Syntaxonomical and ecological characterization of two main alien forest communities: *Robinia pseudoacacia* and *Ailanthus altissima* at their southern limit in Europe

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Al mio Babbo Luciano, che mi ha insegnato l'amore per la natura.
A mia cognata Simonetta, che mi ha insegnato l'amore per lo studio.

To my father Luciano, the one who made me love nature.
To my sister-in-law Simonetta, the one who taught me the love of knowledge.

Abstract

The biological invasions by plant taxa are recognized as one of the main threats to biodiversity, ecosystem services, human health and economy. This research focuses on *Robinia pseudoacacia* and *Ailanthus altissima,* two invasive alien tree species, that are widely distributed in Europe and reaches in Italy the southern limit of distribution with a high potential of diffusion. Both species have pioneer characteristics that let them outcompete native species and form dense populations that could be considered as proper forests. Although *A. altissima* and *R. pseudoacacia* wide expansion all over Europe and Italy, the threats they impose on native ecosystems and their hypothetical floristic-vegetational autonomy there is a significant lack of knowledge on the ecological behaviour and floristic-vegetational composition in their southern limit of distribution, such as central-southern Italy in sub-Mediterranean and Mediterranean areas. Even if there are some ecological studies in continental Europe, ecological and floristic-vegetational studies of syntaxonomical nature are insufficient. The aims of this research are to broaden the knowledge on these two invasive alien forests presents in central-southern Italy and in the European context, from an ecological and syntaxonomical point of view. The study was carried out in the peri-Adriatic sector of central Italy at altitudes between 10 m a.s.l. and 460 m a.s.l, in a Macrobioclimate ranging from Mediterranean to the Temperate sub- Mediterranean variant. We performed phytosociological relevés and sampling of ecological parameters in *R. pseudoacacia* and *A. altissima* forests and in representative and neighbouring native forests that act as elements of comparison and control. Through the comparison to the other central and southern European syntaxa we described 4 new associations (*Melisso altissimae-Robinietum pseudoacaciae, Rubio peregrinae-Robinietum pseudoacaciae, Asparago acutifolii-Ailanthetum altissimae, and Aro italici-Ailanthetum altissimae*) that belong to the newly describe alliance *Lauro nobilis-Robinion pseudoacaciae*, included in the *Robinietea* class. The new alliance *Lauro nobilis–Robinion pseudoacaciae* brings together the naturalized and invasive alien neoformation forests and pre-forest that are dominated by *R. pseudoacacia* and have developed in the Mediterranean territories of the Adriatic sector of central Italy and extends into the temperate macroclimate of the sub-Mediterranean variant. In comparison to the other central and southern European alliances is differentiated by the contingent of Mediterranean species, which testify its belonging to the typically Mediterranean biogeographic, bioclimatic and landscape context. We assessed also altered ecological characteristics in paired comparison with native forests. For *R. pseudoacacia* forests we highlighted that in lower invaded sites (% coverage from 1 to 25%) there is a significant difference in term of the presence of nitrophilous and alien species, Shannon index and changes in Ellenberg indicator values in respect to the *Q. pubescens* forests of the habitat 91AA*. In *A. altissima* forests we found that there is a shift in herbaceous layer richness in comparison to the neighboring native forests, with a higher presence of annual ruderal herbs and the absence of herbaceous species linked to the forest environment. Moreover, there is a significant difference in term of total nitrogen, total carbon, and C/N ratio in the soil. The characterization of these alien coenoses at the ecological, bio-geographic, syntaxonomical and landscape levels is an important starting point to understand and manage these novel forest ecosystems.

Keywords invasive alien tree species; Mediterranean and sub-Mediterranean areas; *Robinietea* class; EU habitat directive

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Part I Research background

Chapter 1. Research context

1.1 An introduction to invasive alien species

Nowadays human activities have grown to become significant geological forces that are reshaping the global biogeography through land-use changes, fossil fuel burning that leads to profound modifications in physical, chemical and biological features of ecosystems (Crutzen, 2006). The current geological epoch could be defined "Anthropocene" and one of its main characteristics are human-mediated biological invasions that "consists of a species' acquiring a competitive advantage following the disappearance of natural obstacles to its proliferation, which allows it to spread rapidly and to conquer novel areas within recipient ecosystems in which it becomes a dominant population" (Valéry et al., 2008). Human mediated disturbances (White and Pickett, 1985), such as intensive agriculture or agricultural abandonment (Malandra et al., 2018,2019), commercial transports, pollution, soil degradation etc., are the main causes of vegetation dynamics. There are different types of vegetation dynamics defined as secondary successions, dynamics linked to the opening of gaps in a continuous vegetation cover, regression dynamics and invasion dynamics (Van der Maaler, 1996). In this sense, anthropic disturbances that lead to the alteration of ecosystems and consequently to a high probability of invasion by naturalized alien species (Invasion dynamics) has been deepened (Lambdon et al., 2008). To get an idea of the quantification of this phenomenon, nowadays 3,7% of all currently known vascular plants species on Earth have become naturalized outside their natural range (Alien species) because of human activities (Van Kleunen et al., 2015), 3749 Naturalized alien plant species were recorded in Europe (Lambdon et al., 2008), 791 Alien plant species taxa are currently established in Italy (570 naturalized, 221 invasive) correspond to 9,6% of the native flora (Galasso et al., 2018) and 83 out of 132 Habitat (Dir. 92/43/EEC) are subjected to some degree of impact by alien plants (Lazzaro et al., 2019; 2020). Invasive alien species (hereafter IAS) are characterized by morphological, phenological, physiological and ecological features that improve their competitive behaviour in respect to native species. Those characteristics along with a high habitat invasibility of the native ecosystems (Lonsdale, 1999) could lead to a certain level of impact on the resident ecosystems to the complete substitution of some areas (Falcucci et al., 2007). In a global context of climatic change, alien vascular plants are predicted to increase their presence in Europe through 2050 by 24% (Seebens et al., 2020). Moreover, transition areas between the Mediterranean areas and the Euro-Siberian regions (e.g. central Italy) are of crucial importance, because we expect the greatest alterations in terms of biodiversity (disappearance of native species and entry of new species) (Thuiller et al., 2005).

1.1.1. Anthropocene and biological invasions

In the current geological era, the human activities have a so significant impact that scientists introduced the "Anthropocene" term to define the era in which humans and our societies have become a global geophysical force (Steffen, et al., 2007). Is the era in which the physical, chemical and biological characteristics of the terrestrial environment are strongly influenced both locally and globally by the action of humans. (Crutzen, 2006). It began with the industrialization period, around 1800, when the use of fossil fuels underwent a strong expansion and started the commercial globalization process (Steffen et al., 2007). It is not a case that the beginning of the increment rates of biological invasions (Lambdon et al., 2008) precisely overlap with the beginning of the Anthropocene era (Figure1). In fact, one defining feature of the Anthropocene is the erosion of biogeographical barriers by human-mediated dispersal of species into new regions, where they can naturalize and cause ecological, economic and social damage (van Kleunen et al., 2015, Kueffer, 2017).
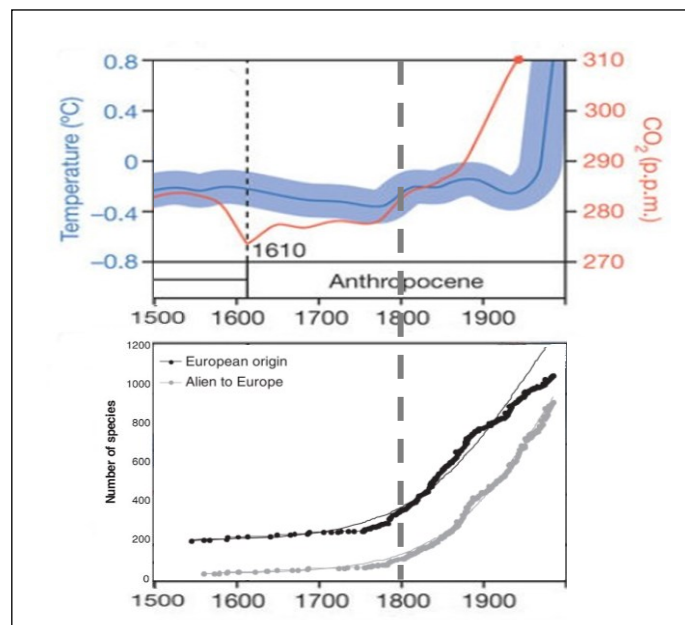
Figure 1 Comparison between the beginning of the Anthropocene era and the number of species recorded as alien to at least one European country, in relation to their introduction date. Modified from Lewis et al., 2015 and Lambdon et al., 2008)

The human activities on biological invasions make this phenomenon global and totally unprecedented, with a greater frequency and a higher number of species. On a global scale, the geographical barriers that once played an essential role in the separation between different species now have a nil effect. Furthermore, the temporal frequency of episodic biological invasion events becomes continuous (Ricciardi et al., 2006). This phenomenon comprehends different taxa such as

amphibians, birds, fishes, fungi, mammals, reptiles, invertebrates and plants. One of the most studied taxa in invasion ecology is terrestrial plants, due to the global scale of the process and the severe impacts that are determined in a wide range of native ecosystems and ecosystem services.

1.1.2. Alien plant species: definitions

As reported by Carlo Linneo "*Nomina si nescis, perit et congnitio rerum*" that means "if I don't know the name of something, knowledge also dies" is crucial to have precise definitions of the terms used in invasion ecology to have robust generalizations in this field of research. Here I report the widely accepted definitions in the scientific literature that deal with biological invasions applied to plant taxa: (Richardson et al., 2000; Pyšek et al., 2004; Walther et al., 2009; Mandák and Pysek, 1998)

- Biological invasion: "a species' acquiring a competitive advantage following the disappearance of natural obstacles to its proliferation, which allows it to spread rapidly and to conquer novel areas within recipient ecosystems in which it becomes a dominant population" (Valery et al.,2008)

- Alien plants: Plant taxa in a given area whose presence is due to intentional or accidental introduction as a result of human activity (synonyms: exotic plants, non-native plants; nonindigenous plants).

- Neophytes: Term used in Europe to define those Alien plants introduced after 1492

- Archeophytes: Term used in Europe to define those Alien plants introduced before 1492

- Naturalized plants: Alien plants that reproduce consistently and sustain populations over many life cycles without direct intervention by humans (or in spite of human intervention); they often recruit offspring freely, usually close to adult plants, and do not necessarily invade natural, seminatural or human-made ecosystems.

- Invasive plants: Naturalized plants that produce reproductive offspring, often in very large numbers, at considerable distances from parent plants ; > 6 m/3 years for taxa spreading by roots, (approximate scales: > 100 m; < 50 years for taxa spreading by seeds and other propagules, rhizomes, stolon, or creeping stems), and thus have the potential to spread over a considerable area

- Transformers: A subset of invasive plants which change the character, condition, form or nature of ecosystems over a substantial area relative to the extent of that ecosystem.

1.1.3.Invasion ecology: the invasion process

Following the given definitions of alien plant species, we can describe the invasion process as a step-based process in which non-native species must pass through at least three stages (barriers) before they are able to inflict ecological or economic harm. All non-native plant species were originally picked up from their native range and transported to a new area becoming "Alien" species (Transport). If these individuals are able to establish a self-sustaining population in the non-native can be called Naturalized (or casual) species (Establishment). These established non-native populations may expand their geographic range and spread over a larger area (Spread). Only when the non-native population is widespread and abundant in the new area and be able to cause ecological or economic harm could be defined as "invasive." Passing between each of these stages requires overcoming several ecological barriers, or problems that need to be overcome. Those could be geographical barriers (intercontinental and/or infra-continental; approximate scale: > 100 km; Environmental barriers (abiotic and biotic) at the site of introduction; Reproduction barriers (prevention of the production of vegetative and/or generative offspring); Local/regional dispersal barriers; Environmental barriers in human-modified, alien-dominated, natural or seminatural vegetation (Richardson et al., 2000; Lockwood et al., 2013; Heger and Trepl, 2003)
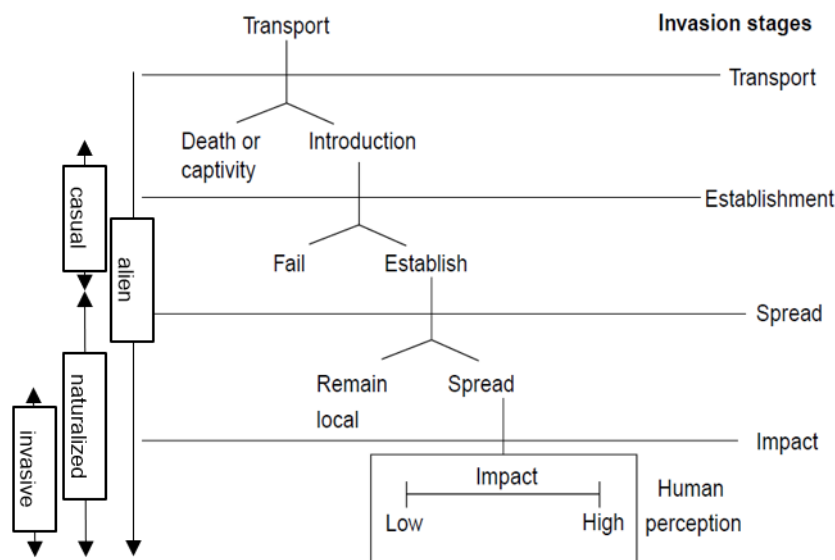
Figure 2 the invasion process. Modified from Lockwood et al., 2013

The barriers that set the stages in the invasion process assure for two important outcomes: learning about how only some species are capable to pass those barriers give essential information to understand the process; the inverse-pyramidal structure of the invasion process let only a small number of species to pass the successive barriers and cause a certain level of impact. It has to be said that considering also the "population" level could be highlighted interesting aspects of the invasion

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process: two populations of an alien plant species that have successfully passed through all the barriers and that have been transported to a variety of different places may become invasive in one area (affecting native biota) and non-invasive in another (Cabra-Rivas et al., 2016). The invasion process is a complex scheme in which play an essential role not only in the characteristics or traits of the alien taxa but also in some extrinsic forces that determine their "success" such as predation, competition, parasitism, other interactions between individuals of different species and climatic/environmental parameters. The invasion process model tries to simplify and explain a complex system in which some forces modifies the effect of the other. Moreover, human actions enter the invasion process at different levels. Humans begin the invasion process by purposefully transporting individuals beyond their natural range limits; can facilitate the geographic range expansion of an established non-native population (e.g. Lemke et al., 2019); strengthen the barriers between invasion stages through the use of eradication techniques or through socio-political actions that regulate the transportation of non-native species (e.g. Sitzia et al., 2015) causes a human-mediated disturbance that is the main trigger to habitat invasion (one side) and habitat invasibility (another side) (e.g. Brown and Peet, 2003).

1.1.4. Identikit of the perfect invader: main characteristics

Invasion is possible and endangers the existing mosaic of species and communities, where neophytes may become invasive because they migrate at such a fast rate that their primary competitors and other negative influences, such as pathogens, stay behind. Alien species that become invasive have specific characteristics or traits that let them pass the barriers and outcompete native species. Those traits could be divided according to different aspects of the ecology, physiology and genetic of the invader (Sukopp, 1998; Heger and Trepl, 2003; Liao et al., 2021). **Reproduction and biology of distribution:** The presence of an early capacity to reproduce (short juvenile period) that is a rapid flowering following a vegetative phase. Frequently is found a self-compatibility and if the species is cross-pollinated, then has a non-specific pollinator or is wind-pollinated. Those species are capable of seed production under a wide range of environmental conditions (with a particularly large seed production under favorable conditions) and a continuous high reproductive capacity (production of many propagules with a rapid seedling growth). The seeds are usually very resistant and long-lived with the capacity to build up seed or create a diaspore bank. Regarding the fruit and seed morphology is found to have shapes suitable for extensive distribution by wind and animals including man.

Vegetative growth and phenology: IAS present fast exploitation of resources because of large photosynthesis and respiration capacity and this led to very rapid growth. Often are able to exploit large Nitrogen supply and have a very flexible distribution of assimilates. If alien species are

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perennial, we found a marked vegetative reproduction because are able to regenerate from lower nodes and roots with a generally short and simple growth cycle.

Genetic characteristics: The scientific research on the genetics of IAS highlight some converging traits in different species that are invasive outside their native range. Is found a large genetic variability with the frequent presence of polyploidy and hybrids; a very flexible genetic system; thus, alterations of recombination rates possible and are frequently phylogenetically young groups.

Population dynamics and ecological characteristics: Those traits are the main causes of a successful competition against native species or ecosystems. Frequently IAS are Generalists, that can vegetate and reproduce in a broad climatic and edaphic range. They have a large acclimation potential and often are phenotypically plastic (e.g. Granata et al., 2019). This can increase the ecological potential to thrive in newly invaded sites. Alien population increase rapidly due to a high growth rate and early, as well as large, reproductive capacity (r – Strategy). The highly competitive character is due to specific features such as rosette form, parasitic growth, allelopathy, or fast and vigorous growth.

1.1.5. Concept of disturbance and habitat invasibility

Researching why an area is more prone to species invasion than another is not to simply make sure if it has more alien species, but to research why it is intrinsically more susceptible to invasion. The characteristics of the alien species itself are not enough to describe the invasion process because they must overlap with "habitat invisibility" concept (Chytry et al., 2005; Lonsdale, 1999; Touza et al., 2008). There are several elements that determine a high habitat invasibility such as the presence of a **disturbance** that modifies the equilibrium of the habitat. "A disturbance is a relatively discrete event over time that disrupts the ecosystem, the community or the structure of the population and modifies the resources, the availability of substrate or physical environment" (White and Pickett, 1985). Each disturbance is characterized by a specific "Regime". The regime of a disturbance depends on the Space-Time scale at which it acts (extension/area and return time), on the Intensity of the disturbance, i.e. the quantification of the entity of the disturbance itself (high or low intensity events), and on the typology such as is Natural or Anthropic (e.g. floods, pests outbreaks, windstorms, or determined by human activities such as fire, biological invasions, urbanization) (Łaska 2001). Even the presence of unused resources is a disturbance element. Whenever there is an increase in the number of unused resources, a plant community becomes more susceptible to invasion (Grime, 1974; Davis et al., 2000). This determines changes to the local climate, soil, structure of vegetation, the competitive characteristics of native species of a given habitat. The disturbance can consequently decrease the resilience of native species, their ability to recover after a disturbance. This process allows the

establishment of vegetation dynamics mechanisms such as Secondary succession, Gap dynamics, Regression and **Habitat invasion** (Van der Maaler, 1996). The second important point that contributes to habitat invasibility is the presence of environments suitable for establishing and reproduction defined as **available ecological niches** for alien taxa (e.g. Camenen et al., 2016). The third point is the massive presence of propagules, that is, a high quantity of seeds or reproductive elements of the alien species (**propagule pressure**). In the context of the current globalization, the propagule diffusion is facilitated by the presence of man-made communication routes e.g. roads, railways, communication routes, human settlements, river environments. This can cause high propagule pressure on native ecosystems (Chytry et al., 2009).

1.1.6. The numbers of invasion

From a global scale to a national scale the invasion by alien plant species is an increasing phenomenon of worrying dimensions. On a global scale, 3,7% of all currently known vascular plants species on Earth have become naturalized outside their natural range because of human activities (Van Kleunen et al., 2015). In Europe 3749 Naturalized alien plant species are currently recorded (Lambdon et al., 2008). In Italy, 791 alien plant species taxa are currently established of which 570 are naturalized and 221 invasives, corresponding to 9,6% of the national native flora (Galasso et al., 2018). Regarding the Italian habitat, 83 out of 132 Habitat (Dir. 92/43/EEC) are subjected to some degree of impact by alien plants. *Ailanthus altissima, Robinia pseudoacacia, Senecio inaequidens, Amorpha fruticosa*, and *Carpobrotus edulis* were the most frequent invaders (Lazzaro et al., 2019;2020). At the Italian national level, the most affected regions are those most densely populated and industrialized in the internal sectors of northern Italy. According to Galasso et al., 2018 there are 1597 alien taxa in Italy, divided between random, invasive, extinct, dubious. Considering the percentage of alien species out of the number of native species, 19,5% of the Italian flora is constituted by alien taxa. The most invaded administrative regions have an average of 20% of the regional flora constituted by alien plant species. The Italian islands are in a very critical situation because they are between the most invaded regions and are more susceptible to invasion (due to geographic isolation and the high presence of endemic species). The species invasion is a phenomenon linked to the industrialization and globalization of the economy (Scherer-Lorenzen et al., 2000; Lambdon et al., 2008; Schulze et al., 2016). In Europe, almost 50% of alien species arrived after 1899 the year of the industrial revolution that marks the beginning of extra-national and transcontinental trade. 25% of the alien species arrived after 1962 and 10% after 1990. The annual entry rate in Europe is 6.2 alien species per year. This is due to an increasing information availability about IAS and the beginning of scientific studies on this topic. In the context of climate change, we expect that in the near future there will be significant

modifications of the invasion by alien species. The scientific community has raised these problems. Bellard et al. (2013) make a prediction to 20150 and 20100, under various scenarios of climate change, on how invasiveness of different taxa will change. For terrestrial plant species, a sharp increase is expected, as is roughly for all other taxa.

1.1.7. Impacts of IAS: from biodiversity loss to economic damage

This global phenomenon can cause severe impacts on different aspects of ecosystems and human society. On a global level, the most invaded continents and at the same time donors of IAS are North America, Europe, Asia and Oceania (van Kleunen et al., 2015). If we compare the map of the global biodiversity hot-spots (sites of high importance for biodiversity conservation) (Meyers et al., 2000) and the map of the global distribution of alien species (Dawson et al., 2017) we can see that there is a sort of overlap between the areas with the highest biodiversity (with the priority of protection) and the areas most invaded by alien taxa. Italy is a striking example of this dangerous coexistence for conservation. The question arises: are IAS a danger to nature? And the answer is yes, because for example in Europe and the number of alien species exceeds the extinct species and 5-25% of the flora of Central Europe can be allochthonous, in cities it reaches about 50%.

The main negative ecological effects of invasive species are (Braat and ten Brink et al., 2008)
- **Competition** with other organisms: causing changes to habitat structure (e.g. *Fallopia japonica* or *Hercleum mantegazzianum*)
- **Predation** on native organisms: causing significant population declines.
- **Hybridization** with a related species or varieties. E.g.: *Spartina alterniflora* which hybridized with the European *Spartina maritima* and produced the very invasive hybrid *Spartina anglica* which has radically changed coastal mudflat habitats.
- **Toxicity**: toxic algae blooms are caused by alien phytoplankton such as *Chattonella verruculosa*
- **Disrupting pollination**: *Impatiens glandulifera* competes for pollinators with the native riverbank species, and so reduces seed set in these other plants.
- **Altering energy and nutrient flows**: alien plants, such as *Robinia pseudoacacia* alter nutrient availability via nitrogen-fixing.
- **Altering the composition and functioning** habitats and ecosystems: *Eichhornia crassipes* changes water flow by overgrowing and blocking water bodies.
- **Extinction** of native species resulting from the effects above.

IAS not only can cause severe impacts on biodiversity and ecosystem services but can cause important effects from an economic point of view. The global economic impact by IAS has been estimated at approximately € 13,000 million, of which 4 million represented by terrestrial species (Kettunen et al., 2009). An important dimension of these impacts is the massive economic losses suffered by our societies such as consumption of crops (Charles and Dukes, 2008) degradation of infrastructures (Shwiff et al., 2010) decreasing business activities (Lockwood et al., 2019), loss of income (Selk et al., 2014) Management efforts aimed at prevention, control and eradication of invaders represent additional, often substantial expenditures for human societies (Simberloff et al., 2013; Jackson, 2015; Courchamp et al., 2017).

