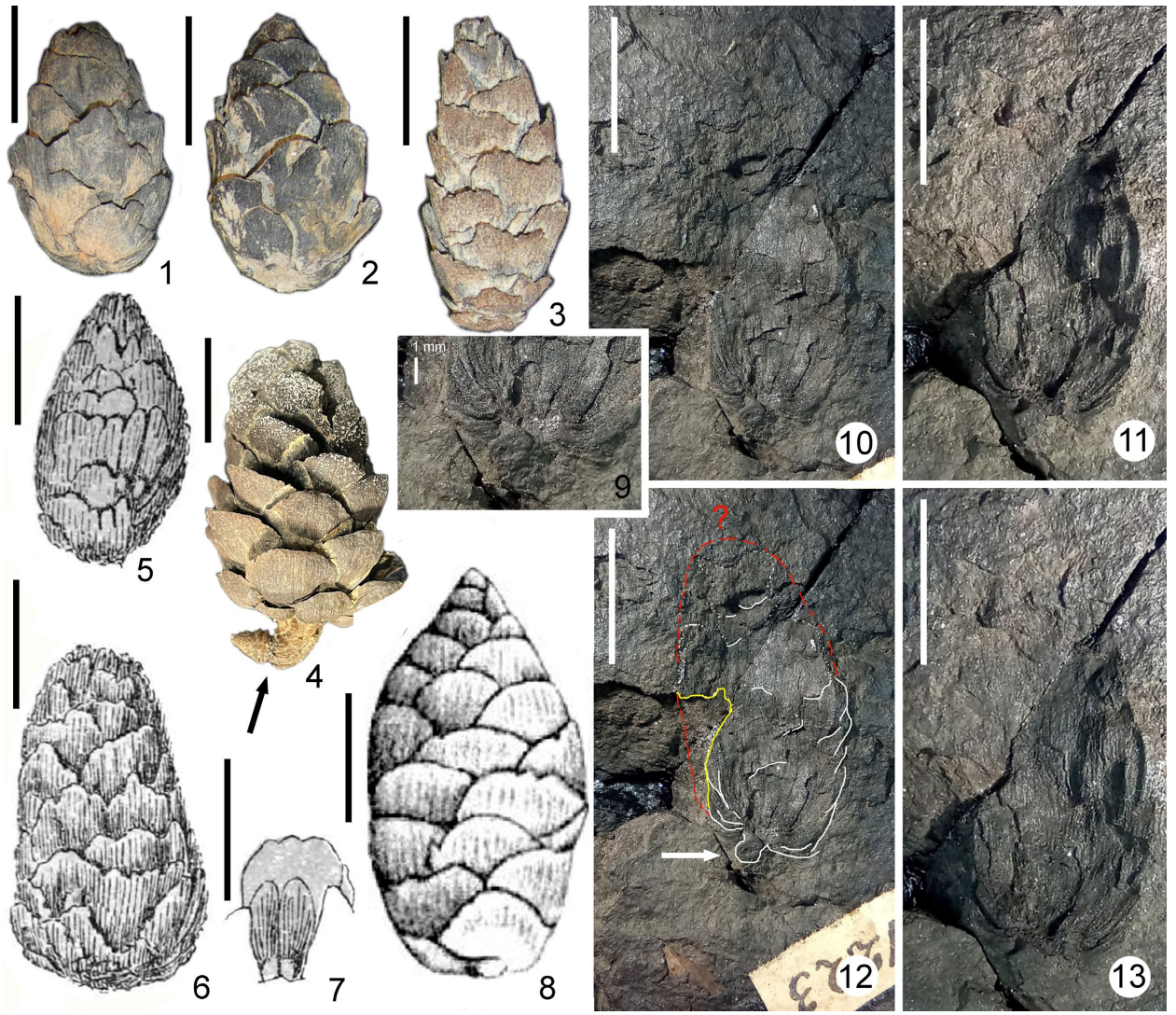

Figure 4. Comparison of small female Pinaceae cones from Leffe with similar ones from other localities. **1–3**. *Tsuga chiarugii* from Steggio, Pleistocene of the Veneto region (MRSN-P/345-CCN8675-8677); **4**. *Larix decidua* from Truc di Miola, Pleistocene of the Piemonte region (MRSN-P/345-CCN8678), arrow pointing at the massive, curved peduncle; **5**. *Picea omorikoides* sp. inc. from Leffe, proposed reference specimen of the name *Picea seriana* Sordelli; **6**. *Larix decidua* sp. inc. from Leffe, specimen assigned by Sordelli (1896) to *Picea seriana*; **7**. detail of the seeds attached to the cone of Fig. 4.5; **8**. *Picea omorikoides* fossil cone from Germany, part of the type material drawn by Weber (1898); **9–13**. *Larix decidua* sp. inc., specimen MCSNB1223 from Leffe seen under different lightning, **9**. Detail of the peduncle impression; **12**. Reconstructed cone outline (red and white lines) on the basis of remaining parts of the numerous thin scales or their impressions, despite the missing part on the left side (yellow line); arrow pointing at the impression of a massive, curved peduncle. Scale bars = 1 cm, excepted Fig. 4.9

Table 1. Catalogue of the carpological remains from Almenno stored at the Caffi Museum of Bergamo

MCSNB	Family	Genus	Species epithet	No. of specimens	Description	Fig. of this paper	Brambilla (1984)
5180	Juglandaceae	*Carya*	*nux-taurinensis*	1	endocarp	Fig. 6.8	*Juglans* cf. *cinerea*
5175	Cupressaceae	*Cupressus*	*rhenana*	1	cone	Fig. 6.4	*Chamaecyparis* cf. *lawsoniana*
5183	Cupressaceae	*Cupressus*	*rhenana*	1	cone	Fig. 6.5	*Cupressus* sp.
5182	Altingiaceae	*Liquidambar*	*europaea*	1	fruiting head (infructescence)	Fig. 6.7	*Sequoia* aff. *sempervirens*
5184	Altingiaceae	*Liquidambar*	*europaea*	1	fruiting head (infructescence)		?
5441 a, b	Altingiaceae	*Liquidambar*	*europaea*	1	fruiting head (infructescence)		?
5720a	Lauraceae	*Litsea*	*sonntagii*	1	endocarp	Fig. 6.6	*Juniperus* sp.
5174	Pinaceae	*Cathaya*	*bergeri* sp. inc.	1	cone	Fig. 6.3	*Tsuga heterophylla*
5173	Pinaceae	*Pinus*	*cortesii*	1	cone	Fig. 6.1	*Pinus vexatoria*
5176	Pinaceae	*Pinus*	*peuce* sp. inc.	1	cone		*Abies* sp.
5181	Pinaceae	*Pinus*	*spinosa*	1	cone	Fig. 6.2	*Pinus* sp.
5720b	indet.	indet.		1	?		*Juniperus* sp.

Table 2. Occurrence of the carpological taxa from Almenno in four Pliocene sites with marine sediments of the Piemonte region, where carpological remains have been collected by hand-picking in the field: BR = Breolungi (Martinetto et al., 2015a); CA = Candelo (Martinetto, 1995); CO = Cossato, site TC1 (Ferrero et al., 2003); SE = Sento I and Sento II sites (Basilici et al., 1997)

Carpological taxa	BR	CA	CO	SE
Carya nux-taurinensis		×		×
Cupressus rhenana sp. inc.	×			×
Liquidambar europaea	×	×	×	×
Litsea sonntagii	×			×
Cathaya bergeri sp. inc.	×	×	×	×
Pinus cortesii	×			
Pinus peuce sp. inc.			×	×
Pinus spinosa				

Ravazzi and Van der Burgh, 1994; Ravazzi, 1995, 2003). The presence of sediments with concentrations of carpological remains in the Caffi Museum collections provided further information on the taphonomy of such fossils; in fact, the sediments recovered from the Leffe Via Europa site were rich in fine sand, which indicated a certain transport of plant fragments from the areas surrounding the Leffe palaeolake (Ravazzi, 2003). The carpological content of the bulk sediment sample LF11 C7F is listed in Table 3. As a whole, in the Calabrian sediments of Leffe, 21 taxa were recognized, 18 of which could be identified to a modern genus (Table 4).

Table 3. Taxonomic list illustrating the content of the sediment bulk sample LF11 C7M from Leffe Via Europa, also including species with fruits and seeds smaller than 5 mm

Taxon	Abundance	Part
Carex sp. (biconvex, smaller than *C. elata*)	1	fruit, apex missing
Carex (trigonous)	1	fruit
Carex (trigonous, different from the one above)	1	fruit
Carpinus betulus subsp. 1	8	fruit
Carya (cf.)	1	immature fruit with husk
Carpolithus minimus	1	fruit
Corylus avellana	9	fragmetary and partly gnawed nuts
Magnolia cor	4	seed
Phellodendron elegans	1	seed fragment
Potentilla pliocenica	11	fruit
Ranunculus reidii	5	fruit
Tilia tuberculata	14	fruit
Viola sp. 1	1	seed fragment
Viola sp. 2	1	seed fragment
Vitis vinifera	1	seed

In the following paragraphs, we provide a summary for each of the species represented in the collections of the Caffi Museum, organised in alphabetical order of families for Gymnosperms and Angiosperms. We start from the material from the older Almenno site (Fig. 6) and proceed with that from the younger Leffe site (Figs 7–11). Open nomenclature is used after Sigovini et al. (2016).

Table 4. Updated list of carpological taxa (fruits and seeds larger than 5 mm) from three sites of the Leffe Basin (VE = Leffe Via Europa site; MA = Leffe Madival site; VGC = Leffe Villa Giuseppina Road Curve site; G = Generic indication "Leffe") and their occurrence in four Pleistocene fossil floras of northern Italy: LO = Lombardore, Piemonte region; CC = Castelletto Cervo II, Piemonte region; BU = Buronzo-Gifflenga, Piemonte region; ST = Steggio, Veneto region

Carpological taxa	Leffe Basin				Northern Italy			
	VE	MA	VGC	G	LO	CC	BU	ST
Carex ex sect. *Phacocystis* (biconvex achenes)	×					×	×	×
Carex spp. (trigonous achenes)	×				×	×	×	×
Carpinus betulus subsp. 1 of Martinetto 2015	×					×	×	×
Carpolithus minimus	×				×	×	×	×
Carpolithus sp. 1		×			×	×	×	
Carya strychnina sp. inc.	×		×	×	×	×	×	×
Corylus avellana	×	×				×	×	×
Juglans bergomensis	×		×	×	×	×	×	×
Larix decidua sp. inc.				×				
Magnolia cor	×	×			×	×	×	
Phellodendron elegans	×	×			×	×	×	
Picea abies sp. inc.				×			×	×
Picea omorikoides sp. inc.				×				
Picea vel *Pinus*			×			×		×
Potentilla pliocenica	×					×	×	×
Ranunculus reidii	×					×	×	×
Tilia tuberculata	×	×						×
Viola sp. 1	×				×	×	×	×
Viola sp. 2	×					×	×	×
Vitis vinifera sensu lato	×	×		×	×	×	×	×
ONLY LITERATURE								
Aesculus hippocastanum sp. inc.				×				
Trapa natans sp. inc.				×	×		×	×
Tsuga chiarugii				×				×

SYSTEMATIC PALAEOBOTANY

SITE: ALMENNO

GYMNOSPERMS

Order PINALES Gorozh.

Family CUPRESSACEAE Gray

Genus *Cupressus* L.

Cupressus rhenana
(Kilpper) Mai et Velitzelos sp. inc.

Fig. 6.4, 6.5

Material. Two female cones from Almenno, MCSNB5175, MCSNB5183. The specimen of Fig. 6.4 was interpreted as *Chamaecyparis* by Brambilla (1984), but each cone scale of this genus shows a transversal ridge that is lacking in the studied fossil.

Description. Two well-preserved complete female cones, one with closed scales, the other with scales separated by the infilling sediment and therefore of larger dimensions.

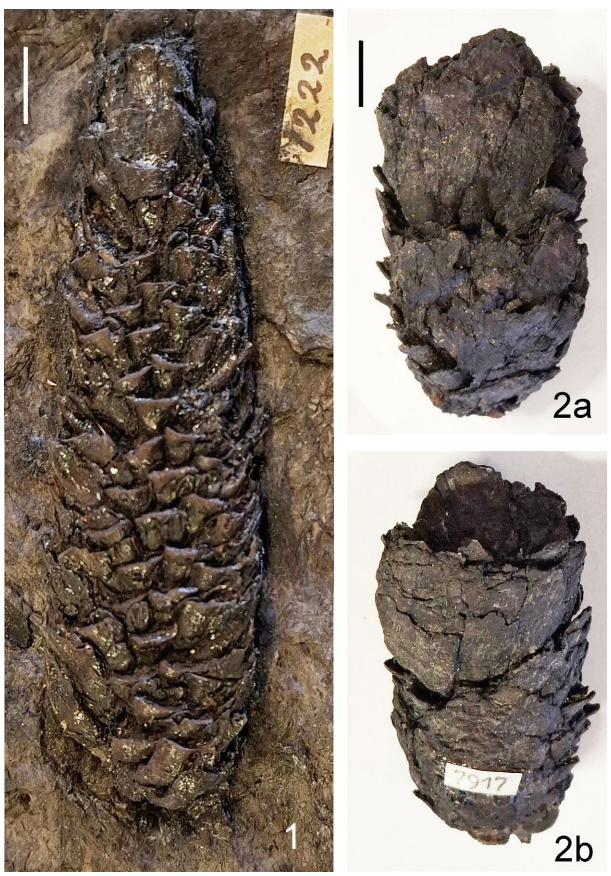

Figure 5. Pinaceae female cones from Leffe, Pleistocene. **1**. *Picea abies* sp. inc., MCSNB1222; **2**. *Picea* vel *Pinus*, seen from both sides, MCSNB7917. Scale bars = 1 cm

Comparison. The two cones show the same characters as the Greek material of this species described by Mai and Velitzelos (1997: pl. 3). These authors discuss the morphological comparison with seven living species, and indicate a stronger similarity to *C. arizonica* Greene due to the abundance of resin channels in the cone scales. However, also *C. sempervirens* L. and *C. macrocarpa* Hartw. produce similar cones of the same size. Further studies are needed to clarify whether the Neogene fossil cones from Europe really represent an extinct species or not.

