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# Vegetation and landscape around Lake Montcortès (Catalan pre-Pyrenees) as a tool for palaeoecological studies of lake sediments

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**Abstract**
Vegetation and landscape around Lake Montcortès (Catalan pre-Pyrenees) as a tool for palaeoecological studies of lake sediments.— Lake Montcortès (42º 19′ N, 0º 59′ E; 1027 m elevation) is an excellent target for high-resolution palaeoecological studies because its annually-laminated sediments extending back to the early-middle Holocene. The detailed knowledge of present vegetation patterns around the lake and the pollen they release to lake sediments is essential for a reliable interpretation of past vegetation dynamics. This study aims to identify and map the vegetation types currently growing around the lake. For this purpose, a quadrangular area of *ca.* 48 ha was defined. The floristic study resulted in a catalogue of 534 species. Vegetation analysis was based on 42 phytosociological inventories used to synthesise and map the relevant plant landscape units. As a result, we obtained 52 vegetation units as expressions of the CORINE habitats previously defined for Catalonia. Each of these habitats was described in floristic, physiognomic, phytogeographic, environmental and human-use terms. The next step will be the palynological study of the more representative species of the described vegetation types, as a means to optimise future palynological interpretations.

Key words: Catalan Pyrenees; flora; habitat mapping; Lake Montcortès; palaeoecology; palynology; vegetation.

**Resumen**
Vegetación y paisaje alrededor del lago de Montcortès (Prepirineos catalanes) como instrumento para el estudio paleoecológico de los sedimentos lacustres.— El lago de Montcortès (42º 19′ N, 0º 59′ E; 1027 m altitud) posee sedimentos con laminaciones anuales, ideales para estudios paleoecológicos de alta resolución. Para el análisis palinológico de estos sedimentos, es necesario conocer en detalle la vegetación local, como fuente del polen sedimentario. El objetivo de este estudio es reconocer y cartografiar los tipos de vegetación presentes alrededor del lago, para lo cual se delimitó un área rectangular de unas 48 ha. Del estudio florístico de este espacio resultó un catálogo de 534 especies, que sirvió de base para el análisis de vegetación. Para ello, se llevaron a cabo 42 inventarios fitosociológicos, que se utilizaron para elaborar una síntesis del paisaje vegetal mediante cartografía digital. Como resultado, se obtuvieron 52 unidades de vegetación, expresión concreta de los hábitats CORINE definidos en la lista de los hábitats de Cataluña. Cada una de estas unidades se describió con criterios florísticos, fisionómicos, fitogeográficos, ambientales y de uso humano. La siguiente etapa consistirá en el estudio palinológico de las especies más representativas de los tipos de vegetación y hábitats establecidos aquí, con el fin de optimizar las interpretaciones paleoecológicas futuras.

Palabras clave: flora; lago de Montcortès; mapa de hábitats; paleoecología; palinología; Pirineos catalanes; vegetación.

[1] Empar Carrillo (University of Barcelona) is a guest editor invited by the Editorial Board.

## INTRODUCTION

Lake Montcortès (Fig. 1) has become a favourite target for palaeoecological study after the finding of laminated sediments (varves) potentially useful to reconstruct Holocene palaeoenvironmental trends at annual or seasonal resolution (Corella *et al.*, 2012). So far, past reconstructions based on Montcortès sediments using different indicators (proxies) such as sedimentology, geochemistry, pollen and diatoms, among others, have been conducted at centennial to millennial resolution (Corella *et al.*, 2011; Rull *et al.*, 2011; Scussolini *et al.*, 2011). However, a project has been launched recently aimed to obtain the maximum resolution possible during the last millennium using a multiproxy approach (Vegas-Vilarrúbia, 2012). The annual varves consist of three laminae each (triplets) representing seasonal trends which biological nature is still under study (Corella *et al.*, 2012). It is expected that some of these laminations coincide with the main flowering season and contain most of the sedimentary pollen. In order to properly interpret these sedimentary pollen assemblages in palaeoecological terms, it is necessary to know the source flora and the vegetation at different levels of spatial resolution.

The pollen that accumulates in a given sedimentary basin proceeds from three main sources, namely local, regional and long-distance (Birks & Birks, 1980; Faegri *et al.*, 2000). In the case of Lake Montcortès, the flora and vegetation of the Catalan pre-Pyrenees is fairly well known thanks to numerous local and regional studies conducted so far (Bolòs, 1961, 1976; Vives, 1964; Lapraz, 1976; Romo, 1989; Conesa, 1991; Vigo *et al.*, 2003; Sáez *et al.*, 2004; Soriano & Devis, 2004, among others), as well as some synthetic works (Bolòs, 1979; Folch, 1981; Vigo & Ninot, 1987). The pollen coming from regional and long-distant sources, as for example the Mediterranean or interior lowlands, is easily detectable as well (Cañellas-Boltà *et al.*, 2009). However, local sources need more detailed studies, as the ecological conditions created by the presence of the water body determine the occurrence of plants and plant associations that otherwise would not occur.

From a palaeoecological point of view, the detailed knowledge of the local component of pollen assemblages is essential as it allows reconstructing small-scale ecological successions influenced by local environmental factors, rather than regional or supra-regional shifts. This has several advantages, as for example the possibility of: (1) disentangling the effect of local features (flooding, landslides, etc.) from more general climatic events, (2) separating ecological shifts determined by human activities (more local in scope) from those induced by more general climate trends and events, and (3) reconstructing in detail local ecological successions over a long-term time scale useful for testing ecological hypotheses (Rull, 2012). These benefits are particularly useful in the case of annually laminated sediments, where several of the quoted drivers of change concur to shape the final pollen assemblage of each year. Without considering local drivers and phenomena in detail it is not possible to take advantage of all the temporal resolution captured in annual laminations.

The aim of this paper is to study in detail the vegetation occurring at present around Lake Montcortès and its area of influence. The next steps will be the study of pollen morphology of the more important species and habitats, and the study of present-day sedimentation patterns of these pollen types in the bottom lake sediments.

## STUDY AREA

Lake Montcortès is situated on the southern flank of the Central Pyrenees, in the Pallars Sobirà region, at 42º 19′ N, 0º 59′ E and 1027 m altitude, with a surface of 12.36 ha. The lake lies in karstic terrain characterized mainly by Triassic limestones, marls and evaporites, and Oligocene carbonatic conglomerates. Triassic ophytes outcrop mainly at the south and Quaternary lacustrine sediments surround the present-day water body (Corella *et al.*, 2011) (Fig. 1). The catchment is small and the lake is fed mainly by groundwater, with intermittent small creeks and scattered springs. The main water losses are due to evaporation and a small seasonal outlet at the north end. The lake is roughly kidney-shaped, with a diameter between 400 and 500 m and a maximum water depth of 30 m near the centre (Camps *et al.*, 1976; Modamio *et al.*, 1988). The annual average air temperature of the area is 10.6ºC, ranging from 1.9ºC in January to 20.3ºC in July. Total annual precipitation is 860 mm, with March as the driest month (46.6 mm) and May as the wettest month (99.2 mm) (Corella *et al.*, 2012).