1.1.8.Legislative instruments for IAS management: European and Italian context

The United Nations (UN) has issued the Global Goals for Sustainable development to be achieved by 2030 (UN General Assembly, 2015). Goal number 15 "Life on Heart" in its sub-objective number 8 foresees by 2030, to introduce measures to prevent the introduction of different and invasive species as well as substantially reduce their impact on terrestrial and aquatic ecosystems and control or eradicate the priority species. The European Union promoted the establishment of the "green deal", according to which the European nations have agreed to have an action plan with substantial investments to plan and implement actions aimed at protecting biodiversity and limiting climate change effects by 2050. This strategy aims to make the Union's economic development sustainable. One of the main fruits of the "green deal" is the "European strategy for biodiversity" (European Commission, 2020) which in point 2.10 sees a chapter dedicated to IAS (Addressing invasive alien species): "Invasive alien species can significantly undermine efforts to protect and restore nature. Besides inflicting major damage to nature and the economy, many invasive alien species also facilitate the outbreak and spread of infectious diseases, posing a threat to humans and wildlife. The rate of release of IAS has increased in recent years. Of the 1,872 species now considered threatened in Europe, 354 are under threat from IAS. Without effective control measures, the rate of invasion and the risks it brings to our nature and health will continue to rise.

1.1.9. Focus: EU Regulation 1143/2014 on IAS and other important frameworks

The Regulation (EU) No 1143/2014 of 22 October 2014 (European Commission, 2014) was published in the Official Journal of the European Union on 4 November 2014. This is the **EU Regulation on Invasive Alien Species** and aims to minimize, and where possible eliminate, the introduction and establishment of alien species in the EU environment. It also aims to manage

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established invasive alien species and **decrease the number of Red List species they threaten by 50%".** One of the main assumptions upon which the regulation is based is that «invasive alien species generally cause damage to ecosystems and reduce the resilience of those ecosystems. Therefore, proportionate restoration measures should be undertaken to strengthen the ecosystems' resilience towards invasions, to repair the damage caused and to enhance the conservation status of species and their habitats with Directives 92/43/EEC and 2009/147/EC». The regulation introduces new definitions of IAS that goes beyond the simple ecological aspects and considers also the impacts they cause defining "invasive alien species […] threaten or adversely impact upon biodiversity and related ecosystem services" and "invasive alien species **of Union concern** […] adverse impact has been deemed such as to require concerted action at Union level". Defining IAS according to their impacts a risk assessment procedure is implemented to identify and list IAS that fall into precise parameters. If one species exerts significant impacts in all the territory of the EU an opinion is expressed and regulations are issued indicating which alien species must be included in the "List of alien species of Union Concern" and the actions that each nation of the European Union must implement for control or eradication are listed. To date, three regulations have been issued that have updated this list for a total of 66 species of which 23 plant species and 26 animal species.:

- Commission Implementing Regulation (EU) 2016/1141 adopting a list of invasive alien species of Union concern
- Commission Implementing Regulation (EU) 2017/1263 updating the list of invasive alien species of Union concern
- **Commission Implementing Regulation 2019/1262 of 25 July 2019 (European Commission, 2019)**

Several lists and frameworks on IAS have been developed over the years.

- EPPO List of invasive alien plants European and Mediterranean plant protection organization (http://www.eppo.int/INVA SIVE_PLANTS/ias_lists.htm). The plants listed in the EPPO list of IAP have been identified by the Panel as being absent or present in the EPPO region; as having a high potential for spread; as posing an important threat to plant health and/or the environment and biodiversity; and eventually as having other detrimental social impacts in the EPPO region. In order to optimize the efforts were selected the species considered to pose the greatest threat to species and ecosystems in the EPPO region and priorities were set EPPO therefore strongly recommends countries endangered by these species to take measures to prevent their introduction and spread or to manage unwanted populations (for example with publicity, restrictions on sale and planting, and control measures). This list is constantly being

reviewed by the Panel (new species can be added, and others removed). The list is not meant to be exhaustive but to focus on the main risks.

- the Global Naturalized Alien Flora (GloNAF) database represents a data compendium on the occurrence and identity of naturalized alien vascular plant taxa across geographic regions around the globe with 13939 taxa and information on whether the taxon is considered to be naturalized in the specific region (van Kleunen et al.,2019)

- IUCN Global Invasive Species Database (GISD, http://www.iucngisd.org/gisd/): is a free, online searchable source of information about alien and invasive species that negatively impact biodiversity. The GISD aims to increase public awareness about invasive species and to facilitate effective prevention and management activities by disseminating specialist's knowledge and experience to a broad global audience. It focuses on IAS that threaten native biodiversity and natural areas and covers all taxonomic groups. In 2013/2014 the GISD underwent a major update with the inclusion of key identifiers such as IUCN Red List species codes, WDPA (World Database of Protected Areas) codes, ISO country codes etc. that allow seamless integration with allied databases such as the IUCN Red List of Threatened Species and the WDPA, as well as other invasive species resources. The collected data allow the production of a list of 100 of the world's worst IAS, compiled by the International Union for Conservation of Nature (IUCN), which aims to help biodiversity conservation efforts worldwide (go.nature.com/qa9z1g). Moreover, IUCN has developed a global standard for classifying the severity and type of impacts caused by IAS (Figure 3), known as Environmental Impact Classification for Alien Taxa (EICAT).
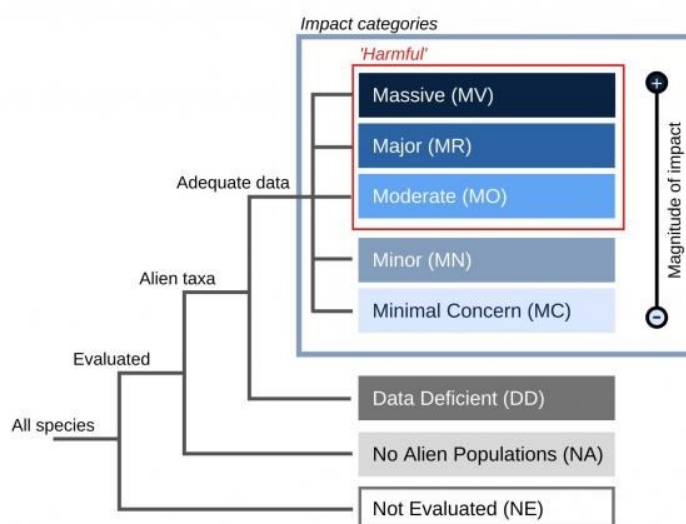
Figure 3 Scheme describing the procedure for using the IUCN Environmental Impact Classification for Alien Taxa (EICAT) Categories and Criteria. (from https://www.iucn.org/theme/species/our-work/invasive-species/eicat)

EICAT has the following five objectives:

- (i) identify alien taxa by levels of environmental impact.
- (ii) compare the level of impact by alien taxa among regions and taxonomic groups.
- (iii) facilitate predictions of potential future impacts of taxa in the target region and elsewhere.
- (iv) aid the prioritization of management actions.
- (v) facilitate the evaluation of management methods.

It is envisaged that EICAT will be used by scientists, environmental managers and conservation practitioners as a tool to gain a better understanding of the magnitude of impacts caused by different alien taxa, to alert relevant stakeholders to the possible consequences of the arrival of certain alien taxa, and to inform the prioritization, implementation and evaluation of management policies and actions

Italy has implemented the European regulation with the Legislative Decree n. 230 15 December 2017, which adapts the national legislation to the European one. The subjects are the administrative regions and are called upon to carry out monitoring and therefore to manage the species of Union concern: control the entry vectors, the marketing, eradication plans for some of these species, where control is not possible and management.

Italy issues the National Biodiversity Strategy which is the adaptation to the European strategy. Reference is made to IAS in the chapter dedicated to forests for which among the identified critical aspects on the integrity of such ecosystems there is the expansion of invasive alien tree species (e.g. *Robinia pseudoacacia, Ailanthus altissima, Prunus serotina*). Based on the critical issues, the following specific objectives can be identified, to be achieved by 2020, including promoting the efficiency and harmonization of monitoring activities and systems for data collection, at regional, national and European level, so as to be able to aggregate the results and make them comparable and develop adequate levels of integrated planning between the agroforestry, environmental, basin and urban-infrastructural sectors. On the basis of the specific objectives in the forest section, the priorities for intervention include in point d) the implementation of monitoring actions, coordinated between the different administrations, based on existing inventory systems, such as INFC, to support the formulation of actions for the protection of forest biodiversity (e.g. monitoring of the state of forest habitats pursuant to the Habitat Directive, identification and protection of old forests, containment measures for invasive alien forest species) by 2015.

1.1.10. Two main Invasive Alien tree species in Europe and Italy: *Robinia pseudoacacia* and *Ailanthus altissima*

The research focuses on two alien tree species that are widely distributed throughout Europe and reaches in Italy a high potential of diffusion: *Robinia pseudoacacia* and *Ailanthus altissima*. Both species are known to determine a serious impact on resident ecosystems in term of changes in the microbial, chemical-physical characteristics of the soils, microarthropod community, plant community in term of composition and functioning.

Robinia pseudoacacia (black locust) arrived for the first time in Europe in the seventeenth century, in France (Peabody, 1982) and now it occurs in 42 countries and is naturalized in 32 (Pyšek et al., 2009). Due to its pioneer characteristics (Boring and Swank, 1984), since the middle of the last century, black locust has been widely used for naturalistic engineering works to limit erosion on slopes and prevent hydrogeological instability, in silvicultural systems for biomass production (Crosti et al., 2016), and as an ornamental species in urban or peri-urban contexts (Denisow et al., 2017).
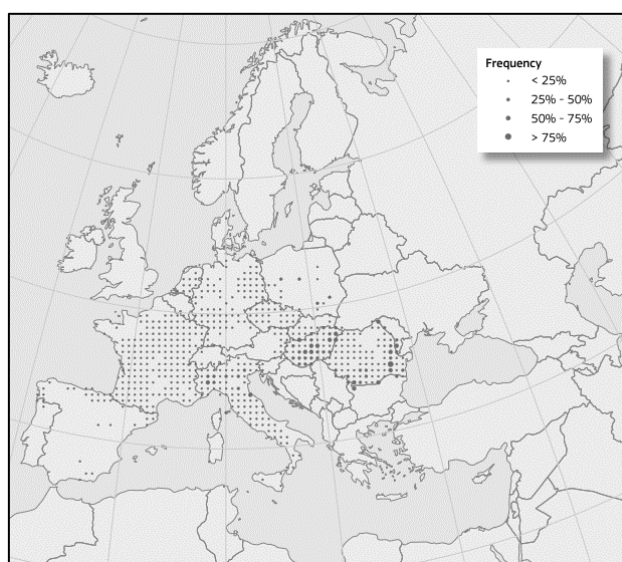
Figure 4 European distribution and simplified chorology map for *Robinia pseudoacacia*. Frequency occurrences within the field observations as reported by the National Forest Inventories (modified from Sitzia et al., 2016)

Its aggressive root and trunk coppice shoots let black locust to penetrates fire-damaged areas, abandoned fields, clear-cuts, and pastures (Vitkova et al., 2010). Black Locust, thanks to its nitrogen-fixing ability and its rapid growth, has advantages that increase competitive abilities compared to native tree species (Cierjacks et al., 2013). Although its invasive behaviour it is not yet considered in the list of species of Union Concern because its risk assessment highlighted both negative and positive aspects. In facts, is a tree species perceived as native by most of the citizens, is part of several cultural landscapes throughout Europe and provides an important economic income thanks to timber/biomass

production, honey, and for ornamental purpose. Despite these factors, black locust is largely present in Italy, is classified as invasive in 18 out of 21 administrative regions and participate in the composition of almost 3,800 km2 of forests (Mariano et al., 2014) invading different habitats and representing a threat to the integrity and resilience of the native ecosystems (e.g. Lazzaro et al., 2020). Is widely proven that *Robinia pseudoacacia* have high invasive potential and is capable to alter local biodiversity and ecosystem services (Rumlerová et al., 2016) through the homogenization process by unifying microenvironmental conditions of stands because of the occurrence of alien, ruderal and non-forest species (e.g. Šibíková et al., 2019; Slabejová et al., 2019, Dyderski and Jagodzinski; 2020). This is for *Robinia* plantations as well as for recent secondary stands escaped from those areas of introduction. In fact, in southern Europe *Robinia* secondary stands hosts compositionally heterogeneous plant communities and can filter the frequency distribution of plant functional traits in the understory of secondary woodlands modifying the functional pattern of the native ecosystems and its services (e.g. Campagnaro et al., 2018; Sitzia et al., 2012, 2018; Lazzaro et al., 2018). Those differences in species composition are caused by local natural conditions such as soil properties, climate, and native forests resilience, and socioeconomic factors such as the traditional land use (Vitkova et al., 2020). Management of *Robinia* plantations (Crosti et al., 2016) secondary stands and the near native forests (Radtke et al., 2013) is of crucial importance to prevent the spread of this alien tree and to favour the restoration and increase the resilience of native forests (e.g. Hruška,1991; Brundu et al., 2020; Langmaier et al., 2020). Although the wide literature on the negative effects of *Robinia pseudoacacia* there is a lack of data from the mature and pure stand as data from areas of anthropogenic origin, in the juvenile stage with low dimensions have often been considered.

Ailanthus altissima (tree of heaven), an invasive alien tree native to China (Hu,1979) that has become invasive all over the world (Pysek et al., 2009). Its first record for the Italian territory dates back to 1760 in the Botanical Garden of Padua (Badalamenti et al., 2012) and now is present in all the administrative regions, classified as neophyte invasive species (Galasso et al., 2018), participate in the composition of almost 70 km2 of forests (Mariano et al., 2014) and recently was added to the list of IAS of European Union concern (European Commission, 2019).

Figure 5 European distribution of *Ailanthus altissima* (modified from Kowarik and Saumel, 2007)

The expansion of *A. altissima* is due to its pioneer characteristics such as high germination rates in gamic reproduction and efficacy in agamic reproduction (Knapp and Canham, 2000), high tolerance to limiting ecological factors such as soil type and drought (Kowarik and Saumel, 2007; Sladonja et al., 2015) and production of a phytotoxic compound called "Ailanthone" that can inhibit the germination of native species (Lawrence et al., 1991; Gómez-Aparicio and Canham, 2008). It is mainly spread in present in abandoned areas, public garden spaces, wastelands, roadsides and railway areas, but is also present in non-urban areas in hedgerows of arable lands, adjacent water courses and, less common, in forests, shrublands, and grasslands (Kowarik and Saumel, 2007; Fotiadis et al., 2011). *A. altissima* can have a high impact on richness of communities in different habitats in fact the understory vegetation in *A. altissima stands* is significantly poorer or more common (Motard et al., 2011; Kožuharova et al., 2014, Knüsel et al., 2019; Lapin et al., 2019), and richer in annual or perennial ruderal species (e.g. Fotiadis et al., 2011). It can also threat rare and endemic species (Grozeva, 2005; Uzunov et al., 2012; Vladimirov, 2013), and alter soil properties and nutrient cycling, which are fundamental components of ecosystem functioning and processes (Vilà et al., 2006; Gómez-Aparicio and Canham, 2008; Castro–Díez et al., 2009; Medina-Villar et al., 2016). These traits allow *A. altissima* to form nearly pure stands and constitute proper forest communities with high canopy density capable to impact native ecosystems and Natura 2000 sites (Sladonja et al., 2015; Lazzaro et al., 2020).

Although *A. altissima* and *R. pseudoacacia* wide expansion all over Europe and Italy (together cover 2,23% of the total national forest coverage) (Tabacchi et al., 2005), the threats they impose on native species/ecosystems and the hypothetical floristic-vegetational autonomy of these forest coenoses there is a significative lack of knowledge on the ecological behaviour and floristic-vegetational composition in central-southern Italy in sub-Mediterranean and Mediterranean bioclimate. Even if

there are some ecological studies in continental Europe there are insufficient floristic-vegetational studies of syntaxonomical nature. Those data are fundamental for understanding the floristic-vegetational characteristics and the vegetation dynamics in these forest coenoses in relation to the local, climatic and management conditions and to detect any effects on species diversity. The effects on the biodiversity of the native forest ecosystems can be investigated only considering the neighbouring native forests as elements of comparison and control. The classification and characterization of this neophyte coenoses at the ecological, bio-geographic, syntaxonomical and landscape levels is an important starting point to understand these novel forest ecosystems and implement proper managing decisions.

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Chapter 2. Vegetation and vegetation dynamics

2.1. Phytosociological method and the concept of plant association

Vegetation science and Geobotany are disciplines that study the presence and distribution of plants on the earth's surface in all its aspects: floristic, historical and ecological. The study of vegetation in the field of Geobotany is carried out through the phytosociological method, an effective and simplified survey method, which consists in the drafting of a complete catalogue of the flora of a site and estimate of the coverage of each species (e.g. percentage scale, cover-abundance scales). This method was proposed at the beginning of the twentieth century (1928) by Josias Braun-Blanquet, father of Phytosociology and founder of the Sigmatist school of Zurich-Montpellier. Phytosociology is the science that analyzes the plant communities in their associative aspects, in relationship to the causes that determine them (ecological and historical factors). In the phytosociological system, the concrete element of the description of vegetation is the plant association, defined as *"The association defines a vegetal grouping more or less stable and in equilibrium with the environment, characterized by a particular floristic composition, in which some exclusive or almost exclusive elements (characteristic species) reveal with their presence a particular and autonomous ecology* " (Braun-Blanquet, 1928). The method was then updated according to the most recent acquisitions (Rivas-Martinez, 2005; Allegrezza et al., 2008; Biondi, 2011; Blasi and Frondoni, 2011), for instance, Biondi (2011) propose an updated definition of plant association that evolve the concept of ''characteristic species'' into ''preferring species'' in statistical and structural terms: ''*The association defines a system of vegetal organisms with a floristic composition that is statistically repetitive; it has a range of different features such as the structure, the ecological value (significant for different environmental parameters) and the quality of the dynamic and catenal relation- ships that it has with other communities. Especially pertinent for its definition and identification is the characteristic specific complex, consisting of the preferring plants which are particularly linked to it in statistical terms and that are biogeographically and ecologically differential compared to similar synvicariant or geosynvicariant associations*''. The identification of plant communities leads to a hierarchical system of classification based on the presence of common groups of plants that allow the identification of higher hierarchical levels starting from the association: alliances, orders and classes each with its own floristic, structural, ecological, chorological and dynamic characteristics. This hierarchical system is called syntaxonomy and respond to precise syntaxonomical nomenclature and regulations (Theurillat et al., 2020).

2.2. Vegetation complexes

Geobotany and more specifically phytosociology, is a holistic discipline of ecology (Rivas-Martinez, 2005) and analyzes all the ecological and historical factors that determine the presence of vegetation, and more specifically of plant associations, in one homogeneous portion of territory. In fact, the communities present in a territory are the resulting from the ecological and anthropic phenomena incidents. Therefore, plant communities assume the role of bioindicators, defined as organisms or biological systems, used to assess the quality of the environment, whatever its level of organization and the use that can be made of it (Iserentant and De Sloover, 1976). In phytosociology, the bioindicator is the community itself (described by the plant association), a group of associations with analogous behavior (described by a syntaxonomic unit of higher hierarchical level) or a system of variously related associations (described by the series of vegetation) (Biondi, 2011). The floristic-vegetational study provides information on the vegetational potential of a territory in relation to the incident ecological factors and to the floristic and dynamic changes that they can occur in relation to a series of disturbance. For this reason, the results of the geobotanical study represent an important tool for understanding the state of conservation of a territory and for sustainable planning in the management of resources, especially in areas aimed at environmental conservation.

2.3. Vegetation dynamics and the concept of ecotone

Vegetation dynamics is a complex concept that involves several ecological and anthropogenic aspects. It can be defined as "a slow and spontaneous evolution during which for progressive floristic substitutions more plant groupings follow each other in the same point observation" (Pirola, 1970) mainly trigger by disturbance. In subsequent studies this conception was respected, replacing the plant association with the grouping. Géhu and Rivas Martinez (1981) define the series of vegetation (sigmetum) "formed by all the plant communities that can be found in a space homogeneous, with the same vegetational potential and which it includes together with the more mature stage all replacement phytocoenoses ". The are several types of succession that can and cannot lead to the final stage called climax vegetation or natural potential vegetation that is "the point of arrival of the time series corresponding to the saturation of the phytocoenoses (maximum structural complexity) and occupies most of the habitats in the area" (Piussi, 1994; Andreis, 1996). There are primarily successions, no successions (para-climax) and secondary successions. The dynamics on which my study focuses concern the secondary successions, that is defined as those processes that start after removal or damage of the pre-existing vegetation cover by natural or anthropogenic disturbances, such as the case of a cultivated field that has been abandoned or a forest that it has been removed.

The first ecologist to deal with the ecotone concepts was Frederic Clements in 1905 and 1916, whom he defined the ecotone as a "zone of conjunction between two communities, where the processes of exchange or competition between neighboring formations can be easily observed". Odum (1971) described an ecotone as "a transition between two or more different communities where the ecotone community it contains many of the organisms of each of the overlapping communities as well as organism's characteristic or limited to the ecotone itself". Ecotones are present every time a discontinuity, a gradient, a change occurs, and their presence can be analyzed at different spatial and temporal scales (Farina, 2001). For instance, we can find a change in the distribution of energy (light-shadow), variation of surface or soil water (dry, humid soils), of nutrients (oligotrophic, eutrophic), organisms (abundant, scarce, scattered, grouped). For phytosociologists, in the ecotone are highlighted vegetation structures with peculiar floristic and ecological characteristics, to distinguish two vegetation structures called respectively mantle and edge. From these originate different dynamic processes that give rise to the vegetation series as a result of disturbances that disrupt the ecological balance between the types of vegetation (e.g. abandonment of agronomic practices that blocked the spontaneous dynamic processes of advancement of the forest). The most important environmental factor that determines the presence of the ecotone is light. This factor follows an increasing gradient, evident through the different types of vegetation: starting from those with shrubby structure up to the heliophilous herbaceous formations in contact with the grassland (farther from the forest) and for this position reached by greater brightness. Shrub formations, when they surround the forest and occupy part of the ecotone space, they take the name of mantel. In these conditions, the shrubs are reached by the shadow of the crown of trees, for which the species of the mantle are mainly sciaphilous (sustain low light conditions). In the external part of the mantle, there are the heliophilous shrubs (thrive in high light conditions) that are of considerable importance in the initiation of dynamic processes. Part of this ecotone is constituted by the edge (e.g. Allegrezza et al., 2015 and 2016) and is characterized by herb plant communities that develop in the ecotonal spaces of contact between the shrub vegetation of the mantle and the herbaceous vegetation of the grassland. Research in the field of geobotany must be approached not only from the cognitive point of view in a systemic key (syntaxonomic classification), but especially from an ecological point of view. This can be done only by considering all incident factors on vegetation, the dynamics between communities/associations, and in particular considering the disturbances that can affect the dynamics between these plant communities.

2.4. The syntaxonomy of alien forest ecosystems

The application of the phytosociological method and the syntaxonomical classification system to alien dominated forest communities is a debated issue. Hadac and Sofron (1980) deal with this problem by defining those vegetation units as "cultural forests". It is a difficult problem because usually are studied tree- and shrub-communities which are natural or near to natural ones. As stated by Tüxen and Ellenberg (1937) "cultural forests are quite different from natural ones and the two cannot be included in one system". This because cultural forests are characterized by "the artificial dominance of foreign tree species, the lability of the community and the absence of their characteristic species". Hadac and Sofron (1980) propose to consider for the classification of these alien dominated forests even if they have a quite different ecological character. The differences from the natural community are usually so great that classification into the "natural" system of plant communities seems not to work. The changes that species like *R. pseudoacacia* or *A. altissima* determine are so big that it is not possible to include such communities in any of the described syntaxa so it was proposed the creation of a new syntaxonomical class, the *Robinietea* class, with its order and alliances (Jurko, 1963). The concept of *Robinietea* class has undergone successive modifications, integrations, and updates according to new floristic-vegetational data all over Europe.