Occurrence. Unpublished female cones of the same type as those from Almenno were observed by us among the material stored in MRSN-P/345-CCN from the following localities: Messinian of Scipione Ponte (MRSN-P/345-CCN1470); Zanclean of Breolungi (MRSN-P/345-CCN1465) and Sento (MRSN-P/345-CCN8678).

Family PINACEAE
Spreng. ex F.Rudolphi

Genus *Cathaya* Chun et Kuang

Cathaya bergeri
(Kirchheim.) Wilf. Schneider ex Mai,
E. Velitzelos sp. inc.

Fig. 6.3

[Referenced species: *Cathaya bergeri* (Kirchheim.) Wilf. Schneider ex Mai, E. Velitzelos, Feddes Repert. 103(1–2): 5th Feb. 1992]

Material. One female cone from Almenno, almost complete, well preserved but with abraded marginal parts, MCSNB5174. The specimen of Fig. 6.3 was interpreted as *Tsuga* by Brambilla (1984), but the cones of this genus have a more truncate or rounded base, and the middle scales (lathery and not woody) are not as large as the basal ones like in the fossil studied here.

Description. The cone is almost complete, with scales that spread laterally due to the penetration of fine grey silty sand among them, which also embeds a turriculate gastropod shell. Length 2.6 cm, width 1.4 cm. The apex is narrowly conical and the base attenuated with many small scales and no peduncle, but

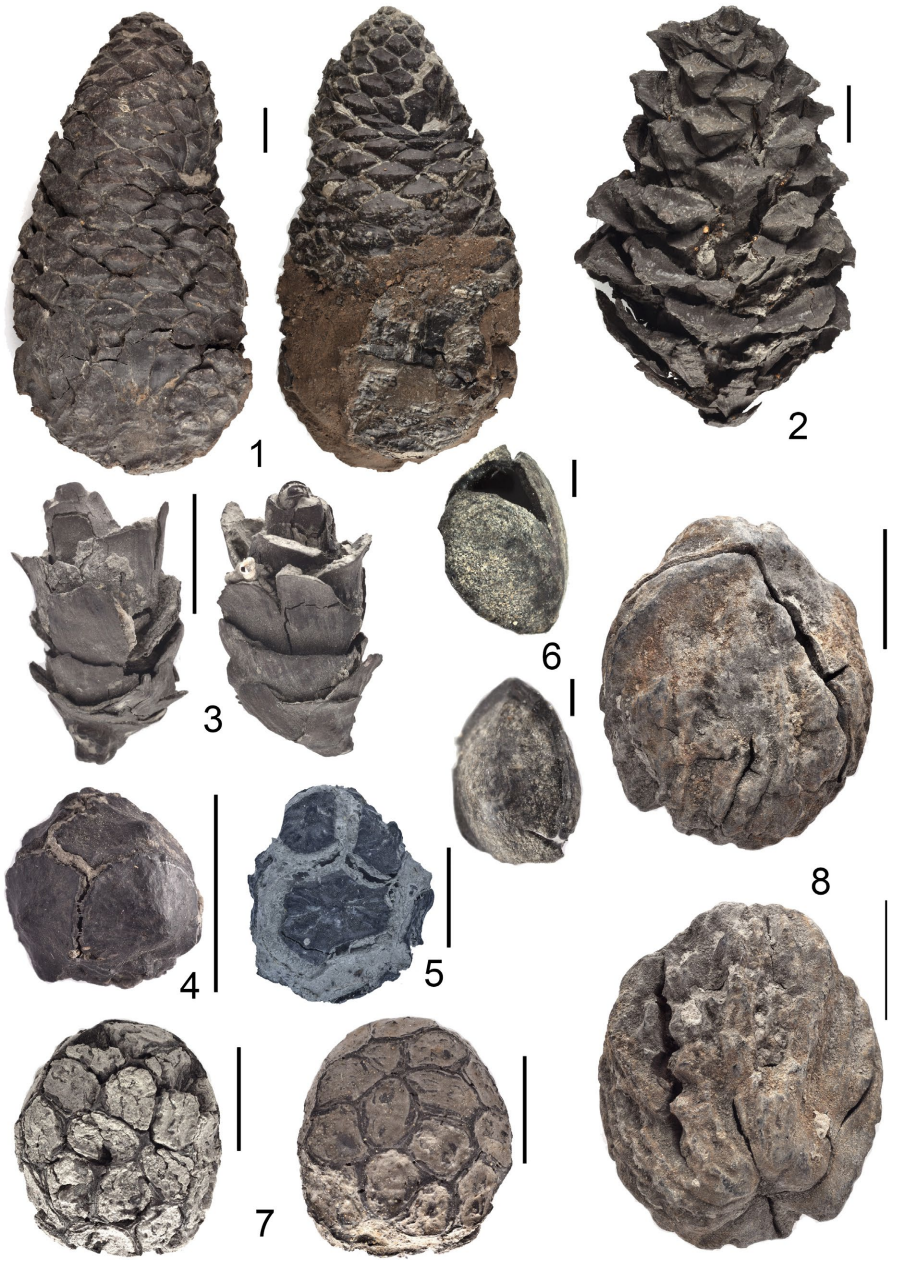

Figure 6. Plant fossils from Almenno, Pliocene; **1**. *Pinus cortesii*, MCSNB5173; **2**. *Pinus spinosa*, MCSNB5181; **3**. *Cathaya bergeri* sp. inc., MCSNB5174; **4**, **5**. *Cupressus rhenana* sp. inc., female cones, MCSNB5175 (**4**), MCSNB5183 (**5**); **6**. *Litsea sonntagii*, endocarp, MCSNB5720a; **7**. *Liquidambar europaea*, fruiting head seen from two opposite sides, MCSNB5182; **8**. *Carya nux-taurinensis*, nut from two opposite sides, MCSNB5180. Scale bars = 1 cm in 1–5, 7, 8; 1 mm in 6

we cannot rule out that this was originally present. However, the ~2.5 mm wide basal attachment of the cone would indicate that either the cone was sessile or the peduncle was around 2.5 mm thick.

The texture of the scales is woody ("*Cathaya*-like": Kunzmann, 2014), they are finely striated longitudinally, and the larger ones are at least 1.5 mm thick at the base. All of the ~20–25 scales have a broken tip that does not allow us to infer whether they were acute or obtuse. However, they do not show any tendency to be curved towards the cone axis at the apical margin.

In the middle part of the cone, the scales are much larger than in the basal and apical parts, and each large scale scarcely covers the ones above. The exposed part of each median scale has the shape of an irregular asymmetric fan. Only one very fragmentary bract is visible externally, at the base, where a large part of the covering scale is broken, but it is not useful to collect any information on its shape.

Comparison. The cone is fairly well preserved but does not permit seeing such relevant characters as bract shape (probably preserved but hidden) and cone scale termination

(broken). Among visible characters, the fact that the central woody scales scarcely cover the above ones, the narrowly conical apex of the cone and the attenuated base with many small scales and no peduncle, mark a correspondence with a precise type of fossil female cones occurring at several sites of the Piemonte region, that were assigned to "*Cathaya van-der-burghi*" by Bertoldi and Martinetto (1995), Martinetto (1995), Basilici et al. (1997), Martinetto and Ravazzi (1997) and many successive papers. The name *Cathaya vanderburghi* Gossmann ex Winterscheid and Gossmann was only recently validated (Winterscheid and Gossmann, 2017), but the holotype selected does not agree in morphology with the Italian cones due to the ~1–1.5 mm thick peduncle, scarce and larger basal scales and more lathery central scales, which cover more extensively the above ones and tend to be curved towards the cone axis at the apical margin. Xu et al. (2022) proposed the new combination *Nothotsuga vanderburghi* (Gossmann ex Winterscheid and Gossmann) Xiaohui Xu, and we agree with their opinion. The holotype of this species corresponds in all the relevant characters (leathery auriculate scales, ligulate-spathulate, terminally triangular and dentate bracts: Appendix 1) with another type of cones of the Pliocene of Italy, recovered in a few dozen specimens. This so-far unpublished material, only occurring at the Boca site (Martinetto, 2015), represents the first recognized Italian record of *Nothotsuga vanderburghi*.

However, a new examination of three cones from the Italian Ca' Viettone site, where a few dozen cones formerly assigned to "*Cathaya van-der-burghii*" have been recovered (Bertoldi and Martinetto, 1995; Martinetto et al., 2018), allowed us to assess that the scale and bract features are typical for *Cathaya*, and not *Nothotsuga*. These Italian specimens cannot be regarded as conspecific with *Nothotsuga vanderburghii*. Instead, the larger specimens of this set (~3.5 cm long) do not seem to differ from small specimens of *Cathaya bergeri* (2.9–5.0 cm long, but only 3 specimens shorter than 3.6 cm and over 50 specimens in the range 3.6–5.0 cm: Kunzmann and Mai, 2005) from the German Miocene site of Wiesa. In the Pliocene of the Piemonte region a broad range of dimensions has been detected in cones with morphology comparable to *Cathaya bergeri*, with a length in the range 2.0 to 3.0 cm in 29 out of the 32 measurable specimens, which are consequently shorter in the mean than the cones of *Cathaya bergeri*. For this reason, following the suggestion of the late D.H. Mai, the Italian cones were not assigned to *C. bergeri* in the past, but to a new species that was openly illustrated by the late Rolf Gossman at the Wien PEPC conference in 1991 and invalidly named "*Cathaya van-der-burghi*" (Mai, 1994). Probably, it was a mistake to put together (Mai, 1994; Martinetto, 1998) the more frequent Italian remains (*Cathaya*!) with Gossman's material. However, we do not feel there is, presently, enough evidence to describe a new species based on them, and we prefer to leave an open possibility that they could represent a smaller variety of *Cathaya bergeri.*

By comparing the fossil European female cones assigned to *Nothotsuga* (Xu et al., 2022) with those reliably assignable to *Cathaya* (Kunzmann and Mai, 2005), *Paranothostuga* (Kowalski, 2024) and *Pseudotsuga* (Kunzmann, 2014), both fossil and extant, we noticed differences in the morphology of the closed cones, summarized in Appendix 1, that could permit assignment to either *Cathaya*, *Nothotsuga*, *Paranothostuga* or *Pseudotsuga*.

In conclusion, the Almenno cone cannot belong to *Nothotsuga*, because of the large basal attachment of the cone, the numerous small basal scales and the thick woody median scales that scarcely cover the above ones, and are definitely larger than the ones at 1/4 and 3/4 from the cone base. Similarly, it cannot belong to *Paranothostuga* or *Pseudotsuga* because of the above-cited scale pattern in combination with an attenuate base (not rounded or truncate) and narrowly conical apex (not rounded: Appendix 1). Therefore, we assign the cone MCSNB5174 from Almenno to *Cathaya bergeri* sp. inc.

Occurrence. Several former reports of "*Cathaya van-der-burghii*" should be revised, and, preliminarily, we indicate as corresponding to *Cathaya bergeri* sp. inc. only the cones from the following sites, which we revised for this work (MRSN-P/345-CCN): Candelo, Ca' Viettone (Bertoldi and Martinetto, 1995), La Cassa, Poggio Rosso near Matassino, Rolino, Sento II (Basilici et al., 1997) and Valle della Fornace (Martinetto and Ravazzi, 1997).

Genus *Pinus* L.

Pinus cortesii Brongn.

Fig. 6.1

Material. One female cone from Almenno, almost complete, flattened but well preserved, ~10 cm long and 5 cm wide, MCSNB5173. The specimen of Fig. 6.1 was interpreted as *P. vexatoria* Gaudin by Brambilla (1984), but this name was considered a synonym of *P. strozzii* Gaudin by Kvaček et al. (2014), a species with larger cones and rounded, more prominent apophyses, which has no similarity with the fossil studied here.

Description. The description of this species is based on a cone from Castell'Arquato figured by Brongniart (1822). The original specimen is not present in the collections of the MNHN of Paris (D. De Franceschi, pers. comm. 2014), but, according to the ICN (Turland et al., 2018), the drawing of Brongniart (1822) can be considered the holotype.

Comparison. According to Mai (1986), the cone scale morphology places this species into sect. *Halepenses* Loud., and it is not related to *P. taeda* (Brambilla, 1984). The cone from Almenno shows very well the diagnostic characters for sect. *Halepenses*: Perexcentromucronate, rudimental and flat umbo surrounded by the prolongation of the transverse carina. Many fossil-species considered by Mai (1986) possibly belonging to sect. *Halepenses* have been described, but the Almenno specimen agrees (although smaller and more compressed) in number of scales and shape with Brongniart's holotype from the Pliocene of Castell'Arquato (15 cm long and 4–5 cm wide). Additionally, it corresponds even better to a specimen from the Piacenzian of Santa Barbara (Valdarno) assigned by Mai to *P. cortesii* (1994: pl. 3, fig. 4: 8 cm long and 4 cm wide).

Occurrence. In addition to the above-cited Pliocene occurrences, fossil female cones of *P. cortesii* were found, according to Meschinelli and Squinabol (1892), in the Tortonian (Stazzano) and Piacenzian (Borzoli) of NW Italy. In MRSN-P/345-CCN, a cone from the Zanclean locality Breolungi (NW Italy) definitely belongs to this species.

Pinus spinosa Herbst

Fig. 6.2

Material. Only the apical half of one female cone from Almenno, well preserved, MCSNB5181.

Description. The portion of an apical part of a long cone (as typical for *P. spinosa*: Mai and Walther, 1988: pl. 3, fig. 5) shows massive, elongated and much prominent umbos, which are retroverted in the lower scales.

Comparison. The mucro, only preserved in a few scales, is typically spiny and is fundamental for a sound assignment to *P. spinosa* and to exclude *P. urani* (Unger) Schimp., which also has a less elongated umbo and more ovoid cone shape (Mai, 1994).

Occurrence. To our knowledge, this is the first report of *P. spinosa* in Italy: Mai (1986) listed several occurrences in Germany from the Middle Miocene to the Upper Pliocene, and only one occurrence outside Germany, in the Upper Miocene of Poland.

Pinus peuce
Griesebach sp. inc.

Material. One female cone from Almenno, MCSNB5176, badly preserved, figured by Brambilla (1984: pl. 1, fig. 3) and considered by us not worthy to be re-figured here. The specimen was interpreted as *Abies* by Brambilla (1984), but the cones of this genus break up at maturity and could never survive intact when affected by such heavy damage as the fossil studied here.