The lake lies near the altitudinal boundary corresponding to Sub-Montane belt, which in the Pyrenees is situated around 800–1000 m elevation, depending on local conditions (Vigo & Ninot, 1987). Four major forest formations occur at the lake region, reflecting this boundary condition (Fig. 2): (1) Mediterranean sclerophyllous forests represented by *Quercus rotundifolia* Lam. woods; (2) Sub-Montane deciduous oak forests, submitted to higher precipitation, and dominated by *Quercus pubescens* Willd. and *Q. subpyrenaica* Villar; (3) conifer forests of *Pinus nigra* J. F. Arnold subsp. *salzmannii* (Dunal) Franco, usually secondary replacing the deciduous oak forests in lower and southern regions (Folch, 1981) but probably natural here (Bolòs *et al.*, 2004); and (4) higher-elevation forests of *Pinus sylvestris* L. marking the transition between Sub-Montane and Montane belts. The possibility of part of these conifer woods to have been planted should not be dismissed. The vegetation around the lake has been poorly described. A belt of littoral vegetation dominated by *Juncus*, *Scirpus*, *Phragmites*, *Typha* and *Sparganium* has been mentioned by Camps *et al.* (1976). There is also an unpublished list of plants and other organisms in studies carried out by the Confederación Hidrográfica del Ebro, which is available online (www.chebro.es).

The region is fairly populated and the lake has been historically an important water source for the numerous surrounding villages and farmhouses. There is also a project to build an artificial pond using the water of the lake for fire-fighting purposes. Cultivation (wheat, oat, barely, olives, rye, hemp and legumes) and livestock (cattle and sheep) have been also common practices during the last millennium and possibly earlier (Rull *et al.*, 2011). At present, cereal and alfalfa fields intermingled with pastures (for cattle and horses) and hay meadows are common and heavily exploited. Protection practices should be focused on controlling water extraction and livestock overexploitation, as well as on avoiding tourism overcrowding and stimulating good environmental practices. The lake area lies within some protection figures, as for example the *PEIN* (*Pla d'Espais d'Interès Natural*), the *Xarxa Natura* 2000 and the *ZEPA* (*Zona d'Especial Protecció per a les Aus*).

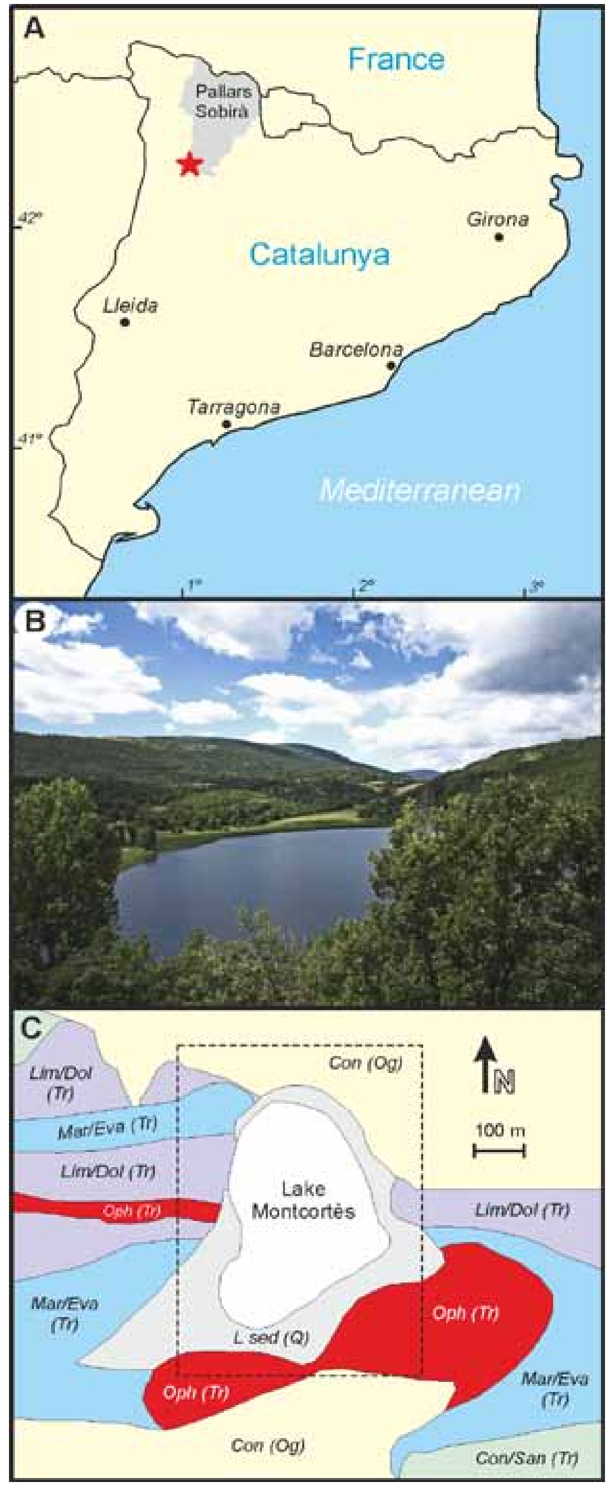


**Figure 1.** Geographical and geological setting of Lake Montcortès: (A), location map. The approximate situation of the lake is indicated by a red star; (B), general view of the lake facing south (Photograph: Q. Boix, with permission); (C), geological map. The dotted box represents the area included in this study. Lim: Limestones; Dol: Dolomies; Mar: Marls; Eva: Evaporites; Con: Conglomerates; Oph: Ophytes; Tr: Triassic; Og: Oligocene; Q: Quaternary (adapted from Corella *et al.*, 2011 and Gutiérrez *et al.*, 2012).

## METHODS

The vegetation map of Lake Montcortès was the result of a three-step progressive process, in which each step fed the next one. These phases were: (1) a detailed floristic survey of the vascular flora, (2) the

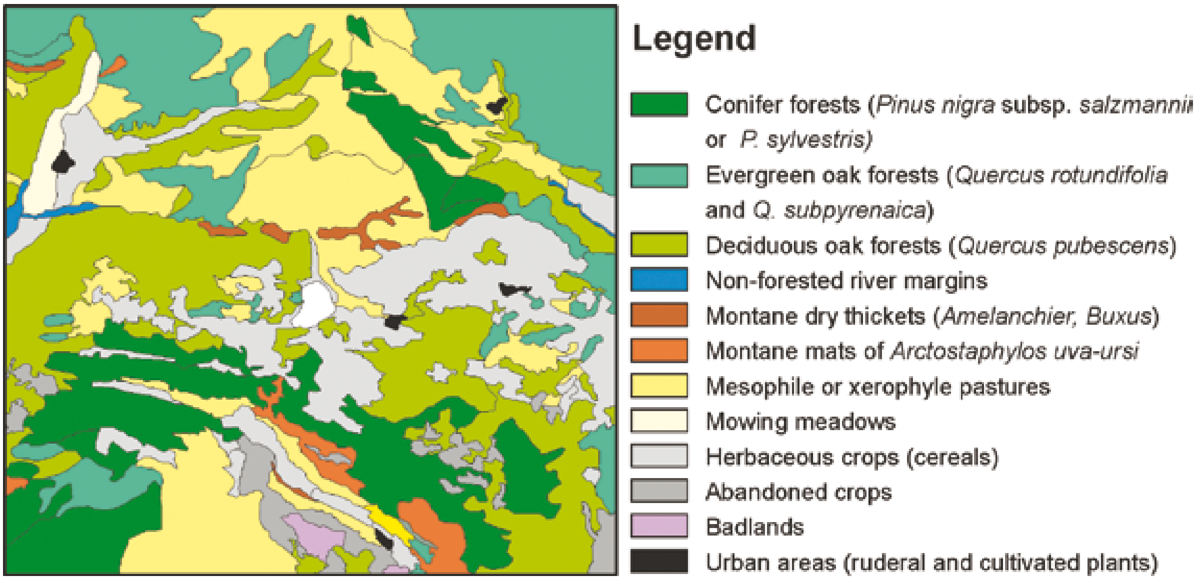


**Figure 2.** Regional vegetation map using the CORINE system (CEC, 1991). Lake Montcortès is represented as a white area in the centre. Modified from Ninot (2006) and Ferré & Carrillo (2007).

identification of plant communities or phytocoenoses present, and (3) the definition of the cartographic units in terms of vegetation habitats.