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Part II Contextualization of specific objectives

Chapter 3. Research objectives and Study area

3.1. Aims and scopes of the research

The general aims of this research project are to broaden the knowledge on these two invasive alien trees presents in the study area and in the European context from an ecological and syntaxonomical point of view. Specifically, the objectives were divided into two specific sections, respectively for *R. pseudoacacia* and *A. altissima*

R. pseudoacacia research

i) identify *R. pseudoacacia* forest communities in the study area.

ii) define the vegetational types present at the community level, and the ecological and landscape context in which they are found.

iii) highlight the possible floristic-vegetational autonomy of these coenoses in the context of the Italian peninsula and of the class *Robinietea*, through comparisons with the analogous coenoses described in the literature.

iv) analyze the effects of increasing cover-abundance values of *R. pseudoacacia* and detect a point of change in the ecological conditions in respect to *Q. pubescens* forests (Habitat 91AA*) in sub-Mediterranean Italy.

A. altissima research

v) identify *A. altissima* forest communities in the study area.

vi) find what are the main differences in vegetation structure and floristic diversity between *A. altissima* forests and native forests through the assessment of the principal ecological parameters that differ between the forest types.

vii) highlight their vegetational autonomy through a syntaxonomical study and a comparison with floristic-vegetational data available for the European context.

3.2. Study area

All the collected filed data (floristic-vegetational and ecological) are in the peri-Adriatic sector of central Italy at altitudes between 0 m a.s.l. and 460 m a.s.l, in the administrative regions of Marche and Abruzzo. The bioclimatic classification sensu Rivas-Martinez et al. (2011) for these territories indicates a Macrobioclimate ranging from Mediterranean, pluviseasonal oceanic bioclimate and upper meso-Mediterranean thermotype to the Temperate sub- Mediterranean variant, oceanic bioclimate and lower meso- temperate thermotype (Pesaresi et al., 2014). The prevailing lithotypes

are pelitic–arenaceous, arenaceous–pelitic and alluvial. According to the Corine Land Cover 2018 (Büttner et al., 2017) the principal land-cover/land-use types in a radius of 500 m^2 around the sampled forest areas are: Agricultural areas (70%) such as arable land, permanent crops, pastures and heterogeneous agricultural areas; Forest and seminatural areas (16%) such as broad leaves/coniferous and mixed forest, shrub and/or herbaceous vegetation associations and open spaces with little or no vegetation; Artificial surfaces (12%) such as urban fabric, industrial, commercial and transport units, mine, dump and construction sites and artificial, non-agricultural vegetated areas; water bodies (0.2%). The native forest vegetation is constituted mainly of oak woods on slopes (*Quercus pubescens, Q. virgiliana*, alliance *Carpinion orientalis*) and riparian woods of *Salix alba* and *Populus nigra* (alliance *Populion albae*). The high-shrub pre-forest vegetation is represented by *Ulmus minor* communities (*Lauro nobilis–Ulmion minoris* alliance) and *Sambucus nigra* communities (*Lauro nobilis–Sambucion nigrae* alliance). According to the most recent available data on the management of the sampled vegetation, it resulted as non-actively managed or abandoned in the last decades.
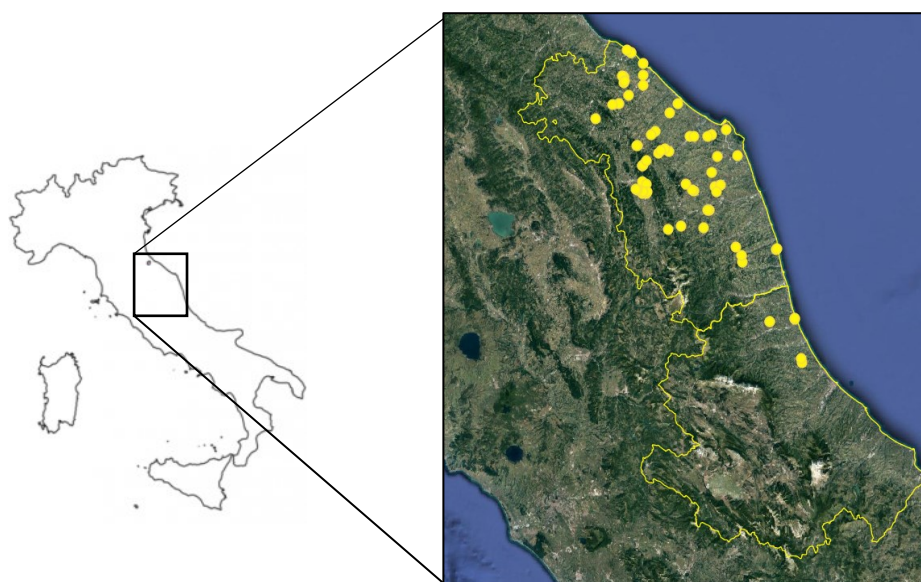
Figure 6 Location of the study area. The analyzed sites are represented by the yellow dots.

3.3. Thesis structure

The results of this thesis consist of four chapters that correspond to four scientific articles, three published in international WOS indexed journals and one published in a SCOPUS indexed journal. The published articles are:

- Allegrezza, M., **Montecchiari, S**., Ottaviani, C., Pelliccia, V., Tesei, G. 2019. Syntaxonomy of the *Robinia pseudoacacia* communities in the central peri–Adriatic sector of the Italian

peninsula. Plant Biosystems – An International Journal Dealing with all Aspects of Plant Biology 153: 616–623. https://doi.org/10.1080/11263504.2019.1610108

- **Montecchiari, S**., Tesei, G., Allegrezza, M. 2020 Effects of *Robinia pseudoacacia* coverage on diversity and environmental conditions of central–northern Italian *Quercus pubescens* sub–Mediterranean forests (habitat code 91AA*): a threshold assessment. Annali di Botanica–Coenology and Plant Ecology 10:33–54. https://doi.org/10.13133/2239–3129/16447

- **Montecchiari S**., Allegrezza M., Pelliccia V., Tesei G. 2020. First syntaxonomical contribution to the invasive *Ailanthus altissima* (Mill.) Swingle forest communities at its southern limit in Europe. Plant sociology. 57(2):145–160. DOI 10.3897/pls2020572/06

- **Montecchiari S.,** Tesei G., Allegrezza M. 2020. *Ailanthus altissima* forests determine a shift in herbaceous layer richness: a paired comparison with hardwood native forests in sub-Mediterranean Europe. Plants, 9:1404; doi:10.3390/plants9101404

The chapter titles correspond to the titles of the published articles, complete with bibliographical references. Chapter 6 comprehend an unpublished synthesis of the described forest communities through a floristic-vegetational and ecological comparison highlighting the main similarities and differences. The final chapter summarizes the main results obtained highlighting the final remarks and future perspectives.

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Part III Results

Chapter 4. Syntaxonomy of the *Robinia pseudoacacia* communities in the central peri-Adriatic sector of the Italian peninsula

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Abstract

This study presents the results of a floristic vegetational study on *Robinia pseudoacacia* neoformation forests in the peri-Adriatic sector of central Italy. This has allowed the characterization of these coenoses at the ecological, biogeographic, syntaxonomic and landscape levels. These currently represent the southernmost syntaxa of the *Robinietea* class described for the Italian peninsula, and the first syntaxonomic contribution of this class in Europe for the Mediterranean biogeographical region. We propose here the new alliance *Lauro nobilis–Robinion pseudoacaciae* of the order *Chelidonio–Robinietalia pseu- doacaciae* and class *Robinietea*, with two new associations: *Melisso altissimae–Robinietum pseudoacaciae* and *Rubio peregrinae–Robinietum pseudoacaciae*. The new alliance *Lauro nobilis–Robinion pseudoacaciae* (typus: *Melisso altissimae–Robinietum pseudoacaciae*) brings together neoformation forests and pre-forest dominated by *R. pseudoacacia* in those territories with a Mediterranean macroclimate of the peri- Adriatic sector of central Italy. The optimum is found for the alluvial plain and low-slope morphologies, on soils that are moist and rich in organic matter and in areas with anthropic disturbance. On the basis of comparisons with the European context, the alliance *Bryonio–Robinion* described for the temperate territories of northern Italy is here validated**.**

Keywords Alien forest communities; central peri-Adriatic; Italy; Mediterranean; plant landscape; *Robinia pseudoacacia*; *Robinietea* class; syntaxonomy

4.1. Introduction

Robinia pseudoacacia L. (black locust) is a deciduous tree species that belongs to the Fabaceae family. It is native to the Appalachian region of North America, where it has assumed the role of an

early successional species in the vegetation dynamics of open and disturbed habitats (Vitkovà and Kolbek 2010). It is currently considered one of the most widespread and globally invasive alien tree species in most temperate regions of the northern hemisphere (Li et al. 2014), with a continuing and expanding trend (Kleinbauer et al. 2010). Black locust arrived for the first time in Europe in the seventeenth century, in France (Peabody 1982). Due to its pioneer characteristics (Boring and Swank 1984), since the middle of the last century, black locust has been widely used for naturalistic engineering works to limit erosion on slopes and prevent hydrogeological instability, in silvicultural systems for biomass production (Crosti et al., 2016), and as an ornamental species in urban or peri-urban contexts (Denisow et al., 2017). Starting from these introduction points, there has been progressive diffusion of black locust (Crosti et al. 2016) and its consequent naturalization in various ecological and territorial areas, and in particular in areas with high and continuous anthropic disturbance, such as coastal, peri-urban and fluvial areas (Planty-Tabacchi 1997; Vitkovà et al. 2015). Currently, *R. pseudoacacia* is among the 100 most-widespread alien species in Europe (Lambdon et al.2008), and it can be found from the south of the Scandinavian peninsula to southern Italy and Sicily, where it reaches its southern limit of distribution in Europe (Sitzia et al. 2016). In Italy, it is present as a naturalized neophyte throughout the peninsula and is invasive in 18 of 21 regions (Galasso et al. 2018). In Italy, according to the latest National Forest Inventory (Tabacchi et al. 2007), which classifies in a single category the *R. pseudoacacia* and *Ailanthus altissima* forests, these formations together occupy 233,553 ha, equal to 2.23% of the total national wooded area. Numerous ecological studies published in Europe over recent years have focused on the effects of the black locust communities, although these have often provided conflicting results. These studies have included the effects on the bio- diversity of the native plant communities (e.g. Benesperi et al. 2012; Sitzia et al. 2012; Deneau 2013; Rawlik et al. 2018), to those on the chemical-physical and microbial characteristics of the soil (e.g. Castro Dìez et al. 2012; Deneau 2013;Vitkovàet al. 2015; Lazzaro et al. 2018). However, floristic-vegetational studies of syntaxonomic nature of black locust have been insufficient due to the lack of available data relating to southern Europe, and especially to the sub-Mediterranean and Mediterranean areas where black locust reaches its southern limit of distribution. Currently, three alliances are recognized for Europe, namely *Chelidonio majoris–Robinion pseudoacaciae*, *Balloto nigrae–Robinion pseudoacaciae* and *Euphorbio cyparissiae–Robinion pseudoacaciae*, which converge into the only order *Chelidonio–Robinietalia pseudoacaciae* and class *Robinietea*. This is a syntaxon that includes seral forest-clearing and anthropogenic successional scrub and thickets on nutrient-rich soils of temperate Europe (Mucina et al. 2016). As in the rest of south- ern Europe, floristic-vegetational studies on neoformation forests of black locust in Italy are few, and they have been mainly limited to the central-northern sector. For southern Italy, there are no currently published floristic-vegetational data have been published to date except for one relev?eof the black locust plantations on Mount Vesuvius (Agostini 1975). For central and northern Italy, there are different black locust coenoses that have been described only at the *R. pseudoacacia* community level (Corbetta and Pirone 1995;Gentile 1995;Biondi et al. 1997; Parolo 2000; Landi et al. 2002;

Andreucci et al. 2003; Lastrucci et al. 2010). Instead, the plant associations that have been described including *R. pseudoacacia* in their name have been referred to different syntaxa of higher orders: class *Querco–Fagetea* (Arrigoni 1997); class *Rhamno–Prunetea* (Wilhalm et al. 2008); class *Robinietea* (Wilhalm et al. 2008) and class *Urtico–Sambucetea* (Ubaldi 2003). Within the available data, we must also consider the syntaxa that have been described for the south-eastern Alps and classified into the class *Rhamno–Prunetea*, as for the association *Bryonio dioicae–Sambucetum nigrae* (Poldini and Vidali 1995), where *R. pseudoacacia* is always present at high cover- age, and sometimes higher than *Sambucus nigra*. There are no reviews available that clarify the syntaxonomy of the *R. pseudoacacia* communities for the Italian pen- insula, although in the Prodrome of the Italian Vegetation (website: http://www.prodromovegetazioneitalia.org/), two alliances have been reported, of order *Chelidonio–Robinietalia pseudoacaciae* and class *Robinietea*: *Balloto nigrae–Robinion pseudoacaciae*, which has already been indicated for central Europe, and *Bryonio–Robinion* Ubaldi, Melloni & Cappelletti in Ubaldi 2003 nom. inv. (Article 5) [holotypus *Bryonio–Robinietum* Ubaldi, Melloni & Cappelletti in Ubaldi 2003 nom. inv. (Article 5)]. The alliance *Bryonio–Robinion* described for northern Italy, is not valid on the basis of Article 5 of the International Code of Phytosociological Nomenclature (Weber et al. 2000). Based on surveys of the hills of Bologna (Ubaldi 2003; Table 7) in the temperate macroclimate, continental bioclimate, this alliance is considered to be the vicariant of the central-European alliance *Chelidonio majoris–Robinion pseudoacaciae* for northern and central temperate Italy. The aim of this study is to extend the floristic-vegetational studies relating to the neoformation forests of *R. pseudoacacia* to the Mediterranean peri-Adriatic sector of central Italy, in the context of the Italian peninsula and Europe for the class *Robinietea*. Specifically, the aims of the present syntaxonomic study are to: (i) define the vegetational types present at the community level, and the ecological and landscape context in which they are found; (ii) highlight the possible floristic-vegetational autonomy of these coenoses in the con- text of the Italian peninsula and of the class *Robinietea*, through comparisons with the analogous coenoses described in the literature.

4.2. Study area

The study area is in the Marche-Abruzzo peri-Adriatic sector (Figure 7) at altitudes between 0m a.s.l. and 450m a.s.l. The bioclimatic classification sensu Rivas-Martìnez et al. (2011) for these territories indicates a Macrobioclimate ranging from Mediterranean, pluviseasonal oceanic bioclimate and upper mesoMediterranean thermotype to the Temperate sub-Mediterranean variant, oceanic bioclimate and lower meso- temperate thermotype (Pesaresi et al. 2014). The prevailing lithotypes are pelitic–arenaceous, arenaceous–

Figure 7 Location of the study area

pelitic and alluvial. The plant landscape is mostly covered by crops, with the native forest vegetation mainly as oak wood slopes (*Quercus pubescens, Q. virgiliana*) (alliance *Carpinion orientalis*) and riparian woods of Salix alba and *Populus nigra* (alliance *Populion albae*). The high-shrub pre-forest vegetation is represented by *Ulmus minor* communities (*Lauro nobilis–Ulmion minoris* alliance) and *Sambucus nigra* communities (*Lauro nobilis–Sambucion nigrae* alliance).

4.3. Materials and methods

The vegetation survey was conducted according to the phytosociological methods of the Zurich-Montpellier school (Braun-Blanquet 1928), updated according to the most recent acquisitions (Rivas-Martinez, 2005; Allegrezza et al. 2008; Biondi 2011; Blasi and Frondoni 2011), for a total of 45 unpublished phytosociological relevès. The surveys were per- formed for black locust woods aged >30 years where black locust was clearly dominant over a minimum homogeneous area of 100m2. For each survey, geolology (ISPRA 2009) and morphostructure (slope, escarpment, alluvional plain) were also indicated. For the comparisons between the Italian pen- insula and the European context, eight synthetic columns were used for a total of 131 phytosociological relevès. These included 25 relevès from tables already published for the Italian peninsula and related to syntaxa defined at the association level (Poldini and Vidali 1995; Arrigoni 1997; Ubaldi 2003), and 61 relevès for the central European context, relating to the typus association of the various alliances of the class Robinietea (Jurko 1963;Vitkovà and Kolbek 2010), as currently recognized in Europe (Mucina et al. 2016). The literature findings were selected according to the following criteria: *R. pseudoacacia* with coverage >3 (Braun-Blanquet scale) and clearly dominant. The nomenclature of the species follows the check-list of Italian flora (Bartolucci et al. 2018). The life forms of the species follow Flora d'Italia (Pignatti 1982), while the chorology of the species follows Flora Alpina (Aeschimann et al. 2004) and Flora d'Italia (Pignatti 1982). For the Ellenberg indicators (Ellenberg et al. 1992), we used the indexes re- formulated for the Mediterranean conditions (Pignatti et al. 2005): L=light, T=temperatures, C=continentality; U=soil moisture, R=soil reaction, N=availability of soil nutrients. The syn taxonomic classification is made according to the Prodrome of the Italian Vegetation (Biondi et al. 2014), as present on the updated site of the Italian Botanical Society (http://www. prodromovegetazioneitalia.org/), with references to that of the European vegetation (Mucina et al. 2016). For the statistical analysis of the vegetation, the abundance values of the phytosociological matrix were converted to the Van der Maarel (1979) scale. Classification of the phytosociological matrix was then carried out through hierarchical cluster analysis, performed by applying the Ward algorithm to the similarity matrix, calculated by applying the Bray-Curtis index. The same similarity matrix was used to perform the non-metric multidimensional (NMDS) scaling ordination of the vegetation relevès. On the NMDS diagram were overlaid the significative re-formulated Ellemberg's indicator values (Appendix 1) and the environmental variables (geology and morphology), using the envfit function of the VEGAN package. The analysis was carried out using the "vegan" package (Oksanen et al. 2018) of the R software (R core team 2018).
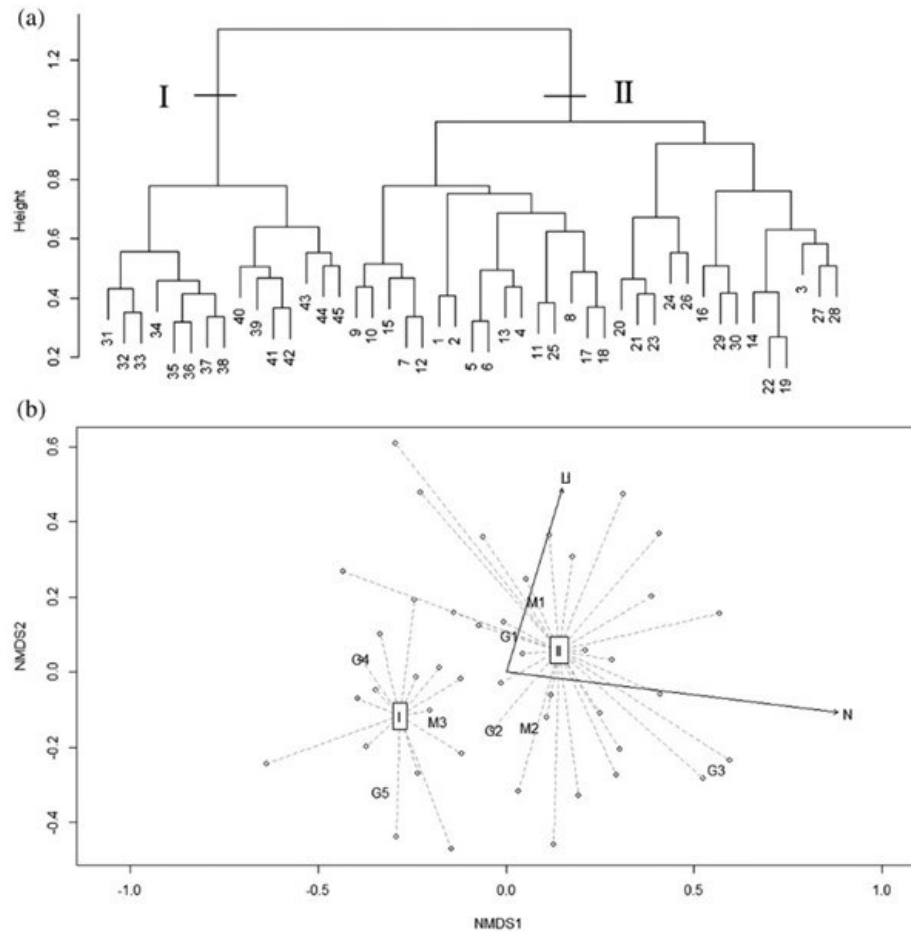
Figure 8 (a) Dendrogram from the phytosociological relevès of the *Robinia pseudoacacia* communities in the study area. Cluster I, *Rubio peregrinae–Robinietum pseudoacaciae*; Cluster II, *Melisso altissimae–Robinietum pseudoacacia*. (b) NMDS scaling ordination (clusters are overimposed to NMDS plot) with the overlaid of the significative ecological variables. For the ecological data see also Appendix 1. Legend: Ellemberg indicators: U, soil moisture; N, soil nutrient availability. Geological elements: G1, alluvional and colluvial deposits; G2, arenaceous-pelitic substrata; G3, pelitic-arenaceous substrata; G4, limestone substrata; G5, marl substrata. Morphostructure: M1, alluvial plains; M2, escarpment; M3, slope

4.4. Results and discussion

4.4.1. Floristic composition and phytosociology

The dendrogram shown in Figure 8a was obtained from the classification of the phytosociological relevès carried out in the study area, and it separated out two main groups of relevès Cluster I and Cluster II. The NMDS ordination (Figure 8b), with the overlap of the significative ecological variables considered (Ellemberg indicators, geology, morphostructure), confirm the separation of the clusters of the dendrogram. Cluster I include the phytocoenoses of *R. pseudoacacia* that have mainly developed on slopes with arenaceous–pelitic lithologies and relatively dry soils. Cluster II refers to the communities dominated by *R. pseudoacacia* that have mainly developed in correspondence with

alluvial plains or on low-slopes, on humid and deep soils that are rich in organic matter. The processing of the relevès in Table 1 and the comparisons with the literature data (Table 2) allow us to propose the new alliance *Lauro nobilis–Robinion pseudoacaciae* that in the Mediterranean area is the vicariant of the alliances of the order *Chelidonio–Robinietalia pseudoacaciae* indicated for temper- ate Europe. Two new associations of the new alliance are proposed and are described below. These correspond to the dendrogram clusters and the non-metric multidimensional (NMDS) scaling ordination diagram (Figure 8b): *Melisso altissimae–Robinietum pseudoacaciae* and *Rubio peregrinae–Robinietum pseudoacaciae*.

Alliance: *Lauro nobilis–Robinion pseudoacaciae* all. nova hoc loco (Typus: *Melisso altissimae-Robinetum pseudoacaciae* ass. nova hoc loco)

This new alliance brings together the naturalised and invasive alien neoformation forests and pre-forest that are dominated by *R. pseudoacacia* and have developed in the Mediterranean territories of the Adriatic sector of central Italy. This syntaxon also extend into the temperate macroclimate of the sub-Mediterranean variant, oceanic bioclimate, of the lower mesotemperate thermotype. The optimum is for alluvial plains and low-slopes morphology, on humid soils that are rich in organic matter, and in areas subjected to anthropic disturbance. This new alliance can also be extended to include the neoformation forests dominated by the naturalized and invasive alien tree species that have developed in the Mediterranean macroclimate territories of central and southern Italy. The characteristic and differential species of the new alliance are: *R. pseudoacacia, Laurus nobilis, Rubus ulmifolius, Fraxinus ornus, Melissa officinalis subsp. altissima, M. officinalis subsp. officinalis, Arum italicum, Chamaeiris foetidissima, Vitis vinifera, Ligustrum vulgare, Arundo plinii, Lonicera etrusca, Asparagus acutifolius, Rubia peregrina, Rosa sempervirens, Inula conyzae, Anisantha diandra, Symphytum tuberosum subsp. angustifolium, Sinapis alba, Bellevalia romana, Parietaria judaica, Brachypodium rupestre, Viola alba subsp. dehnhardtii, Ailanthus altissima, Juglans regia, Ficus carica, Ruscus aculeatus, Viburnum tinus, Rhamnus alaternus, Cyclamen hederifolium, Petasites pyrenaicus.* The neoformation forests of black locust of the new alliance *Lauro nobilis–Robinion pseudoacaciae* can generally be considered the anthropogenic vicariant of the pre-forestal coenosis of the alliances *Lauro nobilis–Ulmion minoris* and *Lauro nobilis–Sambucion nigrae* in the context of the main series of vegetation that characterises the subcostal plant landscape of the central Adriatic sector (Biondi and Allegrezza 2004; Allegrezza et al. 2006; Biondi et al. 2012).