Description. The cone is long and slender with a slightly curved long axis and numerous rather thick scales, which are destroyed in the apical parts, apart from an apical scale that shows a small relief that could indicate the original presence of an umbo. The cone has a narrow-rounded base and a missing apex (but we can infer it was acute originally).

Comparison. The cone scales of this cone are too thick and do not admit an eventual assignment to *Picea*; they correspond to those of several fossil specimens from Northern Italy that have been assigned to *Pinus peuce* (Martinetto, 2009).

Occurrence. Several female cones from Zanclean sites of the Piemonte region were assigned to this species, and scattered occurrences are known from Piacenzian to Chibanian

in northern and central Italy (Mai, 1994; Bertoldi and Martinetto, 1995; Martinetto, 2009; Denk et al., 2022).

ANGIOSPERMS

Family ALTINGIACEAE

Genus *Liquidambar* L.

Liquidambar europaea Al. Braun

Fig. 6.7

Material. Three fruiting heads from Almenno, MCSNB5182, MCSNB5184, MCSNB5193 (lg. Gervasutti). The specimen of Fig. 6.7 had been interpreted as *Sequoia* by Brambilla (1984), but it strongly differs from any conifer cone.

Description. Three fruiting heads (infructescences) are well-preserved, although abraded, and show fruit cavities filled and consolidated by sediment, the fourth one is falling apart. The organization of *Liquidambar* infructescences has been described in detail by Ickert-Bond et al. (2005) and Zidianakis et al. (2020).

Comparison. Pigg et al. (2004) remarked that the relationships of the fossil Altingiaceous fruiting heads from the Neogene of Europe with extant species remained unclear, but Zidianakis et al. (2020) accurately showed the characters enabling their assignment to *Liquidambar*, in particular to a single, widespread fossil-species: *Liquidambar europaea* Al. Braun. There is only one other accepted fossil-species from the Neogene of Europe, *L. wutzleri* Gregor, known from a single locality (Gregor, 1993). The fruiting heads from Almenno match the sort of Altingiaceous infructescences that Ferguson (1989) indicated as badly preserved remains, lacking diagnostic features. However, in the Neogene of NW Italy, a single type of such infructescences was observed so far, and in two localities (Breolungi and Ca' Viettone: MRSN-P/345-CCN) the more abundant abraded fruiting heads were in association with a few well-preserved ones, showing capsules with two carpels and persistent styles, which characters are diagnostic for *Liquidambar*.

In previous papers on the Italian Neogene flora, the leaves and infructescences were associated with two different fossil-species names, as admitted by the ICN (Turland et al., 2018). The leaves were named *L. europaea* (Martinetto, 2003) and the infructescences *L. magniloculata* Czeczott et Skirgiello (Bertoldi and Martinetto, 1995; Fischer and Butzmann, 2000; Martinetto, 2001b). However, Mai (1997, 1999) and Zidianakis et al. (2020) suggested using a single name for leaves and infructescences, and we accept that suggestion in this paper. The only Italian Neogene sites in which infructescences and leaves of *L. europaea* are associated in the same sedimentary layer (but never in connection) are Govone (Messinian: Martinetto et al., 2022) and Crabbia (Pliocene: Martinetto and Caleca, 2024). However, we must remark that, in those localities where infructescences are more abundant, fossil leaves were not observed (Breolungi: Martinetto et al., 2015a; Candelo: MRSN-P/345-CCN, unpublished) or poorly sampled (Ca' Viettone: Martinetto et al., 2018). Since both the infructescences and leaves are exclusively preserved in transported plant assemblages, it is not surprising that the large, globose and rather heavy infructescences were separated from the light and flat leaves by hydrodynamic processes.

Occurrence. Fruiting heads of the type described, which can be assigned to *L. europaea*, occur at several Neogene sites of NW Italy. They are rare in the Messinian succession, but common at several Zanclean sites (Bertoldi and Martinetto, 1995; Basilici et al., 1997 and MRSN-P/345-CCN, unpublished), such as Breolungi, Candelo, Ca' Viettone and Crabbia (Martinetto and Caleca, 2024). In the Piacenzian only the Santa Barbara-Gregor outcrop provided abundant specimens (Martinetto, 2001a).

Family JUGLANDACEAE DC. ex Perleb

Genus *Carya* Nutt.

Carya nux-taurinensis (Brongn.) Martinetto, De Franceschi, C.Del Rio et Manchester

Fig. 6.8

Material. One endocarp from Almenno, well preserved, MCSNB5180, recovered in the 1970s. The specimen of Fig. 6.8 was interpreted as *Juglans* cf. *cinerea* by Brambilla (1984), but the nut does not show the very sharp ridges of *J. cinerea*, it is smaller and has a rounded rather than pointed apex. Furthermore, it shows longitudinal ornamentation that is typical of *Carya*, better described below.

Description. Three of the typical 4 ridges converging to the apex are visible through careful observation, and, together with the dehiscence into two valves, permit reliable identification to the genus *Carya*. The coarsely channeled and grooved external ornamentation characterizes the European fossil-species *Carya nux-taurinensis* (= *Carya globosa* (R.Ludw.) Mädler, see Martinetto et al., 2025). Internal structure not visible. The specimen appears well-suited for micro-CT scanning (Deng et al., 2024).

Comparison. A specimen showing very similar shape and ornamentation was recovered from the site Sento I of Zanclean age (Piemonte Region), other unpublished specimens from the Pliocene of Piemonte (MRSN-P/345-CCN) are similar, but even more coarsely rugose.

Occurrence. In the course of revision, surely present in the Late Miocene of NW Italy (Martinetto et al., 2025) and in the Pliocene site of Castelletto Cervo I (Cavallo and Martinetto, 2001), whereas the Pleistocene records (Gregor, 1990; Ghiotto, 2010) are doubtful.

Family LAURACEAE Juss.

Genus *Litsea* Lam.

Litsea sonntagii Gregor

Fig. 6.6

Material. An endocarp from Almenno, MCSNB5720a. The specimen of Fig. 6.6 was interpreted as *Juniperus* by Brambilla (1984: pl. 1, fig. 10), but the seeds of this genus are not so smooth outside and do not show the characteristic palisade of Lauraceae seeds in cross-section, which is evident in the fossil studied here. The other fossil interpreted as a *Juniperus* seed by Brambilla (1984: pl. 1, fig. 9) is a rounded blackish object without any characteristic morphology.

Description. This endocarp is poor in characters, but can be interpreted as determinable at species level depending on the context of the north Italian Pliocene. It is the only fossil-species with somehow laterally flattened and smooth endocarps, contrasting with the globose or ribbed endocarps of the other fossil-taxa detected in Northern Italy.

Comparison. The endocarp was compared to abundant material from the Piemonte region (MRSN-P/345-CCN2372). In the Lombardy region, better preserved endocarps of the same type were recovered from the Pliocene deposit of Ranica Borgo Sale (MRSN-P/345-CCN8680, unpublished material).

Occurrence. It is a common species in several Zanclean sites of the Piemonte region, in particular at Fossano (Macaluso et al., 2018).

SITE: LEFFE

GYMNOSPERMS

Order PINALES Gorozh.

Family PINACEAE Spreng. ex F.Rudolphi

Genus *Larix* Mill.

Larix decidua Mill. sp. inc.

Fig. 4.9–4.13

Material. Impression of a female cone from Leffe, MCSNB1223.

Description. An impression of a cone in the sediment with a few residual organic remains (scales), from the 19th-century collection of Caffi, originally labeled "*Abies larix*". The specimen was reconstructed in the year 2024 by one of us (F.C.) from five pieces of sediment, which could explain why it was overlooked by previous analyses (Gregor, 1990). The cone outline is clearly marked only in the basal part, it is missing on the left side (yellow line in Fig. 4.12), and it can be only roughly reconstructed in the central and apical parts (red line in Fig. 4.12) on the basis of remaining parts of the numerous thin scales or their impressions (dotted line in Fig. 4.12). A rounded apex is tentatively reconstructed, even if it could have been acute as well. The base is definitely asymmetric and truncated with numerous patent basal scales, and a massive peduncle left its impression in the sediment.

Comparison. Despite the fragmentary state and the loss of most of the scales, the shortly ovate outline, the relatively dense scales and the length of 2.4 cm suggest that this incomplete cone could show affinities with a limited set of pinaceous female cone types. In particular, some diagnostic characters indicate its affinity to *Larix*: numerous thin scales,

a truncated asymmetric base with patent basal scales a and massive peduncle. We also evaluated whether the fossil cone could belong to *Tsuga chiarugii*, female cones of which are known to occur in abundance at a site close to Villa Giuseppina's Road Curve of Leffe (Ravazzi, 1995; Ravazzi et al., 2009b). However, a detailed comparison with abundant cones of *T. chiarugii* from the Steggio site (Ghiotto, 2010) showed us that they differ in the smaller number of scales (Fig. 4.1), more broadly rounded base (Fig. 4.2) and unapparent peduncle (Fig. 4.3). In addition, *Tsuga* cones from Steggio are more frequently less than 2 cm long, so that our cone from Leffe cannot belong to such a taxon. Female cones of other genera differ from MCSNB1223 for the thicker scales (*Cathaya*, *Pseudotsuga*) or slenderer outline (*Nothotsuga*).

Some female cones of the fossil-species *Picea omorikoides* Weber (1898) can be partly similar, but are larger in the mean, never show such a robust peduncle as our fossil and tend to have a small number of scales at the base (Fig. 4.8). Cone MCSNB1223 from Leffe (Fig. 4.9–4.13) is indeed very similar to a fossil that was assigned by Sordelli (1896: pl. 35, fig. 9) to his new species *Picea seriana* (see below), even if we cannot detect any character that could rule out its assignment to *Larix*. However, Sordelli (1896: pl. 35, fig. 8) also published the drawing of another cone, which could be considered better corresponding to the description of *P. seriana*. This cone consistently differs from our cone MCSNB1223 for the rounded base and more symmetrical shape, so we strongly suggest that the single similar fossil specimen available from Leffe (MCSNB1223: Fig. 4.9–4.13) represents another species, likely of the genus *Larix* (as suggested by the old collection label).

Due to the agreement of all the characters still shown by the fossil MCSNB1223 with the ones detectable on cones of the single locally existing species of *Larix* (Fig. 4.4), we assign the fossil to *L. decidua* sp. inc. A Calabrian occurrence of this species was already suggested (Ravazzi et al., 2005) in the neighbouring Ranica Basin, the sediments of which are not much younger than the upper ones of the Leffe Basin (Ravazzi, 2003). One of the two cones drawn by Sordelli (1896: pl. 35, fig. 9) shows the same cone shape and number of scales as extant cones of *L. decidua*. The drawing of Sordelli shows smaller scales at the base, thus suggesting that the cone was not longer than the part preserved, therefore it could also belong to *Larix decidua* sp. inc. Conversely, nothing can be said about the other three lost cones assigned to *P. seriana*, not drawn by Sordelli (1896).

Genus *Picea* Link

Picea abies (L.) H.Karst sp. inc.

Fig. 5.1

Material. One female cone from Leffe in the 19th-century collection of Sordelli, MCSNB1222. This sample is of uncertain stratigraphic provenance, and the cone is surrounded by well-preserved needles of *Picea* cf. *abies*, a kind of assemblage and preservation type that are unknown in the 20th-century stratigraphic excavations. This sample should be considered with caution and not treated together with the others, because there are several layers rich in pollen of *Picea* in the "first lignite bank" and "second lignite bank" (Ravazzi, 1995, 2003; Muttoni et al., 2007) and this fossil could have a different age from the others described from the Leffe basin.

Description. The cone is still partly included in the sedimentary matrix, it has a straight, long axis, a rounded base, an acute apex and numerous thin scales, which are destroyed in those parts emerging from the sediment.

Comparison. The cone is identical to badly preserved fossil cones from Chibanian or Late Pleistocene, which are associated in the same locality (Re in Val Vigezzo, Masserano-Casapinta, Botro Maspino) to excellently preserved ones (MRSN-P/345-CCN). These can be assigned with certainty to *P. abies*. Another partial fossil cone from Leffe, similar to the basal part of the one described above, was drawn and described by Massalongo (1852a: pl. 3, fig. 1). Even if Sordelli (1874) suggested to erect a new species (*Abies balsamoi* Sordelli) for this specimen, later Sordelli (1896) used the name "*Picea balsami* Sdll." for the same drawing of Massalongo, without seeing the original fossil, but he considered another specimen from Leffe, stored at the Natural History Museum of Milan (Stoppani collection), belonging to the same species. We suggest that the drawing in the publication of Massalongo (1852a) does not show any strong character justifying a separation from *P. abies*, and Sordelli (1896: p. 215) admits that female cones not distinguishable from *P. abies* occur in the Leffe lignite-bearing sediments.

The apical termination of the scales is not visible, but there is no sign of a possible apical umbo, like in *Pinus* subgen. *Strobus*, which could probably be verified in the sediment-embedded part of this fossil cone by means of a CT-scan. The straight long axis and the lack of an apical umbo suggest that MCSNB1222 cannot represent *Pinus* subgen. *Strobus* and matches the genus *Picea*. Two species of such a genus that could possibly occur in the Pleistocene of Italy can be excluded from comparison: *P. florschuetzii* Hammen for the larger cones (Mai, 1994; Cavallo and Martinetto, 2001) and *P. omorikoides* C.A. Weber for the smaller ovoid cones (Ravazzi, 2003, see above).

Ravazzi (2003: p. 101) suggested that the Early Pleistocene *P. abies* occurring at Leffe could belong to the subspecies *ovata* (Ledeb.) Domin, but we cannot provide any clue in that direction because the cone of Fig. 5.1 is compatible with those of the Alpine populations of the typical subspecies of *P. abies*.

Occurrence. Definitely characterized female cones of *P. abies* occur in the late Calabrian site of Ranica (possibly the oldest record: Ravazzi et al., 2005), and further occurrences were reported from early Chibanian onwards (Sordelli, 1896; Martinetto, 2009).

Picea vel *Pinus* indet.

Fig. 5.2

Material. An incomplete female cone from Leffe, Villa Giuseppina Road Curve site, MCSNB7917. This material is unsuitable for reliable identification due to total abrasion of the scale margins.