Floristic studies supply the basic information needed to develop any sound botanic or ecological study, from the analysis of species-environment relationships to the definition of the corresponding phytocoenoses and habitats, or the interpretation of landscape dynamics, a key feature in palaeoecological inference using palynology. Without a solid floristic basis, any study of this type could be seriously questioned or overruled. Unfortunately, studies without a robust floristic support are not uncommon. For this study, a rectangular area of *ca.* 48 ha around Lake Montcortès was explored in detail (Figs. 1C and 3), including the flood basin and its neighbourhood, in order to account for both the vegetation influenced directly by the lake and a representative sample of the surrounding plant communities. Fieldwork was conducted systematically during 14 months (July 2012–September 2013) to include a complete annual cycle and, therefore, the different flowering seasons of the involved species.

The resulting floristic list can be considered virtually complete but not exhaustive due to the interference of harvesting and grazing, as well as eventual peculiarities of the particular annual cycle studied, as for example flowering irregularities due to unexpected climatic oscillations. To facilitate botanical and palynological study, all species bearing flowers during our field visits were collected and deposited in the herbarium of the Botanic Institute of Barcelona (BC). All these specimens were re-analysed to confirm or change preliminary field identifications. To elaborate a floristic list as complete as possible, we have also considered previous published records, despite their scarcity and bias towards aquatic macrophytes. Identifications were based on general guides for Catalonia (Bolòs & Vigo, 1984–2001; Bolòs *et al.*, 2005) and the Iberian Peninsula (Castroviejo, 1986–2012), as well as more specific taxonomic revisions, when necessary (e.g. Kerguélen & Plonka, 1989).

Plant communities were tentatively identified in the field and referred to their corresponding habitats. These preliminary communities were then inventoried and the corresponding inventories were analysed using the sigmatist system (Braun-Blanquet, 1951; Géhu & Rivas-Martínez, 1981) to define the preliminary vegetation types or phytocoenoses. These vegetation units were used as preliminary cartographic units in a vegetation map digitalized from orthophotomaps through ArcGis v10.0 (ESRI). These preliminary units were confirmed or modified again in the field to define the final cartographic units, which were a combination of the phytocoenoses and the European CORINE habitat classification adapted for Catalonia (Vigo *et al.*, 2005–2008).

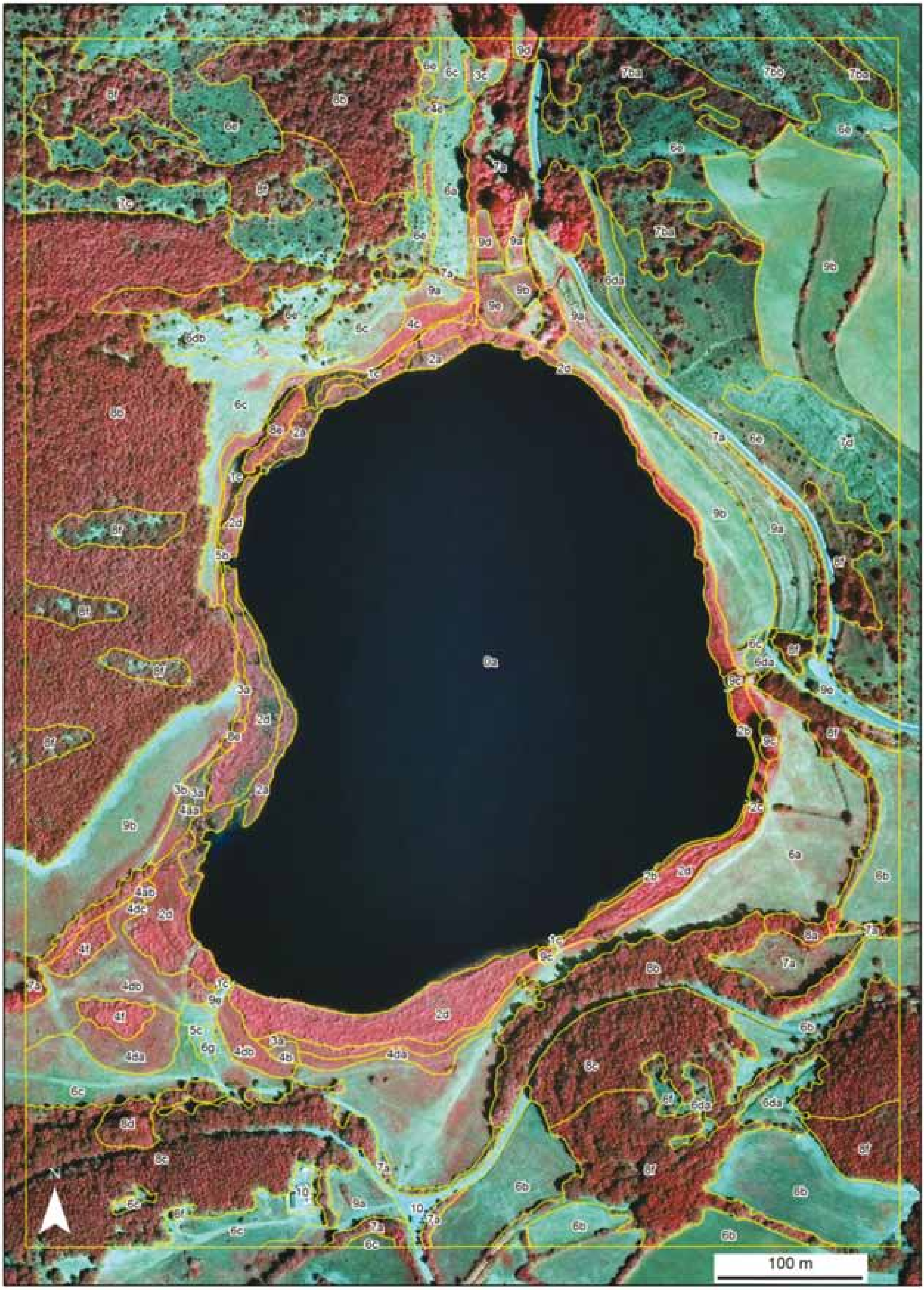


**Figure 3.** CORINE vegetation-habitat map units defined in the study area using an IRC orthophotomap. See results and Appendix for unit names and descriptions.