Table 1 *Robinia pseudoacacia* communities belong to the new alliance *Lauro nobilis–Robinion pseudoacaciae* (typus: *Melisso altissimae–Robinietum pseudoacaciae ass*. nova hoc loco) in the peri-Adriatic sector of central Italy. *Melisso altissimae–Robinietum pseudoacaciae* ass. nova hoc loco (rels. 1-30, typus rel. 5), *Carex pendula* variant (rels. 25-30); *Rubio peregrinae-Robinietum pseudoacaciae* ass. nov. hoc loco (rels. 31-45, typus rel. 44)

Table 1

Relevé metadata (columns 1–45):

Parameter	Values
N. rel.	1 2 3 4 5* 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44+ 45
Group from demdrogram fig.2	II II II II II II II II II II II II II II II II II II II II II II II II II II II II II II I I I I I I I I I I I I I I I
Altitude [m s.l.m.]	350 310 450 400 300 324 68 103 25 251 200 200 100 90 303 84 280 65 400 260 109 35 110 40 299 183 180 250 315 200 260 124 125 98 449 103 250 86 150 197 350 308 272
Aspect	ENE E N N NW N NE NW NE N N NW E S S NE NW N S NW E N N SW SSE SW NW N NNE W W SW NW NE SW N N W E NE E
Slope [°]	20 25 3 5 1 20 9 15 2 25 22 35 10 5 35 2 40 10 3 15 8 20 - 5 25 2 10 - - 30 15 25 20 30 40 6 15 10 20 35 30 35 15
Area [m²]	250 200 150 100 200 200 100 100 200 400 150 200 400 9 200 150 300 300 400 100 100 100 150 250 200 200 200 300 150 100 150 125 150 200 150 250 200 200 120 450 150 300 400
Tree layer height [m]	11 11 9 9 11 16 11 10 14 14 11 11 13 13 12 9 11 10 11 9 10 10 13 13 9 16 14 16 16 14 19 16 11 16 11 9 11 11
N. species x rel.	27 20 17 19 26 24 13 16 18 25 23 20 21 24 20 17 11 15 19 25 16 22 18 22 20 22 23 28 28 31 21 20 19 24 17 15 20 17 24 21 26 17 20 29 30

Melisso altissimae-Robinietum pseudoacaciae ass. nova

Biological Form	Chorotype	Species	Pres.
G rhiz	Medit.	Arum italicum	31
H scap	Subcosmop.	Urtica dioica	24
H scap	Euri-Medit.	Melissa officinalis subsp. officinali	15
H scap	Steno-Medit.	Melissa officinalis subsp. altissim	12
T scap	Eurasiat.	Galium aparine	21
H scap	Eur./W-Asiat.	Lamium maculatum	8
G rhiz	SW-Eur.	Chamaeiris foetidissima	6
T scap	Medit.	Anisantha diandra	5
G rhiz	SE-Eur.	Symphytum tuberosum subsp. angustifolium	4
T scap	Euri-Medit.	Sinapis alba	3
G bulb	Medit.	Bellevalia romana	2

Carex pendula variant

Biological Form	Chorotype	Species	Pres.
H caesp	Eurasiat.	Carex pendula	10
G rhiz	Eur./W-Asiat.	Equisetum telmateia	4
P scap	Eurasiat.	Salix alba	3
G rhiz	S-Eur.	Symphytum bulbosum	3
P lian	S-Eur.	Vitis vinifera s.l.	6

Rubio peregrinae-Robinietum pseudoacaciae ass. nova

Biological Form	Chorotype	Species	Pres.
P lian	Eur./SW-Asiat.	Hedera helix	43
P caesp	Eur.	Cornus sanguinea	28
G rhiz	Medit.	Asparagus acutifolius	15
P lian	W-Eur./Medit.	Rubia peregrina	11
P scap	S-Eur./W-Asiat.	Fraxinus ornus	9
H bienn	Eurasiat./N-Afr.	Inula conyzae	4
G rhiz	Steno-Medit	Arundo plinii	4
T scap	N-Am.	Erigeron canadensis	3
P caesp	Medit.	Rhamnus alaternus	3
P caesp	Medit.	Viburnum tinus	3

Lauro nobilis-Robinion pseudoacaciae all. nova

Biological Form	Chorotype	Species	Pres.
NP	Euri-Medit. Eur.	Rubus ulmifolius	43
P caesp	Medit.	Laurus nobilis	30
NP	Eur./W-Asiat.	Ligustrum vulgare	11
P scap	SE-Eur./SW-Asiat.	Juglans regia	11
H scap	W-Eur./Medit.	Parietaria judaica	10
H caesp	Eur.	Brachypodium rupestre	10
H ros	Medit.	Viola alba subsp. dehnhardtii	10
P scap	E-Asiat.	Ailanthus altissima	8
P scap	Medit./SW-Asiat.	Ficus carica	7
G rhiz	Medit.	Ruscus aculeatus	4
G bulb	S-Eur.	Cyclamen hederifolium	2
G rhiz	Medit.	Petasites pyrenaicus	2
NP	Medit.	Rosa sempervirens	1

Chelidonio-Robinietalia pseudoacaciae and Robinietea

Biological Form	Chorotype	Species	Pres.
P caesp	N-Am.	Robinia pseudoacacia	45
P caesp	Eur.	Sambucus nigra	42
T scap	Eur.	Chaerophyllum temulum	14
H caesp	Eurasiat.	Dactylis glomerata	8
H bienn	Eur./W-Asiat.	Alliaria petiolata	8
T rept	Eur.	Stellaria media	6
H scap	Eurasiat./N-Am.	Poa trivialis	5
P lian	Eurasiat./N-Am.	Humulus lupulus	3
P scap	N-Am.	Acer negundo	3
H scap	Eurasiat.	Geum urbanum	2

Other species

Biological Form	Chorotype	Species	Pres.
P lian	Eur.	Clematis vitalba	36
P caesp	Eur.	Euonymus europaeus	26
P scap	Eur./W-Asiat.	Acer campestre	26
P caesp	Eur.	Ulmus minor	25
P caesp	Eur./W-Asiat.	Crataegus monogyna	25
P caesp	S-Eur.	Quercus pubescens s.l.	18
P caesp	Eur./W-Asiat.	Prunus spinosa	13
H caesp	Eurasiat.	Brachypodium sylvaticum	11
G rad	W-Eur./Medit.	Dioscorea communis	9
H bienn	Eurasiat.	Arctium lappa	7
P caesp	Eur.	Corylus avellana	7
P scap	Eur./W-Asiat.	Prunus avium	6
G rhiz	Asiat.	Arundo donax	5
G rhiz	Eurosib.	Aegopodium podagraria	5
T scap	Medit./SW-Asiat.	Avena barbata	4
H scand	Eurasiat.	Convolvulus sepium	4
H scap	Eur./W-Asiat.	Ranunculus lanuginosus	4
H ros	Eurasiat.	Potentilla reptans	4
H scap	Eurosib.	Rumex acetosa	4
H bienn	Eurasiat.	Silene latifolia	4
G rhiz	S-Eur./W-Asiat.	Convolvulus arvensis	4
P scap	Eurasiat.	Populus nigra	4
T par	S-Eur./W-Asiat.	Orobanche minor	4
H bienn	S-Eur.	Pastinaca sativa subsp. urens	3
P scap	SE-Europ.	Acer opalus subsp. obtusatum	3
H scap	Eurasiat.	Veronica chamaedrys	3
T scap	Medit.	Sonchus asper	2
H scap	Medit.	Clinopodium nepeta	2

Sporadic species: 5 3 - 2 - 1 - 1 1 2 5 - 3 1 2 - - - 1 3 2 - 1 3 1 1 3 4 - 4 2 - - 4 - - 1 1 2 2 2 - 1 4 3

Association: *Melisso altissimae-Robinietum pseudoacaciae* ass. nova hoc loco (Table 1: rels. 1-30, typus rel. 5)

This new association refers to the forest and pre-forest communities of *R. pseudoacacia* that have developed on alluvial plains, low slopes and escarpment morphology, on alluvial and colluvial deposits, with pelitic–arenaceous lithotypes, with moist soils that are rich in organic matter. These com-munities have a mean height of 12m (from 8m to 16 m) with thick shrub and liana layers (mean cover, 60%); they are characterized by annual and perennial herbaceous species of ruderal and nitrophilous natures, many of which are typically Mediterranean. The characteristic and differential species of this new association are *R. pseudoacacia, Melissa officinalis subsp. altissima, M. officinalis subsp. officinalis, Arum italicum, Galium aparine, Lamium maculatum, Urtica dioica, Chamaeiris foetidissima, Anisantha diandra, Symphytum tuberosum subsp. angustifolium, Sinapis alba* and *Bellevalia romana*. This new association includes the *Carex pendula* variant, which is differentiated by *Carex pendula, Equisetum telmateia, Salix alba, Symphytum bulbosum* and *Vitis vinifera,* in

correspondence with the most recent alluvial terraces, and in connection with the poplar stands of the order *Populetalia albae*. The *R. pseudoacacia* coenosis of the new association *Melisso altissimae–Robinietum pseudoacaciae* are inserted into the landscape context as represented by the native woods of the alliances *Population albae*, *Carici remotae–Fraxinion oxycarpae* and *Carpinion orientalis* (*Lauro nobilis–Quercenion virgilianae* suballiance). These mainly involve the following forest habitats: *Lauro nobilis–Quercetum virgilianae* (Habitat *91AA; Eastern white oak woods), *Lauro nobilis–Populetum canescentis* and *Rubo ulmifolii–Salicetum albae* (Habitat 92A0; *Salix alba* and *Populus alba* galleries), *Carici remotae-Fraxinetum oxycarpae* [Habitat 91F0; Riparian mixed forests of *Quercus robur, Ulmus laevis* and *Ulmus minor, Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*)] and *Symphyto bulbosi–Ulmetum minoris*.

Association: <u>*Rubio peregrinae-Robinietum pseudoacaciae*</u> ass. nova hoc loco (Table 1: rels. 31-45, typus rel. 44)

This new association brings together the Mediterranean and subMediterranean forest and pre-forest communities dominated by *R. pseudoacacia* that have developed mainly on slope and escarpment morphostructures on arenaceous-pelitic lithotypes, and on relatively dry soils. These tree communities have a mean height of 12.6m (from 9m to 19 m) and are differentiated into the dominated shrub and lianas layers by a discrete group of species of class *Querco–Fagetea* and class *Rhamno–Prunetea*, as well as species of class Quercetea ilicis (*Rubia peregrina, Rhamnus alaternus, Viburnum tinus*). These species also confirm the Mediterranean character of this community, which distinguishes these coenosis of *Robinia peseudoacacia* in the study area. Although the ruderal and nitrophilous characters of this coenosis are moderate, this is underlined by *Sambucus nigra, Urtica dioica and Inula conyzae*, and by the alien species *Erigeron canadiensis*. The characteristic and differential species of this new association *Rubio peregrinae–Robinietum pseudoacaciae* are: *Hedera helix, Fraxinus ornus, Rubia peregrina, Asparagus acutifolius*, *Rhamnus alaternus, Viburnum tinus, Cornus sanguinea, Arundo plinii, Inula conyzae, Erigeron canadiensis.* The landscape context of the new association *Rubio peregrinae–Robinietum pseudoacaciae* is represented by the native woods of the sub-alliance *Lauro nobilis–Quercenion virgilianae* (*Carpinion orientalis* alliance) with the association *Roso sempervirentis–Quercetum virgilianae* (habitat 91AA*; Eastern white oak woods)

Syntaxonomic scheme
Robinietea Jurko ex Hadac et Sofron1980
+*Chelidonio-Robinietalia pseudoacaciae* Jurko ex Hadac et Sofron 1980
**Lauro nobilis-Robinion pseudoacaciae* all. nova hoc loco
Melisso altissimae-Robinietum pseudoacaciae ass. nov. hoc loco
Rubio peregrinae-Robinietum pseudoacaciae ass. nov. hoc loco

Table 2 Synoptic table of the *Robinia pseudoacacia* syntaxa belonging to the *Chelidonio majoris-Robinietalia pseudoacaciae* order in Italian peninsula and in Europe

Biological form	Chorotype	N. columns	1	2	3	4	5	6	7	8	
		N. rel per column	30	15	10	8	7	13	15	33	Pres.
		Melisso altissimae-Robinietum pseudoacaciae									
H scap	Eur./W-Asiat.	Lamium maculatum	II			II	I			I	4
H caesp	Eurasiat.	Carex pendula	II	I	I						3
G rhiz	SW-Eur.	Chamaeiris foetidissima	I	I							2
T scap	Medit.	Anisantha diandra	I	I							2
H scap	Euri-Medit.	Melissa officinalis subsp. officinalis	III								1
H scap	Steno-Medit.	Melissa officinalis subsp. altissima	II								1
G rhiz	SE-Eur.	Symphytum tuberosum subsp. angustifolium	I								1
T scap	E-Medit.	Sinapis alba	I								1
G bulb	Medit.	Bellevalia romana	I								1
		Rubio peregrinae-Robinietum pseudoacaciae									
P caesp	Eur.	Cornus sanguinea	III	V	I	V			II	I	6
P scap	S-Eur./W-Asiat.	Fraxinus ornus		III	III	II	I				4
P lian	W-Eur./Medit.	Rubia peregrina	I	III	I						3
G rhiz	Steno-Medit	Arundo plinii	I	II							2
G rhiz	Medit.	Asparagus acutifolius	II	III							2
H bienn	Eurasiat./N-Afr.	Inula conyzae	I	II							2
T scap	N-Am.	Erigeron canadensis		I							1
P caesp	Medit.	Rhamnus alaternus		I							1
P caesp	Medit.	Viburnum tinus		I							1
		Sambuco nigrae-Robinietum pseudoacaciae									
P caesp	Eur.	Euonymus europaeus	III	III	V	III	I	I	II		7
P lian	Medit.	Lonicera etrusca		I	III						2
NP	Medit.	Rosa sempervirens	I		I						2
G rhiz	S-Eur.	Asparagus tenuifolius			III	I					2
NP		Rubus hirtus group			III						1
P scap	W-Med.	Pinus pinaster			II						1
		Lauro nobilis-Robinion pseudoacaciae									
NP	Euri-Medit. Eur.	Rubus ulmifolius	V	V	III	II	V				5
G rhiz	Medit.	Arum italicum	V	II	II	I	I				5
NP	Eur./W-Asiat.	Ligustrum vulgare	II	I	II	III			II		5
H ros	Medit.	Viola alba subsp. dehnhardtii	II	I	I		I				4
P caesp	Medit.	Laurus nobilis	III	V	II						3
G rhiz	Medit.	Ruscus aculeatus	I	I	V						3
P scap	Medit.	Quercus ilex	I	I	I						3
G bulb	S-Eur.	Cyclamen hederifolium	I	I	II						3
P lian		Vitis vinifera s.l	I	I		II					3

LF	Chorology	Species	1	2	3	4	5	6	7	8	9	10	11	n
P scap	E-Asiat.	Ailanthus altissima	I	II										2
H caesp	Eur.	Brachypodium rupestre	I	II										2
G rhiz	Medit.	Petasites pyrenaicus	I	I										2
P scap	Medit./SW-Asiat.	Ficus carica	I	II										2
P scap	SE-Eur./SW-Asiat.	Juglans regia	I	II										2
H scap	W-Eur./Medit.	Parietaria judaica	II	I						I				3
		Bryonio dioicae-Sambucetum nigrae												
NP	Eur./W-Asiat.	Rubus caesius					I		IV				IV	3
H scap	Eur.	Heracleum sphondylium							II				I	2
H scap	S-Eur.	Xanthoselinum venetum							II					1
P lian	SE-Eur.	Lonicera caprifolium							II					1
G rad	S-Eur.	Aristolochia clematitis							II					1
H scap	E-Asiat.	Artemisia verlotiorum							II					1
P lian	S-Eur./W-Asiat.	Clematis viticella							II					1
		Bryonio-Robinietum and ***Bryonio-Robinion***												
P lian	Eur./SW-Asiat.	Hedera helix	V	V	IV	IV	IV							5
P lian	Eurasiat./N-Am.	Humulus lupulus	I		I	IV	IV			II				5
G rad	W-Eur./Medit.	Dioscorea communis	I	I	IV	II	V							5
G bulb	Medit.	Muscari comosum		I		I	I	I						4
H scand	W-Eur./Medit.	Bryonia dioica				V	IV							2
H scap	Eurasiat.	Artemisia vulgaris				III		I						2
H bienn	Eurasiat.	Lactuca serriola				IV	IV							2
G rhiz	Eurasiat.	Elymus repens				III	II							2
		Balloto nigrae-Robinion pseudoacaciae												
T scap	Eur.	Chaerophyllium temulum	II	I			I	II		I				5
H scap	E-Eur.	Ballota nigra					II	V		II	I			4
T scap	Eurasiat.	Anisantha sterilis				II	IV	V						3
H caesp	Eurasiat.	Poa angustifolia						V		I	I			3
H caesp	Eurasiat.	Calamagrostis epigeios						II			I			2
H bienn	Eurasiat.	Cynoglossum officinale						III						1
		Chelidonio majoris-Robinietum pseudoacaciae and ***Chelidonio majoris-Robinion pseudoacaciae***												
T scap	Eurasiat./N-Am.	Geranium robertianum							I	II	IV	I		4
H caesp	Eurasiat./N-Am.	Poa nemoralis								I	IV	III		3
H scap	Eur.	Anthriscus sylvestris									II	I		2
H ros	Eurasiat.	Viola hirta				II					III			2
		Euphorbio cyparissiae - Robinietum pseudoacaciae and ***Euphorbio cyparissiae - Robinion pseudoacaciae***												
H scap	Eur.	Euphorbia cyparissias								I			IV	2
T scap	S-Eur.	Arenaria serpyllifolia								I			I	2
Ch suffr	Eurasiat.	Artemisia campestris											III	1
H bienn	Eurasiat.	Verbascum lychnitis											III	1

Life form	Chorology	Species	1	2	3	4	5	6	7	8	N
G rhiz	Eurasiat.	Carex humilis								II	1
H bienn	Eurasiat.	Centaurea stoebe							I	III	2
H caesp	E-Eur./W-Asiat.	Melica transsilvanica								IV	1
T scap	Medit.	Clinopodium acinos							I	I	2
H caesp	Eurasiat.	Phleum phleoides								I	1

Chelidonio-Robinietalia pseudoacaciae* and *Robinietea

Life form	Chorology	Species	1	2	3	4	5	6	7	8	N
P caesp	N-Am.	Robinia pseudoacacia	V	V	V	V	V	V	V	V	8
P caesp	Eur.	Sambucus nigra	V	V	III	V	V	III	V	I	8
H scap	Subcosmop.	Urtica dioica	IV	I	I	II	IV		V	I	7
T scap	Eurasiat.	Galium aparine	III	I		III	V	V	V	II	7
H scap	Eurasiat.	Geum urbanum	I			III	III	III	V	I	6
T rept	Medit.	Stellaria media	I		I	I	I		II	I	6
H caesp	Eurasiat./N-Am.	Poa trivialis	I	I	I		II	I			5
H caesp	Eurasiat.	Dactylis glomerata	I	I	I			IV	II		5
H bienn	Eur./W-Asiat.	Alliaria petiolata	II	I			I		I		4
H scap	Eurasiat.	Chelidonium majus					I	I	V	I	4
P scap	N-Am.	Acer negundo	I	I							2
T scap	Eur.	Galeopsis tetraihit							I		1
T scap	Eur./W-Asiat.	Moehringia trinervia							I		1
		Taraxacum sect. Taraxacum							I		1
NP	Eurasiat./N-Am.	Rubus fruticosus agg.							II		1

Other species

Life form	Chorology	Species	1	2	3	4	5	6	7	8	N
P caesp	Eur./W-Asiat.	Crataegus monogyna	III	IV	IV	III	II	I	II	I	8
P caesp	Eur./W-Asiat.	Prunus spinosa	II	II	IV	II	I	I	II	I	8
P scap	Eur./W-Asiat.	Acer campestre	III	IV	II	II			II	I	6
P lian	Eur.	Clematis vitalba	IV	V	I	IV	V		II		6
H bienn	Eurasiat.	Arctium lappa	I	I		I	I	III	II		6
H bienn	Eurasiat.	Silene latifolia	I			II	I	II	II	I	6
H caesp	Eurasiat.	Brachypodium sylvaticum	II	I	III	I			IV		5
NP	Eurasiat.	Rosa canina	I			IV	I		I	III	5
P caesp	Eur.	Ulmus minor	III	IV		II	I		I		5
P scap	Eur./W-Asiat.	Prunus avium	I	II	II					I	4
P caesp	S-Eur.	Quercus pubescens *s.l.*	II	IV	I		I				4
P scap	Eur.	Quercus robur			III	I			I	I	4
T scap	Circumb.	Fallopia convolvulus			I			IV	II	I	4
P caesp	Eur.	Corylus avellana	I	II		I					3
H caesp	Eur.	Melica uniflora	I			I			I		3
P caesp	SE-Eur./SW-Asiat.	Mespilus germanica		I	I		I				3
H scap	Eurasiat.	Campanula trachelium		I		I			II		3
T scap	Medit.	Viola arvensis						III	II	I	3
H scap	Eurasiat.	Cruciata laevipes	I		I	I					3
T scap	Eurasiat.	Lapsana communis				I			III	I	3
		Sporadic species	52	23	32	34	14	24	35	62	

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4.4.2. General considerations on the syntaxonomy of the *Robinia pseudoacacia* communities in the Mediterranean and sub-Mediterranean areas

At the European level, considering the comparisons with the literature data (Table 2), a clear floristic differentiation emerges between black locust communities belonging to the new alliance *Lauro nobilis–Robinion pseudoacaciae*, which is characterized by typically Mediterranean and southern European species and the central European alliances *Chelidonio majoris–Robinion pseudoacaciae*, *Balloto nigrae–Robinion pseudoacaciae* and *Euphorbio cyparissiae–Robinion pseudoacaciae* (Table 2 and chorological spectra of Appendix 2). The major floristic affinities can be found with the alliance *Bryonio–Robinion* nom. inv. (Article 5), which was described for the hilly and plain territories of northern Italy by Ubaldi, Melloni & Cappelletti in Ubaldi (2003), due to the presence of south-European species such as *Hedera helix* and *Rubus ulmifolius*. The alliance *Lauro nobilis–Robinion pseudoacaciae*, however, is differentiated by the contingent of Mediterranean species, most of which are transgressive of the class *Quercetea ilicis*, which testify that this syntaxon belongs to the typically Mediterranean biogeographic, bioclimatic and landscape context in agreement with the classification and mapping of the ecoregion of Italy (Blasi et al. 2014). On the basis of the comparisons with Table 2, the floristic autonomy of the alliance *Bryonio–Robinion* is shown, due to the presence of southern and western European species (Table 2 and chorological spectra, Appendix 2), which are not found in the analogous syntaxa of central Europe. Therefore, the alliance *Bryonio–Robinion* is validated here, and its distribution area and specific characteristic combination are clarified. The alliance *Bryonio–Robinion* Ubaldi, Melloni & Cappelletti in Ubaldi ex Allegrezza, Montecchiari, Ottaviani, Ubaldi, Melloni & Cappelletti in Ubaldi 2003 nom. inv. art. 5) Pelliccia & Tesei all. nova hoc loco (=*Bryonio-Robinion* [Holotypus: *Bryonio-Robinietum* Ubaldi, Melloni & Cappelletti in Ubaldi ex Allegrezza, Montecchiari, Ottaviani, Pelliccia & Tesei ass. nova hoc loco (Lectotypus hoc loco: Ubaldi, Melloni & Cappelletti in Ubaldi 2003: releve 33, Table 7, p. 301) (=Bryonio-Robinietum Ubaldi Melloni & Cappelletti in Ubaldi 2003 nom. inv. art. 5)] is already indicated as the vicariant of the central European alliance *Chelidonio majoris–Robinion pseudoacaciae* (http://www.prodromovegetazioneitalia.org/). The alliance *Bryonio -Robinion* brings together the *R. pseudoacacia* forest phytocoenoses from the temperate macro-climate territories, with the continental bio- climate of central-northern Italy, to the hottest sectors of the southern pre-alpine arc, from the mesotemperate thermotype to the lower supratemperate thermotype. In central Italy, the alliance penetrates the Apennines and infra- Apennine sector, while it fades in the subMediterranean pre-Appenine hilly and plain areas, where it is vicariated by the alliance *Lauro nobilis–Robinion pseudoacaciae,* which typically develops in the coastal and subcoastal territories. The characteristic and differential species of the alliance *Bryonio–Robinion* [(typus: *Bryonio–Robinietum* (Ubaldi Melloni Melloni & Cappelletti in Ubaldi 2003) ass. nova)] are: *R. pseudoacacia, Bryonia dioica, Tamus communis, Leopoldia comosa, Artemisia vulgaris, Hedera helix, Lactuca serriola* and *Rubus*

caesius, while *Rubus ulmifolius* assumes the meaning of transgressive species. In addition, it is proposed to refer to this alliance the association *Bryonio dioicae–Sambucetum nigrae* described for the south-eastern Alps (Poldini and Vidali 1995), and the different *R. pseudoacacia* communities described in the literature for central-northern Italy, in correspondence with river basins and the plain areas of the Po Valley. Finally, the association *Sambuco nigrae–Robinietum pseudoacaciae* described for western Tuscany in central Italy (Arrigoni 1997) and also indicated for the Island of Elba (Foggi and Signorini 2006), shows major floristic affinities with the new alliance *Lauro nobilis–Robinion pseudoacaciae* (Table 2) for the contingent of Mediterranean species at the level of the relevè typus (Table 9, typus rel. 18, in Arrigoni 1997), which include: *Laurus nobilis, Rubus ulmifolius, Rosa sempervirens, Quercus ilex and Pinus pinaster*; therefore, we proposed their classification into the new alliance *Lauro nobilis–Robinion pseudoacaciae*.