Comparison. Similarly, preserved cones have been noticed among fossil assemblages of both *Pinus* subgen. *Strobus* and *Picea* spp. stored in MRSN-P/345-CCN (Re in Val Vigezzo, Masserano-Casapinta, Botro Maspino). Cone scales are usually a little bit thicker in fossils of *Pinus* subgen. *Strobus*, but in case of bad preservation, also the cones of *Picea* seem to undergo a sort of shrinking, causing the scales to look thicker at the base, i.e. in the portion that is preserved in the Leffe fossil. In addition, considering that the apex of all the cone scales is missing, it is not possible to check the presence of an umbo and, therefore, we cannot list any character that may consent to go beyond the determination as *Picea* vel *Pinus* indet. At least, we suggest that in the Pleistocene of Italy, the possible occurrence of other genera (e.g. *Keteleeria*), characterized by long and slender cones with many scales is improbable. It is possible that also specimen MCSNB7917, in addition to MCSNB1222, represents *Picea* cf. *abies* and it does not prove that a distinct taxon occurs in the Leffe Formation.

It should be noticed that another specimen of the MCSNB collection, MCSNB1870, was labeled as *Picea* or *Pinus*, implying that it represented a conifer cone. However, we believe that the whitish luster of its long, spirally arranged elements suggests they represent remains of petioles attached to a fern stem or rhizome (Sordelli, 1896: p. 215), and therefore this specimen has not been considered in the present work, dealing with carpological remains.

ANGIOSPERMS

Family BETULACEAE Gray

Genus *Carpinus* L.

Carpinus betulus L. subsp. 1 of Martinetto 2015

Fig. 8.3–8.5

Material. Seven fruits from Leffe Via Europa's sample LF11 C7M (MCSNB 14899a–g).

Description. Isolated flat nuts with an ovate outline, 3 to 5 vascular bundles, and mean dimensions (4.7 × 3.0 mm) characteristically smaller in comparison to the extant nuts of *C. betulus*.

Comparison. In the case of this species, we suggest the use of the name of the extant taxon because there is a record of fruits with the same morphology from the Holocene backwards to the Pliocene and even Messinian (Cavallo et al., 1986; see also Martinetto, 2015). However, the fossil fruit assemblages older than the Eemian interglacial show a definitely smaller mean size, and, according to Martinetto (2015), the pre-Eemian populations of *C. betulus* can be assigned to a definite subspecies. In the Calabrian (Denk et al., 2022), Piacenzian (Pavia, 1970; Martinetto, 2003) and Messinian (Cavallo et al., 1986) floras, the fruits and typical fruit-bracts are associated with a few leaves corresponding in morphology to those of the extant plants of *C. betulus*.

Occurrence. Fossil nuts that can be assigned to *C. betulus* subsp. 1 of Martinetto (2015) occurred at a few Messinian and Zanclean sites of NW Italy (Cavallo et al., 1986; Basilici et al., 1997), then became more common in the Piacenzian (Martinetto et al., 2015a and references therein) and extremely abundant at a few Early Pleistocene sites: Buronzo-Gifflenga (Martinetto and Festa, 2013), Casnigo (MRSN-P/345-CCN, unpublished) and Steggio (Ghiotto, 2010). The fruits from Leffe show the same morphology and dimensions as some specimens from the early Chibanian site of Pianico (Martinetto, 2009).

Genus *Corylus* L.

Corylus avellana L.

Fig. 8.1, 8.2

Material. About fifty six fruits from Leffe Via Europa (5 incomplete or much deformed ones from sample LF11 C7M: MCSNB14898a/c), 9 fruits from Leffe Madival.

Description. Ovate nuts with several vascular bundles. Length 16–8 mm, width 10–7 mm, comparable to those of the extant nuts of wild Italian populations of *Corylus avellana* by considering an 80% contraction due to decay and desiccation.

Comparison. Again, in the case of this species, we suggest the use of the name of the extant taxon because there is a record of fruits with the same morphology from the Holocene backwards to the Pliocene and even Messinian (Cavallo et al., 1986; Cavallo and Martinetto, 2001; Martinetto, 2015). In the Messinian, they are associated with a few leaves corresponding to those of the extant plants of *C. avellana*. Similar leaves were observed among the material of the Pliocene flora of Arboschio stored at the Museum of Geology and Palaeontology of the Turin University (Pavia, 1970; Martinetto, 2003), in which a few fruits also occur. Two fossil fruits from Leffe assigned to *C. avellana* were already reported by Sordelli (1896: pl. 37, figs 1, 2).

Occurrence. A few nuts already occur in the Messinian of NW Italy (Cavallo et al., 1986). In MRSN-P/345-CCN fossil nuts with the same characters as those of the extant *C. avellana* are well represented and originate from a broad array of Pliocene and Pleistocene sites.

Family CYPERACEAE Juss.

Genus *Carex* L.

Carex spp.

Figs 7.3, 11.1, 11.2

Material. Three trigonous achenes, incomplete and deformed, from Leffe Via Europa (one in the Museum's specimen MCSNB7911b and two from sample LF11 C7M: MCSNB14901a, b).

Description. The fruit MCSNB7911b is still enclosed in the lignite-bearing sediment, only one face is visible, but the curvature of the margins suggests a 3-sided pattern. The two fruits from sample LF11 C7M are clearly trigonous, but their style base suggests that they could belong to two different taxa. Comparison: The best-preserved fruit has a broken style, and it is consequently indeterminable at species level. The remaining fruit is strongly deformed but clearly shows a regularly truncated style base as it occurs in extant species with a style that is deciduous at maturity, such as *Carex* gr. *flava*, *C. sylvatica* and C. *strigosa*. The elongated shape of the achene suggests a lack of affinity with *Carex* gr. *flava*.

Occurrence. Trigonous achenes of this type occur in many sites of the late Cenozoic of Italy.

Carex ex sect. *Phacocystis* Dumort.

Fig. 11.3

Material. One biconvex achene, incomplete for the lack of the apex, from sample LF11 C7M, MCSNB14902.

Description. The fruit shows two faces with easily visible cell patterns.

Comparison. The regularly curved, broadly elliptic outline suggests affinity to sect. *Phacocystis* rather than subgen. *Vignea*. The achenes of different species of sect. *Phacocystis* are scarcely distinct, so that identification at species level can only be attempted for well-preserved and abundant material, which is not the case for the incomplete Leffe achene.

Occurrence. Better preserved and abundant specimens of the same type, still unpublished (MRSN-P/345-CCN), occur at the neighbouring Casnigo site (Ravazzi, 1995), as well as in the sites of Buronzo-Gifflenga (Piemonte region: Martinetto and Festa, 2013) and

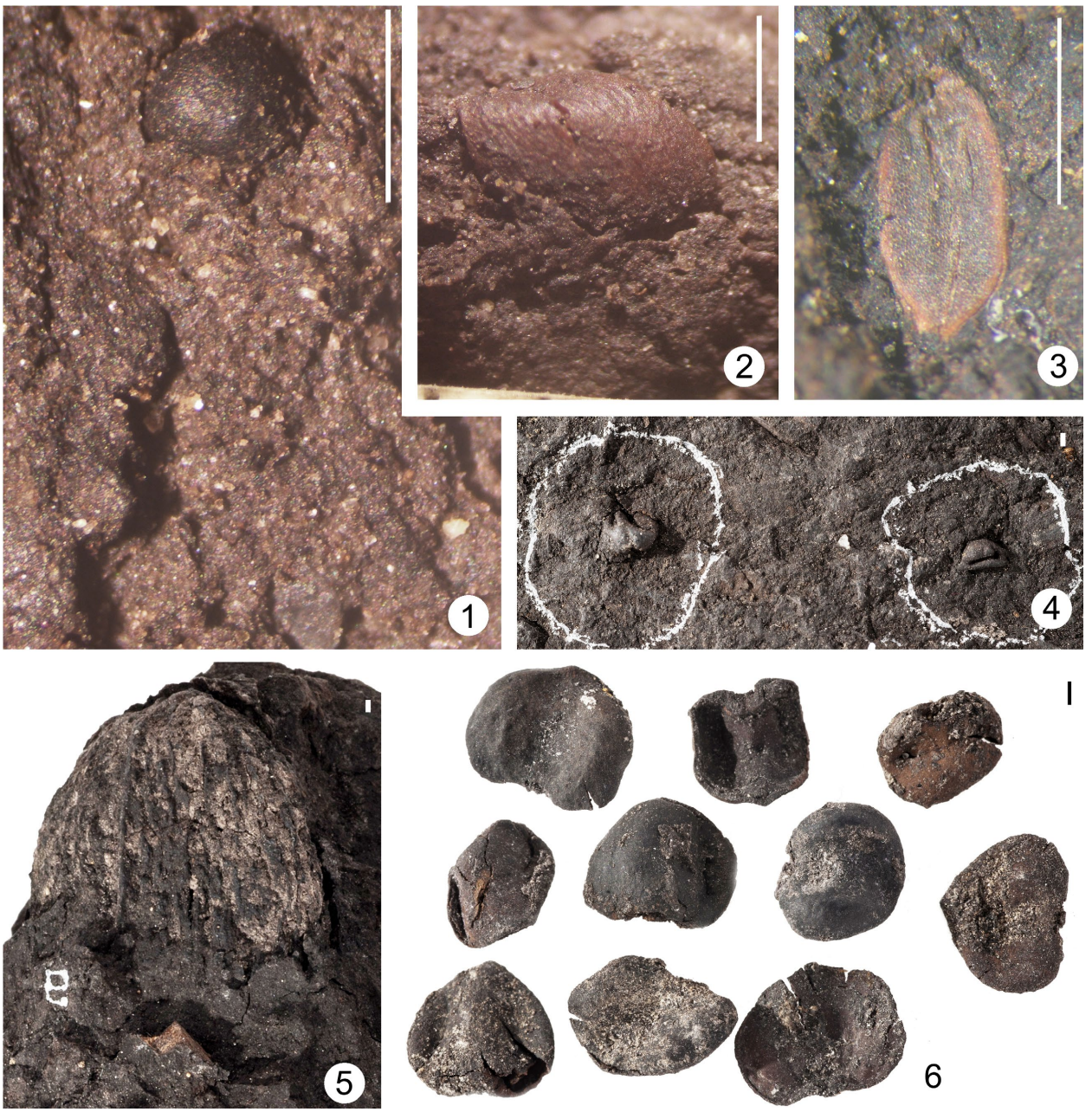

Figure 7. Sediment and plant fossils from Leffe. **1**. Sediment recovered from the Leffe Via Europa excavation; the black rounded object is most probably *Coenococcum*; **2**. *Viola* sp. 2, fragment of seed embedded in the sediment, thus showing that fragmentation occurred before the preparation of the sample, MCSNB14907; **3**. *Carex* sp., achene embedded in the sediment; MCSNB7911b; **4**. Two seeds of *Vitis vinifera* sensu lato, still embedded in the sediment; MCSNB7921b; **5**. *Carya strychnina* sp. inc., nut still embedded in sediment, MCSNB7921a; **6**. *Magnolia cor*, ten seeds recovered in the field at the Leffe Via Europa site, MCSNB8807. Scale bars = 1 mm

Steggio (Veneto region: Ghiotto, 2010), all of Pleistocene age.

Family JUGLANDACEAE DC. ex Perleb

Genus *Carya* Nutt.

Carya strychnina (Sternb.) Mai sp. inc.

Fig. 9.3–9.9

Material. A few dozen endocarps from Leffe (MCSNB7910a,b, 7913a/d, 7914a/I, 7921a, 7923a,b, 7927a/c, 7932, 7934a/c, 7938, 7942a,b, 7943a/i, 7944a/i, 7945a/c, 13051a/m), from well preserved externally (but closed and deformed) to strongly compressed, often covered by sticking sediment that hides the morphology. The few specimens showing internal structures are strongly deformed (Fig. 9.4–9.5), and one was probably cracked by animals (Fig. 9.4). Already Gregor (1986) cited the presence of two species of *Carya* at Leffe, *C. quadrangula* (Kirchheimer) Leroy and *C. globosa*, but he never published a description of the Leffe

or other Italian material. These names were referred, respectively, to specimens MCSNB 7938, 7943a/I, 7944a/I, 7945a/c and specimens MCSNB7913a/d, 7921a, 7923a/b, 13051a/m of the Caffi Museum collection. Another name was mentioned in the catalogue of MCSNB: "*Carya angulata*?", referred to specimen MCSNB7914a/I (Fig. 9.8) and MCSNB7927a/c.

Description. The best preserved globose juglandaceous nuts from Leffe show characters that permit a definite assignment to *Carya*, first of all for the 4 external ribs corresponding to the dehiscence of the husk (Fig. 9.3d, 9.7a, 9.8, 9.9). The Leffe specimens show a variable ornamentation, from nearly smooth (Fig. 9.8) to faintly (Fig. 9.7) and coarsely striate (Fig. 9.3). The internal structure is poorly visible and strongly deformed, but a primary septum is visible in 3 specimens, and a deformed secondary septum restricted to the basal 1/4 of the nut length is visible in Fig. 9.4 (MCSNB13051h). The badly preserved internal morphology does not allow for the detection of the features of the inner longitudinal ribs (Deng et al., 2024) in other Leffe specimens. However, the better-preserved nuts from the Piemonte region sites Castelletto Cervo II (Fig. 9.10) and Lombardore (Fig. 9.1, 9.2), that are extremely similar to the Leffe ones, do not show any internal rib.

Even if different species of *Carya* from Leffe were reported in previous works, we did not find solid evidence for such diversity. Only the specimen of Fig. 9.8 deviates more strongly from the morphology of the others because of the smooth sculpture and asymmetric base. However, an intraspecific variation of the nuts from smooth to rugose has been described for *C. strychnina* (Mai, 1981), and the asymmetric base could be due to diagenetic deformation.