## RESULTS

The floristic study resulted in more than 1700 records of vascular plants including our own field observations and collections, the analysis of herbarium specimens and previously published records. Once carefully analysed, these records yielded a total of 534 species, corresponding to 291 genera and 76 families. The complete list of these taxa is beyond the objectives of the present paper and will be published separately. Concerning vegetation types, a total of 42 inventories were analysed to define 31 phytocoenoses. The combination of these plant communities and the habitats of Vigo *et al.* (2005–2008) resulted in 52 units represented by an alphanumeric code. Each of these units has an additional code, given in brackets after the name of the unit, corresponding to the general habitat classification for Catalonia (Vigo *et al.*, 2005–2008). The suffix "bis" after the code of some of these units indicates that they slightly differ from the original ones. The CORINE units, which are the legend of the map (Fig. 3), are listed below. A more detailed description of these units is provided in Appendix, in both environmental and floristic terms. Some units do not appear in the map because they correspond to submerged vegetation (1a, 1b, 1c, 1e) or because they do not attain the minimum critical size to be represented (50 m$^2$) (5a, 8x, 8y, 8z). Exceptions are units considered to be of special significance.

### Habitat-vegetation units (based on the CORINE system)

A Aquatic and semi-aquatic habitats

0 Non-marine waters
- 0a Lime-rich oligo-mesotrophic waters [22.15]

1 Submerged vegetation, sometimes with floating leaves
- 1a Formations of smaller pondweeds (*Potamogeton crispus*, *Potamogeton pectinatus*) and other submerged rooted plants (*Myriophyllum spicatum*...) [22.422]
- 1b *Chara* spp., *Nitellopsis obtusa* submerged carpets [22.441]
- 1c Formations of *Utricularia australis*, *Ranunculus trichophyllus*..., with both submerged and floating leaves of shallow waters with fluctuating water levels [22.414; 22.432]
- 1d Formations of rooted pondweeds with large floating leaves (*Potamogeton coloratus*...) [22.4314]
- 1e *Polygonum amphibium* formations, often rooted and with floating leaves [22.4315]

2 Water-fringe vegetation
- 2a *Cladium mariscus* beds [53.33]
- 2b Reedmace (*Typha domingensis*) beds [53.13]
- 2c *Iris pseudacorus* formations [53.18$^+$]
- 2d Flooded *Phragmites* beds [53.111]

B Hygrophile vegetation (of wet or inundated soils)

3 Vegetation of inundated soils
- 3a Formations dominated by *Carex riparia* in areas almost permanently flooded [53.213]
- 3b Common spikerush (*Eleocharis palustris*) beds [53.14A]
- 3c Formations occupying the banks of small rivers or springs [53.4]

4 Vegetation of always wet (or temporary flooded) soils
- 4aa Clubrush (*Scirpus lacustris*) beds [53.12]
- 4ab Formations dominated by *Juncus subnodulosus* and other rushes [52.213bis]
- 4b Brown sedge (*Carex disticha*) beds [53.211]
- 4c Subnitrophilus rush (*Juncus inflexus*) formations of hairy sedge (*Carex hirta*) swards on occasionally flooded soils [37.241; 37.242]
- 4da Calcareous purple moorgrass (*Molinia coerulea*) meadows [37.311]
- 4db Humid grasslands, similar to 44da, dominated by *Cirsium monspessulanum* [37.311]
- 4dc Humid grasslands, similar to 4da, with *Carex lepidocarpa* and other sedges [37.311]
- 4e Hygrophile rush and tall grass formations with *Scirpus holoschoenus* [37.4]
- 4f Reed beds dry for a large part of the year [53.112]

C Communities of temporarily wet or flooded soils

5a *Juncus bufonius* communities on temporarily flooded soils [22.3231]
5b Communities dominated by annual galingales (*Cyperus fuscus*) on temporarily flooded soils [22.3232]
5c Grasslands on compact impermeable soils with *Plantago serpentina* [37.5]

D Meadows, pastures and dwarf grasslands

6a Hay meadows with false oat-grass (*Arrhenatherum elatius*) [38.23]
6b Calcicolous mesophile (usually mowed) grasslands, with *Trifolium incarnatum* subsp. *molineri* [34.32611+bis]
6c Mesophile grasslands with *Filipendula vulgaris* [34.32611+]
6da Xerophile calcareous grasslands with *Festuca* gr. *ovina*, *Koeleria vallesiana*... [34.332G1+]
6db Xerophile calcareous grasslands with abundant therophytes [34.332G1+bis]
6e Calcicolous *Aphyllanthes* grasslands rich in chamaephytes [34.721]
6f Dwarf annual siliceous grasslands often on sandy soils [35.21]
6g Dwarf annual grasslands with *Poa bulbosa* on compact soils [35.21bis]

E Shrubby vegetation

7a Sub-Mediterranean blackthorn-bramble thickets [31.8122]
7ba Box formations with scattered trees [32.641+]
7bb Open box formations intermingled with *Aphyllanthes* grasslands and low scrubs [32.641+]
7c *Genista scorpius* formations [32.4811+]
7d Calcicolous open low scrubs with *Thymus vulgaris* (thyme), *Satureja montana* (winter savory), *Onobrychis hispanica*... [34.721bis]

F Forests (and forest fringes)

8a Ash forests [41.33]
8b Calcicolous white oak (*Quercus pubescens*, *Q. subpyrenaica*) woods [41.7131+]
8c Silicicolous white oak (*Quercus pubescens*, *Q. subpyrenaica*) woods [41.7132+]
8d Mesophile aspen stands [41.D4]
8e Willow shrubby formations (of *Salix atrocinerea*) [44.124]
8f Mixed forests with *Quercus rotundifolia* and *Quercus pubescens*, *Q. subpyrenaica* (white oak) [45.3416+]
8x Hems of semi-dry oak woods and related communities, often with *Coronilla varia* [34.41]
8y Hems of mesophile woods with *Trifolium medium*, *Valeriana officinalis*... [34.42]
8z Subnitrophilous shady woodland edges [37.72]

G Anthropic habitats

9a Dry or mesophile intensive pastures [81.1]
9b Dry extensive crop fields [82.33+]
9c Deciduous tree spots [84.12+]
9d Kitchen gardens [85.3]
9e Ruderal communities [87.22+]
10 Country houses [86.2bis]

## FLORISTIC AND PHYTOGEOGRAPHIC NOTES

From a floristic perspective, the better represented family is Asteraceae (15.7%) followed by Poaceae (10.4%), Papilionaceae (9%) and Cyperaceae (3.9%). Of the five pteridophytes (0.9% of the flora) recorded, only the horsetail (*Equisetum arvense* L.) is associated to aquatic environments. Overall, the Montcortès flora is comparable to those found in similar pre-Pyrenean environments (Vigo & Ninot, 1987) but the micro-environmental particularities created by the lake results in a higher floristic diversity.

Phytogeographically, the Montcortès flora is mostly a combination of Euro-Siberian and Mediterranean elements, with some differences according to the vegetation type. Euro-Siberian species prevail in forests, meadows and pastures, particularly those of meridional and sub-Mediterranean character, whereas strictly Mediterranean elements dominate in drier environments. Figure 4 shows the chorological spectrum of the Montcortès flora, at species level.

