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Epiphytic lichens of woodland habitats in the lower Ticino river valley and in the "Bosco Siro Negri" Integral Nature State Reserve (NW Italy)

Gabriele Gheza[1,2], Juri Nascimbene[1,*], Matteo Barcella[2], Francesco Bracco[2], Silvia Assini[2]

[1] BIOME Lab, Department of Biological, Geological and Environmental Sciences, Alma Mater Studiorum – University of Bologna, Via Irnerio 42, I-40126 Bologna, Italy

[2] Section of Landscape Ecology, Department of Earth and Environmental Sciences, University of Pavia, Via S. Epifanio 14, I-27100 Pavia, Italy

E-mail: gheza.gabriele@gmail.com
matteo.barcella@unipv.it
francesco.bracco@unipv.it
silviapaola.assini@unipv.it

* Corresponding author: juri.nascimbene@unibo.it

Abstract - Epiphytic lichens were surveyed in the “Bosco Siro Negri” Integral Nature State Reserve (province of Pavia, Lombardy, NW Italy), which hosts a well-preserved fragment of oak-elm floodplain forest (Natura 2000 Habitat 91F0). The core woodland fragment hosted only four species on the tree boles, i.e. *Lepraria finkii* plus the forest specialists *Coenogonium pineti*, *Diarthonis spadicea*, and *Opegrapha vermicellifera*. An additional eight nitro- and photophytic species were recorded on the highest twigs of the canopy. The whole Reserve, including the neighbouring degraded woodlands and poplar plantations, hosted 27 epiphytic lichen taxa. The lower Ticino River valley between Vigevano and Pavia, in which the Reserve is located, was surveyed for epiphytic lichens in an additional 45 sites, including 15 well-preserved oak-elm/hornbeam woodlands (Habitat 91F0), 15 degraded broadleaved woodlands with high occurrence of black locust and 15 poplar plantations. Overall, 32 species were recorded. Well-preserved woodlands had a lower species richness, but they hosted forest specialists not occurring in the other two habitats. *Graphis pulverulenta* and *Lecania cyrtellina* are new to Lombardy. *Anisomeridium polypori*, *Diarthonis spadicea*, *Lecanora expallens* and *Pseudoschismatomma rufescens* are reported from Lombardy for the second time.

Keywords: floodplain forests, Habitat 91f0, Natura 2000 Network, plantations, river parks.

Riassunto – Licheni epifiti di habitat boschivi nella bassa valle del Ticino e nella Riserva Naturale Integrale Statale "Bosco Siro Negri" (Italia nordoccidentale).

Sono stati censiti i licheni epifiti presenti nella Riserva Naturale Integrale Statale "Bosco Siro Negri" (provincia di Pavia, Lombardia, Italia nordoccidentale), che ospita un frammento ben conservato di foresta alluvionale a dominanza di farnia e olmo (Natura 2000 Habitat 91F0). Il frammento centrale del bosco ospitava sui tronchi degli alberi solamente quattro specie, cioè *Lepraria finkii* più le specialiste forestali *Coenogonium pineti*, *Diarthonis spadicea* e *Opegrapha vermicellifera*. Altre otto specie nitrofitiche e fotofitiche sono state rilevate sui rami più alti della canopea. L'intera riserva, considerando anche i boschi degradati e i pioppeti limitrofi, ospitava 27 taxa di licheni epifiti. La bassa valle del Ticino tra Vigevano e Pavia, nella quale si trova la Riserva, è stata oggetto di un'indagine per la presenza di licheni epifiti in altri 45 siti, tra i quali 15 boschi ben conservati a dominanza di farnia, olmo e/o carpino bianco (Habitat 91F0), 15 boschi di latifoglie degradati con elevata presenza di robinia e 15 pioppeti. Complessivamente, sono state registrate 32 specie. I boschi ben conservati mostravano una ricchezza specifica inferiore, ma ospitavano foresta specialiste forestali che non si trovavano negli altri due ambienti. *Graphis pulverulenta* e *Lecania cyrtellina* sono nuove per la Lombardia. *Anisomeridium polypori*, *Diarthonis spadicea*, *Lecanora expallens* e *Pseudoschismatomma rufescens* sono riportati dalla Lombardia per la seconda volta.

Parole chiave: foreste planiziali, Habitat 91F0, parchi fluviali, piantagioni, Rete Natura 2000.

INTRODUCTION

The Po Plain is the most human-impacted area of Italy: most of its surface is occupied by inhabited centers, industries, infrastructures and agricultural land, and the pollution levels are very high. All these factors contributed to a huge loss of natural habitats, which has impacted biodiversity for centuries. Due to its impacted and depleted condition, the Po Plain is the lichen-poorest area of Italy (Nimis, 1993, 2016). The Ticino River valley, which lies in the western part of the Po Plain, at the boundary between the regions of Lombardy and Piedmont, is a focal area for the protection and conservation of biodiversity: the entire river valley and the surrounding part of the plain are protected by two regional natural parks which have safeguarded natural habitats and wild species since the 1970s.

Within this landscape, the Ticino River valley is also one of the few areas where lichenological research is going on since the 19th century (Gheza *et al.*, 2019): 123 taxa were reported in the checklist by Valcuvia Passadore *et al.* (2002a, b) and additional 28 taxa were reported later (Gheza, 2018). However, the lower part of the river valley has been regarded as poorer in lichen species than the upper and middle parts (Valcuvia Passadore *et al.*, 2002a, b), and was also less investigated.

Paradoxically, even if most of the efforts in studying lichens in the Ticino River valley and surroundings were focused on epiphytic lichens (Casarini *et al.*, 1995; Zocchi *et al.*, 1997; Roella, 1999; Furlanetto *et al.*, 2000; Delucchi, 2005), woodlands were left almost completely overlooked. This happened because most studies applied the standardized method of "air quality biomonitoring" (ANPA 2001), which focused on trees outside dense woodlands. This resulted in a biased knowledge of epiphytic lichens, which did not take into account either the forest habitats with the highest naturalistic value, i.e. well-preserved woodlands attributed to Natura 2000 Habitats 9160, 91E0 and 91F0, or those with the lowest value, i.e. artificial plantations of poplars or conifers. Therefore, in recent years we focused our research on Natura 2000 Habitat 91F0, which is the most widespread forest habitat of conservation value in the lower river valley (Perracino, 2010). The importance of this habitat is increased by the fact that it hosts the last relicts of the primeval floodplain forests of the Po Plain (Tomaselli & Gentile, 1971; Sartori, 1984). A better understanding of the lichen biota of such relicts can likely improve our knowledge of the lichens occurring in the Po Plain before its anthropization.

Among the sites still hosting well-preserved woodland stands, outstanding is the "Bosco Siro Negri" Integral Nature State Reserve, donated by Giuseppe Negri to the University of Pavia in 1967. The Reserve is managed by the Department of Earth and Environmental Sciences, focusing on the maintenance of natural dynamics: no active management is allowed, in order to leave the woodland to its natural evolution (Tomaselli & Gentile, 1971; Motta *et al.*, 2009).