Comparison. We compared the specimens of *Carya* from Leffe to several specimens available in a few Italian collections, comprising well-preserved specimens from the localities Arda (MRSN-P/345-CCN), Buronzo-Gifflenga (MRSN-P/345-CCN), Castelletto Cervo I and II (MRSN-P/345-CCN), Enza-Traversetolo (MRSN-P/345-CCN), Lombardore (MRSN-P/345-CCN), Fighille (Baldanza and Spirito, 2010), Poggio Rosso (photographed material of the Otello collection of Montevarchi, no more available), Steggio (Ghiotto, 2010), Stirone-Laurano (collection of the Museum of Salsomaggiore) and Stura di Lanzo (MRSN-P/345-CCN: Martinetto, 1994a, 2015; Martinetto et al., 2015a). The internal anatomy is well preserved and visible in 1 halved specimen from Arda and Castelletto Cervo II (Fig. 9.10), 2 from Lombardore (Fig. 9.1, 9.2), 2 from Stirone-Laurano and 2 from Steggio. The available evidence is in favour of the occurrence of a single *Carya* species in the Pleistocene of the whole of Northern Italy, because all the specimens with better preservation show the same striation and septa organization as in *C. strychnina*. Only a few are smooth, and those with visible septa always show a well-developed primary septum, a tongue-shaped secondary septum in the plane of splitting, and a nutshell only 1 to 3 mm thick. Some specimens show up as different just because of a strong deformation and/or the presence of the husk. Other specimens represent immature fruits, but there are no good examples of the morphology of the species *C. angulata* or *C. globosa* (= *C. nux-taurinensis*) in the Pleistocene of Italy. However, the smoothest specimens show the same external characters as *C. askenasii* (Kinkelin) Mai. This last fossilspecies seems to be very similar to the American *C. tennesseensis* Huang et al., which is always less striate (Huang et al., 2014).

The nuts from Leffe are not well preserved enough for a sound assignment to a species, based only on their analysis. However, we believe that an integration of the information retrieved from other Italian sites of the Calabrian could provide the characters missing in the Leffe material, as reported in Appendix 2. Especially the materials (MRSN-P/345-CCN) from Arda (Martinetto et al., 2015a), Castelletto Cervo II, Lombardore, Stirone-Laurano (Mus. Salsomaggiore), Steggio and Poggio Rosso totally agree with the Leffe nuts as for shape, dimensions, ornamentation and evidence of the 4 ribs marking the dehiscence of the husk. Conversely, *Carya globosa* is a synonym of *Carya nux-taurinensis*, discussed above for Almenno. This fossil-species is also represented in the Pliocene of the Piemonte region (Martinetto, 2015; Martinetto et al., 2025) and differs from the nuts from Leffe in the longitudinally channeled external ornamentation, with striking grooves (Deng et al., 2024), and in the presence of an apparent secondary septum (Appendix 2). The Leffe nuts, as well as the better-preserved ones from Stirone-Laurano, Steggio and Poggio Rosso, show (Appendix 2) a very broad variation of the external striation, from barely

Figure 8. Plant fossils from Leffe, Via Europa excavation. **1**, **2**. *Corylus avellana*; **1**. fruit seen from two opposite sides, **2**. fruit seen from two slightly different lateral positions, MCSNB14898a/b; **3**–**5**. *Carpinus betulus* subsp. 1 of Martinetto 2015; nuts, the first one seen from the two opposite flat sides, MCSNB14899a, b, c; **6**–**8**. *Magnolia cor*, seeds seen from two opposite flat sides (apart one), MCSNB14900a, b, c. Scale bars = 1 cm

visible to much apparent, but in any case, they are only deeply striated and not really channeled and grooved. Therefore, we do not believe that the variation in the external ornamentation displayed by the Leffe nuts can justify their assignment to more than one species.

The Castelletto Cervo II (Fig. 9.10), Lombardore (Fig. 9.1, 9.2), Stirone-Laurano and Poggio Rosso nuts show an important internal character that further marks the difference from *C. nux-taurinensis*: The secondary septum is more weakly developed at the base. In synthesis, the Italian sites of the Early Pleistocene yielded *Carya* nuts that are tentatively assigned to a single, variable fossil-species, which shares most of the characters with *C. strychnina* from Germany (Mai, 1981; Deng et al., 2024). However, this last species is only known from Oligocene and Miocene sites, and it could be argued that the German nuts are morphologically very similar, but not really assignable to the same fossil taxon as the Pleistocene ones from Italy.

The Italian Pleistocene nuts show a well-developed primary septum and a tongue-shaped secondary septum in the plane of splitting; the nutshell is only 1 to 3 mm thick, therefore definitely thinner than in *Carya strychnina* (more than 3 mm thick and up to 6 mm: Mai, 1981). In addition, the external ornamentation of some of the Italian specimens is coarser. The Italian fruits, including those from Leffe, may represent the product of a Plio-Pleistocene plant population that derived from the Miocene one (*C. strychnina*), but already experienced some changes in fruit morphology. A detailed comparison using micro-CT scanning (Deng et al., 2024) of the Miocene nuts from Germany and the Pleistocene ones from Italy has not yet been performed, but could be fundamental to assess if the Italian material must be assigned to a new species or not.

As noted by Mai (1981) and Deng et al. (2024) for *C. strychnina*, the shallow or absent inner longitudinal ribs in the Early Pleistocene *Carya* from Italy suggest a similarity to the extant *C. poilanei* (A.Chev.) Leroy, a very rare plant from Vietnam and China (Zhang et al., 2022). However, unlike those of the extant species, the fossil nuts are externally more markedly ribbed and lack a well-developed secondary septum.

Genus *Juglans* L.

Juglans bergomensis
(Balsamo Crivelli) Massalongo

Figs 4, 9.11

Material. Several dozens of endocarps from Leffe, variously preserved according to the sediment facies in which they are embedded; not compressed in massive clay-silt (1 specimen, MCSNB7916, Fig. 9.11), poorly compressed in muddy sand (several specimens from the Leffe via Europa site (MCSNB7931) and Caffi collection (Fig. 4: 39 specimens MCSNB1224, MCSNB1225) and much compressed in lignitic clay or lignite (several tens of specimens from various collections, incl. Sordelli collection at Milan Museum).

Description and comparison. See Martinetto (2015) and Van der Ham (2015). Neotype stored in Padua (Martinetto et al., 2015b).

Occurrence. See Martinetto (2015).

Family MAGNOLIACEAE Juss.

Genus *Magnolia* L.

Magnolia cor Ludwig

Figs 7.6, 8.6–8.8

Material. About twenty nine seeds from Leffe Via Europa (1 complete seed and two fragmentary ones from sample LF11 C7M: MCSNB14900a–c), 17 seeds from Leffe Madival.

Description. The diagnostic seed morphological traits of this fossil-species were synthetically described by Mai (1975) and Mai and Wähnert (2000). The number of fossil specimens presently available in Italy is probably larger than that available in the rest of Europe, and the hundreds of specimens recovered from Castelletto Cervo II (Cavallo and Martinetto, 2001) also include some very broad specimens that agree with the morphology of the fossil-species *Magnolia ultima* Kirchheimer. This fossil-species does not appear as having been reported from other sites after its description and could be considered only an extreme morphotype of *M. cor*, rather than a fossil-species on its own.

Comparison. Each of the variable Leffe seeds (Fig. 7.6) totally corresponds in morphology to at least one specimen from Castelletto Cervo II, which suggests that material from both sites belongs to the same fossil-species. Conversely, all the seeds of Piacenzian age assigned to *M. cor* have smaller dimensions (Martinetto, 1994a; Martinetto and Mai, 1996; Martinetto et al., 2015a), but the morphology is so similar that it is not necessary to consider the possibility that they could belong to a separate taxon. As for the extant species producing seeds that are most similar to *M. cor*, Mai and Wähnert (2000) indicated the extant *M. stellata* Maxim.

Occurrence. Mai and Wähnert (2000) reported that *M. cor* occurred very locally in the Upper Miocene of Europe (Rhine Embayment), otherwise it was found in Pliocene sediments of Western and Middle Europe. The only non-Italian Early Pleistocene record was at Tegelen, whereas in Italy it occurred at 7 Early Pleistocene localities (apart from Leffe): Arda-AD3 (Martinetto et al., 2015a), Castelnuovo Bormida (Irace et al., 2017), Buronzo-Gifflenga (Martinetto and Festa, 2013), Castelletto Cervo II (Cavallo and Martinetto, 2001), Lombardore (Martinetto, 2015), Ponte Naja (Martinetto, 2001a) and Torre Picchio (Girotti et al., 2003). Only a few seeds have been recovered from most of the Piacenzian localities (stored in MRSN-P/345-CCN): Boschi di Barbania, Castelletto Cervo I, Front, Santa Barbara, Stura di Lanzo Fossil Forest, and Villafranca d'Asti-RDB. The single abundant set of Piacenzian seeds (64 specimens) occurred at Terzoglio-TZ8 (Piacenzian). Remarkably, this fossil-species never occurred in the Zanclean and Messinian sediments of Italy.

Family MALVACEAE Juss.

Genus *Tilia* L.

Tilia tuberculata Szafer

Fig. 10.1–10.8

Material. Twenty two fruits from Leffe Via Europa (8 from sample LF11 C7M, MCSNB14905a/h), 2 fruits from Leffe Madival.

Description. The fruits are 5-angled, with blunt ribs, and can be considered indehiscent ellipsoid capsules, probably with hairy pericarp, since the abundant tubercles still present in the fossils are similar to those that, in extant species with mamillate fruits, subtend a dense mass of hairs (Pigott, 2012).

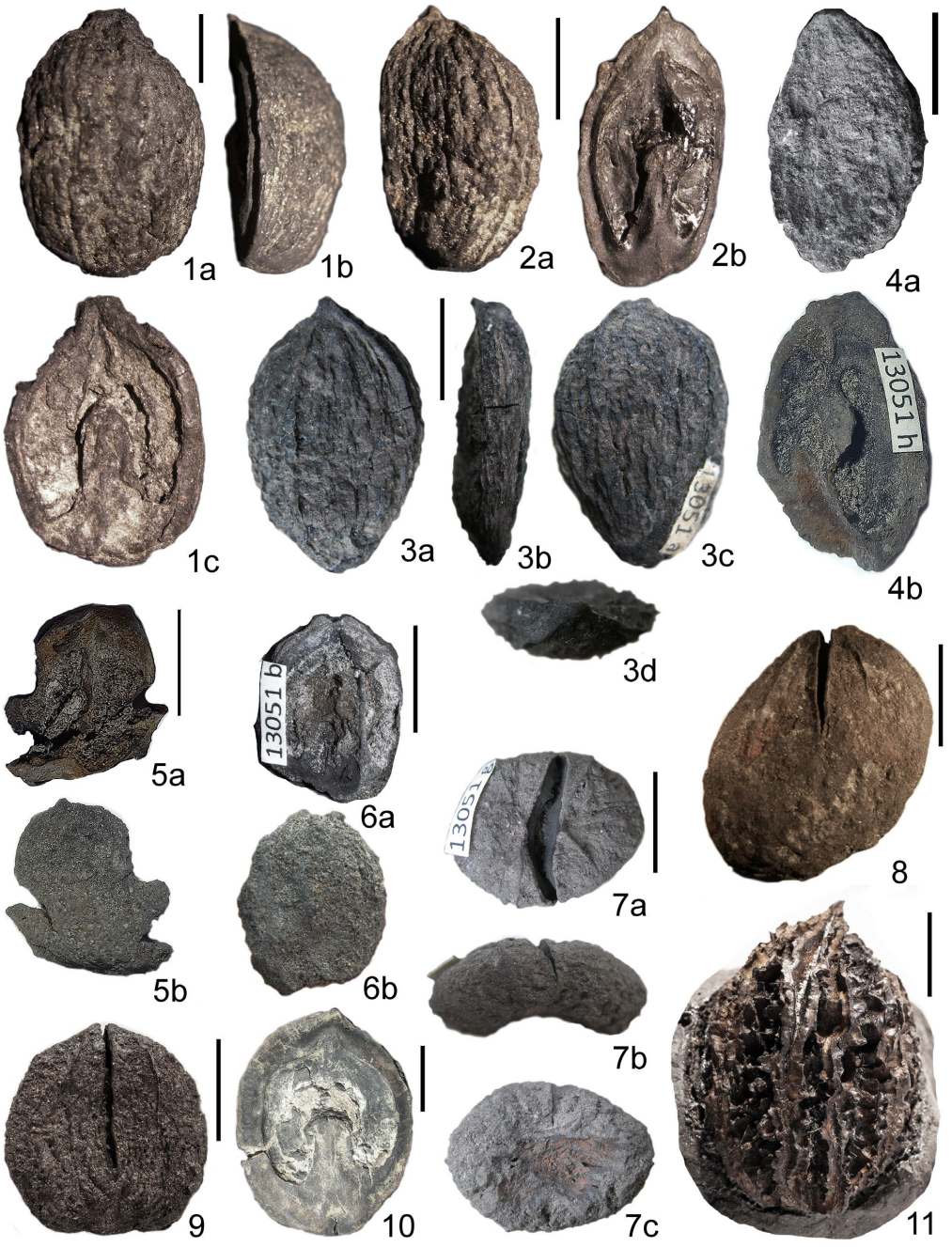

Figure 9. Fossil nuts of Juglandaceae from Leffe and two other Early Pleistocene sites, for comparison. **1–10**. *Carya strychnina* sp. inc., nuts; **1**, **2**. From Lombardore, Piemonte region (Martinetto, 2015), two half nuts (MRSN-P/345-CCN8672, MRSN-P/345-CCN8673, dehisced before burial) in different views: Lateral-external parallel to the primary septum (1a, 2a), lateral-external orthogonal to the primary septum (1b); internal parallel to the primary septum (1c, 2b); the last kind of view permits to see very clearly the tongue-shaped secondary septum; **3–9**. From Leffe Via Europa; **3**. MCSNB13051a, nut with a shape and sculpture very similar to those at Fig. 9.1, 9.2, seen from two opposite flat sides (3a, 3c); the orthogonal view (3b) shows the strong diagenetic compression; the apical view (3d) shows the four ridges diagnostic for *Carya*; **4**. Half nut, badly grown, in lateral-external view and internal view, parallel to the primary septum; the secondary septum is odd due to the asymmetrical growth, MCSNB13051h; **5**, **6**. Two half nuts (dehisced), MCSNB13051d and MCSNB13051b, in internal and lateral-external view, parallel to the visible primary septum; the nuts are strongly deformed (diagenesis and post-sampling alteration) so that the original morphology of the secondary septum is not preserved; **7**. Nut strongly compressed against the equatorial plane, seen in apical (7a), lateral (7b) and basal view (7c); the apical view shows the four ridges diagnostic for *Carya*, MCSNB13051g; **8**. Complete nut with initial dehiscence, smooth sculpture and oblique base, probably diagenetically deformed; two of the four ridges diagnostic for *Carya* are apparent in the apical part, MCSNB7914a; **9**. Complete nut, but strongly compressed (diagenesis) against the plane of the primary septum; notice the initial dehiscence and two of the four ridges diagnostic for *Carya*, MCSNB7923; **10**. Half nut from Castelletto Cervo II (Cavallo and Martinetto, 2001) in internal view, parallel to the primary septum; the external sculpture is very similar to that of the specimen of Fig. 9.9, and the pre-burial dehiscence of this nut permitted a good preservation of the internal structure with an evident secondary septum, MRSN-P/345-CCN8674; **11**. *Juglans bergomensis*, nut from Villa Giuseppina Road Curve, MCSNB7916. Scale bars = 1 cm