Examples of forest species of wide Euro-Siberian distribution are *Betula pendula* Roth, *Cornus san-*

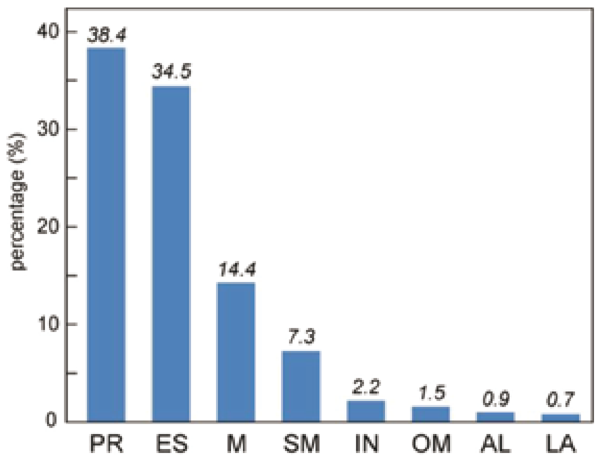


**Figure 4.** Chorological spectrum of the flora from the studied area, at species level. PR: Pluriregional; ES: Euro-Siberian; M: Mediterranean; SM: Sub-Mediterranean; IN: Introduced; OM: Oro-Mediterranean; AL: Alpine; LA: Lateatlantic.

*guinea* L., *Hepatica nobilis* Schreb., *Hieracium lachenalii* C. C. Gmel. and *Lonicera xylosteum* L., whereas *Buxus sempervirens* L., *Coronilla emerus* L., *Cytisophyllum sessilifolium* (L.) O. Lang, *Cotoneaster tomentosus* (Aiton) Lindl. and *Primula veris* L. subsp. *columnae* (Ten.) Maire & Petitmengin are more sub-Mediterranean.

Euro-Siberian elements typical of hay meadows are the Poaceae *Arrhenatherum elatius* (L.) J. Presl & C. Presl, *Avenula pubescens* (Huds.) Dumort., *Holcus lanatus* L. and *Trisetum flavescens* (L.) P. Beauv., as well as members of a varied array of other families (*Carum carvi* L., *Geranium pratense* L., *Rhinanthus minor* L. or *Rumex acetosa* L). In the mesophile pastures, the more common Euro-Siberian elements are *Briza media* L., *Carex caryophyllea* Latourr., *Cirsium acaule* (L.) Scop., *Plantago media* L. and *Trifolium montanum* L. It is worth mentioning the occurrence of species of Atlantic distribution as for example *Centaurea nigra* L. (hay meadows, mesophile pastures and forest edges) and *Pulmonaria longifolia* (Bast.) Boreau (forests).

Regarding Mediterranean elements, species such as *Catananche coerulea* L., *Lavandula latifolia* Medik., *Leuzea conifera* (L.) DC. and *Thymelaea pubescens* (L.) Meisn. dominate in the *Aphyllanthes* grasslands, while *Brachypodium retusum* (Pers.) Beauv., *Dorycnium pentaphyllum* Scop., *Helichrysum stoechas* (L.) Moench, *Santolina chamaecyparissus* L. and others grow on dry slopes and low scrubs. Species typical of high Mediterranean mountains are *Merendera montana* (L.) Lange and *Rosa sicula* Tratt.

A large part of the Montcortès flora is calcicolous due to the prevalence of calcareous substrates (Fig. 1C); however, the presence of acidic ophytes leads to the occurrence of silicicolous or acidophile species such as *Chamaespartium sagittale* (L.) P. E. Gibbs., *Danthonia decumbens* (L.) DC., *Dianthus armeria* L., *Hieracium sabaudum* L., *Trifolium arvense* L. and *Trifolium glomeratum* L.

Some currently rare arvense species, as for example *Camelina sativa* (L.) Crantz subsp. *microcarpa* (DC.) Hegi & Em. Schmid, *Caucalis platycarpos* L., *Centaurea cyanus* L., *Delphinium peregrinum* L. subsp. *verdunense* (Balb.) Cout. or *Galium tricornutum* Dandy, still thrive within cultivated fields, suggesting a limited or no use of herbicides and pesticides.

Overall, the vegetation is mostly of sub-Mediterranean character, with some Mediterranean encroachments, and spiked by azonal communities linked to the lake and other moist areas. The aquatic vegetation is fairly rich, even if we consider only the vascular plants, and is constituted by a conspicuous belt of helophytic and hygrophyle plants subdivided into four (in the more complex case), clearly distinguishable fringes (from water to land): (1) formations of *Typha domingensis* Pers. or *Cladium mariscus* (L.) Pohl [2a, 2b], (2) reedbeds of *Phragmites australis* (Cav.) Steud. [2d], (3) communities of *Carex riparia* Curtis [3a], and (4) rush formations and grasslands on sporadically flooded soils [4d]. The distribution of these fringes along the lake shore is irregular, only the second one [2d] forms a continuous belt. Besides those specified in Appendix (units 1a to 4b), other aquatic and heliophytic species worth to be mentioned are *Alisma plantago-aquatica* L. var. *lanceolatum* (With.) Kunth, *Myosostis scorpioides* L. subsp. *tuxeniana* (O. Bolòs & Vigo) O. Bolòs, Nuet & Panareda, *Oenanthe lachenalii* C. C. Gmel., *Sparganium erectum* L. and *Veronica anagallis-aquatica* L.

The assumed natural vegetation beyond the direct influence of the lake is dominated by oak forests of *Quercus pubescens* Willd., *Q. subpyrenaica* Villar (possible hybrid between the first and *Q. faginea* Lam.) and *Q. rotundifolia*. The secondary vegetation is mostly characterised by shrubland formations of box (*Buxus sempervirens* L.) scrubs and *Genista scorpius* (L.) DC., as well as pastures of Euro-Siberian (*Bromion erecti* Koch alliance) or Mediterranean (*Aphyllanthes* grasslands) character. Thickets, forest edges, wetlands and annual grasslands grow on small areas.

## FURTHER STUDIES

The next step in this study will be the palynological characterisation of the more relevant species and the initiation of a pollen reference collection. The more interesting species will be selected according to their importance in the units defined in this study combined with the results of a monthly survey of modern pollen sedimentation on the bottom of the lake using traps. These procedures will help establish qualitative and quantitative relationships among the composition of modern pollen assemblages from lake sediments, the nature and location of their potential sources, and the more influential climatic parameters. These modern-analogue studies will be used to infer eventual vegetation and environmental changes occurred in the past by analysing ancient lake sediments, using the principle of uniformitarianism (Birks & Birks, 1980).

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**Appendix**. More detailed descriptions of the CORINE habitat-vegetation units defined in this paper for Lake Montcortès and its surroundings (see results and Fig. 3).

**1a. Formations of smaller pondweeds and other submerged rooted plants**
Not studied in detail in this paper, most of the information is from previous references (Font Quer, 1928; Margalef Mir, 1981; Montserrat Martí, 1981). This unit has been found until a water depth of at least 4 m and the main components are *Myriophyllum spicatum* L., *Najas marina* L., *Potamogeton berchtoldii* Fieber, *Potamogeton crispus* L. and *Potamogeton pectinatus* L.

**1b. Charophytes submerged carpets**
Present in the lake and also in the artificial pond called Font Senta. The main species are *Chara* spp. and *Nitellopsis obtusa* (Desv.) J. Groves.

**1c. Formations of *Utricularia australis*, *Ranunculus trichophyllus*..., with both submerged and floating leaves in shallow waters with fluctuating water levels**
Restricted to the western and south-western lake shores, favoured by the occurrence of more or less extensive shallow-waters due to the flat morphology of the substrate.