The main aim of this paper is to report the epiphytic lichen flora of the "Bosco Siro Negri" Reserve, since thorough lichenological studies have never been carried out in the site, in spite of its importance for the conservation of a primeval floodplain forest fragments. By extending to other sites in the surroundings of the river valley, this paper also provides deeper insights into the epiphytic lichen flora of the Natura 2000 Habitat 91F0 in the western Po Plain, also comparing it to epiphytic lichen biota of apparently similar habitats in the same area, namely degraded woodlands encroached by invasive species and poplar plantations.

MATERIALS AND METHODS

Study area

The main study site was the "Bosco Siro Negri" Integral Nature State Reserve (Fig. 1), established in 1970 within the Lombardy Ticino Regional Park (Northern Italy), which covers about 11 hectares. Historically, the Reserve has always been forested, but formerly it was managed for wood production and used as a hunting reserve. Nevertheless, it currently represents one of the best-preserved relicts of the original floodplain forest once occurring along the Ticino River, and has remained unmanaged for over six decades. The last important human disturbances coincided with the two World Wars (1910-1920 and 1940-1960), while no logging has been carried out after the establishment of the Reserve in 1970 (Motta *et al.*, 2009). The Reserve, located on the western side of the Ticino River, protects a broadleaved oak-elm woodland attributed to the Natura 2000 Habitat 91F0 ("Riparian mixed forests of *Quercus robur*, *Ulmus laevis* and *Ulmus minor*, *Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*)") in accordance with the Directive 92/43/EEC, and it is included in the EU Special Area of Conservation IT2080014 "Boschi Siro Negri e Moriano". The woodland is dense, structurally complex, and rich in biomass, as expected for a stand left unmanaged for decades. It is dominated by common oak (*Quercus robur* L.); other main tree species are elm (*Ulmus minor* Mill.), hornbeam (*Carpinus betulus* L.), poplar (*Populus alba* L.), and maple (*Acer campestre* L.); black locust (*Robinia pseudoacacia* L.) also occurs widely around the core area which hosts the best-preserved woodland fragment (Motta *et al.* 2009). The forested area was attributed to the association *Polygonato multiflori-Quercetum roboris* (Sartori, 1984). The mean annual precipitation is about 800 mm and the mean annual temperature is 13.6 °C (Pavia weather station, 10 km from the study site). Floods occur in spring and/or autumn every 5-10 years (Castagneri *et al.*, 2013). Except during such events, the groundwater level is around -2.50 m in winter, while it reaches -3.50 m during summer, being mainly influenced by the hydrometric levels of the river (unpubl. data). At the local scale, the surface is flat, but different irregularities are present, with depressions, reaching in some points 2 m in depth, opposed to bumps, resulting in an articulated general morphology (Tomaselli & Gentile, 1971). The vascular flora and vegetation of the Reserve have been studied by Tomaselli & Gentile (1971), Sartori (1984) and Motta *et al.* (2009), the bryophyte flora by Brusa (2014). The study was extended to the whole lower part of the Ticino River course (Fig. 1), an area ranging from the Municipalities of Vigevano (western side) and Motta Visconti (eastern side) to that of Pavia (Provinces of Pavia and Milan). According to Castaldini *et al.* (2019), this area is located in the physiographic unit of the Holocene Floodplain, and Castiglioni and Pellegrini (2001) attributed it to a floodplain with surface lithology characterized mainly by gravel and sand. The bioclimate is temperate (Biondi & Baldoni, 1994), with mean annual precipitation of about 900 mm/year (Navati *et al.*, 1983), lower than those recorded along the middle and higher courses of the same river (1000 and 1400 mm/year, respectively). The vegetation of the lower Ticino River valley is framed in the hygrophilous Western plain geosigmetum (Verde *et al.*, 2010), in which different plant communities are placed, from the active riverbed towards the surrounding plain. The woody vegetation farther from the active riverbed consists of communities dominated by oak and elm or hornbeam. Due to the intense human activity

(agriculture, urbanization and alteration and banking of river course), the natural vegetation of the Ticino valley is fragmented, occurring only on limited surfaces. Particularly, the primeval natural oak-elm forests are drastically reduced and often replaced by poplar plantations and/or degraded groves dominated by invasive woody species (e.g. *Robinia pseudoacacia*). Natural oak-elm/oak-hornbeam woodlands attributed to the Natura 2000 Habitat 91F0 still persist, in this area, inside two EU Special Areas of Conservation: IT2080002 "Basso Corso e Sponde del Ticino" and IT2080014 "Boschi Siro Negri e Moriano".

Surveyed sites

The "Bosco Siro Negri" Reserve was fully explored in order to obtain a complete list of epiphytic lichens. Three habitat types were considered separately: (1) the core woodland area, with the well-preserved fragment of riparian oak-elm forest (UTM WGS84 32T 504530.5006418, 62-68 m); (2) the surrounding woodlands, with a poorer environmental quality and invaded by black locust (UTM WGS84 32T 504667.5006116-504035.5005298, 63-65 m); (3) the poplar plantations nearest to the core area (UTM WGS84 32T 504105.5006285-503947.5005620, 63-64 m).
For the study of the epiphytic lichen flora of woodlands and plantations, 45 sites were selected in the lower part of the Ticino River valley, between Vigevano and the confluence with the river Po south of Pavia (Tab. 1, Fig. 1). The conceptual setting of this wider sampling was the same applied in the "Bosco Siro Negri" Reserve: epiphytic lichens were sampled in (1) broadleaved oak-hornbeam or oak-elm woodlands with good ecological continuity attributed to Habitat 91F0, (2) degraded broadleaved woodlands with high occurrence of black locust, and (3) poplar plantations.

Lichen sampling

In the "Bosco Siro Negri" Reserve the core woodland area was intensively explored and the trunks of about 100 trees were surveyed from the ground level up to 2.5 m, but also twigs and branches fallen from the canopy were collected in order to obtain information on the differences between the lichen biota occurring on trunks in the understory and those of tree crowns. In the other two habitat types, lichens were surveyed on the trunks and main branches of trees located along the main trails. Every tree species in the three habitat types was surveyed, including *Acer campestre* L., *Corylus avellana* L., *Populus nigra* L., *Populus* x *canadensis* Moench, *Quercus robur* L., *Ulmus minor* Mill., *Robinia pseudoacacia* L., *Tilia sp*.
For the study of the epiphytic lichen biota of woodlands and plantations in the lower Ticino River valley, in each selected site a 200 m long transect was randomly placed along an already existing trail crossing the woodland patch. At both ends and in the central point of the transect, epiphytic lichens were recorded on three randomly selected trees chosen at a distance of at least 10 m from the path. Nine trees per transect were sampled, for a total of 405 trees. Lichen occurrences were sampled in an area of 20 x 200 cm on the northern and southern sides of the trunks, starting from the ground level. The sampled tree species was *Quercus robur* in both the woodland types and *Populus* x *canadensis*. in poplar plantations. In addition, scattered observations on the other main trees – *Carpinus betulus* in well-preserved woodlands, *Robinia*

pseudoacacia in degraded woodlands – and on dead wood (logs, stumps) were collected and are reported in the notes to the floristic list.
In spite of the heterogeneity of the sampling methods, the gathered data provide a fairly reliable, albeit not exhaustive overview on the epiphytic lichen biota occurring in the surveyed habitats. Fieldwork was carried out in 2019. Easily recognizable species were identified in the field, while specimens of other taxa were collected and identified in the laboratory (Nimis & Martellos, 2012). All collected specimens are preserved in the personal herbarium of the senior author.
The nomenclature follows Nimis & Martellos (2020).