Figure 10. Plant fossils from Leffe, Via Europa excavation. **1–8**. *Tilia tuberculata*, variation of fruits in external view, MCSNB14905a–h; Fig. 10.8 shows part of an open fruit from outside and inside; **9–11**. *Phellodendron elegans*, seeds, MCSNB8796a (Fig. 10.9, internal view of a broken seed), MCSNB8797b (Fig. 10.10, lateral external view) and MCSNB8797c (Fig. 10.11, respectively ventral view with the hilum (a), lateral view of the fractured side (b) and lateral view (c) of the opposite, undamaged side); **12**. *Viola* sp. 1, seed fragment, MCSNB14906; **13**. *Viola* sp. 2, deformed seed fragment, MCSNB14907; **14**. *Vitis vinifera* sensu lato, seed seen from three sides (a–c), MCSNB14908; **15**. *Carpolithus* sp. 1, seed fragment seen from three different orientations (a–c), MCSNB8815; **16**. *Carpolithus minimus*, half specimen from two opposite sides, MCSNB14909. Scale bars = 1 mm

Comparison. For the dimensions, the scarce relief of edges and the abundant tubercles, the fruits from Leffe agree with the type specimens of Mizerna II in Poland (Szafer, 1954). Only a few fossil-species of *Tilia* are based on fruits (Spitzelberger, 1984), and *T. tuberculata* is characterized by the mamillate fruits associated with apparent longitudinal ribs. Among the extant European species, only *T. tomentosa* produces moderately mamillate fruits, but the longitudinal ribs are poorly visible or null. However, a detailed comparison of the European fossil fruits with those of the extant species described in Pigott's (2012) monograph has not yet been carried out. Such a comparison could state if the fossil fruits are very similar to those of an extant species or if they are an extinct plant taxon.

Occurrence. Remains of the genus *Tilia* are extremely rare in the Italian Neogene assemblages, where a few specimens occurred only at two Piacenzian localities: Front and Terzoglio. In the Early Pleistocene, more abundant fossil fruits, referred to as *T. tuberculata*, occurred only at (Ghiotto, 2010). Rare fruits of *Tilia* occurred at Codrignano, Castel San Pietro (Pandolfi et al., 2017) and San Pietro di Ragogna (Martinetto et al., 2012), but only a single fruit from the last locality was assigned to *T. tuberculata*. Fossil fruits of *Tilia*, clearly different from *T. tuberculata*, were reported more abundantly from the Chibanian (Martinetto, 2009; Vassio, 2012).

Family RANUNCULACEAE Juss.

Genus *Ranunculus* L.

Ranunculus reidii Szafer

Fig. 11.7–11.8

Material. Five fruits from Leffe Via Europa, sample LF11 C7M, MCSNB 14904a/e.

Description. Flattened, small dimensions, rounded shape, very scarcely visible tubercles, cells apparent.

Comparison. For the small dimensions, rounded shape and the very scarcely visible tubercles, the fruits are very peculiar, and there are probably a few extant species to be compared. The features of the fossils could correspond to those of the living *R. ophioglossifolius*, which Field (2013) only described but did not illustrate. The fruits of *R. lateriflorus* are more elongated and show more prominent tubercles. Anyway, these fossil remains from Leffe are relevant to assess the systematic placement and require further study.

Among the most accurately described fossils, a fruit of *Ranunculus reidii* shown by Ghiotto (2010) is extremely similar. *R. pliocenicus*, as described by Velichkevich and Zastawniak (2003), seems to differ in the thicker fruits and absence of tubercles.

Occurrence. In Italy, a few reliable records of *R. reidii* were reported from Piacenzian (Martinetto, 1994a; Cavallo and Martinetto, 2001) and Early Pleistocene sites, e.g. Buronzo-Gifflenga (Martinetto and Festa, 2013) and Steggio (Ghiotto, 2010).

Family ROSACEAE Juss.

Genus *Potentilla* L.

Potentilla pliocenica E. Reid.

Fig. 11.4–11.6

Material. Eleven achenes from Leffe Via Europa's sample LF11 C7M, MCSNB14903a/m.

Description. The specimens from Leffe correspond quite well in all morphological details to those described by Reid (1920) and Mai and Walther (1988). The combination of diagnostic characters is the following: length 0.5–1.1 mm in combination with a slightly narrower width, straight ventral side and rounded dorsal one; presence of a keel and smooth surface; acrostylic style remain.

Occurrence. Several samples of fossil achenes assignable to *P. pliocenica* are stored in MRSN-P/345-CCN, but they were not correctly identified earlier (e.g. as *P. supina* in Martinetto, 1994a). They pertain to only two Zanclean sites (Crosaroglio, Sento II) and several Piacenzian ones. The single published Early Pleistocene occurrence is from central Italy (Pandolfi et al., 2017), but unpublished specimens referable to *P. pliocenica* occur in MRSN-P/345-CCN from Buronzo-Gifflenga (Martinetto and Festa, 2013) and Steggio (Ghiotto, 2010 as *P. supina*).

Figure 11. Plant fossils from Leffe, Via Europa excavation. **1**, **2**. *Carex* indet., trigonous achenes, MCSNB14901a, b; **3**. *Carex* sect. *Phacocystis*, biconvex achene, MCSNB14902; **4–6**. *Potentilla pliocenica*, achenes, MCSNB149031a, b, c; **7–9**. *Ranunculus reidii*, achenes, MCSNB14904a, b. Scale bars = 1 mm

Family RUTACEAE Juss.

Genus *Phellodendron* Rupr.

Phellodendron elegans (C.Reid et E.Reid) C.Reid et E.Reid

Fig. 10.9–10.11

Material. Thirteen seeds from Leffe Via Europa (only a seed fragment in sample LF11 C7M, not catalogued), 8 seeds from Leffe Madival.

Description. The specimens from Leffe correspond quite well in all morphological detail to those described by Reid and Reid (1907, 1915) from the type locality of *P. elegans*, Tegelen. An effective description of *Phellodendron* seed morphology can be found in Tiffney (1980). For a detailed description of the seed morphology and the geographic and stratigraphic distribution of *P. elegans* see Mai and Wähnert (2000). In synthesis, *P. elegans* is characterized by seeds larger than those of the other European fossil-species, with sculpturing intermediate between that of the fossil-species *P. lusaticum* and that of the extant species *P. amurense* (Tiffney, 1980).

Comparison. *P. elegans* is a fossil-species based on material from the classical Early Pleistocene site of Tegelen, in the Netherlands. It was at first described as a member of the aquatic genus *Stratiotes*, still living in Europe (Reid and Reid, 1907), but soon after recognized as a member of the rutaceous genus *Phellodendron*, presently growing only in East Asia (Reid and Reid, 1915).

The seeds from Leffe totally correspond in morphology and range of variation to the sets of fossil seeds obtained from the neighbouring Early Pleistocene site of Casnigo (4 specimens: MRSN-P/345-CCN3040) as well as from the Piemonte region sites of Buronzo-Gifflenga (26 specimens, MRSN-P/345-CCN3029-3037), Castelletto Cervo II (15 specimens MRSN-P/345-CCN3043-3047) and Lombardore (3 specimens MRSN-P/345-CCN8679). Other sites only yielded 1 or 2 seeds, and all the specimens of Piacenzian or Zanclean age have smaller dimensions and were often reported as "*P.* cf. *elegans*" (= *P. elegans* sp. inc.; Bertoldi and Martinetto, 1995; Basilici et al., 1997).

Occurrence. In Italy, *P. elegans* is particularly common at Early Pleistocene sites (Cavallo and Martinetto, 2001; Martinetto and Festa, 2013; Martinetto, 2015). In contrast, the reports of *Phellodendron* fossil seeds from Europe are relatively scarce, and it could seem surprising that in the MRSN-P/345-CCN collection these are represented by several specimens from at least 20 late Cenozoic Italian localities. Yet, it is true that "There are a few fossil-species reported from Europe" (Ma et al., 2006), possibly only 3: *P. elegans*, *P. lusaticum* and *P. tessellatum*. Agreed that there are few fossil-species, the Italian record and the data

reported by Mai and Wähnert (2000) do not allow us to state that there are a few fossil specimens from Europe. If this bulk of fossils does not show up in the literature or in web searches, it is not only due to the lack of knowledge of a somehow obscure literature, but also to our fault, as European palaeobotanists, to omit the accurate description of many fossil seeds extracted from late Cenozoic sediments.

Family VIOLACEAE Batsch

Genus *Viola* L.

Viola sp. 1

Figs 7.2, 10.12

Material. A seed fragment in sample LF11 C7M (Leffe Via Europa), MCSNB14906.

Description. The seed fragment is rather large and permits reconstructing an original drop-shaped seed with a chalaza evidenced by a raised margin, only preserved in a small portion. The seed wall is thick, and the external surface is rough and apparently striated in a basal-apical direction.

Comparison. The seed fragment is rather large and permits reconstructing an original drop-shaped seed with a chalaza evidenced by a raised margin, only preserved in a small portion. The seed wall is thick, and the external surface is rough and apparently striated in a basal-apical direction. The preserved portion is identical to the same part of complete seeds from the Pliocene and Gelasian of the Piemonte region, assigned to *V. neogenica*. However, the late Cenozoic seeds of *Viola* have not yet been studied in sufficient detail and the diagnostic characters of different fossil and extant species have not been pointed out, so that a generic assignment to *Viola* sp. 1 seems to be preferable than a tentative assignment to *V. neogenica* (see Mai and Walther, 1988).

Occurrence. Fossil seeds that are similar to the described fragment occurred in Italy at several Piacenzian sites and a few Early Pleistocene ones, such as Steggio (Ghiotto, 2010)

Viola sp. 2

Fig. 10.13

Material. A seed fragment in sample LF11 C7M (Leffe Via Europa), MCSNB14907.

Description. The seed fragment, although much deformed, permits reconstructing an original drop-shaped seed with a chalaza evidenced by a raised margin, only preserved in a small basal portion. The seed wall is definitely thinner than in *Viola* sp. 1 and the external surface is rather smooth, poorly striated in the basal-apical direction, and shows longitudinal rows of cells, so that this fossil likely belongs to another species.

Comparison. The seed fragment is sufficient to reconstruct an original drop-shaped seed similar to complete fossil specimens from the Pliocene and Gelasian of the Piemonte region, assigned to *V. bergaensis*. However, a generic assignment to *Viola* sp. 2 is preferable for the same reason discussed for *Viola* sp. 1.

Occurrence. *Viola* sp. 1 is a smaller type of fossil seeds that corresponds to specimens found in many Italian sites, especially from the Piacenzian to the Holocene.

Family VITACEAE Juss.

Genus *Vitis* L.

Vitis vinifera L. sensu lato

Figs 7.4, 10.14

Material. 27 seeds from Leffe Via Europa (one from sample LF11 C7M: Fig. 10.14, MCSNB14908), 8 seeds from Leffe Madival.

Description. The seed assortment has the usual shape variation observed in Early Pleistocene sites (Ucchesu et al., 2024), since most specimens are identical to the living *V. vinifera sylvestris* (Gmelin). The morphological difference between Italian Pliocene assortments and Holocene samples assigned to *V. vinifera sylvestris* (Vassio, 2012) is very small. Those Pliocene specimens were often named "*Vitis parasylvestris* Kirchheimer", and they agree morphologically with specimens from central Europe treated under the same name (Geissert et al., 1990). However, this name is not considered as validly published by IFPNI (2014 onwards), and in any case, the differential characters of "*V. parasylvestris*" and "*V. sylvestris* Gmelin" (or *V. vinifera*) were never described with an acceptable precision; moreover, in those fossil assemblages that provided hundreds of seeds, the two types are mixed together and linked by intermediate

forms (Ucchesu et al., 2024). There are also other fossil-species names that have been proposed for Neogene or Pleistocene seeds similar to those of *V. vinifera sylvestris*, for example *V. sphaerocarpa* Kinkelin and *V. neuwirthiana* Sordelli. The last one was described on the basis of fossils from Leffe (Sordelli, 1896) that can no longer be located. Indeed, further studies on specimen-rich fossil assemblages of Neogene seeds, similar to those of *V. vinifera sylvestris*, would be needed in order to verify if one or more fossil-taxa could be consistently pinpointed. It has been proposed to assign the fossils, even if older than the Middle Pleistocene (Mai and Walther, 1988), to *Vitis vinifera* subsp. *sylvestris*. However, it is presently suspected that this subspecies could be the result of a bottleneck effect due to isolation of various populations in the Mediterranean area over the last 400.000 years (Ucchesu et al., 2024). Therefore, it is more appropriate to classify the fossil seeds older than Chibanian as *Vitis vinifera* L. sensu lato, thus implying that the strong analogy in seed characters demonstrates the past record, within a single species, of *Vitis* populations from which both the wild and the cultivated subspecies originated.

Comparison. In MRSN-P/345-CCN only a few fossil seeds of *Vitis vinifera* s.l. are available from Middle Pleistocene (Pianico) and Holocene sites (Pianezza, Rugo di Valeriano); they are, however, identical to selected specimens of Leffe. The fossil seeds that show the best morphological match with those of Leffe are the abundant specimens from the Gelasian of the Cervo River succession in Piemonte (Ucchesu et al., 2024), assigned to *V. vinifera* s.l.

Occurrence. Fossils that can be assigned to *V. vinifera* s.l. are represented, in MRSN-P/345-CCN, by specimens from the Zanclean sites of Ca' Viettone and Sento II, the Piacenzian sites of Villafranca d'Asti-RDB Quarry, Stura di Lanzo Fossil Forest and Castelletto Cervo I, the Gelasian and Calabrian sites of the Cervo River succession and the Chibanian site of Pianico.