**1d. Formations of rooted pondweeds with large floating leaves**
This unit has not been recognised in detail but it is largely dominated by *Potamogeton coloratus* Hornem.

**1e. *Polygonum amphibium* formations**
In the north-western side, this unit occurs inside the reeds, whereas in the southernmost part, the unit is terrestrial and develops on moist soils.

**2a. *Cladium mariscus* beds**
Discontinuously distributed along the western lake shores and co-dominated by *Cladium mariscus* (L.) Pohl and *Phragmites australis* (Cav.) Steud.

**2b. Reedmace (*Typha domingensis*) beds**
Forming a narrow fringe along the eastern lake shore, close to the reed, from which is difficult to differentiate.

**2c. *Iris pseudacorus* formations**
Only present in a patch at the eastern lake shore.

**2d. Flooded *Phragmites* beds**
Forming an almost continuous belt along the entire lake perimeter, in contact with open waters. The taxonomic composition of this unit varies slightly according to the shore topography. In the more general case of fairly gradual shores, the more common species are *Epilobium hirsutum* L., *Galium palustre* L., *Phragmites australis* (Cav.) Steud., and *Sparganium erectum* L.

**3a. Formations dominated by *Carex riparia* in permanently flooded areas**
This is the second helophytic fringe, beyond the units of group 2, and is better developed at the western and southern shores, which are those with a more gradual topography. Important components are *Agrostis stolonifera* L., *Carex riparia* Curtis, *Epilobium hirsutum* L., *Galium palustre* L., *Lythrum salicaria* L., *Mentha aquatica* L., *Phragmites australis* (Cav.) Steud., *Plantago major* L., *Poa trivialis* L. and *Ranunculus repens* L.

**3b. Common spikerush (*Eleocharis palustris*) beds**
Occasional formations occurring on some depressed zones of the north-western shore.

**3c. Formations occupying the banks of small rivers or springs**
The only patch found is situated in the northern side of the lake, close to the outlet. The unit is composed basically of *Glyceria plicata* Fr., with *Carex hirta* L., *Lycopus europaeus* L., *Mentha longifolia* (L.) Huds., *Poa trivialis* L. and *Ranunculus repens* L. Close to the Font Senta, there is a community of *Scrophularia auriculata* L subsp. *pseudoauriculata* (Sennen) O. Bolòs & Vigo of irregular appearance and not indicated in the map.

**4aa. Clubrush (*Scirpus lacustris*) beds**
Besides the small patch represented in the map, this sedge occurs here and there within the helophytic and hygrophilous vegetation, mainly in the third fringe further on the flooded *Phragmites* bed. *Scirpus lacustris* L. subsp. *tabernaemontani* (C. C. Gmel.) Syme is dominant, accompanied by *Agrostis stolonifera* L., *Carex lepidocarpa* Tausch, *Juncus articulatus* L. and *Juncus subnodulosus* Schrank.

**4ab. Formations dominated by *Juncus subnodulosus* and other rushes**
Analogous to 4aa but dominated by rushes (*Juncus subnodulosus* Schrank, *Juncus articulatus* L.). The unit contains also *Scirpus lacustris* L. subsp. *tabernaemontani* (C. C. Gmel.) Syme, *Carex riparia* Curtis, *Agrostis stolonifera* L., etc.

**4b. Brown sedge (*Carex disticha*) beds**
There is only one patch worth to be represented in the map, which develops on a small humid depression close to a *Carex riparia* community. Abundant elements are *Agrostis stolonifera* L. and *Juncus inflexus* L. together with *Festuca arundinacea* Schreb., *Galium palustre* L. and *Ranunculus acris* L.

**4c. Subnitrophilus rush (*Juncus inflexus*) formations or hairy sedge (*Carex hirta*) swards on occasionally flooded soils**
These two formations are difficult to distinguish as they are often intermingled. The patch represented in the map, to the northern end of the lake, is the more extensive and is dominated by *Carex hirta* L.

**4da, 4db and 4dc**
These three units are difficult to distinguish one from another as they occur very closely and share a number of species that are common on humid grasslands, as for example *Agrostis stolonifera* L., *Cirsium monspessulanum* (L.) Hill, *Dactylis glomerata* L., *Deschampsia media* (Gouan) Roem. & Schult., *Festuca arundinacea* Schreb., *Lythrum salicaria* L., *Lysimachia vulgaris* L., *Molinia coerulea* (L.) Moench and *Ranunculus acris* L.

**4da. Calcareous purple moorgrass (*Molinia coerulea*) meadows**
Situated within the third heliophytic fringe, further on *Carex riparia* community. Co-dominant species are *Molinia coerulea* (L.) Moench and *Deschampsia media* (Gouan) Roem. & Schult., together with *Holcus lanatus* L., *Leontodon autumnalis* L., *Mentha aquatica* L., *Potentilla reptans* L., *Succisa pratensis* Moench and *Taraxacum* "*officinale*".

**4db. Humid grasslands, similar to 4da, dominated by *Cirsium monspessulanum***
Very conspicuous communities owing to the abundance and relevance of the dominant species, especially during its flowering season. This unit is present at the lake shores, with *Phragmites australis* (Cav.) Steud. and *Galium palustre* L., and also beyond the lacustrine area, where they are intermingled with species from meadows and pastures.

**4dc. Humid grasslands, similar to 4da, with *Carex lepidocarpa* and other sedges**
Fairly diverse meadows with elements rather typical of rush beds or fens, as for example a *Triglochin palustre* L. A small spot in south-western river, not shown in the map.

**4e Hygrophile rush and tall grass formations with *Scirpus holoschoenus***
Away from the lake. Complex units with *Carex lepidocarpa* Tausch, *Carex flacca* Schreb., *Carex mairii* Coss. & Germ., *Carex panicea* L., *Cirsium monspessulanum* (L.) Hill, *Dactylorhiza elata* (Poir.) Soó subsp. *sesquipedalis* (Willd.) Soó, *Lysimachia ephemerum* L., *Scirpus holoschoenus* L. and *Tetragonolobus maritimus* (L.) Roth.

**4f. Reed beds dry for a large part of the year**
Low-diversity formations situated beyond the helophytic band of the lake, dominated by *Phragmites australis* (Cav.) Steud. accompanied by *Epilobium hirsutum* L. and *Lycopus europaeus* L. In the steeper eastern shores there is a narrow belt, adjacent to flooded reed bed, comprising—besides the dominant *Phragmites*—*Rubus caesius* L. and *Calystegia sepium* (L.) R. Br.

**5a. *Juncus bufonius* communities on temporarily flooded soils**
Not represented in the map because its contingency and small extension. This unit occurs in a patchy pattern at the western shore during lowstand and also on small depressions away from the lake, even on the pathway ruts. Common elements are *Juncus bufonius* L., *Juncus articulatus* L. and *Plantago major* L.

**5b. Communities dominated by annual galingales (*Cyperus fuscus*) on temporarily flooded soils**
Only found in the western side of the lake, more evident at the end of summer on the muddy soils emerging from the water. Common species are *Alisma plantago-aquatica* L. var. *lanceolatum* (With.) Kunth, *Cyperus fuscus* L., *Epilobium parviflorum* Schreb., *Juncus articulatus* L., *Polygonum persicaria* L., *Trifolium repens* L. and *Veronica beccabunga* L.