Characterization of the lichen biota

Spectra were computated for growth forms, photobionts, main reproduction strategy, ecological indices and poleotolerance. Data were retrieved from the database ITALIC (Nimis & Martellos, 2020).
Growth forms include leprose, crustose, squamulose, foliose and fruticose lichens. Photobionts include chlorococcoid and trentepohlioid green algae. Main reproduction strategies include sexual reproduction, asexual reproduction by means of isidia and asexual reproduction by means of soredia.
Ecological indices (see Nimis 2016) indicate ecological requirements of each species on an ordinal scale from 1 to 5 for the following features: substrate pH (1 = very acidophytic; 2 = acidophytic; 3 = acidophytic to subneutrophytic; 4 = slightly basiphytic; 5 = basiphytic), light (1 = very skiophytic; 2 = skiophytic; 3 = moderately photophytic; 4 = photophytic; 5 = very photophytic), moisture (1 = hygrophytic; 2 = rather hygrophytic; 3 = mesophytic; 4 = rather xerophytic; 5 = xerophytic) and eutrophication (1 = anitrophytic; 2 = slightly nitrophytic; 3 = rather nitrophytic; 4 = nitrophytic; 5 = very nitrophytic).
The poleotolerance index indicates the tendency of each species to occur in sites with different degrees of human disturbance on an ordinal scale from 3 to 0, as follows: 3 = species occurring also in heavily disturbed areas; 2 = species occurring also in moderately disturbed areas; 1 = species mostly occurring in natural or semi-natural habitats; 0 = species exclusive of old trees in ancient, undisturbed forests.

RESULTS

Floristic list

The complete floristic list includes 38 taxa, among which 10 never reported before from the Ticino river valley (Gheza *et al.*, 2019): *Anisomeridium polypori*, *Athallia cerinella*, *Blastenia ferruginea*, *Coenogonium pineti*, *Diarthonis spadicea*, *Graphis pulverulenta*, *Lecania cyrtellina*, *Lecanora expallens*, *Lepraria finkii*, *Pseudoschismatomma rufescens*. Furthermore, 5 taxa are new to the Padanian ecoregion (Nimis 2016; Nimis & Martellos 2020): *Anisomeridium polypori*, *Coenogonium pineti*, *Diarthonis spadicea*, *Graphis pulverulenta*, *Opegrapha vermicellifera*. *Graphis pulverulenta* and *Lecania cyrtellina* are new to Lombardy.

Anisomeridium polypori, *Diarthonis spadicea*, *Lecanora expallens* and *Pseudoschismatomma rufescens* are reported from Lombardy for the second time.
In the "Bosco Siro Negri" Reserve, 27 taxa were found: 12 in the core riparian forest fragment (2 exclusively), 24 in the surrounding woods (8 exclusively), and 12 in the surrounding poplar plantations (2 exclusively). In the core, lichen diversity is differentiated according to the position of the species on the trees: only four species, which can be considered forest specialists, have been recorded on tree boles within 2.5 m from the ground, whereas the other eight species occurred only on branches and twigs fallen from the highest part of the tree canopy. On the boles, the most widespread species is *Lepraria finkii*, followed by *Opegrapha vermicellifera*, while *Diarthonis spadicea* and *Coenogonium pineti* are much rarer, both occurring only on a few trees. In the poplar plantations, lichen diversity was higher also thanks to the scattered occurrence among the poplar lines of oak and black locust trees – which hosted some species absent from poplar trunks – while the richest habitat was represented by degraded woodlands, but in both these habitat types forest specialists were missing.
Overall, the floristic list of the lower Ticino River valley includes 32 taxa. Only 13 taxa (6 exclusively) were found within well-preserved oak-hornbeam and oak-elm woods, whereas 21 taxa (4 exclusively) were found in degraded woodlands and 18 taxa (7 exclusively) in poplar plantations.
The annotated floristic list is reported below. Species new to the Ticino River valley (Gheza *et al.*, 2019) are marked with *, species new to Lombardy are marked with **, red-listed species (Nascimbene *et al.*, 2013) are marked with #.

Amandinea punctata (Hoffm.) Coppins & Scheid.
Bosco Siro Negri: in the surrounding woodlands, on *Tilia sp.*; in poplar plantations, on *Populus sp*.

*** *Anisomeridium polypori*** (Ellis & Everh.) M.E.Barr
Site 2.10.

Arthonia radiata (Pers.) Ach.
Sites 2.03, 2.07, 3.01, 3.06, 3.14.

*** *Athallia cerinella*** (Nyl.) Arup, Frödén & Søchting
Sites 3.01, 3.02, 3.03, 3.04, 3.05.

Athallia pyracea (Ach.) Arup, Frödén & Søchting
Bosco Siro Negri: in poplar plantations, on *Populus sp*.
Sites 3.01, 3.02, 3.03, 3.04, 3.05, 3.06, 3.07, 3.08, 3.09, 3.10, 3.11, 3.12, 3.14, 3.15.

*** *Blastenia ferruginea*** (Huds.) A.Massal.
Site 3.03.

Candelaria concolor (Dicks.) Stein

Bosco Siro Negri: in the core forest fragment, only on twigs fallen to the ground from the canopy, on *Quercus robur*; in the surrounding woodlands, on *Populus nigra*, *Quercus robur*, *Robinia pseudoacacia*, *Tilia sp*.; in poplar plantations, on *Populus sp*., *Quercus robur*.
Sites 1.01, 1.02, 1.07, 1.09, 2.01, 2.02, 2.04, 2.06, 2.07, 2.08, 2.10, 2.12, 2.13, 2.14, 2.15, 3.01, 3.02, 3.03, 3.04, 3.05, 3.07, 3.09, 3.11, 3.12, 3.13, 3.15.

Candelariella reflexa (Nyl.) Lettau
Bosco Siro Negri: in the surrounding woodlands, on *Quercus robur*, *Robinia pseudoacacia*, *Tilia sp*.; in poplar plantations, on *Populus sp*., *Quercus robur*.
Sites 1.01, 1.02, 1.03, 2.01, 2.02, 2.04, 2.06, 2.07, 2.09, 2.10, 2.11, 2.13, 2.14, 3.01, 3.02, 3.04, 3.05, 3.07, 3.09, 3.11, 3.12.

Catillaria nigroclavata (Nyl.) J.Steiner
Bosco Siro Negri: in the surrounding woodlands, on *Populus sp*.; in poplar plantations, on *Populus sp*.
Sites 1.09, 2.10, 2.11, 3.01, 3.02, 3.03, 3.04, 3.05, 3.06, 3.07, 3.09, 3.10, 3.11, 3.13.