4.5. Conclusions

The present study provides the characterization of the neo-formation forests of *R. pseudoacacia* at the ecological, bio-geographic, syntaxonomic and landscape levels, which is present in the peri-Adriatic sector of central Italy. This represents the southernmost syntaxa of the class *Robinietea* that have been currently described for the Italian peninsula, and the first syntaxonomic contributions of this class in Europe for the Mediterranean biogeographical region. On the basis of the comparisons with the literature data, the new alliance *Lauro nobilis–Robinion pseudoacaciae* (typus: *Melisso altissimae–Robinietum pseudoacaciae*) is proposed. In the Mediterranean context, it is the vicariant of the temperate Europe alliances of the order *Chelidonio-Robinietalia*, with two associations: M*elisso altissimae–Robinietum pseudoacaciae* and *Rubio peregrinae–Robinietum pseudoacaciae*. Here, the alliance *Bryonio–Robinion* described for the temperate territories of northern Italy is also validated, with its distribution area and specific combination clarified. The presence of two distinct alliances in central Italy, *Lauro nobilis–Robinion pseudoacaciae* and *Bryonio–Robinion*, derives not only from the different floristic compositions, but also from their belonging to two distinct biogeographical, bioclimatic and landscape contexts in agree with classification and mapping of ecoregion of Italy (Blasi et al. 2014): Mediterranean (*Lauro nobilis–Robinion pseudoacaciae*) and temperate (*Bryonio–Robinion*).

4.6. Appendices

Appendix 1
Correlation coefficient R^2 and significances of ecological variables considered (Ellemberg indicators as vectors; geology and morphostructure as factors) with phytosociological relevès position (indirect gradient analysis) in the NMDS1 and NMDS2 axis. Significance codes p<: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

	NMDS1	NMDS2	R^2
U Humidity	0.29298	0.95612	0.1411*
N NUtrient	0.99299	-0.11816	0.4977***
Geology			0.2749***
Morphostructure			0.2620***

Appendix 2

Weighted chorological spectra of the *Robinia pseudoacacia* syntaxa presented in Table S1. (values represent percentages)

	1	2	3	4	5	6	7	8
Endemic	0	0	0	0	0,9	0	0	0
Mediterranean	27,3	25	18,9	6,3	16,8	10,7	4,3	7,4
Eurasiatic	55,8	61,4	66,9	73,6	63,6	77,7	82,1	80,7
Atlantic	3,0	3,8	4,7	4,9	9,3	0,0	0,0	0,0
Boreal	2,4	1,5	2,4	1,4	0,9	5,8	5,7	5,9
Wide distribution	3,0	1,5	2,4	1,4	3,7	1,0	3,6	1,5
Alien	8,5	6,8	4,7	12,5	4,7	4,9	4,3	4,4

Appendix 3 List of plant communities referred to the columns of the synoptic Table 2

Column 1. *Melisso altissimae-Robinietum pseudoacaciae ass. nova hoc loco*; Column 2. *Rubio peregrinae-Robinietum pseudoacaciae ass. nova hoc loco*; Column 3. *Sambuco nigrae-Robinietum pseudoacaciae* from Tab. 9, Rel. 12, 17, 18, 23, 30, 32, 34, 57, 58, 63 in Arrigoni 1997; Column 4. *Bryonio dioicae-Sambucetum nigrae* from Tab. 5 Rels. 1, 3-7, 10, 11 in Poldini and Vidali 1995; Column 5. *Bryonio-Robinietum* from Tab. 7, Rels. 16-19, 22, 25, 26, 32-35 in Ubaldi 2003; Column 6. *Balloto nigrae-Robinion pseudoacaciae* from Tab. 1, Rels. 1-15 in Jurko 1963; Column 7. *Chelidionio majoris-Robinietum pseudoacaciae* from Tab. 2 in Jurko 1963; Column 8. *Euphorbio cyparissiae-Robinietum pseudoacaciae* from Tab. 2 Column 4 in Vítková and Kolbek 2010.

Sporadic species of the synoptic Table 2

Col 1: *Cirsium arvense* I, *Chenopodium album* I , *Juglans regia* I, *Allium vineale* I, *Aegopodium podagraria* I, *Avena fatua* I, *Bromus ramosus* I, *Convolvulus arvensis* I, *Malus sylvestris* I, *Orobanche minor* I, *Pastinaca sativa* subsp. *urens* I, *Potentilla reptans* I, *Ranunculus lanuginosus* I, *Rumex acetosa* I, *Sambucus ebulus* I, *Viburnum lantana* I, *Convolvulus sepium* I, *Viola reichenbachiana* I, *Equisetum telmateia* I, *Anredera cordifolia* I, *Arundo donax* I, *Symphyotrichum × salignum* I, *Avena barbata* I, *Carduus pycnocephalus* s.l. I, *Cydonia oblonga* I, *Cynoglossum creticum* I, *Daphne laureola* I, *Daucus carota* s.l I, *Galium album* I, *Geranium rotondifolium* I, *Helleborus foetidus* I, *Scirpoides holoschoenus* I, *Ligustrum lucidum* I, *Linaria vulgaris* I, *Melittis melissophyllum* I, *Mercurialis annua* I, *Olea europaea* I, *Oxalis acetosella* I, *Oxalis dillenii* I, *Pinus*

pinea I, *Populus alba* I, *Populus nigra* I, *Pulicaria dysenterica* I, *Ranunculus bulbosus* I, *Ficaria verna* I, *Ranunculus neapolitanus* I, *Rumex conglomeratus* I, *Solanum nigrum* I, *Sonchus asper* I, *Sorghum halepense* I, *Veronica chamaedrys* I, *Salix alba* I, *Symphytum bulbosum* I. Col. 2: *Aegopodium podagraria* I, *Bromopsis ramosa* I, *Orobanche minor* I, *Pastinaca sativa* subsp. *urens* I, *Sambucus ebulus* I, *Equisetum telmateia* I, *Pteridium aquilinum* subsp. *aquilinum* I, *Celtis australis* I, *Acer monspessulanum* I, *Acer opalus* subsp. *obtusatum* I, *Acer pseudoplatanus* I, *Alnus glutinosa* I, *Avena barbata* I, *Aegonychon purpurocaeruleum* I *Clinopodium vulgare* I, *Diplotaxis erucoides* I, *Picris hieracioides* s.l. I, *Primula veris* subsp. *columnae* I, *Prunus laurocerasus* I, *Smyrnium olusatrum* I, *Sorbus domestica* I, *Juglans regia* II. Col. 3*: Malus sylvestris* I, *Ranunculus lanuginosus* I, *Rumex acetosa* I, *Fallopia convolvulus* I, *Agrostis capillaris* I, *Galium mollugo* I, *Polygonatum multiflorum* I, *Poa sylvicola* I, *Holcus lanatus* I, *Agrostis stolonifera* I, *Asperula* cfr I, *Bromus* (tipo*) maximus* I, *Cardamine hirsuta* I, *Clematis flammula* I, *Cruciata glabra* I, *Frangula alnus* I, *Holcus mollis* I, *Lolium perenne* I, *Lonicera japonica* I, *Luzula forsteri* I, *Ostrya carpinifolia* I, *Pyracantha coccinea* I, *Pyrus communis* I, *Ranunculus* cfr. *polyanthemus* I, *Sorbus torminalis* I, *Pteridium aquilinum* II, *Quercus cerris* II, *Festuca heterophylla* II, *Ilex aquifolium* II, *Viola riviniana* II, *Castanea sativa* III, *Anemonoides nemorosa* III, *Quercus petraea* IV. Col. 4: *Holcus lanatus* I, *Celtis australis* I, *Alnus glutinosa* I, *Viola reichenbachiana* I, *Veronica chamaedrys* I, *Salix alba* I, *Rubus canescens* I, *Vincetoxicum hirundinaria* I, *Viola odorata* I, *Rhamnus cathartica* I, *Parietaria officinalis* I, *Erigeron annus* I, *Solanum dulcamara* I, *Amorpha fruticosa* I, *Arrenatherum elatius* I, *Buddleja davidii* I, *Carex hirta* I, *Circaea lutetiana* I, *Equisetum arvense* I, *Stellaria acquatica* I, *Parthenocissus quinquefolia* I, *Platanus hybrida* I, *Prunus domestica* I, *Rhus typhina* I, *Rubus corylifolius* I, *Rumex crispus* I, *Thalictrum aquilegifolium* I, *Valeriana officinalis* I, *Polygonatum odoratum* II, *Rosa arvensis* II, *Artemisia verlotiorum* II, *Carex pairaei, Poa sylvicola* III, *Convolvulus sepium* III, *Morus alba* III. Col. 5: *Viburnum lantana* I, *Taraxacum officinale* I, *Allium carinatum* I, *Alopecurus myosuroides* I, *Veronica hederifolia* I, *Cirsium vulgare* I, *Eupatorium cannabium* I, *Fumaria officinalis* I, *Helleborus viridis* subsp. *bocconei* I, *Papaver rhoeas* I, *Galium mollugo* II, *Geranium dissectum* II, *Avena fatua* III. Col. 6: *Rhamnus cathartica* I, *Chenopodium album* I, *Potentilla reptans* I, *Bromus tectorum* I, *Eryngium campestre* I, *Glechoma hederacea* I, *Sanguisorba minor* I, *Asparagus officinalis* I, *Berberis vulgaris* I, *Erodium* cicutarium I, *Tragopogon dubius* I, *Bromus squarrosus* I, *Carex spicata* I, *Galium verum* I, *Geranium pusillum* I, *Marrubium peregrinum* I, *Ornithogalum umbellatum* I, *Potentilla reptans* I, *Potentilla incana* I, *Prunella vulgaris* I, *Rubus* sp. I, *Viola rupetris* I, *Cirsium arvense* II, *Poa compressa* II, *Torilis japonica* V. Col. 7: *Taraxacum officinale* I, *Hypericum perforatum* I, *Crataegus curvisepala* I, *Crataegus laevigata* I, *Elymus caninus* I, *Alopecurus pratensis* I, *Anthriscus trichosperma* I, *Bromopsis benekenii* I, *Clinopodium vulgare* I,

Carex pilosa I, *Dryopteris filix max* I, *Fagus sylvatica* I, *Luzula nemorosa* I, *Lysimachia nummularia* I, *Mycelis muralis* I, *Oxalis stricta* I, *Alkekengi officinarum* I, *Polygonum hydropiper* I, *Primula elatior* I, *Pulmonaria mollis* I, *Scrophularia nodosa* I, *Bromus tectorum* II, *Glechoma hederacea* II, *Viola odorata* II, *Polygonatum multiflorum* II, *Quercus cerris* II, *Galeopsis pubescens* II, *Galeopsis speciosa* II, *Sonchus mollis* II, *Stachys sylvatica* II, *Stellaria nemorium* II, *Fragaria moschata* III. *Lamium purpureum* III, *Viola sylvatica* III, *Torilis japonica* IV. Col. 8: *Crataegus curvisepala* I, *Crataegus laevigata* I, *Galeopsis pubescens* I, *Lapsana communis* I, *Eryngium campestre* I, *Sanguisorba minor* I, *Polygonatum odoratum* I, *Agrostis capillaris* I, *Allium vineale* I, *Convolvulus arvensis* I, *Fraxinus excelsior* L. I, *Allium oleraceum* I, *Anthoxanthum odoratum* I, *Crataegus* sp. I, *Festuca rubra* agg. I, *Fragaria vesca* I, *Fragaria viridis* I, *Impantientiens parviflora* I, *Ribes uva-crispa* I, *Sorbus acuparia* I, *Teucrium chamaedrys* I, *Achillea millefolium* I, *Allium lusitanicum* I, *Anthericum liliago* I, *Asplenium septentrionale* I, *Avenella flexuosa* I, *Brachypodium pinnatum* I, *Bupleurum falcatum* I, *Arabidopsis arenosa* I, *Centaurea triumfettii* I, *Cotoneaster integerrimus* I, *Echium vulgare* I, *Festuca rupicola* I, *Galeopsis ladanum* I, *Galium glaucum* I, *Geranium sanguineum* I, *Pilosella officinarum* I, *Hylotelephium maximum* I, *Juniperus communis* I, *Pimpinella saxifraga* I, *Pinus sylvestris* I, *Pulsatilla pratensis* I, *Pyrus pyraster* I, *Sedum acre* I, *Sedum album* I, *Sedum sexangulare* I, *Stipa pennata* I, *Stipa pulcherrima* I, *Thlaspi perfoliatum* I, *Veronica sublobata* I, *Viola collina* I, *Hypericum perforatum* II, *Quercus petraea* II, *Asperula cynanchica* II, *Aurinia saxatilis* II, *Dianthus carthusianorum* II, *Potentilla incana* II, *Potentilla verna* II, *Sedum rupestre* II, *Seseli osseum* II, *Thymus pulegioides* II, *Vincetoxicum hirundinaria* III, *Festuca pallens* III.

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Chapter 5. Effects of *Robinia pseudoacacia* coverage on diversity and environmental conditions of central-northern Italian *Quercus pubescens* sub-Mediterranean forests (habitat code 91AA*): a threshold assessment

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Abstract

The invasive alien species *Robinia pseudoacacia* may lead to species homogenization in high invaded forest ecosystems. Its invasive behaviour is poorly known in dry forest habitats and low cover-abundance conditions. We have investigated central-northern Italian *Quercus pubescens* forest habitats (code 91AA* - EU Habitat Directive) without and with the presence of *R. pseudoacacia* and in respect of *R. pseudoacacia* dominant communities that are present in the same forest potential areas. Using levels of *R. pseudoacacia* cover-abundance values (Braun-Blanquet scale) we classified the vegetation relevés in five groups: from 0 (total absence) to 4 (dominant conditions). Through the calculation of some indices, we highlighted the relations between groups of relevés and the variation in term of ecological features. A threshold has been identified at low coverage values of *R. pseudoacacia*. We detected a significant difference in the lower invaded sites in term of presence of nitrophilous and alien species, Shannon diversity index and changes in nutrient, moisture, light and reaction Ellenberg indicator values. These results inform about the early alarm level to set in monitoring *Q. pubescens* forest habitats in sub-Mediterranean areas.

5.1. Introduction

The global trend of naturalization of species outside their natural habitat is a phenomenon in increasing speed, it has been demonstrated that almost 4% of all currently known vascular plants

species on Earth have become naturalized outside their natural range linked to some human activities (Van Kleunen et al., 2015). Moreover, the number of alien species found in all types of habitats is permanently increasing in Europe (Lambdon et al., 2008; Vilà et al., 2010; Essl et al., 2011) where the Mediterranean basin is one of the biodiversity hotspots under threat. In Europe black locust (*Robinia pseudoacacia*) is one of the three most widely distributed invasive alien species (Lambdon et al., 2008; Pysek et al., 2009). Its physiological characteristics, e.g.: nitrogen-fixing and light-demanding species with a fast growth and high capacity of vegetative reproduction, make it an efficient pioneer tree species also in its native range (Boring and Swank, 1984). This species acts as a 'transformer' species (sensu Richardson et al., 2000), an invasive species that is able to alter the conditions of an ecosystem over a substantial area (Lazzaro et al., 2018a; Slabejová et al., 2019). *R. pseudoacacia* invasion has been proven to have an impact, in comparison with the native habitats, on plant communities (e.g.: Benesperi et al., 2012; Sitzia et al., 2012; Staska et al., 2014; Campagnaro et al., 2018a; Lazzaro et al., 2018a; Sitzia et al., 2018; Slabejová et al., 2019). Furthermore, the indirect effect of *R. pseudoacacia* on species composition is strongest on poor sandy soils in which nitrogen is the primary limiting soil resource (Dzwonko and Loster, 1997). In this European context of concern, and moreover, in the Mediterranean basin, forest habitats are under threat by alien tree species (Cierjacks et al., 2013; Wagner et al., 2017; Dyderski and Jagodzin, 2018; Dyderski and Jagodzinski, 2021), in particular through competition in the process of natural vegetation succession (Campagnaro et al., 2018b). Currently, in central-northern Italy, the spread of *R. pseudoacacia* is enhanced by the urbanization in hilly areas and forest management. In this context it can outcompete native trees in dry and nutrient poor sites (Mondino and Scotta, 1987) where it may alter ecosystem structure and dynamics of native oak forests (Tani et al., 2012), being able to vegetate in the potential areas of these coenoses, occupying similar functional space (Dalle Fratte et al., 2019). In particular, we focus on *Quercus pubescens* 91AA* priority habitat (Eastern white oak woods- Annex I of the Habitats Directive), one of the forest habitats types under threat of invasion by invasive alien tree species according to the Italian interpretation manual (Biondi et al., 2009). Its conservation status at the national level, assessed in the EU-28 interpretation manual, goes from unfavourable to bad (European Commission, 2013). Outside central Europe, precise information about patterns and levels of invasion in natural oak wood habitats are extremely poor (Vitkova and Kolbek, 2010). Most studies tend to compare heavily invaded sites, but it has been indicated that to assess the level of ecosystem change is necessary to consider the gradient of alien plant cover-abundance (Hulme et al., 2013; Panetta and Gooden, 2017). Moreover, the recent assessments provided at the national scale by the Italian Society of Vegetation Science (SISV) under the project "Updating of the National alien species database under the work program to support the Implementation of Regulation (EU) n. 1143/2014 on invasive alien species" (Lazzaro et al., 2018b; Bagella et al., 2019), consider only alien species with cover-abundance values above class 3 of Braun-Blanquet scale (corresponding to 25- 50% of cover). The level of impact threshold through invaded ecosystems, along alien + species cover-abundance gradient, in respect of temperate sub-Mediterranean oak wood habitats, is poorly known. Therefore,

shifting the focus from the species composition of a single plot or group to the ecological characteristics of the considered area, to analyze the effects of increasing cover-abundance values of *R. pseudoacacia* and detect a point of change in the ecological conditions in respect of *Q. pubescens* forests, in the present study we want to:

1. Investigate central-northern Italian *Quercus pubescens* forest habitats (habitat code 91AA* - Eastern white oak woods- Annex I of the Habitats Directive) without and with the presence of *R. pseudoacacia* and in respect of *R. pseudoacacia* dominant communities that are present in the same landscape position of the typical native forests of the hilly area (see section "Data collection").

2. Investigate these communities along different *R. pseudoacacia* cover-abundance values (Braun-Blanquet scale) with a focus on the low cover-abundance situations inside *Q. pubescens* forests.

3. Find a relation between levels of *R. pseudoacacia* coverabundance values and vegetation indices related to modified condition in respect to *Q. pubescens* forests.

4. Find a cover-abundance threshold value to assess the alarm level to monitor this sensitive habitat type.

5.2. Materials and Methods

5.2.1. Study area and sites

We investigated the *R. pseudoacacia* communities of central-northern Italy (Figure 9) through the selection of literature vegetation cover-abundance data and unpublished data (Appendix 1). The selection of the sites follows strictly the distribution of the *Q. pubescens* 91AA* habitat in central-northern Italy, according to the third report of the habitat directive (Genovesi et al., 2014). The sites were further screened to achieve homogeneous conditions that indicate the potential areas of *Q. pubescens* forests. We only selected data on slope morphologies from hilly sites within a temperate bioclimate with sub-Mediterranean variant (according to Rivas-Martines, 2001; Pesaresi et al., 2014, and information about bioclimate at local scale from the published vegetation studies).