**5c. Grasslands on compact impermeable soils with *Plantago serpentina***
In the southern lake shore on non-flooded soils. *Centaurium pulchellum* (Sw.) Druce can be abundant temporarily.

**6a. Hay meadows with false oat-grass (*Arrhenatherum elatius*)**
Those situated at the eastern shore of the lake are rather typical and highly diverse. Significant species are *Arrhenatherum elatius* (L.) J. Presl & C. Presl, *Carum carvi* L., *Chaerophyllum aureum* L., *Dactylis glomerata* L., *Lathyrus pratensis* L., *Medicago lupulina* L., *Poa pratensis* L., *Rhinanthus minor* L., *Taraxacum* "*officinale*", *Trifolium pratense* L. and *Trisetum flavescens* (L) P. Beauv. Other meadows corresponding to this unit are less diverse and not so characteristic due to the

presence of species from pastures such as *Agrostis capillaris* L., *Anthoxanthum odoratum* L., *Centaurea scabiosa* L. or *Festuca nigrescens* Lam.

**6b. Calcicolous mesophile (usually mowed) grasslands, with *Trifolium incarnatum* subsp. *molineri***
In addition to the characteristic clover, other elements from grasslands and pastures may occur, they are: *Arrhenatherum elatius* (L.) J. Presl & C. Presl, *Avenula pubescens* (Huds.) Dumort., *Briza media* L., *Bromus erectus* Huds., *Dactylis glomerata* L., *Galium pumilum* Murray, *Festuca arundinacea* Schreb., *Onobrychis supina* (Vill.) DC., *Plantago media* L., *Poa pratensis* L., *Ranunculus bulbosus* L., *Trifolium campestre* Schreb., *Trisetum flavescens* (L.) P. Beauv. and *Vicia sativa* L. subsp. *sativa*.

**6c. Mesophile grasslands with *Filipendula vulgaris***
Homologous to the *Bromion* alliance, a montane community widely extended in the Pyrenees. The more characteristic elements are *Bromus erectus* Huds. (abundant), *Carex caryophyllea* Latourr., *Cerastium fontanum* Baumg., *Cirsium acaule* (L.) Scop., *Galium verum* L., *Onobrychis supina* (Vill.) DC., *Plantago media* L., *Potentilla neumanniana* Rchb., *Ranunculus bulbosus* L., *Salvia pratensis* L., *Trifolium montanum* L., etc.

**6da. Xerophile calcareous grasslands with *Festuca* gr. *ovina*, *Koeleria vallesiana...***
Highly-diverse dry pastures with elements common in other montane pastures from the Pyrenees (*Bromus erectus* Huds., *Salvia pratensis* L.), as well as species from truly dry areas, as for example *Centaurea alba* L., *Festuca* gr. *ovina* L., *Inula montana* L., *Koeleria vallesiana* (Honck.) Gaudin and *Odontites lanceolatus* (Gaudin) Rchb. subsp. *pyrenaeus* (Bubani) O. Bolòs. Some terophytes are also present [*Althaea hirsuta* L., *Arenaria serpyllifolia* L., *Cerastium pumilum* Curtis, *Medicago minima* (L.) L. or *Trifolium campestre* Schreb].

**6db. Xerophile calcareous grasslands with many therophytes**
Pastures similar to the preceding but less characteristic, drier and with abundant therophytes, suggesting overgrazing. Typical species are *Allium sphaerocephalon* L., *Althaea hirsuta* L., *Artemisia alba* Turra, *Brachypodium phoenicoides* (L.) Roem. & Schult., *Brachypodium retusum* (Pers.) P. Beauv., *Medicago minima* (L.) L., *Micropus erectus* L., *Plantago lanceolata* L. or *Sanguisorba minor* Scop. subsp. *polygama* (Waldst. & Kit.) Holub. Ruderal plants as for example *Carthamus lanatus* L. or *Asteriscus spinosus* (L.) Sch. Bip. are also present.

**6e. Calcicolous *Aphyllanthes* grasslands rich in chamaephytes**
Dry pastures of rather Mediterranean character. Besides the characteristic species (*Aphyllanthes monspeliensis* L.), other abundant plants are *Avenula pratensis* (L.) Dumort. subsp. *iberica* (St.-Yves) O. Bolòs & Vigo, *Carex humilis* Leyss., *Coronilla minima* L., *Festuca* gr. *ovina* L., *Globularia vulgaris* L. subsp. *willkommii* (Nyman) Wettst., *Helianthemum italicum* L., *Odontites luteus* (L.) Clairv., *Prunella laciniata* (L.) L., *Satureja montana* L., *Teucrium chamaedrys* L. subsp. *pinnatifidum* (L.) Rchb. f., *Thesium humifusum* DC. subsp. *divaricatum* (Mert. & Koch) Bonnier, *Thymelaea pubescens* (L.) Meisn., and *Thymus vulgaris* L. This community can be highly diverse depending on the environmental conditions. In some cases, these grasslands are relatively mesophile, as for example in the southern part of the lake, whereas in others they are truly dry with abundant small bushes. Colonisation by *Buxus sempervirens* L. and/or trees or forest patches is not uncommon.

**6f. Dwarf annual siliceous grasslands often on sandy soils**
They appear as small and scattered patches. Several annual acidophile plants are well represented, as is the case of *Arabidopsis thaliana* (L.) Heynh., *Filago minima* (Sm.) Pers., *Herniaria glabra* L., *Scleranthus annuus* L. subsp. *polycarpos* (L.) Bonnier & Layens, *Trifolium glomeratum* L., *Trifolium striatum* L. or *Vulpia myuros* (L.) C. C. Gmel.

**6g. Dwarf annual grasslands with *Poa bulbosa* on compacted soils**
Only in the south-western side of the lake (Prat del Comú), which is the more visited by the bathers. This unit attains its maximum development during spring, as in summer *Poa* and most of the acompanying therophytes [*Arenaria serpyllifolia* L., *Cerastium pumilum* Curtis, *Scleranthus annuus* L. subsp. *polycarpos* (L.) Bonnier & Layens, *Veronica arvensis* L.] lose their relevance or disappear. Ruderal species such as *Bromus hordeaceus* L. and *Lepidium campestre* (L.) R. Br. also occur.

**7a. Sub-Mediterranean blackthorn-bramble thickets**
Complex unit, sometimes with arboreal components, which commonly develops at the margin of pathways, forests and fields but it occurs in long-time abandoned crops, as well. Some shrubs and small trees, often thorny, are frequent (*Crataegus monogyna* Jacq., *Evonymus europaeus* L., *Ligustrum vulgare* L., *Malus sylvestris* Mill., *Prunus spinosa* L., *Prunus insititia* L., *Rosa canina* L., *Rosa rubiginosa* L., *Sorbus domestica* L.). A formerly cultivated and naturalised species, *Rosa moschata* Herrm., may be abundant sometimes.

**7ba. Box formations with scattered trees**
Occur as patches dominated by *Buxus sempervirens* L. Trees may occur in a sparse pattern or developing more dense stands. Clearings colonised by *Aphyllanthes* grasslands are also common.

**7bb. Open box formations intermingled with *Aphyllanthes* grasslands and low scrubs**
Complex unit with clusters of *Buxus sempervirens* L. more sparsely distributed than in the preceding unit. A very common unit, as in all sub-Montane belt of the Pyrenees.