Cladonia coniocraea (Flörke) Spreng.
Bosco Siro Negri: in the surrounding woodlands, on *Quercus robur*.
Sites 1.04, 2.09.
It was often observed on stumps and logs in both well-preserved and degraded woodlands (sites 1.01, 1.02, 1.03, 1.06, 1.09, 1.10, 1.11, 2.01, 2.10).

Cladonia fimbriata (L.) Fr.
Bosco Siro Negri: in the surrounding woodlands, on *Tilia sp*.
Sites 1.02, 1.03, 1.06, 1.10, 2.14.
It was often observed on stumps and logs in both well-preserved and degraded woodlands (sites 1.01, 1.02, 1.03, 1.06, 1.09, 1.10, 1.11, 1.14, 1.15, 2.01, 2.05, 2.10).

Cladonia squamosa Hoffm.
Sites 1.01, 1.04.
It was observed also on stumps and logs (sites 1.01, 1.04).

*** *Coenogonium pineti*** (Ach.) Lücking & Lumbsch
Bosco Siro Negri: in the core forest fragment, on *Quercus robur*.
Sites 2.01, 2.05.

 # *Diarthonis spadicea (Leight.) Frisch, Ertz, Coppins & P.F.Cannon
Bosco Siro Negri: in the core forest fragment, on *Quercus robur*.
Sites 1.01, 1.02, 1.05, 1.09, 1.10, 1.13.

Flavoparmelia caperata (L.) Hale
Bosco Siro Negri: in poplar plantations, on *Quercus robur*.

** ***Graphis pulverulenta*** (Pers.) Ach.
Site 1.09.
This species is uncommon on oak, but it was observed more frequently in well-preserved woodlands on *Carpinus betulus* (sites 1.02, 1.03, 1.07, 1.09, 1.10).

Hyperphyscia adglutinata (Flörke) H. Mayrhofer & Poelt
Bosco Siro Negri: in the core forest fragment, only on twigs fallen to the ground from the canopy, on *Quercus robur*; in the surrounding woodlands, on *Quercus robur*; in poplar plantations, on *Populus sp*.
Sites 2.02, 2.05, 2.06, 2.07, 2.08, 2.10, 2.12, 2.13, 2.15, 3.02, 3.04, 3.05, 3.09, 3.11, 3.12.

Lecania cyrtella (Ach.) Th. Fr.
Sites 3.01, 3.02, 3.03, 3.04, 3.05, 3.06, 3.07, 3.08, 3.10, 3.13, 3.14, 3.15.

** ***Lecania cyrtellina*** (Nyl.) Sandst.
Sites 3.02, 3.05, 3.06, 3.10, 3.11, 3.14.

Lecania naegelii (Hepp) Diederich & van den Boom
Sites 3.10.

Lecanora chlarotera Nyl.
Bosco Siro Negri: in the core forest fragment, only on twigs fallen to the ground from the canopy, on *Quercus robur*; in the surrounding woodlands, on *Quercus robur*; in poplar plantations, on *Populus sp*.
Sites 2.07, 2.10, 3.02, 3.05, 3.11, 3.12, 3.15.

* ***Lecanora expallens*** Ach.
Bosco Siro Negri: in the surrounding woodlands, on *Quercus robur*, *Robinia pseudoacacia*, *Tilia sp*.
Sites 1.02, 1.03, 1.05, 1.06, 1.08, 1.09, 2.01, 2.02, 2.03, 2.04, 2.05, 2.06, 2.07, 2.08, 2.10, 2.11, 2.13, 2.14.

Lecidella elaeochroma (Ach.) M.Choisy
Bosco Siro Negri: in the core forest fragment, only on twigs fallen to the ground from the canopy, on *Quercus robur*; in the surrounding woodlands, on *Quercus robur*, *Robinia pseudoacacia*.
Sites 2.12, 3.01, 3.03, 3.14, 3.15.

* ***Lepraria finkii*** (B. de Lesd.) R.C.Harris
Bosco Siro Negri: in the core forest fragment, on *Acer campestre*, *Corylus avellana*, *Quercus robur*, *Robinia pseudoacacia*, *Ulmus minor*; in the surrounding woodlands, on *Populus nigra*, *Quercus robur*.
Sites 1.01, 1.02, 1.03, 1.04, 1.05, 1.06, 1.07, 1.08, 1.09, 1.10, 1.11, 1.12, 1.13, 1.14, 1.15, 2.01, 2.04, 2.05, 2.08, 2.09, 2.10, 2.11, 2.13, 2.15.

Melanelixia subaurifera (Nyl.) O. Blanco, A. Crespo, Divakar, Essl., D. Hawksw. & Lumbsch
Bosco Siro Negri: in the surrounding woodlands, on *Quercus robur*.

Myriolecis hagenii (Ach.) Sliwa, Zhao Xin & Lumbsch
Sites 3.01, 3.03, 3.04, 3.05, 3.06, 3.08, 3.10, 3.11, 3.12, 3.13, 3.14.

Normandina pulchella (Borrer) Nyl.
Site 1.03.
Observed also on logs (Site 1.03).

Opegrapha vermicellifera (Kunze) J.R.Laundon
Bosco Siro Negri: in the core forest fragment, on *Acer campestre*, *Corylus avellana*, *Populus nigra*, *Quercus robur*, *Robinia pseudoacacia*, *Ulmus minor*; in the surrounding woodlands, on *Populus nigra*, *Quercus robur*.
Sites 1.06, 1.07, 1.08, 1.09, 1.10, 1.11, 1.12, 1.14, 1.15, 2.01, 2.04, 2.08, 2.10, 2.15.
Fertile specimens were observed in a few well-preserved woodlands (Bosco Siro Negri core woodland and sites 1.07, 1.12, 1.14, 1.15).

Parmelia sulcata Taylor
Bosco Siro Negri: in the core forest fragment, only on twigs fallen to the ground from the canopy, on *Quercus robur*; in the surrounding woodlands, on *Quercus robur*, *Tilia sp*.
Sites 2.10, 2.12.

Parmelina tiliacea (Hoffm.) Hale
Bosco Siro Negri: in the surrounding woodlands, on *Quercus robur*.

Parmotrema perlatum (Ach.) M. Choisy
Bosco Siro Negri: in the surrounding woodlands, on *Quercus robur*.

Phaeophyscia orbicularis (Neck.) Moberg
Bosco Siro Negri: in the surrounding woodlands, on *Populus sp*.; in poplar plantations, on *Populus sp*.
Sites 2.07, 2.11, 2.12, 2.15, 3.01, 3.03, 3.05, 3.07, 3.08, 3.09, 3.10, 3.11, 3.12, 3.14, 3.15.

Phlyctis argena (Spreng.) Flot.
Bosco Siro Negri: in the surrounding woodlands, on *Robinia pseudoacacia*.