5.2.2. Data collection

The vegetation survey was conducted according to the phytosociological methods of the Zurich-Montpellier school (Braun-Blanquet, 1928), in 100 m2 plots, for a total of 30 phytosociological relevés. To select the literature findings, we selected ecological criteria aiming the maintenance of topographic, climatic and site conditions that assure for the *Q. pubescens* natural potential vegetation. Suitable *R. pseudoacacia* data were selected from phytosociological studies that fitted in the defined study area to maintain homogeneous conditions along the dataset Firstly, we excluded data belonging to a different environment such as data from floodplain forests, related to grassland invasion conditions or in a different landscape position in respect of the typical native forests of the hilly area. In GIS environment we overlapped the remaining sites to the distribution map of the priority habitat 91AA* (Genovesi et al., 2014) to choose only the sites that fall in the squares of distribution. We

selected *R. pseudoacacia* vegetation data defined at the association level or community level and *Q. pubescens* forest data with the presence of *R. pseudoacacia* with low cover-abundance values (+, 1 and 2 expressed in Braun-Blanquet scale). Moreover, we collected data of *Q. pubescens* dominating forests associations, geographically representative of each area of distribution belonging to 91AA* habitat, without the presence of *R. pseudoacacia* (Table 4).
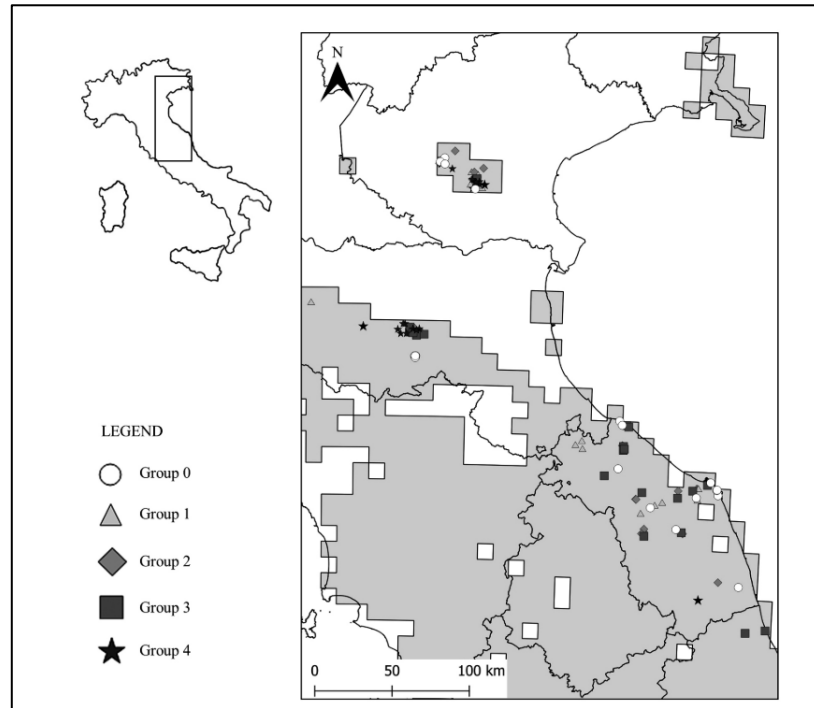
Figure 9 Map showing the study area corresponding to the *R. pseudoacacia* communities found within the distribution of central-northern Italian *Quercus pubescens* sub-Mediterranean forests (Eastern white oak woods - habitat CODE 91AA*) indicated in grey. The shapes of the sites labels indicate for the group belonging

After the selection following the chosen criteria, 104 literature plots were remaining. The *R. pseudoacacia* vegetation data goes from clearly dominant *R. pseudoacacia* forests up to conditions of presence in the oak forest covering all the possible cover-abundance values according to the Braun-Blanquet scale (Braun-Blanquet, 1928). To reach a balanced number of plots it was also performed a constrained selection method on the already selected vegetation matrix (see "Data analysis chapter"). The final dataset counts a total of 105 plots as shown in Table 4 (28 sampled plots and 77 literature plots), and 341 total species. The nomenclature of the species follows the updated checklists by Bartolucci et al. (2018) for native taxa and by Galasso et al. (2018) for alien taxa.

Table 3 The five groups with the indication of number of plots, the respective *R. pseudoacacia* percentage cover range (0% indicate for the *R. pseudoacacia* absence and the dominance of *Q. pubescens*), the *R. pseudoacacia* cover-abundance values (Braun-Blanquet, 1928), and corresponding values of van der Maaler scale (van der Maaler, 1979).

Groups	N° plots	*R. pseudoacacia* % Cover	Braun-Blanquet scale	van der Maaler scale
0	22	0%	-	-
1	21	<1%	+	2

		1-5%	1	3
		6-25%	2	5
2	22	26-50%	3	7
3	22	51-75%	4	8
4	18	76-100%	5	9

5.2.3. Creation of the indices matrix

To highlight peculiar ecological conditions related to a specific level of cover-abundance value of *R. pseudoacacia* we consider indicators widely used in invasion studies (Simonova and Lososova, 2008). We chose to use Ellenberg indicator values because they allow the shifting from a multidimensional system based on floristic matrices, to a smaller system reduced to 6 dimensions. This system is able to express and synthesize the environmental requirements of species and communities in an ecosystem (Diekmann, 2003). We used Ellenberg indicator values (EIVs) (Ellenberg, 1992), re-formulated for the Mediterranean conditions (Pignatti et al., 2005), for light (L), temperature (T), continentality (C), moisture (M), reaction (R) and nutrients (N). We also used the first update of Ellenberg's Indicator values for the Flora of Italy for *Pteridophyta, Gymnospermae* and *Monocotyledoneae* (Guarino et al., 2012). Ellenberg indicator values of alien species follow Domina et al. (2018). EIVs were mediated at plot level and downscaled from 1 to 9, to be comparable through groups. To compare the ecological indicator values of the plots, we used weighted average values because they are reliable predictors of site conditions. All the species were assigned to different syntaxonomic groups according to Mucina et al. (2016) and Biondi et al. (2014). The status of alien species was assigned following the Italian checklist for alien species (Galasso et al., 2018). Percentage weighted presence of syntaxonomical classes for each plot was calculated. The syntaxonomical classes considered are: *Querco-Fagetea*, *Rhamno-Prunetea*, *Trifolio-Geranietea*, *Festuco-Brometea*, *Galio-Urticetea/Artemisietea/Stellarietea* (the latter considered all together as Nitrophilous communities) and others (Table 5, syntaxonomical attributes). The *Querco-Fagetea* class includes forest species of native woods and nemoral herbaceous species. To better comprehend the response of the nemoral component to the different *R. pseudoacacia* cover-abundance values we also considered the herbaceous elements of the *Querco-Fagetea* class (Nem_herb). To analyze the changes in vegetation structure and life strategies, we considered also the Raunkiaer life-forms in the indices matrix. The following categories were distinguished, according to Pignatti (1982): chamaephytes (Ch), geophytes (G), hemicryptophytes (H), nanophanerophytes (NP), phanerophytes (P), therophytes (Thero). We used weighted average values. For each plot total number of species (Richness), Shannon diversity index (H), (Simpson index (D) and Evenness index – data not shown) were also calculated and averaged at the plot level.

5.3. Data analysis

Before calculations, the same species occurring in more layers were merged, taken the highest cover value. In the resulting data set, each species was present once. For the statistical analysis of the vegetation, the species cover-abundance values of the considered plots were converted to the Van der Maarel (1979) ordinal scale. To highlight the effects of the *R. pseudoacacia* presence on *Q. pubescens* forests, we created five groups of *R. pseudoacacia* plots sorted by their cover-abundance values and transformed in percentage values (Table 3). In a GIS environment, we assessed the equal distribution of each group within the study area. To reach a balanced number of plots within each group for a significative comparison we used the Heterogeneity-constrained random resampling (HCR) method to operate a selection (Lengyel et al., 2011).

Table 4 Localities and sources of the used phytosociological relevés. Number of relevés in each group.

Localities	Prov	Authors	N° of releves					
			Gr. 0	Gr. 1	Gr. 2	Gr. 3	Gr. 4	Tot
Euganei hills	PD	Buffa & Ghirelli, 1993	0	7	3	0	6	16
Onferno Nature Reserve	RN	Zitti et al., 2005	0	3	0	0	0	3
Val Baganza	PA	Adorni, 2001	0	1	0	0	0	1
Central Apennine/Marche region	-	Allegrezza et al. 2002	6	0	0	0	0	6
Gallignano	AN	Biondi &Allegrezza, 2004	0	3	0	0	0	3
Ancona hills	AN	Biondi & Allegrezza, 1996	5	1	0	0	0	6
Vallecorsa	FR	Blasi & Di Pietro, 1998	1	1	0	0	0	2
Vicenza	VI	Campagnaro et al., 2018a	0	0	6	1	1	8
Euganei hills	PD	Lorenzoni, 1976	1	0	0	0	0	1
Berici hills	VI	Tasinazzo & Fiorentin, 2000	5	0	2	1	3	11
Mount Sole	BO	Ubaldi, 1980	4	0	0	0	0	4
Bologna hills	BO	Ubaldi, 2003	0	0	2	6	8	16
Central Italy	AN	sampled plots	0	5	9	14	0	28

5.4. Statistical analysis

The data were processed using the "vegan" package (Oksanen et al., 2018) of the R software (R core team, 2018). The indices matrix was undergone at a normalization process using the "decostand" function on vegan package. Before calculation, we performed an exploratory investigation. To simplify the model, a Spearman correlation analysis was performed through the indices matrix using the corrplot package (Wei and Simko, 2017) in R studio software to assess covariation or significative relations among indices. Some indices show a strong collinearity, so we chose to select them among those. We chose to use the Shannon index to highlight the vegetation composition diversity and the weighted indices to express better the ecological characteristics. We identified the relationships between *R. pseudoacacia* cover groups and the vegetation indices and tested correlation among the parameters. The Shapiro test was used to test the normality of the analyzed data and the Bartlett test for the homoscedasticity. Box plot diagrams were used to illustrate data distribution along groups. As the distribution of the data was not normal, we used the non-parametric Kruskal-Wallis rank sum test

to analyze the variance of the groups. To assess the differences between the compared groups the Wilcoxon rank sum test (p < 0.05) was used as a post hoc analysis. To identify the principal gradients of variation of the indices through the groups a Principal Component Analysis (PCA) was performed. Finally, we tested the five cover-abundance groups against all species occurring on (Table 5). In Appendix 2 the complete list of species was reported.

Table 5 List of the species present in >20% of the plots with the indication of life form, syntaxonomical attribute, EIVs and the medium percentage cover (%) of the species for each of the five groups. Species significantly related to groups are indicated with the significance level and in a progressive grey colored scale (from dark grey corresponding to 15% of medium percentage coverage, to white that corresponds to 0% of medium percentage coverage). *** p ≤ 0.001; ** p ≤ 0.01; * p ≤ 0.05; p ≤ 0.1. (Legend of syntaxonomical attributes: AL alien species; NTR Nitrophilous species of the classes *Galio-Urticetea/Artemisietea/Stellarietea*; RP *Rhamno-Prunetea*; QF *Querco-Fagetea*; Nem_herb herbaceous nemoral species of the class *Querco-Fagetea;* TG *Trifolio-Geranietea*).

	Life form	Syntaxonomical attribute	L	T	U	R	N	Gr.0	Gr.1	Gr.2	Gr.3	Gr.4	p-value
Robinia pseudoacacia	P	AL	3,8	5,3	3,0	X	8,0	0,0	4,0	11,6	14,5	14,8	***
Sambucus nigra	P	NTR	5,3	3,8	3,8	X	9,0	0,0	2,0	3,5	6,8	6,7	***
Galium aparine	T	NTR	4,5	X	3,0	5,0	5,0	0,0	0,3	1,9	1,6	3,5	***
Stellaria media	T	NTR	4,5	X	3,0	7,0	8,0	0,0	0,6	1,5	0,3	4,2	*
Urtica dioica	H	NTR	X	X	4,5	X	8,0	0,0	0,0	1,1	3,1	1,2	***
Arum italicum	G	NTR	4,5	6,0	3,0	5,0	5,0	0,1	1,1	1,6	2,6	1,0	*
Clematis vitalba	P	RP	5,3	5,3	3,8	7,0	7,0	1,7	1,3	2,4	3,2	2,0	*
Rubus ulmifolius	NP	RP	3,8	6,0	3,0	5,0	8,0	1,5	2,6	2,7	5,1	3,0	p
Quercus pubescens s.l.	P	QF	5,3	6,0	2,3	7,0	4,0	9,6	9,2	1,9	1,2	0,7	***
Fraxinus ornus	P	QF	3,8	6,0	2,3	8,0	3,0	4,1	4,0	2,0	1,2	0,3	***
Rubia peregrina	P	QF	3,8	6,8	3,0	5,0	3,0	2,3	2,2	0,5	1,0	0,0	*
Cornus sanguinea	P	RP	5,3	3,8	5,3	8,0	X	3,0	2,3	1,6	1,8	0,8	**
Viola alba subsp. dehnhardtii	H	Nem_herb	3,8	6,0	3,8	7,0	6,0	2,2	1,0	0,2	0,4	0,4	***
Crataegus monogyna	P	RP	4,5	5,3	3,0	6,0	3,0	3,2	3,0	2,1	1,9	1,6	***
Brachypodium rupestre	H	TG	6,0	4,5	3,8	8,0	4,0	2,9	1,0	0,2	1,0	0,0	***
Laurus nobilis	P	QF	1,5	5,3	6,0	4,0	6,0	0,3	3,0	2,0	3,4	0,0	***
Euonymus europaeus	P	RP	4,5	3,8	3,8	8,0	5,0	1,0	1,0	2,0	2,8	0,7	**
Hedera helix	P	QF	3,0	3,8	3,8	X	X	3,2	7,0	7,4	7,6	5,5	p
Prunus spinosa	P	RP	5,3	3,8	X	X	X	0,7	1,7	0,7	1,5	0,4	
Ligustrum vulgare	NP	RP	5,3	4,5	X	8,0	X	1,0	2,2	1,9	0,6	1,3	p
Ruscus aculeatus	G	Nem_herb	3,0	6,0	3,0	5,0	5,0	1,9	2,7	2,2	1,4	1,2	
Asparagus acutifolius	G	Nem_herb	4,5	6,8	1,5	5,0	5,0	2,5	2,0	1,1	0,9	0,5	
Acer campestre	P	QF	3,8	5,3	3,8	7,0	6,0	1,7	1,6	2,9	1,0	1,3	
Ulmus minor	P	RP	3,8	5,3	X	8,0	X	0,5	2,2	2,4	2,1	2,3	
Dioscorea communis	G	Nem_herb	3,8	5,3	3,8	8,0	6,0	1,3	1,7	2,6	1,5	2,5	

5.5. Results

The results from the PCA ordination diagram (Figure 10) show a clear separation between groups 0 and 1 and from these groups and the others. The main separation is made along the first axis (PC1 34,1%). *Q. pubescens* forest plots (Group 0) and plots with low *R. pseudoacacia* cover (Group 1) are related to the weighted presence of herbaceous nemoral species, forest species, reaction and continentality Ellenberg indicators. More invaded groups are found to be related to exotic, nitrophilous, therophytes species and Ellenberg indicators for nutrient and moisture. The second axis (PC2 19,0%) separates plot related to the weighted presence of phanerophytes and nanophanerophytes species from the ones related to the weighted presence of hemicryptophytes species.
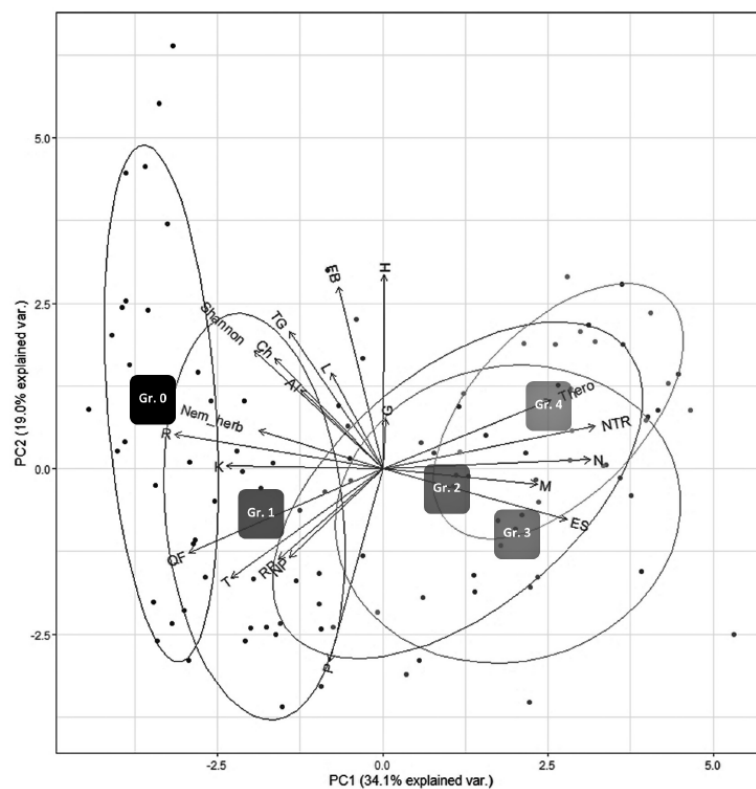
Figure 10 Principal Component Analysis (PCA) ordination diagram of the 105 plots (clusters are overimposed to PCA plot) with the overlaid of the significative ecological variables (Total variation explained 53.1%: axis PC1 34.1% and 19% axis PC2). Legend: see table 5.

5.5.1. Effects of the increasing *R. pseudoacacia* cover-abundance values

The trends of the indices are well visualized by the box plots in Figure 11 and 12. Along the 5 groups, Shannon diversity Index (H) shows a decreasing trend from group 0 to group 5 (p<0.01) with the lowest diversity values in pure *R. pseudoacacia* stands (Figure 11e). Ellenberg indicators for nutrients, reaction and moisture (Figure 11 a, c, b) are the most significative (p<0.001). Nutrient indicator is linked to Nitrogen availability and it shows already an increasing trend from the group 1 with a significative presence of nitrophilous species such as *Sambucus nigra* (p<0.001)*, Galium aparine* (p<0.001)*, Stellaria media* (p<0.001) and *R. pseudoacacia* (p<0.001) itself (Table 5 and

Figure 12 f). From the post hoc analysis, we can see a significative difference between group 1 and the others for this index. Moreover, we cannot detect a significative difference in nutrient indicator levels linked to the most invaded groups (groups 2, 3 and 4). Moisture indicator values along the cover abundance scale flat on groups with higher coverage values and it shows a changing point from group 1. Through the pairwise post hoc comparison, moisture indicator is significatively different between *Q. pubescens* pure forests and the other groups; moreover, in plots with the presence of *R. pseudoacacia* it begins to be significative only from group 3 relatively to the group 1 conditions ($p<0.05$). Also, EIV for light shows a significant trend in the gradient (Figure 11 d). *Q. pubescens* forest has higher EIV for light and it differs significantly from the first three groups, while not from the fourth. EIV for reaction (Figure 11 c) shows a linkage with *R. pseudoacacia* environmental conditions. Lower values of this index are found on higher invaded groups that indicate for more species linked to low soil pH conditions (sub-acid/acid soils). Moreover, through the explorative correlation analysis, we detected a negative correlation between this indicator and the weighted presence of exotic and nitrophilous species (Spearman coefficient respective -0.75 and -0.79). Regarding the presence of exotic species (Figure 12 g), we observed a similar trend both in the overall progression shown by the box plots and in the comparison among groups, with the absolute distance of the *Q. pubescens* forest from other conditions. Some exotic species recorded are *Ailanthus altissima, Anredera cordifolia, Erigeron canadensis, Parthenocissus quinquefolia, Phytolacca americana, Solidago canadiensis*. Group 1 is significantly different from both group 0 ($p<0.05$) and the others that are also statistically similar. Herbaceous nemoral species are not statistically different among group 1 and group 0 (Figure 12 h). Considering nemoral species all together (herbaceous and non-herbaceous) groups 0 and 1 show significative higher values of forest species belonging to native woods (of the *Querco-Fagetea* class) such as *Fraxinus ornus*, *Cornus sanguinea*, *Crataegus monogyna*, and *Q. pubescens* itself, and more specifically of herbaceous nemoral species such as *Asparagus acutifolius*, *Viola alba* subsp. *dehnhardtii*, *Rubia peregrina* (Table 5). Herbaceous nemoral species don't statistically differ along the last three groups, where begin to lose their cover-abundance values and presence (Table 5). Regarding the life forms, therophytes annual species respond significantly along the *R. pseudoacacia* cover abundance gradient (Figure 12 i). This index characterizes the groups with higher coverage values of *R. pseudoacacia*, indicating disturbance conditions. More specifically we can see how group 4 is the richest in annual species and differ from the others. The effect of this index is detectable from group 2 that differs significantly from group 1.

5.6. Discussions

The *R. pseudoacacia* invasive behaviour has been studied in dry forest habitats (Italian *Q. pubescens* forest habitat code 91AA* - EU Habitat Directive) and in low cover-abundance conditions. Testing for the response of the five groups of plots with respect to the set of ecological indices we found a significative relationship between these values and increasing levels of *R. pseudoacacia* cover-

abundance. Especially we highlighted the central role of the low cover-abundance group. There is a clear impact threshold at level of group 1 (<1%-25% *R. pseudoacacia* coverage), in condition of dominating *Q. pubescens* forests with the copresence of non-dominating *R. pseudoacacia*. According to literature findings (Benesperi et al., 2012; Trentanovi et al., 2013; Slabejová et al., 2019), Shannon diversity index was significantly higher in the *Q. pubescens* reference forests. In accordance with Touza et al. (2008), we observed a decrease in species diversity and changes in community functional
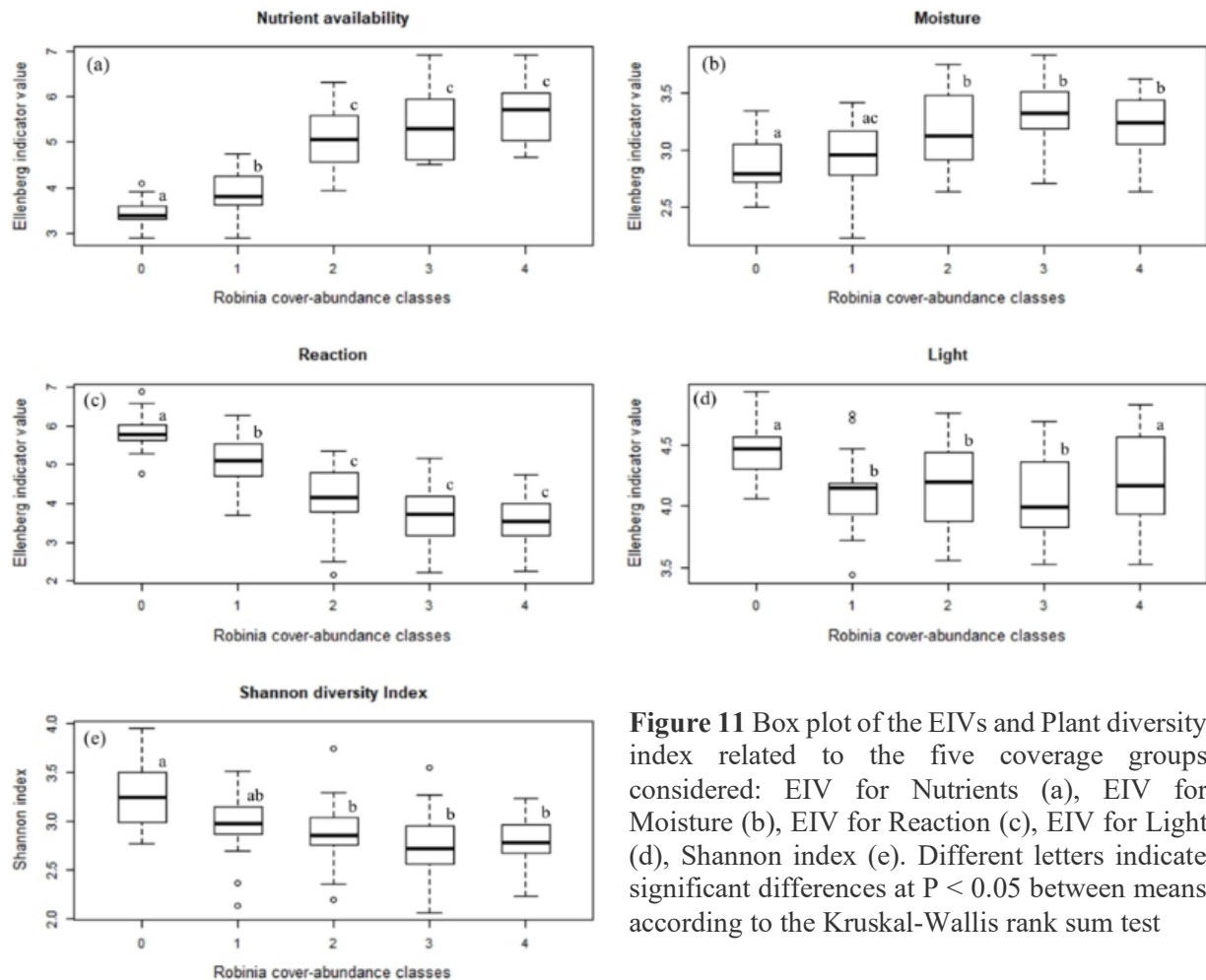
Figure 11 Box plot of the EIVs and Plant diversity index related to the five coverage groups considered: EIV for Nutrients (a), EIV for Moisture (b), EIV for Reaction (c), EIV for Light (d), Shannon index (e). Different letters indicate significant differences at $P < 0.05$ between means according to the Kruskal-Wallis rank sum test