Family INCERTAE SEDIS

Genus *Carpolithus* Artis

The formal nomenclature of plant fossil-taxa that are recognized as carpological remains, but are not considered as belonging to any definite extant genus or fossil-genus, has been somewhat controversial. Even in the Italian palaeocarpological literature, a single author used the generic name *Carpolithus* L. (Martinetto, 1994b), *Carpolithes* Brongn. (Martinetto, 1995) and *Carpolites* Sternberg (Martinetto, 2015). However, Cleal and Thomas (2018) demonstrated that the valid name to apply is *Carpolithus* Artis (validly published by Artis, 1825) and argued that a previous proposal to conserve the name *Carpolithus* by Wang (2011) was not necessary.

Carpolithus minimus Szafer

Fig. 10.16

Material. A single fragment from Leffe Via Europa's sample LF11 C7M, almost corresponding to one half of a specimen, MCSNB14909.

Description: Comparison: The fossils are similar in external appearance (Martinetto, 2001b) to the fruits of some extant species of *Thalictrum* from China, but these fruit of *Thalictrum* are indehiscent, whereas those of the fossils are clearly dehiscent in two parts and their assignment to the extant genus (Martinetto, 2001b), or even to Ranunculaceae, was a mistake.

Occurrence. This fossil-species occurred in Italy from the late Zanclean to the Calabrian, particularly abundant in the Early Pleistocene sites of Buronzo-Gifflenga (Martinetto and Festa, 2013), Casnigo and Steggio (Ghiotto, 2010).

Carpolithus sp. 1

Fig. 10.15

Material. A single seed fragment from Leffe Madival, MCSNB8815.

Description. The shining seed coat, the conserved part of the outline and the typical cell pattern assure that this fragmentary seed belongs to the same species represented by complete seeds in two Pleistocene sites of the neighboring Piemonte region, Buronzo-Gifflenga and Lombardore (MRSN-P/345-CCN, unpublished data).

Comparison. The incomplete seed shows the same characters of several complete seeds, still not accurately described, from the Early Pleistocene of teh Piemonte region. Those seeds are similar to the extant ones of *Corydalis*, but also of *Dicentra* (both Fumariaceae).

Those of *Phytolacca* show a similar shape, but have a different hilum and cell pattern. This last genus belongs to the order Caryophyllales, in which several families produce seeds with the same architectural plan ("Centrospermae": Bittrich, 1993). At the present state of research, without a detailed SEM or anatomical analysis of the fossils, we can only suggest that the enigmatic seed fragment of Leffe (and those of the same type from Piemonte) should belong to either the Fumariaceae or the Caryophyllales.

Occurrence. Known from 3 other sites of proved or supposed Early Pleistocene age in northern Italy: Arda, Buronzo-Gifflenga , Lombardore (MRSN-P/345-CCN, unpublished data).

LEFFE, CARPOLOGICAL TAXA MISSING IN THE CAFFI MUSEUM COLLECTION

The Caffi Museum is not the single institution that stores carpological material originating from the Calabrian sediments of Leffe. Samples of *J. bergomensis* from Leffe are certainly stored at Bologna, Florence, Milan, Padua, Verona and, probably, Domodossola. However, carpological remains of other taxa from Leffe cited in the literature were only stored, to our knowledge, at the Museums of Milan (Sordelli, 1896), Padua (Martinetto et al., 2015b) and Verona (Massalongo, 1852a, b). In particular, four taxa missing in the Caffi Museum collection of Bergamo are described below.

GYMNOSPERMS

Family PINACEAE Spreng. ex F.Rudolphi

Genus *Picea* Link

Picea omorikoides C.A. Weber sp. inc.

Figs. 4.5, 4.7

The reference female cone specimen of *P. seriana* that we proposed above (Sordelli, 1896: pl. 35, fig. 8), formerly stored at the Natural History Museum of Milan, has an outline that is not typical for *Larix* (rounded base) and the rounded, long wing of its seeds (Fig. 4.7) rather confirm the affinity to *Picea*. Since it was said to be 2.5–3 cm long (Sordelli, 1896), it was too small to be referred to *Picea abies*, unless it represented only the apical part of a longer cone (which cannot be ruled out). We also compared the drawing of Sordelli (1896) with abraded fossil cones (Fig. 4.1, 4.3) of *Tsuga charugii*, frequent in the Steggio site (Ghiotto, 2010) and known to occur in the Leffe basin too (Ravazzi, 1995, 2003; Ravazzi et al., 2009b). Some of the cones from Steggio looked similar, but the largest one (among more than 200 specimens: Fig. 4.3) was 2.7 cm long and just 1.3 cm broad (too narrow to represent the same cone type as Sordelli's cone). *Tsuga* cones from Steggio also differ for the smaller number of scales (Fig. 4.2), more broadly rounded base and usually smaller dimensions. Cones of other genera differ from the cone of Sordelli's fig. 8 (pl. 35) for the thicker scales (*Cathaya*, *Pseudotsuga*) or slenderer cone (*Nothotsuga*).

In the case that the cone of Sordelli's fig. 8 (pl. 35) would not belong to *Picea abies* (cone apex) or *Larix*, *Tsuga* or another genus, it could really represent a new, validly named fossil-species of *Picea* with small ovate cones. In reference to the correct name to assign to the last fossil-species, the lack of characters that could mark a distinction between the cone of Sordelli's fig. 8 of pl. 35 (Fig. 4.5) and *Picea omorikoides* C.A. Weber (Fig. 4.8) opens the possibility that the name *P. seriana* may have priority over *P. omorikoides*. In spite of this, we would suggest that the last name should be conserved, because it was based on excellently preserved type material showing all the useful diagnostic characters, excellently described and figured by Weber (1898). Conversely, *Picea seriana* was only superficially described by Sordelli (1896), with possibly misinterpreted characters ("*squamis ... apice rotundato*, *crenato-erosulo*": Every scale in the drawing does not seem to be complete, the character "*crenato-erosulo*" is probably due to pre-burial erosion or post-burial alteration). In conclusion, we prefer to use the name *P. omorikoides* sp. inc. for a framing, in open nomenclature, of the cone drawn in Sordelli's fig. 8 of pl. 35.

Occurrence. It is remarkable that *Picea omorikoides* does not have any other well-assessed occurrence in other Italian sites, which casts doubts on this possible record; it was mentioned by Emmert-Straubinger (1991) for Pianico, but never figured and was not confirmed later (Martinetto, 2009).

Genus *Tsuga* (Endl.) Carrière

Tsuga chiarugii
Tongiorgi
Fig. 4.1–4.3

As reported above, fossil female cones of *Tsuga* are known to occur in abundance in a site close to Villa Giuseppina's Road Curve of Leffe (Ravazzi, 1995). Two of them have been figured in Ravazzi et al. (2009b), but most of the material is still not published and analysed in detail (C. Ravazzi, pers. comm.).

Occurrence. Very abundant in the Calabrian site of Steggio (Ghiotto, 2010) and originally described from a Pleistocene site in Tuscany (Tongiorgi, 1936) on the basis of well-preserved cones, still available at the Natural History Museum of Calci.

ANGIOSPERMS

Family LYTHRACEAE J.St.-Hil.

Genus *Trapa* L.

Trapa natans L. sp. inc.

There is no carpological material referable to *Trapa* among the Leffe materials at the Caffi Museum of Bergamo. However, the fossils from Leffe and figured by Sordelli (1896) leave no doubt as to their assignment to *Trapa*. More questionable is their assignment to the fossil-species *T. heeri* (Sordelli, 1896: 237). The original specimens were stored at the Natural History Museum of Milan, but are impossible to be located at present.

Occurrence. In the neighbouring Piemonte region *Trapa* fruits occur abundantly in two Pliocene sites (Arboschio, Front-Rio Secco) and in three ones suspected to be of Early Pleistocene age: Buronzo-Gifflenga, Buronzo-Colombera and Rivarossa. At Arboschio and at the two sites of Buronzo the fruits are very similar to the extant ones of *T. natans*; at Front-Rio Secco and Rivarossa a small type matching the fossil-species *T. heeri* (Mai and Walther, 1988) occurs, but possibly it is only material selected by size, since identical small specimens occur, among larger ones, also at Buronzo-Gifflenga and Buronzo-Colombera.

Family SAPOTACEAE Juss.

Genus *Aesculus* L.

Aesculus hippocastanum L. sp. inc.

For sure there is no carpological material referable to *Aesculus* at the Caffi Museum of Bergamo, and Ravazzi (2003) reported that it is also missing from the Natural History Museum of Milan, where the fossils described and figured by Sordelli (1896) were stored. We confirm that, in a recent visit to this collection, with the supervision of Giorgio Teruzzi, we were not able to locate them. Likewise, we do not know whether the fossils described by Massalongo (1856) are still present in the collections of the Verona Museum. However, pollen of *Aesculus* was detected by Ravazzi (1995, 2003) in the Leffe basin, sometimes with a percentage so high as 15%, so that we argue that the fossils described by Massalongo (1856) and Sordelli (1896), even if unavailable today, could actually represent *Aesculus hippocastanum* sp. inc. seeds. However, it is not possible to exclude that the Leffe specimens would belong to the fossil-species *A. spinosissima* C. Reid et E. Reid, occurring in the Pliocene of the Rhein valley (Alsace, Germany, The Netherlands: Van der Burgh, 1978)

To our knowledge, there is no other carpological record of *Aesculus* in the late Cenozoic of Italy, so that the fossils from Leffe were particularly important, and an attempt to recover new material would be worthwhile.

DISCUSSION

The Pliocene and Early Pleistocene fruits and seed floras have been mostly studied in the western and south-eastern part of northern Italy, as well as in central Italy (Gregor, 1990; Martinetto, 1994a, b, 2015; Bertoldi and Martinetto, 1995; Mai, 1997; Martinetto et al., 2014, 2015a, 2017). The data from the surroundings of Bergamo fill a geographic gap towards the few assemblages known in north-eastern Italy (Ghiotto, 2010; Martinetto et al., 2012).

The relatively poor Pliocene assemblage represented by the Almenno carpoflora is most probably biased by the depositional environment and/or scarce collecting, and all of the species but one correspond to those found in a few,

more extensively sampled, Zanclean deposits (Table 2) cropping out at the foothill of the western Alps, in particular at Breolungi (Martinetto et al., 2015a and unpublished data), Candelo (Martinetto, 2001c), Castellengo (Ferrero et al., 2003) and Sento II (Basilici et al., 1997).

The analysis of the distribution in Italy of the species found at Almenno does not provide precise age indications. The occurrence of the two *Pinus* species, limited to the Pliocene, is sporadic and linked more to local environmental conditions than to the age of sediments. *Cathaya bergeri* sp. inc. is common in the Zanclean and persists till to the upper Gelasian in central Italy (Poggio Rosso in the Upper Valdarno, unpublished data of the MRSN-P/345-CCN collection). *Liquidambar europaea* in northern Italy is common in the Zanclean and rare in the Piacenzian; however, a *Liquidambar* species (but not yet ascertained if *L. europaea*) still occurs in the Early Pleistocene of central Italy (Girotti et al., 2003). The most relevant occurrence for the chronological and palaeoclimatic framing of the Almenno flora is *Litsea sonntagii*, listed by Martinetto et al. (2014) as an element of "Group 2" (thermophilous elements), which is restricted to the Zanclean and to the warm blip (3.0–2.8 Ma) of the Piacenzian in northern Italy. The occurrence of the last species would indicate that the Almenno deposits were formed between 5.3 and 2.8 Ma.

The Early Pleistocene fruit and seed assemblages from Leffe are mainly interesting for the good stratigraphic framing within the Calabrian (~1.5–0.9 Ma: Muttoni et al., 2007) of the plant-bearing deposits. The Leffe Via Europa (1.5–1.0 Ma) and Madival (~1.5 Ma) sites provide the last dated record in Europe of *Magnolia cor*, *Phellodendron elegans* and *Tilia tuberculata*. Otherwise, *Carpolithus minimus* and *Juglans bergomensis* have their last record in a bed of the Stirone-Laurano section (Martinetto et al., 2015a) that is ~1.0 Ma old, and *Carya* is even supposed to persist in the Chibanian of central Italy (e.g., Magri and Palombo, 2013).

The 19th century reports of female pinaceous cones from Leffe must be interpreted with much caution because the originals have been lost and the material recovered in the 20th century does not include well preserved specimens. The stratigraphic provenance of both the older and younger findings is unclear and the determination is uncertain. We can certainly discard the occurrence of the genus *Abies* (Sordelli, 1896), whereas *Picea abies* is likely occurring in the Leffe Basin, but cannot be assigned to a definite stratigraphic position, even if the "first lignite bank" or related layers are the most probable option (see Ravazzi, 2003). It is possible that the same species may be represented in the Villa Giuseppina Road Curve site but, the single cone recovered there is not diagnostic (MCSNB7917). The occurrence of a second species of *Picea* is suggested by a single cone drawn by Sordelli (1896: pl. 35, fig. 8) and that of *Larix decidua* sp. inc. by a badly preserved cone (MCSNB 1223).

The Leffe carpofloras are difficult to compare with similar and richer assemblages from northern Italy, sieved out from sediment bulk samples, (Cavallo and Martinetto, 2001; Ghiotto, 2010; Martinetto and Festa, 2013; Martinetto, 2015), due to different methods of extraction. However, when considering only the fruits and seeds larger than 5 mm (more easily picked from the outcrops), the Leffe floras (Lombardy region) closely resemble the uncertainly dated Buronzo-Gifflenga, Castelletto Cervo II and Lombardore assemblages (Table 4) from the Piemonte region. These NW Italian sites have a putative Gelasian age and their floras differ from the Leffe one mainly for the abundance of *Pterocarya*. However, Ravazzi (2003) reported that *Pterocarya* pollen is rather abundant in 4 intervals of the Calabrian pollen diagram of Leffe, as to suggest its presence not too far from the Leffe palaeolake.

A slightly lower similarity can be detected between the Leffe carpoflora and the carpoflora of Steggio in NE Italy (Veneto region: Ghiotto, 2010), most probably of Calabrian age, due to the lack in the last one of *Magnolia cor* and *Phellodendron elegans*. However, *Tilia tuberculata* is a shared element that lacks, conversely, in the NW Italian floras.