Physcia adscendens H. Olivier
Bosco Siro Negri: in the core forest fragment, only on twigs fallen to the ground from the canopy, on *Quercus robur*; in the surrounding woodlands, on *Populus nigra*, *Quercus robur*, *Robinia pseudoacacia*, *Tilia sp*.; in poplar plantations, on *Populus sp*., *Quercus robur*.
Sites 2.02, 2.04, 2.05, 2.06, 2.07, 2.08, 2.10, 2.12, 2.13, 2.14, 3.01, 3.02, 3.03, 3.04, 3.05, 3.06, 3.07, 3.08, 3.09, 3.10, 3.11, 3.12, 3.13, 3.14, 3.15.

Physconia grisea (Lam.) Poelt
Bosco Siro Negri: in the core forest fragment, only on twigs fallen to the ground from the canopy, on *Quercus robur*; in the surrounding woodlands, on *Populus sp*., *Robinia pseudoacacia*, *Tilia sp*.; in poplar plantations, on *Quercus robur*.
Sites 2.10, 2.12, 3.09, 3.11.

*** *Pseudoschismatomma rufescens*** (Pers.) Ertz & Tehler
Bosco Siro Negri: in the surrounding woodlands, on *Quercus robur*, *Robinia pseudoacacia*; in poplar plantations, on *Quercus robur*, *Robinia pseudoacacia*.
Sites 1.04, 1.05, 1.06, 1.08, 1.10, 1.11, 1.13, 1.14, 2.01, 2.02, 2.03, 2.06, 2.07, 2.10, 2.13, 2.14, 2.15.
Observed frequently in well-preserved woodlands also on *Carpinus betulus* (sites 1.01, 1.03, 1.04, 1.06, 1.07, 1.09, 1.10, 1.11, 1.12, 1.13, 1.14, 1.15) and less frequently in degraded woodlands on *Robinia pseudoacacia* (sites 2.04, 2.07, 2.08, 2.09, 2.13).

Punctelia subrudecta (Nyl.) Krog
Bosco Siro Negri: in the surrounding woodlands, on *Quercus robur*, *Tilia sp*.
Site 2.07.

Xanthoria parietina (L.) Th. Fr.
Bosco Siro Negri: in the core forest fragment, only on twigs fallen to the ground from the canopy, on *Quercus robur*; in the surrounding woodlands, on *Populus sp*., *Quercus robur*, *Robinia pseudoacacia*, *Tilia sp*.; in poplar plantations, on *Populus sp*.
Sites 2.02, 2.06, 2.07, 2.10, 2.11, 2.12, 2.13, 2.15, 3.01, 3.02, 3.03, 3.04, 3.05, 3.06, 3.07, 3.08, 3.09, 3.10, 3.11, 3.12, 3.13, 3.14, 3.15.

Characterization of the lichen biota

Spectra referred to growth forms, photobionts, reproduction strategy, ecological indices (substrate pH, light, moisture, eutrophication) and poleotolerance are reported in Tab. 2.
In the "Bosco Siro Negri" the distinction of the lichen biota across the three habitat types is quite clear for all the considered features. Only leprose and crustose species occur in the core woodland area, while growth forms are more differentiated in the surrounding woodlands and poorer again, but with a different pattern, in the poplar plantations. Species with a trentepohlioid photobiont dominate in the core woodland, while they decrease in the surrounding woodlands and are completely missing in poplar plantations; there, only species with chlorococcoid photobionts occur. The dominant reproduction strategy is mainly sexual in the core woodland, mainly asexual by means of soredia in the other two habitat types. The core woodland hosts more acidophytic, moderately skiophytic, hygrophytic to mesophytic and anitrophytic species, whereas poplar plantations host mainly subneutrophytic, photophytic, mesophytic to slightly xerophytic and moderately to strongly nitrophytic species. Poleophobic species are more represented in the core woodland, whereas poleotolerant species dominate in poplar plantations. Degraded woodlands show mostly an intermediate situation.

In the three habitats surveyed in the lower Ticino River valley, the situation is overall similar, except for growth forms and photobionts. In fact, growth forms are more differentiated in well-preserved woodlands, while they decrease to only two – crustose and foliose – in poplar plantations. The most represented photobiont is always chlorococcoid, but the percentage of species with trentepohlioid algae decreases evidently from well-preserved woodlands to poplar plantations. Reproduction strategies are more differentiated in well-preserved woodlands, and asexual reproduction dominates in both woodland types, whereas in poplar plantations species which reproduce mainly sexually dominate the spectrum. Well-preserved woodlands host more acidophytic, moderately skiophytic, hygrophytic to mesophytic and anitrophytic species, whereas poplar plantations host mainly subneutrophytic, photophytic, xerophytic and moderately to strongly nitrophytic species. Poleophobic species are more represented in well-preserved woodlands, while poleotolerant species dominate in poplar plantations. Degraded woodlands always show an intermediate situation, and are richer in species than both well-preserved woodlands and poplar plantations.

DISCUSSION

Lichens of the "Bosco Siro Negri" Integral Nature State Reserve

Within the core of the "Bosco Siro Negri" Integral Reserve, only four epiphytic lichen species were found on the boles: *Lepraria finkii* and *Opegrapha vermicellifera* were the most widespread, while *Diarthonis spadicea* and *Coenogonium pineti* were much rarer. Three of them can be considered forest specialists, being anitrophytic, moderately skiophytic and mesophytic, whereas *L. finkii* has a slightly broader ecological amplitude. An additional eight nitro- and photophytic species were recorded on twigs fallen to the ground from the canopy, indicating that ecological conditions are very different between the understory and the canopies. This probably happens because the forest fragment is very small, and, even being able to maintain forest-like conditions in the understory, it is not large enough to do the same in the crowns, which are influenced by the surrounding agricultural landscape.

This situation is overall similar to that reported by Härdtle *et al.* (1996) from oak-elm forests in the Elbe floodplain, where the most frequent species were *Lepraria incana* (L.) Ach. on the trunks and *Lecanora conizaeoides* Cromb. on the lower branches, generally being the only occurring species. Furthermore, Härdtle *et al.* (1996) also reported the occurrence of photo- and nitrophytic species (i.e. *Amandinea punctata*, *Parmelia sulcata*, *Physcia adscendens*, *Physcia tenella* (Scop.) DC., *Phaeophyscia orbicularis*, *Polycauliona candelaria* (L.) Frödén, Arup & Søchting) in the crown twigs, but they found there also more interesting species (i.e. *Platismatia glauca* (L.) W.L. Culb. & C.F. Culb., *Pseudevernia furfuracea* (L.) Zopf), which did not occur in our study area, probably due to both the different climate and the severely compromised lichenological situation of the Po Plain (cf. Nimis, 1993).

The species recorded in the surrounding woodlands and poplar plantations are generally common and widespread in the Ticino river valley (Valcuvia Passadore, 2002a, b; Gheza *et al.*, 2019) and, in most cases, in the whole Po Plain (Nimis & Martellos, 2020).

In short, the situation recorded in the "Bosco Siro Negri" Reserve is representative on a smaller scale of the same situation existing on a larger scale in the rest of the lower Ticino River valley (see next paragraphs).