composition. This is caused by the shift of the species pool to more homogeneous composition. Indeed *R. pseudoacacia* forests show a specific floristic composition, characterized by nitrophilous and non-forest species (e.g.: Allegrezza et al., 2019), masking the floristic variability typical of forest coenoses in a landscape. Analyzing those communities in a gradient of cover-abundance values we found that diversity expressed by Shannon index is detectable when *R. pseudoacacia* cover-abundance values are higher than 25% of the total specific coverage of the sampling minimum area. Our main finding is that *R. pseudoacacia* with low cover-abundance values (represented by the plots in the group 1) inside *Q. pubescens* forests of the 91AA* habitat, can determine changes in ecological features expressed by the species and the indices here considered. In contrast with the findings of Staska et al. (2014), we detected that in temperate sub-Mediterranean bioclimate in hilly sites, low

cover values of *R. pseudoacacia* (group 1: cover values <1- 25%) determine an initial effect on the community in term of changes in ecological indices. We found that the initial enrichment in nitrophilous species starts from <1% to 25% of *R. pseudoacacia* coverage (group 1) and gain cover-abundance values starting from this condition. The trends of EIV for nutrient follows the trend of weighted percentage presence of nitrophilous species of the groups, assessed by syntaxonomical classes, such as *Sambucus nigra, Galium aparine, Stellaria media* and *R. pseudoacacia* and linked to .
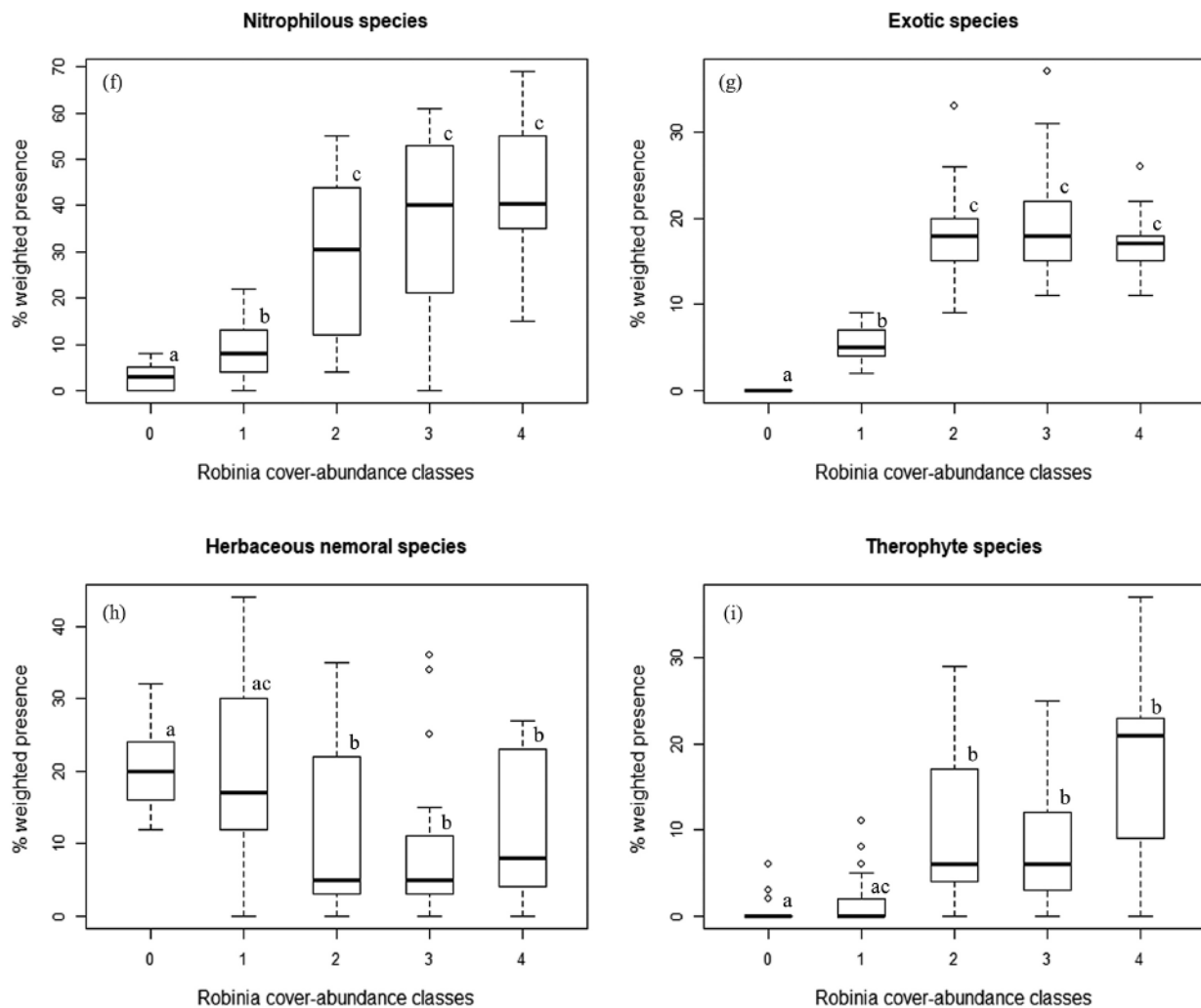
Figure 12 Box plot of the syntaxonomical classes and life forms related to the five coverage groups considered: Nitrophilous species (f); Exotic species (g); Herbaceous nemoral species (h); Annual species (therophyte) (i). Different letters indicate significant differences at $P < 0.05$ between means according to the Kruskal-Wallis rank sum test.

annual life forms (Table 5). The trend of EIVs for moisture and light along the five groups confirm the low adaptive capacity to dry and arid conditions (Jin et al., 2011) and the low canopy cover of *R. pseudoacacia* coenoses (Slabejová et al., 2019). It is known that *Q. pubescens* forests are characterized by a relatively open canopy, but also *R. pseudoacacia* stands have a considerable amount of light reaching the understory layer over the whole vegetation (Krumm and Vitkova, 2016).In both cases, high light levels reaching the forest floor enable the survival of light-demanding species. As been proven by Sitzia et al. (2018) the effects of light availability in the understory layer

and the detectable response in term of EIV for light, are only detectable in most invaded and uninvaded groups (Figure 11 d). The lowest *R. pseudoacacia* coverage group also shows a significant difference in reaction EIVs in respect of the pure *Q. pubescens* forests in which they are found. This is in accordance with several studies that described the relationships between *R. pseudoacacia* stands and changing in soil reaction conditions due to the increase in nitrogen (Montagnini et al., 1986; Vitkova et al., 2015; Lazzaro et al., 2018a). In our dataset, at the level of group 1 an enrichment in alien, ruderal, annual and non-forest species is detectable. The presence of exotic species is an indicator of disturbed environments and is enhanced by the *R. pseudoacacia* itself (Von Holle et al., 2006). These detectable changes could be a sign of initial alterations of growing conditions and relative effects on the competitive success of species. Nemoral plants species are known to vegetate in nutrient-poor soils and suffer the competition with faster-growing species in invaded conditions (Touza et al., 2008). Considering group 1 as a key element, while on the one hand, we are witnessing the progressive enrichment of species linked to the disturbance, on the other we observe how the species linked to forest conditions progressively decrease their coverage in groups with *R. pseudoacacia* dominance (Table 5). The forest and nemoral species of the dataset, such as *Fraxinus ornus, Rubia peregrina, Cornus sanguinea, Crataegus monogyna*, *Asparagus acutifolius*, *Viola alba* subsp. *dehnhardtii* are defined as target species of the habitat 91AA* (Biondi et al., 2009; European Commission, 2013). In the group 1 are also comprised forest coenoses of the 91AA* habitat; the decrease in coverage of the target species of the habitat is not enough to determine the loss of the habitat itself but reflects the homogenization process carried out by *R. pseudoacacia* (Figure 10). Although these novel forests ecosystems are also characterized by the presence of forests and herbaceous nemoral species (Allegrezza et al., 2019; Vitkova et al., 2020), in comparison with the Italian oak woods of the habitat 91AA*, they lose coverage and presence of the nemoral target species (Table 3). The considered groups, even if not in direct contact with each other, express successive phases of the invasion process in the potential area of the oak forest and in conditions of direct presence into the same oak woods. These *R. pseudoacacia* coenoses are inserted in the theme outlined by the so-called "novel ecosystems" which are defined as "Synthetic ecosystems, include conditions and combinations of organisms never before in existence" (Odum, 1962). Novel ecosystems are mediated by anthropic intervention and bring about modifications to the resident ecosystems that are not yet completely clarified (Hobbs et al., 2006; Zavaleta et al., 2001). The successional dynamics in the case of *R. pseudoacacia* communities, in the same landscape position of the native oak forests, are still an open topic. The main results of the present paper highlight the effects of *R. pseudoacacia* coverage on the typical forests communities of the hilly landscape, that if iterated for a long period could lead to modifications of the vegetational succession as we know it.

5.7. Conclusions

This work is important in the context of the assessment of impacts by alien species on Italian forest habitats; usually, it is considered only the classic definition for dominant alien tree species: coverage

higher than class 3 of Braun-Blanquet scale (25-50% of coverage) (Lazzaro et al., 2018b). We demonstrate that considering the only medium-high cover-abundance range of the invasive alien tree species could cause an underestimation of the potential impacts on protected forests coenoses. It is possible to state that by carrying out monitoring in *Q. pubescens* forests of the habitat 91AA* and detecting a presence of *R. pseudoacacia* with cover values from <1% to 25% is enough to start planning strategies to optimize efforts in maintaining the integrity of the 91AA* forest habitat. It is also essential the detection of nitrophilous, alien and annual species along with low cover-abundance values of 91AA* habitat target species. It is precisely in these *R. pseudoacacia* low coverage conditions that it is preferable to concentrate monitoring activities to avoid the loss of the habitat itself. These results can be useful for forest managers and planners to implement an effective monitoring model and to cope with the replacement of native forest habitats with alien tree species, which has ecological and economic impacts with consequences for nature and society.

5.8 Appendices

Appendix 1 Origins, localities and coordinates (WGS89 UTM 33) of the plots
GROUP 0
Localities: Plot 89: rel. 185, tab. 3 in Allegrezza et al., 2002, (rel. 12, tab. 10 in Taffetani, 2000), from Colle Petrella-M. Ascensione (AP); Plot 91: rel. 30, tab. 2 in Allegrezza et al., 2002, (rel. 8, tab. 3 in Ubaldi et al., 1984), from Cappuccini di Fossombrone (PU); Plot 94: rel. 138, tab. 2 in Allegrezza et al., 2002, (rel. 1, tab. 13 in Ubaldi, 1988), from Fiorenzuola di Focara (PU); Plot 95: rel. 139, tab. 2 in Allegrezza et al., 2002, (rel. 2, tab. 13 in Ubaldi, 1988), from Fiorenzuola di Focara (PU); Plot 97: rel. 26, tab. 2 in Allegrezza et al., 2002, (Baldoni & Sanchioni), from Sant'Elena (AN); Plot 99: rel. 176, tab. 3 in Allegrezza et al., 2002, (Taffetani & Giannangeli), from San Lorenzo Treia (MC); Plot 101: rel. 7 in Lorenzoni, 1976 from Sassonegro-Arquà Petrarca Colli Euganei (PD); Plot 102: rel. 59, tab. 3 in Tasinazzo & Fiorentin, 2000, from Colli Berici (VI); Plot 105: rel. 62, tab. 3 in Tasinazzo & Fiorentin, 2000, from Colli Berici (VI); Plot 107: rel. 64, tab. 3 in Tasinazzo & Fiorentin, 2000, from Colli Berici (VI); Plot 108: rel. 65, tab. 3 in Tasinazzo & Fiorentin, 2000, from Colli Berici (VI); Plot 109: rel. 66, tab. 3 in Tasinazzo & Fiorentin, 2000, from Colli Berici (VI); Plot 119: rel. 3, tab. 1 in Ubaldi, 1980, from Monte Sole (BO); Plot 120: rel. 4, tab. 1 in Ubaldi, 1980, from Monte Sole (BO); Plot 122: rel. 6, tab. 1 in Ubaldi, 1980, from Monte Sole (BO); Plot 123: rel. 7, tab. 1 in Ubaldi, 1980, from Monte Sole (BO); Plot 125: rel. 6, tab. 2 in Blasi & Pietro, 1998, from Monte Rotondo, Vallecorsa (FR); Plot 127: rel. 6, tab. 1 in Biondi & Allegrezza, 1996, from Pietralacroce (AN); Plot 129: rel. 7, tab. 1 in Biondi & Allegrezza, 1996, from M. Conero (AN); Plot 130: rel. 2, tab. 1 in Biondi & Allegrezza, 1996, from M. Conero (AN); Plot 131: rel. 3, tab. 1 in Biondi & Allegrezza, 1996, from M. Conero (AN); Plot 132: rel. 4, tab. 1 in Biondi & Allegrezza, 1996, from M. Conero (AN).
Coordinates: Plot 89, 398407.5, 4761595.3, gr. 0; Plot 91, 323441.1, 4838853.4, gr.0; Plot 94, 325487.2, 4869650.4, gr.0; Plot 95, 326906.5, 4866850.4, gr.0; Plot 97, 343261.5, 4813510.3, gr.0; Plot 99, 359171.4, 4799316.4, gr.0; Plot 127, 381958.0, 4828891.8, gr.0; Plot 129, 372812.1,

4819355.3, gr.0; Plot 130, 386340.3, 4820367.0, gr.0; Plot 131, 385641.4, 4823702.7, gr.0; Plot 132, 385838.2, 4823951.5, gr.0; Plot 125, 368882.4, 4589756.9, gr.0; Plot 101, 240425.1, 5017202.6, gr.0; Plot 102,221504.0, 5033746.3, gr.0; Plot 105, 220569.8, 5034447.0, gr.0; Plot 107, 222284.9, 5036852.5, gr.0; Plot 108, 219314.2, 5034684.2, gr.0; Plot 109, 222243.0, 5033055.1, gr.0; Plot 119, 198704.1, 4914703.1, gr.0; Plot 120, 198029.2, 4914677.5, gr.0; Plot 122, 198362.0, 4913546.6, gr.0; Plot 123, 198476.9, 4914646.1, gr.0.

GROUP 1

Localities: Plot 1: rel. 14, tab. 1 in Buffa & Ghirelli, 1993, from Colli Euganei; Plot 2: rel. 15, tab. 1 in Buffa & Ghirelli, 1993, from Colli Euganei; Plot 3: rel. 16, tab. 1 in Buffa & Ghirelli, 1993, from Colli Euganei; Plot 4: rel. 13, tab. 2 in Blasi & Pietro, 1998, from Carpinella Colle Palombi, Vallecorsa (FR); Plot 5: rel. 2, tab. 1 in Biondi & Allegrezza, 2004, from Gallignano (AN); Plot 6: rel. 3, tab. 1 in Biondi & Allegrezza, 2004, from Gallignano (AN); Plot 7: rel. 1, tab. 1 in Biondi & Allegrezza, 1996, from Monte della Crescia (AN); Plot 8: unpublished from Gallignano (AN); Plot 9: unpublished from Scisciano (AN); Plot 10: unpublished from Albacina (AN); Plot 11: unpublished from Pontechiaradovo (AN); Plot 12: unpublished from Castelbellino (AN); Plot 13: rel. 4, tab. 1 in Biondi & Allegrezza, 2004, from Gallignano (AN); Plot 14: rel. 10, tab. 1 in Buffa & Ghirelli, 1993, from Colli Euganei; Plot 15: rel. 11, tab. 1 in Buffa & Ghirelli, 1993, from Colli Euganei; Plot 16: rel. 12, tab. 1 in Buffa & Ghirelli, 1993, from Colli Euganei; Plot 17: rel. 13, tab. 1 in Buffa & Ghirelli, 1993, from Colli Euganei; Plot 140: rel. 9, tab. 2 in Adorni, 2001, from Monticello, Felino-Val Baganza (PA); Plot 141: rel. 1, tab. 2 in Zitti et al., 2005, from Onferno Nature Reserve: next to Ca' Bernardo (RN); Plot 142: rel. 2, tab. 2 in Zitti et al., 2005, from Onferno Nature Reserve: next to Ca' Bernardo (RN); Plot 143: rel. 4, tab. 2 in Zitti et al., 2005, from Onferno Nature Reserve: next to Ca' Bernardo (RN).

Coordinates: Plot 14, 242243.4, 5025326.6 gr.1; Plot 15, 243322.9, 5019501.6, gr.1; Plot 16, 239964.9, 5023731.0, gr.1; Plot 17, 238346.4, 5026924.6, gr.1; Plot 1, 244503.8, 5016812.9, gr.1; Plot 2, 237444.0, 5019366.0, gr.1; Plot 3, 243456.6, 5020376.2, gr.1; Plot 141, 301071.9, 4856755.0, gr.1; Plot 142, 296923.5, 4854312.9, gr.1; Plot 143, 301279.6, 4851672.5, gr.1; Plot 140, 135375.4, 4953466.6, gr.1; Plot 5, 373529.6, 4824874.5, gr.1; Plot 6, 372851.4, 4824705.0, gr.1; Plot 13, 373905.4, 4824801.2, gr.1; Plot 7, 373373.6, 4817373.4, gr.1; Plot 4, 366577.7, 4590173.5, gr.1; Plot 8, 372660.8, 4824706.1, gr.1; Plot 9, 346025.1, 4814458.1, gr.1; Plot 10, 338783.7, 4799836.9, gr.1; Plot 11, 336950.6, 4809590.4, gr.1; Plot 12, 350832.6, 4816155.3, gr.1.

GROUP 2

Localities: Plot 18: unpublished, from San Bartolo (PU); Plot 19: rel. 38, tab. 1 in Allegrezza et al., 2019, from Mombaroccio (PU); Plot 20: rel. 44, tab. 1 in Allegrezza et al., 2019, from Arcevia (AN); Plot 21: rel. 43, tab. 1 in Allegrezza et al., 2019, from Arcevia (AN); Plot 22: rel. 17, tab. 1 in Allegrezza et al., 2019, from Treia (MC); Plot 23: unpublished from Oretzzano (FM); Plot 26: rel. 33, tab. 1 in Allegrezza et al., 2019, from Albacina (AN); Plot 28: rel. 20, tab. 1 in Allegrezza et al.,

2019, from Monsano (AN); Plot 29: rel. 19, tab. 1 in Allegrezza et al., 2019, from Cerreto d'Esi (AN); Plot 30: rel. 22, tab. 7 in Ubaldi, 2003, from Bologna hills (BO); Plot 31: rel. 19, tab. 7 in Ubaldi, 2003, from Bologna hills (BO); Plot 33: rel. 15, tab. S2 in Campagaro et al., 2018, from Vicenza; Plot 34: rel. 16, tab. S2 in Campagaro et al., 2018, from Padova; Plot 35: rel. 9, tab. S2 in Campagaro et al., 2018, from Padova; Plot 36: rel. 23, tab. S2 in Campagaro et al., 2018, from Vicenza; Plot 37: rel. 28, tab. S2 in Campagaro et al., 2018, from Padova; Plot 38: rel. 27, tab. S2 in Campagaro et al., 2018, from Vicenza; Plot 39: rel. 74, tab. 3 in Tasinazzo & Fiorentin, 2000, from Colli Berici (VI); Plot 40: rel. 76, tab. 3 in Tasinazzo & Fiorentin, 2000, from Colli Berici (VI); Plot 41: rel. 7, tab. 1 in Buffa & Ghirelli, 1993, from Colli Euganei; Plot 42: rel. 8, tab. 1 in Buffa & Ghirelli, 1993, from Colli Euganei; Plot 43: rel. 9, tab. 1 in Buffa & Ghirelli, 1993, from Colli Euganei.

Coordinates: Plot 41, 240927.0, 5023621.6, gr.2; Plot 42, 238753.3, 5022887.4, gr.2; Plot 43, 240347.7, 5022821.6, gr.2; Plot 33, 228867.7, 5040816.1, gr.2; Plot 34, 240073.6, 5027439.0, gr.2; Plot 35, 239966.9, 5019997.0, gr.2; Plot 36, 218861.0, 5033972.9, gr.2; Plot 37, 245860.4, 5029401.7, gr.2; Plot 38, 221498.4, 5036100.7, gr.2; Plot 39, 221972.0, 5036733.9, gr.2; Plot 40, 220731.8, 5035102.1, gr.2; Plot 30, 199478.7, 4936271.5, gr.2; Plot 31, 197800.4, 4933961.3, gr.2; Plot 18, 330829.1, 4864960.1, gr.2; Plot 23, 385372.7, 4764942.3, gr.2; Plot 19, 326544.8, 4853487.5, gr.2; Plot 20, 334058.8, 4819246.6, gr.2; Plot 21, 334353.8, 4819089.2, gr.2; Plot 22, 363377.3, 4796527.4, gr.2; Plot 26, 338875.4, 4800114.2, gr.2; Plot 28, 361215.9, 4823782.4, gr.2; Plot 29, 337228.0, 4797247.3, gr.2.

GROUP 3

Localities: Plot 44: rel. 41, tab. 1 in Allegrezza et al., 2019, from San Bartolo (PU); Plot 45: rel. 7, tab. 1 in Allegrezza et al., 2019, from San Bartolo (PU); Plot 47: rel. 35, tab. 1 in Allegrezza et al., 2019, from Mombaroccio (PU); Plot 48: rel. 37, tab. 1 in Allegrezza et al., 2019, from Mombaroccio (PU); Plot 49: rel. 39, tab. 1 in Allegrezza et al., 2019, from Mombaroccio (PU); Plot 50: unpublished from Aqualagna (PU); Plot 51: unpublished from Arcevia (AN), loc. Montale; Plot 52: rel. 45, tab. 1 in Allegrezza et al., 2019, from Treia (MC); Plot 54: rel. 1, tab. 1 in Allegrezza et al., 2019, from Giulianova (TE); Plot 55: rel. 6, tab. 1 in Allegrezza et al., 2019, from Bellante (TE); Plot 56: rel. 8, tab. 1 in Allegrezza et al., 2019, from Ancona; Plot 58: unpublished from Jesi (AN); Plot 60: rel. 21, tab. 1 in Allegrezza et al., 2019, from Cerreto d'Esi (AN); Plot 61: rel. 25, tab. 1 in Allegrezza et al., 2019, from Agugliano (AN); Plot 62: rel. 25, tab. 7 in Ubaldi, 2003, from Bologna hills (BO); Plot 63: rel. 24, tab. 7 in Ubaldi, 2003, from Bologna hills (BO); Plot 64: rel. 23, tab. 7 in Ubaldi, 2003, from Bologna hills (BO); Plot 65: rel. 17, tab. 7 in Ubaldi, 2003, from Bologna hills (BO); Plot 66: rel. 16, tab. 7 in Ubaldi, 2003, from Bologna hills (BO); Plot 67: rel. 26, tab. 7 in Ubaldi, 2003, from Bologna hills (BO); Plot 69: rel. 8, tab. S2 in Campagaro et al., 2018, from Padova; Plot 70: rel. 79, tab. 3 in Tasinazzo & Fiorentin, 2000, from Colli Berici (VI).

Coordinates: Plot 69, 241573.9, 5023148.1, gr.3; Plot 70, 220103.7, 5034976.7, gr.3; Plot 62, 195636.4, 4934003.5, gr.3; Plot 63, 200455.6, 4931662.8, gr.3; Plot 64, 202068.6, 4933885.5, gr.3; Plot 65, 196403.5, 4937131.1, gr.3; Plot 66, 205019.1, 4932488.9, gr.3; Plot 67, 197742.9,

4929299.7, gr.3; Plot 50, 313836.5, 4834105.9, gr.3; Plot 51, 338090.0, 4823267.6, gr.3; Plot 58, 360595.0, 4819861.4, gr.3; Plot 44, 329095.7, 4866168.4, gr.3; Plot 45, 330885.7, 4865086.5, gr.3; Plot 47, 327266.4, 4852881.1, gr.3; Plot 48, 327212.3, 4850191.2, gr.3; Plot 49, 327718.8, 4851120.7, gr.3; Plot 52, 362604.0, 4797291.2, gr.3; Plot 54, 415133.4, 4733446.5, gr.3; Plot 55, 402294.9, 4732120.0, gr.3; Plot 56, 379813.4, 4827006.9, gr.3; Plot 60, 338763.0, 4795535.0, gr.3; Plot 61, 370428.0, 4823568.3, gr.3.