**7c. *Genista scorpius* formations**
Dominated by light clusters of *Genista scorpius* (L.) DC. with intercalated herbaceous vegetation, mainly *Aphyllanthes* grasslands.

**7d. Calcicolous open low scrubs**
A drier and more diverse form of the *Aphyllanthes* grasslands (unit 6b) dominated by bushes, occurring on a steep and rocky slopes with poorly developed soils. Outstanding species are *Asperula cynanchica* L., *Avenula pratensis* (L.) Dumort. subsp. *iberica* (St.-Yves) O. Bolòs & Vigo, *Festuca* gr. *ovina* L., *Fumana procumbens* (Dunal) Gren. & Godr., *Helianthemum italicum* L., *Paronychia kapela* (Hacq.) A. Kern *subsp. serpyllifolia* (Chaix) Graebn., *Teucrium chamaedrys* L. subsp. *pinnatifidum* (L.) Rchb. f. and *Thymus vulgaris* L. Especially significant is the presence of the *Onobrychis hispanica* Širj., a legume of eastern-Iberian distribution.

**8a. Ash forests**
Only a small patch present in the study area. The unit is totally dominated by *Fraxinus excelsior* L. without any other significant tree species. Other abundant elements are *Buxus sempervirens* L., *Campanula trachelium* L., *Lonicera xylosteum* L. and *Primula veris* L. subsp. *columnae* (Ten.) Maire & Petitmengin.

**8b. Calcicolous white oak woods**
Forests analogous to the typical sub-Montane white oak forests from the central calcareous pre-Pyrenees dominated by *Quercus pubescens* Willd. and *Q. subpyrenaica* Villar. Other species are *Amelanchier ovalis* Medik., *Buxus sempervirens* L., *Cornus sanguinea* L., *Coronilla emerus* L., *Cytisophyllum sessilifolium* (L.) O. Lang, *Helleborus foetidus* L., *Hepatica nobilis* Schreb., *Lonicera xylosteum* L., *Prunus mahaleb* L., *Sorbus domestica* L., *Viburnum lantana* L. and *Viola alba* Besser. *Quercus rotundifolia* Lam. may also be present on dryer sites.

**8c. Silicicolous white oak woods**
Present only in the southern slopes around the lake, which are oriented to the north, on acidic ophytes outcrops. In the westernmost side of these forests (les Bedolleres), an understory with *Carex montana* L. is present. The easternmost side (l'Estaqueta) is drier and less acidophile. Significant species are *Buxus sempervirens* L., *Hepatica nobilis* Schreb., *Hieracium murorum* L., *Pulmonaria longifolia* (Bast.) Boreau, *Quercus pubescens* Willd., *Q. subpyrenaica* Villar and *Stachys officinalis* (L.) Trevis.

**8d. Mesophile aspen stands**
Small forests of *Populus tremula* L. distributed in sparse and light patches among other deciduous forests.

**8e. Willow shrubby formations**
Small and floristically poor formations of *Salix cinerea* L. subsp. *oleifolia* (Sm.) Macreight growing on the western lake shore.

**8f. Mixed forests with *Quercus rotundifolia* and white oak (*Quercus pubescens*, *Q. subpyrenaica)***
Irregular mixture of the dominant trees that can sometimes resemble, at least physiognomically, a typical *Quercus rotundifolia* Lam. wood. The understory is devoid of plants typical of sclerophyllous forests and the more mesophile deciduous shrubs characteristic of white oak forests are also lacking. Common non-arboreal species are *Buxus semprevirens* L., *Brachypodium phoenicoides* (L.) Roem & Schult., *Lonicera etrusca* Santi, *Prunus mahaleb* L. and *Teucrium chamaedrys* L. subsp. *pinnatifidum* (L.) Rchb. f.

**8x. Hems of semi-dry oak woods and related communities**
Poorly structured unit present along the western part of the study area, associated to the calcicolous white oak forest (unit 8b). Common species are *Coronilla varia* L., *Dianthus hyssopifolius* L., *Inula salicina* L., *Melampyrum pratense* L., *Odontites viscosa* (L.) Clairv., *Origanum vulgare* L., *Silene nutans* L., *Torilis japonica* (Houtt.) DC. and *Vicia cracca* L. subsp. *incana* (Gouan) Rouy. Not represented in the map because its small size and scarcity.

**8y. Hems of mesophile woods**
Mostly in the southern part of the catchment, in the ecotone between oak or ash forests and grasslands. Typical species of this irregular and fragmentary unit are *Knautia dipsacifolia* Kreutzer subsp. *arvernensis* (Briq.) O. Bolòs & Vigo, *Saxifraga granulata* L., *Trifolium medium* L., *Valeriana officinalis* L. and *Vicia cracca* L. subsp. *tenuifolia* (Roth) Bonnier & Layens. Not represented in the map because its small size and scarcity.

**8z. Subnitrophilous shady woodland edges**
Irregular and fragmentary herb communities. The more typical correspond to the *Chaerophyllum aureum* community, well represented along the eastern part of the study area. Other worth-mentioning species are *Geum urbanum* L., *Poa trivialis* L. and *Taraxacum* "*officinale*". Not represented in the map because its small size and scarcity.

**9a. Dry or mesophile intensive pastures**
Former pastures or abandoned crops now submitted to evident overgrazing.

**9b. Dry extensive crop fields**
Mostly cereal crops of *Hordeum distichum* L. but also an extensive alfalfa (*Medicago sativa* L.) field situated at the south-western slopes of the study area. This unit also includes fallows. Characteristic species are *Ajuga chamaepitys* (L.) Schreb., *Anthemis cotula* L., *Caucalis platycarpos* L., *Convolvulus arvensis* L., *Coronilla scorpioides* (L.) Koch, *Delphinium peregrinum* L. subsp. *verdunense* (Balb.) Cout., *Fumaria officinalis* L., *Galium tricornutum* Dandy, *Lamium amplexicaule* L., *Valerianella coronata* (L.) DC., *Valerianella rimosa* Bast., *Veronica persica* Poir., *Viola arvensis* Murray, etc. The crop fields present in the lowermost part of the lake catchment are rather ruderalized, with some nitrophilous species such as *Amaranthus retroflexus* L., *Chenopodium album* L., *Chenopodium vulvaria* L., *Chondrilla juncea* L. or *Euphorbia helioscopia* L.

**9c. Deciduous tree spots**
A hedgerow with abundant fruit trees (*Malus sylvestris* Mill., *Prunus domestica* L., *Prunus insititia* L., *Pyrus communis* L.) occurs among the hay meadows of the eastern part. In the northern sector, some riverine planted trees as for example *Populus nigra* L. 'italica' or *Salix alba* L. are also present.

**9d. Kitchen gardens**
Restricted to the northern part of the study area.

**9e. Ruderal communities**
This unit includes nitrophilous grasslands (with *Arctium minus* Bernh., *Artemisia vulgaris* L., *Galium aparine* L., *Pastinaca sativa* L., *Urtica dioica* L.), ruderal edges [with *Melilotus albus* Medik., *Melilotus officinalis* (L.) Lam., *Torilis japonica* (Houtt.) DC.] and trampled sites (with *Hordeum murinum* L., *Lolium perenne* L., *Matricaria discoidea* DC., *Polygonum* gr. *aviculare* L.).