In conclusion, the palaeocarpological material from Leffe in the collections of the Caffi Museum (Table 5) can be considered very relevant for the study of the history of vegetation development in northern Italy during the late Cenozoic, because it originates from independently dated sediments and shows a strong taxonomic affinity with similar, but uncertainly dated assemblages from the Piemonte region (Buronzo-Gifflenga, Castelletto Cervo II and Lombardore). These last sites are still available for further investigations (Martinetto, 2001c, 2015), which are difficult to be carried

Table 5. Catalogue of the carpological remains from Leffe stored at the Caffi Museum of Bergamo

Inventory nr.	Family	Genus	Species epiteth	Nr. specimens	Plant part	Accession history	Recovered by	Accession year	Sampling code	Locality
1222	Pinaceae	*Picea*	*abies* sp. inc.	1	cone	unknown	unknown	before 1990	none	in a lignite seam
1223	Pinaceae	*Larix*	*decidua* sp. inc.	1	part of a cone	Historical Enrico Caffi collection	unknown	before 1990	none	in a lignite seam
1224	Juglandaceae	*Juglans*	*bergomensis*	16	endocarp					in a lignite seam
1225	Juglandaceae	*Juglans*	*bergomensis*	23	endocarp					in a lignite seam
1870	indet.	Filicopsida	indet.	1	rhizome or stem	unknown	unknown	before 1990	none	unknown
1885	Juglandaceae	*Juglans*	*bergomensis*	12	endocarp	unknown	unknown	before 1990	none	unknown
2570	Juglandaceae	*Juglans*	*bergomensis*	1	endocarp	Historical Enrico Caffi collection	unknown	before 1990	none	unknown
7910	Juglandaceae	*Carya*	*strichnina* sp. inc.	2	endocarp	Delivered to the museum	Barbero Carlo	before 1990	S.870	unknown
7911a,b	Juglandaceae	*Juglans*	*bergomensis*	2	endocarp					
7911c	Cyperaceae	*Carex*	sp.	1	fruit	Delivered to the museum	unknown	before 1990	S.870	unknown
7912	Juglandaceae	*Juglans*	*bergomensis*	5	endocarp	Delivered to the museum	Barbero Carlo	before 1990	S.870	unknown
7913	Juglandaceae	*Carya*	*strichnina* sp. inc.	4	endocarp					
7914a-i	Juglandaceae	*Carya*	*strichnina* sp. inc.	9	endocarp					
7915	Juglandaceae	*Juglans*	*bergomensis*	1	endocarp					
7916	Juglandaceae	*Juglans*	*bergomensis*	1	endocarp	Delivered to the museum	Mottinelli Bortolo	before 1990	S.717	Villa Giuseppina Road Curve
7917	Pinaceae	*Picea*	vel *Pinus* indet.	1	incomplete cone					
7921a	Juglandaceae	*Carya*	*strichnina* sp. inc.	2	endocarp	Delivered to the museum	Fossa Virgilio, Rivola Martino, Fradusco Cinzia	before 1982	S.864, S.865, S.866	in a lignite seam
7921b	Rutaceae	*Phellodendron*	*elegans*	1	seed					
7921c	Vitaceae	*Vitis*	*vinifera* s.l.	2	seed					
7922	Rutaceae	*Phellodendron*	*elegans*	20	seed					
7923	Juglandaceae	*Carya*	*strichnina* sp. inc.	2	endocarp	Field work, museum's staff	Paganoni Anna, Pandolfi Mario	1982	S.1100	Via Europa
7924	Juglandaceae	*Juglans*	*bergomensis*	1	endocarp					
7925	Juglandaceae	*Juglans*	*bergomensis*	3	endocarp					
7926	Betulaceae	*Corylus*	*avellana*	1	fruit					
7927	Juglandaceae	*Carya*	*strichnina* sp. inc.	3	endocarp					
7928	Juglandaceae	*Juglans*	*bergomensis*	9	endocarp					
7929	Magnoliaceae	*Magnolia*	*cor*	2	seed					
7930	Betulaceae	*Corylus*	*avellana*	20	fruit					
7931	Juglandaceae	*Juglans*	*bergomensis*	20	endocarp					
7932	Juglandaceae	*Carya*	*strichnina* sp. inc.	1	endocarp					
7933	Juglandaceae	*Juglans*	*bergomensis*	3	endocarp					
7934	Juglandaceae	*Carya*	*strichnina* sp. inc.	3	endocarp					
7935	Juglandaceae	*Juglans*	*bergomensis*	3	endocarp					
7936	Juglandaceae	*Juglans*	*bergomensis*	9	endocarp					
7937	Juglandaceae	*Juglans*	*bergomensis*	9	endocarp					
7938	Juglandaceae	*Carya*	*strichnina* sp. inc.	1	endocarp					
7939	Juglandaceae	*Juglans*	*bergomensis*	9	endocarp					
7940	Juglandaceae	*Juglans*	*bergomensis*	9	endocarp					
7941	Juglandaceae	*Juglans*	*bergomensis*	4	endocarp					

Table 5. Continued

Inventory nr.	Family	Genus	Species epiteth	Nr. specimens	Plant part	Accession history	Recovered by	Accession year	Sampling code	Locality
7942	Juglandaceae	*Carya*	*strichnina* sp. inc.	2	endocarp	Delivered to the museum	Fossa Virgilio	before 1982	S.864	unknown
7943	Juglandaceae	*Carya*	*strichnina* sp. inc.	9	endocarp					unknown
7944	Juglandaceae	*Carya*	*strichnina* sp. inc.	9	endocarp					unknown
7945	Juglandaceae	*Carya*	*strichnina* sp. inc.	3	endocarp					unknown
7946	Juglandaceae	*Juglans*	*bergomensis*	2	endocarp					in a lignite seam, likely from Villa Giuseppina road curve
7947	Juglandaceae	*Juglans*	*bergomensis*	6	endocarp	Delivered to the museum	Rivola Martino	before 1982	S.865	in a lignite seam, likely from Villa Giuseppina road curve
7948	Juglandaceae	*Juglans*	*bergomensis*	4	endocarp	Delivered to the museum	Fradusco Cinzia	before 1982	S.866	
8544	Juglandaceae	*Juglans*	*bergomensis*	9	endocarp	Delivered to the museum	Scolari Gino	1989	S.1444	Villa Giuseppina
8794	Vitaceae	*Vitis*	*vinifera* s.l.	6	seed	Field work, museum's staff	Paganoni Anna, Pandolfi Mario	1982	S.1100	Via Europa
8795	Vitaceae	*Vitis*	*vinifera* s.l.	12	seed					
8796	Rutaceae	*Phellodendron*	*elegans*	6	seed					
8797	Rutaceae	*Phellodendron*	*elegans*	7	seed					
8798	Malvaceae	*Tilia*	*tuberculata*	2	fruit					
8799	Malvaceae	*Tilia*	*tuberculata*	9	fruit					
8800	Malvaceae	*Tilia*	*tuberculata*	2	fruit					
8801	Betulaceae	*Corylus*	*avellana*	11	fruit					
8802	Betulaceae	*Corylus*	*avellana*	12	fruit					
8803	Betulaceae	*Corylus*	*avellana*	11	fruit					
8804	Betulaceae	*Corylus*	*avellana*	2	fruit					
8806	Magnoliaceae	*Magnolia*	*cor*	6	seed					
8807	Magnoliaceae	*Magnolia*	*cor*	23	seed					
8809	Vitaceae	*Vitis*	*vinifera* s.l.	8	seed					
8810a/b	Malvaceae	*Tilia*	*tuberculata*	2	fruit	Field work, museum's staff	Paganoni Anna, Pandolfi Mario, Malzanni Matteo	1983	S.1108 B	Madival
8811	Magnoliaceae	*Magnolia*	*cor*	11	seed					
8812	Magnoliaceae	*Magnolia*	*cor*	6	seed					
8813	Betulaceae	*Corylus*	*avellana*	9	fruit					
8814	Rutaceae	*Phellodendron*	*elegans*	8	seed					
8815	indet.	*Carpolithes*	sp. 1	1	seed					
13051a-m	Juglandaceae	*Carya*	*strichnina* sp. inc.	11	endocarp	Field work, museum's staff	Paganoni Anna, Pandolfi Mario	1982	S.1100	Via Europa
14898a-c	Betulaceae	*Corylus*	*avellana*	3	fruit					
14899a-g	Betulaceae	*Carpinus*	*betulus* subsp. 1	7	fruit					
14900a-d	Magnoliaceae	*Magnolia*	*cor*	4	seed					
14901a/b	Cyperaceae	*Carex*	sp.	2	fruit					
14902	Cyperaceae	*Carex*	sect. *Phacocystis*	1	fruit					
14903a-m	Rosaceae	*Potentilla*	*pliocenica*	11	fruit					
14904a-e	Ranunculaceae	*Ranunculus*	*reidii*	4	fruit					
14905a-h	Malvaceae	*Tilia*	*tuberculata*	8	fruit					
14906	Violaceae	*Viola*	sp. 1	1	seed					
14907	Violaceae	*Viola*	sp. 2	1	seed					
14908	Vitaceae	*Vitis*	*vinifera* s.l.	1	seed					
14909	indet.	*Carpolithes*	*minimus*	1	endocarp?					

out at Leffe, due to the closure of all the excavations and to the present dense cover of buildings. Therefore, a joint analysis of the Leffe and Piemonte carpofloras is likely to provide very detailed contributions to the definition of the Early Pleistocene palaeoflora, palaeovegetation and palaeoclimate of northern Italy, which was, however, beyond the scope of the present paper.

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ADDITIONAL INFORMATION

CONFLICT OF INTEREST. The authors have declared that no competing interests exist.

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Appendix 1. Summary of the diagnostic characters of a female cone from Almenno (*Cathaya bergeri* sp. inc.) compared to different fossil-species of Pinaceae cones and *Larix decidua*

Genus	Species	Peduncle	Scale consistency	Cone base	Cone apex	Median scales	Median scales coverage	Shape of external uncovered area, median scales
Cathaya	*C. bergeri* sp. inc. (Almenno)	absent or thick	woody	attenuated	narrowly conical	larger than the ones at 1/4 and 3/4 from the cone base	scarce	irregular asymmetric fan
Cathaya	*C. bergeri* sp. inc. (Italy)	absent or thick	woody	attenuated	narrowly conical	larger than the ones at 1/4 and 3/4 from the cone base	scarce	irregular asymmetric fan
Cathaya	*C. bergeri* (Germany)	absent or thick	woody	attenuated	narrowly conical	larger than the ones at 1/4 and 3/4 from the cone base	scarce	irregular asymmetric fan
Nothotsuga	*N. vanderburghii*	thin and long (Xu et al., 2022)	leathery	truncate	narrowly conical	similar to the ones at 1/4 and 3/4 from the cone base	scarce	broadly fusiform and auriculate
Tsuga	*T. chiarugii* (Steggio, Italy)	absent	leathery	truncate	broadly to narrowly conical	similar to the ones at 1/4 and 3/4 from the cone base	scarce	regular fan
Paranothotsuga	*P. jechoreckae*	short and massive (Czaja, 2000)	leathery	rounded	rounded	similar to the ones at 1/4 and 3/4 from the cone base	extensive	fusiform
Pseudotsuga	*P. loehri*	thin (after peduncle scar: Kunzmann, 2014: fig. 8a)	woody	truncate or rounded	rounded	similar to the ones at 1/4 and 3/4 from the cone base	extensive	fusiform

Appendix 2. Diagnostic characters of *Carya* nuts from Leffe and the similar ones from Lombardore, compared to the most similar fossil-species

Species, age, location	Nutshell shape	Length × width (mm)	Nutshell surface	Thickness (mm)	Nr, strength internal ribs at equator	Lacunae/ low-density layer	Placental bundle course	Secondary septum	Basal locule lobes	Sources consulted
LEFFE [*C. strychnina* (Sternberg) Mai sp. inc.]	subglobose to ovoid	16–26 × 13–19	longitudinal wrinkles; four angled	1–3	4, prominent	unknown	unknown	present	unknown	own observation
LEFFE Fig. 10.8 [*C. strychnina* (Sternberg) Mai sp. inc.]	subglobose to ovoid, deformed	26 × 22	very finely longitudinally wrinkled; four angled	?	?	unknown	unknown	unknown	unknown	own observation
LOMBARDORE [*C. strychnina* (Sternberg) Mai sp. inc.]	subglobose to ovoid	32–33 × 23–24	longitudinal wrinkles; four angled	1–3	4, prominent	unknown	unknown	present	unknown	own observation
C. angulata C. Reid et E. Reid, Upper Pliocene, Netherlands, Germany, France	globose	13–24 × 11–19	smooth with longitudinal grooves	?	4, prominent	"apparently absent"	unknown	present	4	Reid and Reid, 1915; Manchester, 1987
C. askenasyi (Kinkelin) Mai, Pliocene, Germany	ovoid	17–32 × 11–15	smooth or faintly wrinkled; four angled	1–2	4, prominent	present (in primary septum and internal ribs)	unknown	present	4	Mädler, 1939; Manchester, 1987
C. costata (Presl) Unger, Oligocene Czech Republic	subglobose	~25 × 20	longitudinally striate	2.5–3	4, broad, shallow	unknown	peripheral	weak	4	Manchester, 1987
C. globosa (R.Ludw.) Mädler, Miocene, Germany	globose to ovoid	15–35 × 15–28	longitudinally channeled with striking grooves; four angled	1–2.5	4, broad, shallow	present (in nutshell)	unknown	present	2	Mai, 1981
C. paludis-naabi Gregor, Miocene Germany	long ovoid	40–44 × 33–38	smooth to wrinkled; not angled	3–5	unknown	unknown	unknown	absent to weak	2	Mai, 1981; Manchester, 1987
C. quadrangula (Kirchheimer) Leroy, mid Oligocene, Germany	globose to ovoid	22–37 × 13.5–22	smooth to longitudinally striate; four angled	up to 3	4, prominent	present (in nutshell and primary septum)	peripheral	absent to weak at base	2	Mai, 1981
C. strychnina (Sternberg) Mai, Upper Oligocene, Middle Miocene, Germany	subglobose to ovoid	20–35 × 18–22	longitudinal wrinkles; four angled	3–6	4, prominent	present (in ribs and primary septum)	peripheral	present	?	Zablocki, 1930; Manchester, 1987