Lichens of woodlands and plantations in the lower Ticino River valley

Woodlands with higher naturality were poorer in species, but overall hosted rarer species and often forest specialists. Habitat 91F0 is considered poor in lichen species of conservation concern in Italy (Nascimbene *et al.*, 2013); indeed, the only red-listed species recorded in this survey was *Diarthonis spadicea*, which was assessed as NT (near-threatened) by Nascimbene *et al.* (2013). *Lepraria finkii* was the most widespread and abundant species in well-preserved woodlands. A lichen community dominated by *Lepraria spp*. (*Leprarietum incanae* James, Hawksworth & Rose 1977) is often the "climax" epiphytic lichen community in dense and old oak-dominated woods, since the high cover of the canopy and the shrubs of the understory foster the transition of epiphytic communities toward this skio- and hygrophitic association (Prigodina Lukošienė & Naujalis, 2006). However, where habitat quality is high and environmental conditions are stable and favourable to typical species, also communities dominated by *Opegrapha vermicellifera* or *Diarthonis spadicea* can last (Bricaud, 2010; Van Haluwyn, 2010). The former is typical of old, dense, shaded forests, where it develops in moist sites protected from direct rainfall (Berger & Türk, 1995; Berger & Priemetzhofer, 2010; Bricaud, 2010). The latter is typical of moist old forests, well-lit but without direct irradiation (Van Haluwyn, 2010). Such communities have been generally reported as developing in the lowermost parts of the boles, or even being limited to the roots (Berger & Türk, 1995; Berger & Priemetzhofer, 2010; Van Haluwyn, 2010), but in our study area they occurred in some cases up to 2.5 m from the ground. Lichen communities recorded in degraded woodlands and poplar plantations can be referred to *Parmelion* and *Xanthorion* respectively (ANPA 2001) and have a low conservation value.

Overall, there was a clear pattern in growth forms, photobiont and ecology gradually changing from well-preserved woodlands to poplar plantations. Woodlands were more diverse in both growth forms and photobionts, while in poplar plantations the situation was poorer and more homogeneous. Species with a trentepohlioid photobiont were more abundant, even dominating the epiphytic community in some cases, in well-preserved woodlands. This is due to the fact that such woodlands have a higher cover of the canopy, and trentepohlioid algae have their photosynthetic optimum in shaded, moist and warm conditions (Jüriado & Paal, 2019). However, lichens with a trentepohlioid photobiont are rare in areas with intensive land use (Stofer *et al.*, 2006), and this is probably the reason for their low overall richness in the study area. On the other hand, they are expected to increase their range and become more widespread due to the rising temperatures of climate change, as reported from the Netherlands for some species recorded also by us, i.e. *Anisomeridium polypori*, *Coenogonium pineti*, and *Diarthonis spadicea* (Aptroot & van Herk, 2007).

The communities of well-preserved woodlands were less photophytic, more hygrophytic and anitrophytic, whereas the communities of poplar plantations were strongly photophytic, xerophytic and nitrophytic, the communities of degraded woodlands having an intermediate ecology. The communities of well-preserved woodlands were also more acidophytic, since the

bark pH of *Quercus* is acidic, whereas the bark of *Populus* is subneutral and in plantations its pH is often even higher due to eutrophication caused by atmospheric deposition from neighbouring agricultural areas (ANPA, 2001). Also in this case, the degraded woodlands stood in an intermediate situation, being more open than well-preserved woodlands but more closed than plantations. This situation results in a few forest specialists being limited to well-preserved woodlands, with degraded woodlands hosting a richer lichen biota due to their intermediate conditions and poplar plantations hosting chiefly generalist, pioneer and fast-developing species.

Noteworthy species

Diarthonis spadicea and *Opegrapha vermicellifera* are the two most interesting species among those found in well-preserved woodlands. *Diarthonis spadicea*, the only red-listed species (NT) (Nascimbene *et al.*, 2013), is an indicator of good habitat quality and ecological continuity in broadleaved woodlands dominated by *Quercus robur*, also considered an old-growth indicator by some authors (Printzen *et al.*, 2002; Ikauniece *et al.*, 2012; Moisejevs, 2016; Štikāne *et al.*, 2017). The only previous record from Lombardy dates back to the middle of the 19th century from the hills surrounding Como (Anzi, 1860). *Opegrapha vermicellifera* is considered an indicator of primeval lowland forests (Czyżewska & Cieśliński, 2003; Wieczorek, 2018) and of good ecological continuity in broadleaved forests as well (Bricaud, 2010). It seems to be bound to stands located near rivercourses (Nimis, 1993). In some sites, always in well-preserved stands, the species was found fertile, which is rare and likely to imply a good environmental quality (Wieczorek, 2018). The only two previous records from Lombardy are recent, from the upper Ticino river valley (Valcuvia Passadore *et al.*, 2002a, b) and Bosco della Fontana (Valcuvia Passadore & Truzzi, 2008). In the study area, both these species occurred only in well-preserved, dense oak woodlands, often near to the main rivercourse of the Ticino, to its secondary canals or to oxbow lakes. Their occurrence can be considered as a further confirmation of a relatively good quality of those woodland stands.
Graphis pulverulenta, recorded as well in such woodlands, was never reported before from Lombardy, since the citation reported by Nimis (2016) is likely due to a misinterpretation of the map by Neuwirth & Aptroot (2011), who actually reported the species from Piedmont and not from Lombardy, as inferrable from the text. Since the species has been confirmed only recently as separated from *Graphis scripta* (L.) Ach. (Neuwirth & Aptroot, 2011), some older records of the latter could instead be referred to *Graphis pulverulenta* (see Gheza *et al.*, 2019), which occurs also in the upper river valley (Gheza, unpubl. data).
Anisomeridium polypori and *Coenogonium pineti* are the two most interesting species among those found only or mainly in degraded woodlands. *Anisomeridium polypori* was reported before only once from Lombardy, based on a herbarium specimen collected in the Adamello Natural Park (UPS-L-166802, cited by Nimis, 2016). The record reported here widens its range in the region down to the lowlands. *Coenogonium pineti* was found not only in low-quality groves, but also in the well-preserved core woodland of "Bosco Siro Negri". In spite of having been reported rarely from Lombardy (Anzi, 1860; Stizenberger, 1882; Gheza, 2018), this species is probably more widespread not only in the woodlands of the Ticino River valley, but also in the whole region, but it can be easily overlooked when sterile. Similarly, also *Lecanora*

expallens, reported previously only once from Lombardy (Stofer, 2006), was found in several study sites, especially in open woodlands, suggesting that it can be more widespread in the whole region.
Pseudoschismatomma rufescens occurred quite frequently in both woodland types, and occurred also in some poplar plantations, but never on poplar, therefore only when the plantations hosted rows of different tree species (i.e. *Quercus robur*, *Robinia pseudoacacia*). The only previous record of this species in Lombardy dates back to the early 1900s from the surroundings of the upper Ticino River valley (Cozzi, 1917). In some forests of central Europe this species is even rarer than *Diarthonis spadicea* (Cieśliński, 2000); however, in Italy it is not considered a species of conservation concern and was not assessed in the Red List (Nascimbene *et al*., 2013). Based on recent collections in the Orobic Prealps (Gheza, unpubl. data), also this species is probably more widespread in broadleaved forests of Lombardy, from the lowlands to the montane belt.
The poplar plantations hosted chiefly common and widespread species, but one of them, *Lecania cyrtellina*, had never been reported before from Lombardy. This species can be easily confused with the very similar *Lecania cyrtella*, which is widespread in poplar plantations; this suggests that perhaps also *L. cyrtellina* can be more widespread, at least in this synanthropic habitat. Similarly, also *Lecania naegelii*, in spite of having been reported rarely from Lombardy (Anzi, 1860; Valcuvia Passadore *et al.*, 2002a, b), could be more widespread.
Lepraria finkii was the only *Lepraria* species recorded, and it was frequently occurring and abundant in well-preserved woodlands, but also quite frequently occurring in degraded woodlands. The high occurrence of this species, the fact that *Lepraria incana* was never found during these and other recent surveys in the river valley (Gheza, unpubl. data), and the fact that in literature records of *L. incana* from the same area TLC was never mentioned (therefore probably never used), suggest that most, if not all, of the old records of *L. incana* from the same area should probably be assigned to this species. More in general, all literature records of "*Lepraria incana*" from the Po Plain not based on TLC analyses should be verified, since this species has a narrower ecological amplitude and poleotolerance than *L. finkii* (Nimis, 2016), the study of secondary metabolites being indispensable to identify *Lepraria* species with certainty (Baruffo *et al.*, 2006). This question deserves to be studied more deeply.

CONCLUSIONS

This research provided a first insight into the epiphytic lichen biota of the relict floodplain forest of the Po Plain and an accurate description of the lichens of the "Bosco Siro Negri" Integral Nature State Reserve, which is one of the best preserved remains of it. It is also a contribution to better understand relations between epiphytic lichens and Natura 2000 Habitats, which is an overlooked topic in Italy, unlike in other European countries (e.g. Moisejevs, 2016). Furthermore, we showed that also synanthropic habitats with little environmental value, like poplar plantations, can be interesting for floristic research, hosting previously unreported species.
Overall, the need for basic floristic research on the lichens of the Po Plain is highlighted by the fact that 10 taxa out of 38 (26% of the surveyed species) were never reported before from a well-studied area like the Ticino river valley, and species which are probably not rare in the

whole of Lombardy (e.g. *Coenogonium pineti*, *Lecania naegelii*, *Lecanora expallens*, *Pseudoschismatomma rufescens*) have been reported only very rarely in the previous literature, in spite of the fact that this region is to date one of the richest in both lichenological papers and reported lichen taxa in Italy (Nimis, 2016). This highlights that new field investigations in unexplored or overlooked areas are crucial to widen knowledge of lichen biota and to get recent and reliable data which can be useful from the perspective of a first critical checklist of the lichen flora of Lombardy. Checklists can be a precious tool to plan both further investigations and conservation actions (e.g. Gheza *et al.*, 2021).

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Figure 1. The study area, corresponding to the lower Ticino River valley. The “Bosco Siro Negri” Integral Nature State Reserve is indicated with a black star, the 15 well-preserved woodlands with white stars, the 15 degraded woodlands with white triangles and the 15 poplar plantations with white circles. Patches of vegetation attributed to Habitat 91F0 are highlighted with a vertical line pattern. / L'area di studio, corrispondente alla bassa valle del Ticino. La Riserva Naturale Integrale Statale "Bosco Siro Negri" è indicata con una stella nera, i 15 boschi ben conservati con stelle bianche, i 15 boschi degradati con triangoli bianchi e i 15 pioppeti con cerchi bianchi. Le aree di vegetazione attribuite all'Habitat 91F0 sono evidenziate con una trama a linee verticali.

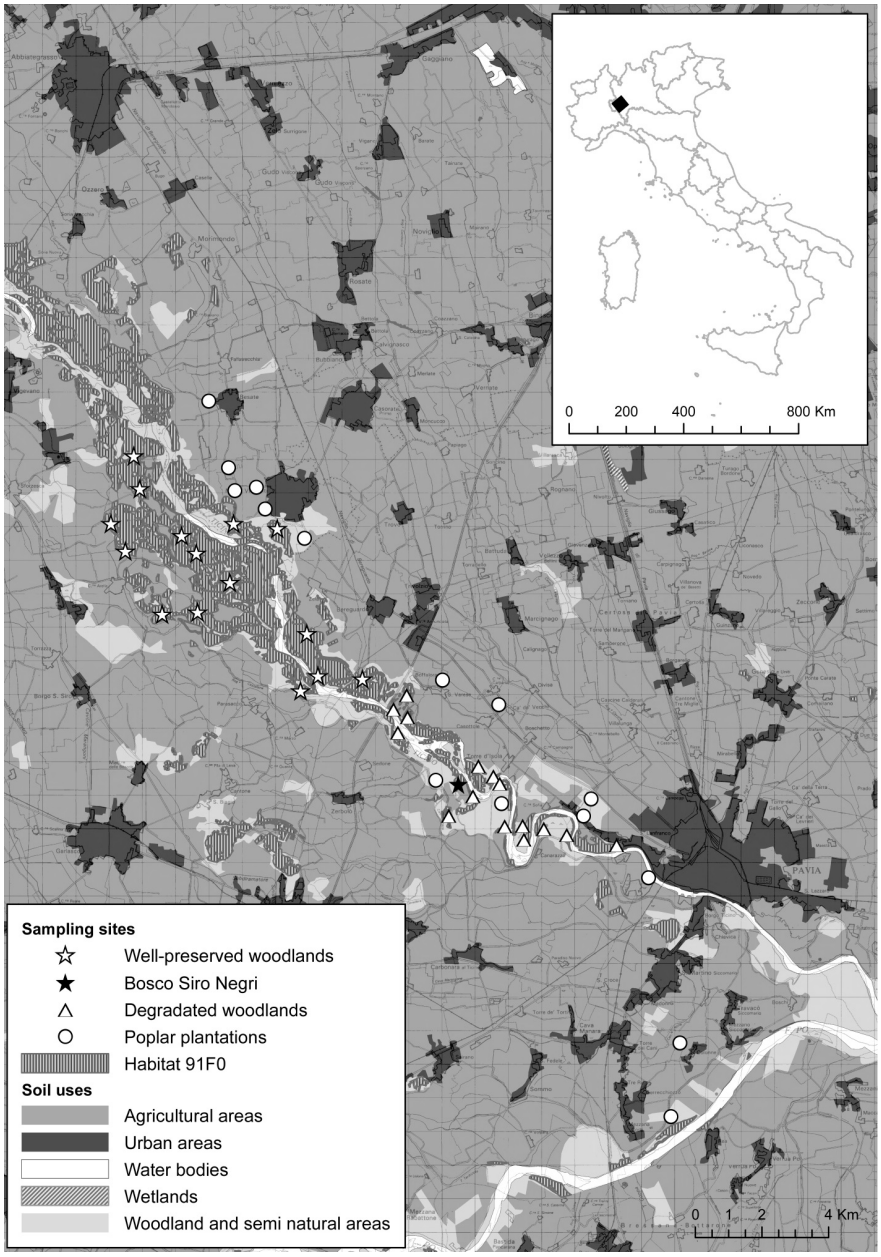

Table 1. The 45 sites in which epiphytic lichens were surveyed. Site number, locality, municipality, coordinates (UTM WGS84 system, zone 32T) and mean altitude above the sea level are reported.

1. Broadleaved oak-hornbeam or oak-elm woodlands with good ecological continuity attributed to Habitat 91F0.				
1.01	Bosco del Modrone	Vigevano	494715.5016086	83 m
1.02	Bosco del Modrone	Vigevano	494895.5015109	81 m
1.03	Bosco della Ghisolfa	Vigevano	494030.5014075	84 m
1.04	San Rossore	Motta Visconti	497721.5014075	86 m
1.05	I Geraci	Motta Visconti	499032.5013926	75 m
1.06	Bosco Ronchi	Vigevano	496159.5013714	80 m
1.07	Cascina Baracca	Gambolò	494465.5013254	88 m
1.08	Bosco Ronchi	Gambolò	496600.5013191	78 m
1.09	Bosco del Castagnolo	Borgo San Siro	497605.5012319	81 m
1.10	Bosco del Castagnolo	Borgo San Siro	496636.5011436	87 m
1.11	Bosco del Castagnolo	Borgo San Siro	495575.5011370	91 m
1.12	Cascine Orsine	Bereguardo	499923.5010794	73 m
1.13	Ponte di Barche	Bereguardo	499731.5009098	70 m
1.14	Ponte di Barche	Bereguardo	500254.5009542	72 m
1.15	Road between Bereguardo and Ponte di Barche	Bereguardo	501590.5009443	68 m
2. Degraded broadleaved woodlands with high occurrence of black locust.				
2.01	Vigna del Pero	Bereguardo	502915.5008920	67 m
2.02	Vigna del Pero	Bereguardo	502518.5008503	66 m
2.03	Vigna del Pero	Bereguardo	502945.5008266	66 m
2.04	Between Ponte di Barche and Bosco Siro Negri	Zerbolò	502655.5007807	65 m
2.05	Near the Spiaggia sul Ticino	Torre d'Isola	505076.5006807	68 m
2.06	Near the Spiaggia sul Ticino	Torre d'Isola	505529.5006508	65 m
2.07	Bosco del Mezzanone	Carbonara Ticino	505716.5006288	62 m
2.08	Surroundings of Bosco Siro Negri	Zerbolò	504912.5005913	64 m
2.09	Surroundings of Bosco Siro Negri	Zerbolò	504183.5005330	65 m
2.10	Cascina Santa Sofia	Torre d'Isola	506408.5005035	63 m
2.11	Bosco del Mezzanone	Carbonara Ticino	505865.5005021	62 m
2.12	Canarazzo	Carbonara Ticino	507044.5004945	62 m
2.13	Canarazzo	Carbonara Ticino	507729.5004759	62 m
2.14	Cascina Santa Sofia	Torre d'Isola	506445.5004623	63 m
2.15	Massaua	Pavia	509226.5004459	59 m
3. Poplar plantations.				
3.01	Besate	Motta Visconti	496979.5017710	92 m
3.02	Outskirts of Motta Visconti	Motta Visconti	497571.5015730	102 m
3.03	Outskirts of Motta Visconti	Motta Visconti	498405.5015147	100 m
3.04	Outskirts of Motta Visconti	Motta Visconti	497759.5015045	100 m
3.05	Outskirts of Motta Visconti	Motta Visconti	498669.5014503	99 m

3.06	Outskirts of Motta Visconti	Motta Visconti	499851.5013626	97 m
3.07	Vigna del Pero	Bereguardo	503996.5009411	89 m
3.08	Casottole	Torre d'Isola	505693.5008679	89 m
3.09	Surroundings of Bosco Siro Negri	Zerbolò	503795.5006428	65 m
3.10	Massaua	Pavia	508467.5005871	86 m
3.11	Bosco del Mezzanone	Carbonara Ticino	505779.5005734	63 m
3.12	Massaua	Pavia	508239.5005366	84 m
3.13	Lido di Pavia	Pavia	510194.5003526	61 m
3.14	Near the confluence between Ticino and Po	Cava Manara	511133.4998614	61 m
3.15	Near the confluence between Ticino and Po	Mezzana Corti	510865.4996420	63 m

Table 2. Spectra referred to growth forms, photobionts, sexual strategy, ecological (substrate pH, light, moisture, eutrophication) and poleotolerance indices. The first three columns report data from "Bosco Siro Negri" (1: core woodland; 2: surrounding woodlands; 3: poplar plantations), the last three report data from the 45 sites surveyed in the study area (1: well-preserved woodlands; 2: degraded woodlands; 3: poplar plantations). In the core woodland of "Bosco Siro Negri" only the species recorded on the boles have been considered, for uniformity with the other habitats, in which lichens on twigs and branches were not surveyed.

	Bosco Siro Negri			**Lower Ticino river valley**		
	1	**2**	**3**	**1**	**2**	**3**
Number of species	4	24	12	13	21	18
Growth form						
Leprose	25%	4%	–	8%	5%	–
Crustose	75%	38%	42%	54%	48%	67%
Squamulose	–	–	–	8%	–	–
Foliose	–	50%	58%	8%	38%	33%
Fruticose	–	4%	–	23%	10%	–
Photobiont						
Chlorococcoid green alga	25%	92%	100%	69%	76%	94%
Trentepohlioid green alga	75%	8%	–	31%	24%	6%
Reproduction						
Sexual by spores	75%	29%	42%	38%	43%	67%
Asexual by soredia	25%	67%	58%	54%	57%	33%
Asexual by isidia	–	4%	–	8%	–	–
Substrate pH						
1	25%	25%	8%	23%	19%	–
2	100%	83%	58%	85%	76%	56%
3	100%	83%	100%	85%	95%	100%
4	25%	42%	67%	23%	43%	56%
5	–	13%	25%	–	14%	22%
Light						
1	–	–	–	–	–	–
2	75%	13%	–	31%	19%	–
3	100%	75%	42%	77%	95%	33%
4	25%	88%	100%	62%	81%	67%
5	–	46%	83%	16%	48%	83%
Moisture						
1	75%	8%	–	23%	14%	–
2	100%	46%	–	77%	52%	11%
3	75%	92%	100%	85%	86%	100%
4	–	33%	67%	8%	33%	67%
5	–	29%	–	–	5%	11%
Eutrophication						

1	100%	50%	8%	77%	52%	17%
2	100%	67%	42%	77%	62%	56%
3	–	75%	100%	38%	71%	100%
4	–	42%	83%	16%	43%	67%
5	–	29%	58%	16%	33%	39%
Poleotolerance						
0	25%	–	–	8%	–	–
1	75%	100%	100%	92%	100%	100%
2	50%	92%	100%	69%	86%	100%
3	25%	58%	75%	23%	62%	72%