GROUP 4

Localities: Plot 71: rel. 31, tab. 7 in Ubaldi, 2003, from Bologna hills (BO); Plot 72: rel. 30, tab. 7 in Ubaldi, 2003, from Bologna hills (BO); Plot 73: rel. 34, tab. 7 in Ubaldi, 2003, from Bologna hills (BO); Plot 74: rel. 33, tab. 7 in Ubaldi, 2003, from Bologna hills (BO); Plot 75: rel. 32, tab. 7 in Ubaldi, 2003, from Bologna hills (BO); Plot 76: rel. 26, tab. 7 in Ubaldi, 2003, from Bologna hills (BO); Plot 77: rel. 35, tab. 7 in Ubaldi, 2003, from Bologna hills (BO); Plot 78: rel. 18, tab. 7 in Ubaldi, 2003, from Bologna hills (BO); Plot 79: rel. 29, tab. S2 in Campagaro et al., 2018, from Vicenza; Plot 80: rel. 75, tab. 3 in Tasinazzo & Fiorentin, 2000, from Colli Berici (VI); Plot 81: rel. 77, tab. 3 in Tasinazzo & Fiorentin, 2000, from Colli Berici (VI); Plot 82: rel. 78, tab. 3 in Tasinazzo & Fiorentin, 2000, from Colli Berici (VI); Plot 83: rel. 1, tab. 1 in Buffa & Ghirelli, 1993, from Colli Euganei; Plot 84: rel. 2, tab. 1 in Buffa & Ghirelli, 1993, from Colli Euganei; Plot 85: rel. 3, tab. 1 in Buffa & Ghirelli, 1993, from Colli Euganei; Plot 86: rel. 4, tab. 1 in Buffa & Ghirelli, 1993, from Colli Euganei; Plot 87: rel. 5, tab. 1 in Buffa & Ghirelli, 1993, from Colli Euganei; Plot 88: rel. 6, tab. 1 in Buffa & Ghirelli, 1993, from Colli Euganei.

Coordinates: Plot 83, 238571.5, 5017139.3, gr.4; Plot 84, 240268.2, 5020548.4, gr.4; Plot 85, 242997.7, 5019431.0, gr.4; Plot 86, 242777.7, 5021255.8, gr.4; Plot 87, 238594.8, 5022782.3, gr.4; Plot 88, 240958.7, 5020981.0, gr.4; Plot 79, 226780.3, 5029986.0, gr.4; Plot 80, 221966.1, 5035019.5, gr.4; Plot 81, 220560.3, 5034391.7, gr.4; Plot 82, 220156.0, 5033322.0, gr.4; Plot 71, 192998.5, 4935116.0, gr.4; Plot 72, 193947.7, 4933297.7, gr.4; Plot 73, 197744.6, 4931626.6, gr.4; Plot 74, 201755.4, 4931506.2, gr.4; Plot 75, 200472.0, 4934688.2, gr.4; Plot 76, 190614.2, 4933439.3, gr.4; Plot 77, 191848.7, 4935129.3, gr.4; Plot 78, 187827.9, 4936638.5, gr.4.

Appendix 2

Complete list of species with the indication of the life form, syntaxonomical attribute, EIVs, and the medium percentage cover (%) of the species for each of the five groups. Species present one-time per-group were omitted. Species significantly related to groups are indicated with the significance level and in a progressive grey colored scale (from dark grey corresponding to 15% of medium percentage coverage, to white that corresponds to 0% of medium percentage coverage). *** $p \leq 0.001$; ** $p \leq 0.01$; * $p \leq 0.05$; $p \leq 0.1$

	Life form	Syntaxon omical attribute	L	T	U	R	N	Gr.0	Gr.1	Gr.2	Gr.3	Gr.4	p
Robinia pseudoacacia L.	P	AL	3,75	5,25	3	X	8	0,0	4,0	11,6	14,5	14,8	***
Sambucus nigra L.	P	NTR	5,25	3,75	4	X	9	0,0	2,0	3,5	6,8	6,7	***
Galium aparine L.	T	NTR	4,5	X	3	5	5	0,0	0,3	1,9	1,6	3,5	***
Stellaria media (L.) Vill. subsp. media	T	NTR	5	X	3	7	8	0,0	0,6	1,5	0,3	4,2	*
Urtica dioica L. subsp. dioica	H	NTR	X	X	5	X	8	0,0	0,0	1,1	3,1	1,2	***
Arum italicum Mill. subsp. italicum	G	NTR	4,5	6	3	5	5	0,1	1,1	1,6	2,6	1,0	*
Clematis vitalba L.	P	RP	5,25	5,25	3,75	7	7	1,7	1,3	2,4	3,2	2,0	**
Rubus ulmifolius Schott	NP	RP	3,75	6	3	5	8	1,5	2,6	2,7	5,1	3,0	p
Quercus pubescens Willd. s.l.	P	QF	5,25	6	2	7	4	9,6	9,2	1,9	1,2	0,7	***
Fraxinus ornus L. subsp. ornus	P	QF	4	6	2	8	3	4,1	4,0	2,0	1,2	0,3	***
Rubia peregrina L.	P	QF	4	7	3	5	3	2,3	2,2	0,5	1,0	0,0	*
Cornus sanguinea L.	P	RP	5,25	3,75	5	8	X	3,0	2,3	1,6	1,8	0,8	**
Viola alba Besser subsp. dehnhardtii (Ten.) W. Becker	H	Nem_herb	4	6	4	7	6	2,2	1,0	0,2	0,4	0,4	***
Crataegus monogyna Jacq.	P	RP	4,5	5,25	3	6	3	3,2	3,0	2,1	1,9	1,6	***
Brachypodium rupestre (Host) Roem. & Schult.	H	TG	6	4,5	3,75	8	4	2,9	1,0	0,2	1,0	0,0	***
Laurus nobilis L.	P	QF	1,5	5,25	6	4	6	0,3	3,0	2,0	3,4	0,0	***
Euonymus europaeus L.	P	RP	4,5	3,75	4	8	5	1,0	1,0	2,0	2,8	0,7	**
Hedera helix L. subsp. helix	P	QF	3	3,75	4	X	X	3,2	7,0	7,4	7,6	5,5	p
Prunus spinosa L. subsp. spinosa	P	RP	5,25	3,75	X	X	X	0,7	1,7	0,7	1,5	0,4	
Ligustrum vulgare L.	NP	RP	5,25	4,5	X	8	X	1,0	2,2	1,9	0,6	1,3	p
Ruscus aculeatus L.	G	Nem_herb	3	6	3	5	5	1,9	2,7	2,2	1,4	1,2	
Asparagus acutifolius L.	G	Nem_herb	4,5	6,75	2	5	5	2,5	2,0	1,1	0,9	0,5	
Acer campestre L.	P	QF	3,75	5,25	3,75	7	6	1,7	1,6	2,9	1,0	1,3	
Ulmus minor Mill. subsp. minor	P	RP	3,75	5,25	X	8	X	0,5	2,2	2,4	2,1	2,3	
Dioscorea communis (L.) Caddick & Wilkin.	G	Nem_herb	3,75	5,25	4	8	6	1,3	1,7	2,6	1,5	2,5	
Presence <20%													
Castanea sativa Miller	P	QF	3,75	6	X	4	X	0,1	4,3	0,8	0,4	0,5	
Prunus avium L. subsp. avium	P	QF	3	3,75	4	7	5	0,3	1,1	0,9	0,5	0,4	
Corylus avellana L.	P	QF	4,5	3,75	4	5	8	0,3	0,6	0,9	0,4	0,7	
Muscari comosum (L.) Mill.	G	NTR	5,25	6	2,25	7	0	0,1	0,1	0,7	1,2	0,7	
Viola reichenbachiana Jord. ex Boreau	H	Nem_herb	3	3,75	4	7	6	0,2	1,1	0,3	0,1	0,7	
Rosa canina L.	NP	RP	6	3,75	3	X	X	0,2	0,6	1,0	0,3	0,3	
Symphytum tuberosum L. s.l	G	Nem_herb	3	3,75	4,5	7	5	0,1	0,4	0,8	0,1	1,0	
Mespilus germanica L.	P	QF	3,75	6	3	X	X	0,2	0,8	0,2	0,4	0,4	
Geum urbanum L.	H	NTR	3	3,75	4	6	7	0,0	0,1	0,3	0,4	0,8	
Hepatica nobilis Miller	G	Nem_herb	3	4,5	3	7	X	0,3	0,1	0,2	0,1	0,1	
Rubus plicatus Weihe & Nees	NP	RP	5,25	4,5	3	5	7	0,0	0,8	2,1	0,5	1,3	
Veronica hederifolia L.	T	FB	4,5	4,5	4	3	7	0,0	0,3	0,4	0,2	2,1	
Lonicera caprifolium L.	P	RP	4,5	3,75	5	X	5	0,9	1,0	0,3	0,0	0,4	
Cardamine bulbifera (L.) Crantz	G	Nem_herb	2,25	3,75	4	7	6	0,0	1,0	0,1	0,1	1,4	
Bryonia cretica subsp. dioica (Jacq.) Tutin	G	NTR	6	5,25	4	8	6	0,0	0,3	0,5	0,4	1,2	
Lamium maculatum L.	H	NTR	5,25	5,25	3	5	4	0,0	0,4	0,2	0,2	1,3	
Ailanthus altissima (Mill.) Swingle	P	AL	4,5	5,25	4	5	5	0,0	0,3	0,8	0,8	0,2	
Brachypodium sylvaticum (Huds.) P. Beauv. subsp. sylvaticum	H	Nem_herb	3	3,75	4	6	6	0,5	0,8	0,2	0,5	0,0	
Alliaria petiolata (M. Bieb.) Cavara & Grande	H	NTR	3,75	4,5	3,75	7	9	0,1	0,0	0,5	0,6	0,6	
Ranunculus bulbosus L.	H	FB	6	4,5	2	7	3	0,5	0,4	0,0	0,2	0,6	

Species											
Viola odorata L.	H	FB	3,75	4,5	4	X	8	0,1	0,7	0,3	0,0	0,5
Viburnum lantana L.	P	RP	5,25	3,75	3	8	5	1,1	0,2	0,0	0,1	0,2
Inula conyzae (Griess.) Meikle	H	NTR	5	5	3	7	3	0,8	0,1	0,1	0,4	0,0
Rubus hirtus Waldst. et Kit.	NP	RP	5,25	4,5	3	5	7	0,3	0,2	0,0	0,6	0,1
Rosa arvensis Huds.	NP	QF	3,75	3,75	3,75	7	5	0,7	0,2	0,0	0,0	0,2
Helleborus odorus Waldst. & Kit.	G	TG	3,75	5,25	4	8	6	0,0	0,1	0,2	0,1	0,6
Asparagus tenuifolius Lam.	G	Nem_herb	4,5	5,25	3	6	5	0,2	0,4	0,3	0,0	0,2
Acer opalus Mill. subsp. obtusatum (Waldst. et Kit. ex Willd.) Gams	P	QF	3,75	3,75	5	7	7	0,2	0,3	0,3	0,2	0,0
Campanula trachelium L. subsp. trachelium	H	Nem_herb	3	3,75	3,75	8	8	0,1	0,3	0,2	0,3	0,0
Rhamnus alaternus L. subsp. alaternus	P	QF	3	6,75	1,5	4	4	0,2	0,2	0,3	0,1	0,0
Helleborus viridis L. subsp. bocconei (Ten.) Peruzzi	G	TG	3,75	3,75	4,5	7	6	0,1	0,2	0,0	0,2	0,1
Clinopodium nepeta (L.) Kuntze	Ch	TG	3,75	5,25	2	9	3	0,0	0,1	0,1	0,1	0,2
Pulmonaria officinalis L	H	Nem_herb	4	5	4	8	6	0,0	0,1	0,2	0,1	0,1
Poa trivialis L.	H	NTR	4,5	X	5	X	7	0,0	0,0	1,3	1,0	1,8
Aegonychon purpurocaeruleum (L.) Holub	H	Nem_herb	3,75	5,25	3	8	4	1,8	1,1	0,0	0,1	0,0
Lonicera etrusca Santi	P	RP	5,25	6	2	6	4	1,5	1,3	0,0	0,2	0,0
Parietaria judaica L.	H	NTR	5,25	6	2	X	6	0,0	0,0	0,8	1,0	0,6
Ostrya carpinifolia Scop.	P	QF	3	6	3	X	X	1,6	0,2	0,2	0,0	0,0
Allium ursinum L.	G	Nem_herb	1,5	X	5	7	8	0,0	0,0	0,7	0,2	0,9
Chaerophyllum temulum L.	T	NTR	4	5	3,75	X	8	0,0	0,0	0,4	1,0	0,2
Polygonatum multiflorum (L.) All.	G	TG	1,5	3,75	3,75	7	4	0,0	0,7	0,0	0,4	0,5
Geranium robertianum L.	T	TG	3	4,5	3	5	5	0,0	0,0	0,7	0,1	0,7
Juglans regia L.	P	NTR	4,5	4,5	4	6	6	0,0	0,3	0,7	0,5	0,0
Taraxacum F.H.Wigg. sect. Taraxacum	H	NTR	5,25	X	4	X	7	0,0	0,0	0,6	0,4	0,5
Lamium orvala L.	H	TG	2,25	3,75	5	7	8	0,0	0,0	0,7	0,1	0,7
Quercus ilex L. subsp. ilex	P	QF	1,5	6,75	2	X	X	0,9	0,1	0,4	0,0	0,0
Ballota nigra L.	H	NTR	6	4,5	4	X	8	0,0	0,0	0,3	0,2	1,0
Melittis melissophyllum L.	H	Nem_herb	3,75	4,5	3	7	3	0,8	0,3	0,0	0,4	0,0
Dactylis glomerata L. subsp. glomerata	H	FB	5,25	4,5	3	5	6	0,4	0,3	0,0	0,6	0,0
Sorbus torminalis (L.) Crantz	P	QF	3	4,5	3	7	4	0,8	0,0	0,0	0,3	0,2
Celtis australis L.	P	RP	5,25	6	2	7	4	0,0	0,1	0,7	0,0	0,4
Avena fatua L.	T	AL	4,5	X	5	7	X	0,0	0,0	0,3	0,4	0,4
Sinapis alba L. subsp. alba	T	NTR	6	7,5	2,25	7	2	0,0	0,1	0,1	0,9	0,0
Parietaria officinalis L.	H	NTR	3	6	4	7	7	0,0	0,0	0,6	0,1	0,4
Cornus mas L.	P	RP	5	5	4	8	4	0,5	0,0	0,5	0,1	0,0
Silene nutans L.	H	NTR	5,25	3,75	2	7	3	0,4	0,4	0,2	0,0	0,0
Anemonoides nemorosa (L.) Holub	G	Nem_herb	X	X	X	5	X	0,0	0,4	0,0	0,1	0,6
Stachys sylvatica L.	H	TG	3	X	5,25	7	7	0,0	0,6	0,2	0,2	0,0
Cirsium arvense (L.) Scop.	G	NTR	6	X	3	X	7	0,0	0,0	0,1	0,2	0,6
Arctium lappa L.	H	NTR	6,75	3,75	4	7	9	0,0	0,0	0,1	0,4	0,4
Aegopodium podagraria L.	G	NTR	3,75	X	4,5	7	8	0,0	0,1	0,6	0,1	0,0
Ficaria verna Huds.	G	FB	3	4	5	7	7	0,0	0,3	0,2	0,0	0,3
Viola hirta L.	H	FB	4,5	3,75	2	8	2	0,2	0,0	0,4	0,0	0,2
Primula vulgaris Huds.	H	FB	5	4	4	7	5	0,0	0,3	0,1	0,3	0,0
Epimedium alpinum L.	H	Nem_herb	4,5	3,75	5	7	6	0,0	0,0	0,1	0,1	0,4
Vitis vinifera L.	P	NTR	4,5	6	4,5	8	6	0,0	0,1	0,4	0,1	0,0
Veronica chamaedrys L.	H	TG	4,5	X	3	X	X	0,0	0,2	0,1	0,0	0,3
Arum maculatum l.	G	NTR	2,25	4,5	5	7	8	0,0	0,0	0,2	0,1	0,3
Sonchus asper (L.) Hill	T	NTR	5,25	3,75	3	7	7	0,0	0,1	0,3	0,1	0,0

Species	Form	Group										
Campanula trachelium L. subsp. trachelium	H	Nem_herb	3	3,75	4	8	8	0,1	0,3	0,0	0,1	0,0
Mycelis muralis (L.) Dumort. subsp. muralis	H	Nem_herb	3	3,75	3,75	X	6	0,0	0,1	0,1	0,1	0,0
Asplenium scolopendrium L. subsp. scolopendrium	H	Al	1,5	4,5	4	8	6	0,0	0,0	0,0	0,1	0,2
Anisantha sterilis (L.) Nevski	T	NTR	5	5	3	X	5	0,0	0,0	2,0	0,0	4,2
Rosa sempervirens L.	NP	QF	4,5	6	2	4	6	1,8	1,3	0,0	0,0	0,0
Smilax aspera L.	NP	QF	4,5	7,5	2	5	3	1,6	1,2	0,0	0,0	0,0
Carex flacca Schreb. subsp. flacca	G	FB	5	4	5	8	X	1,7	0,8	0,0	0,0	0,0
Quercus cerris L.	P	QF	4,5	6	3	4	4	1,8	0,5	0,0	0,0	0,0
Emerus major Mill. subsp. emeroides (Boiss. & Spruner) Soldano & F.Conti	NP	RP	5,25	4,5	2	9	2	1,1	0,8	0,0	0,0	0,0
Cytisophyllum sessilifolium (L.) O.Lang	P	RP	4,5	3,75	4,5	4	5	1,7	0,1	0,0	0,0	0,0
Humulus lupulus L.	P	NTR	5,25	4,5	6	6	8	0,0	0,0	0,0	0,9	0,9
Sorbus domestica L.	P	QF	3	5	2,25	8	3	1,5	0,2	0,0	0,0	0,0
Elymus repens (L.) Gould subsp. repens	G	FB	5,25	X	3,75	X	8	0,0	0,0	0,9	0,0	0,7
Teucrium chamaedrys L.	Ch	FB	5,25	4,5	2	8	1	1,3	0,2	0,0	0,0	0,0
Osyris alba L.	NP	QF	5,25	6	2	4	2	1,1	0,3	0,0	0,0	0,0
Geranium sanguineum L.	H	TG	4,5	5,25	2	5	4	0,7	0,0	0,4	0,0	0,0
Lactuca sativa L. subsp. serriola (L.)	H	NTR	6,75	5,25	3	6	4	0,0	0,0	0,2	0,0	0,8
Artemisia vulgaris L.	H	NTR	6,75	5,25	3	X	5	0,0	0,0	0,0	0,2	0,8
Rumex sanguineus L.	H	Nem_herb	3	3,75	6	7	7	0,0	0,4	0,0	0,0	0,6
Geranium dissectum L.	T	NTR	5,25	6	1,5	5	2	0,0	0,0	0,0	0,1	0,8
Silene latifolia Poir. subsp. alba	H	NTR	4,5	6,75	2,25	4	2	0,0	0,0	0,0	0,5	0,4
Galium mollugo L. subsp. mollugo	H	FB	4,5	3,75	3,75	5	4	0,0	0,0	0,1	0,0	0,7
Epipactis helleborine (L.) Crantz	G	Nem_herb	2,25	3,75	4	7	5	0,7	0,1	0,0	0,0	0,0
Quercus petraea (Matt.) Liebl.	P	QF	4,5	4,5	4	4	6	0,3	0,0	0,0	0,5	0,0
Ficus carica L.	P	NTR	5,25	6	X	5	X	0,0	0,0	0,7	0,1	0,0
Glechoma hederacea L.	H	NTR	4,5	5,25	3	5	3	0,0	0,0	0,4	0,0	0,3
Carpinus orientalis Mill. subsp. orientalis	P	QF	3	5,25	2	4	5	0,6	0,1	0,0	0,0	0,0
Cephalanthera longifolia (L.) Fritsch	G	Nem_herb	3	3,75	2,25	8	3	0,4	0,3	0,0	0,0	0,0
Cruciata glabra (L.) C.Bauhin ex Opiz	H	TG	3,75	4,5	4	6	6	0,5	0,1	0,0	0,0	0,0
Cirsium vulgare (Savi) Ten.	H	NTR	6	3,75	4	X	8	0,0	0,0	0,1	0,0	0,5
Anisantha diandra (Roth) Tutin ex Tzvelev	T	NTR	6	6	2	5	4	0,0	0,0	0,3	0,3	0,0
Asplenium adiantum-nigrum L.	H	Nem_herb	4,5	5,25	3	2	3	0,0	0,4	0,0	0,2	0,0
Avena sterilis L.	T	AL	6	6,75	2	6	4	0,0	0,0	0,3	0,4	0,0
Cercis siliquastrum L.	P	QF	6	5,25	3	7	4	0,5	0,1	0,0	0,0	0,0
Tanacetum corymbosum (L.) Sch.Bip.	H	Nem_herb	6	X	4	X	5	0,2	0,5	0,0	0,0	0,0
Prunus mahaleb L.	P	RP	5,25	3,75	2	8	2	0,4	0,2	0,0	0,0	0,0
Petasites fragrans (Vill.) C. Presl	G	NTR	5,25	6	5	7	6	0,0	0,0	0,1	0,5	0,0
Clinopodium vulgare L. subsp. vulgare	H	NTR	5,25	3,75	3	7	3	0,3	0,0	0,0	0,2	0,0
Vincetoxicum hirundinaria Medik.	H	TG	4,5	3,75	2	7	3	0,4	0,0	0,0	0,0	0,2
Pistacia terebinthus L.	P	QF	6,75	6	1,5	7	2	0,5	0,1	0,0	0,0	0,0
Melissa officinalis L. subsp. altissima	H	NTR	4,5	6	3	6	4	0,0	0,1	0,0	0,4	0,0
Serratula tinctoria L.	H	FB	5,25	4,5	X	8	5	0,3	0,0	0,0	0,0	0,2
Solidago virgaurea L.	H	Nem_herb	3,75	X	4	X	5	0,4	0,2	0,0	0,0	0,0
Bromopsis erecta (Huds.) Fourr.	H	FB	6	3,75	2	8	3	0,4	0,1	0,0	0,0	0,0
Viburnum tinus L. subsp. tinus	P	QF	4	7	3	5	3	0,0	0,0	0,3	0,2	0,0
Scandix pecten-veneris L.	T	NTR	5,25	5,25	2,25	8	4	0,0	0,0	0,0	0,1	0,4
Inula salicina L.	H	FB	5,25	3,75	3	9	2	0,3	0,1	0,0	0,0	0,0
Alopecurus myosuroides Huds.	T	NTR	4,5	4,5	5	7	7	0,0	0,0	0,0	0,3	0,1
Festuca heterophylla Lamm	H	Nem_herb	3,75	3,75	3	5	4	0,3	0,0	0,0	0,2	0,0

Lonicera xylosteum L.	P	QF	3,75	3,75	4	7	X	0,3	0,1	0,0	0,0	0,0
Chamaeiris foetidissima (L.) Medik.	G	Nem_herb	5,25	5,25	3	4	5	0,0	0,0	0,1	0,2	0,0
Spartium junceum L.	P	RP	5,25	5,25	3	7	2	0,2	0,2	0,0	0,0	0,0
Erigeron canadensis L.	T	AL	6	4,5	3,75	X	7	0,0	0,0	0,3	0,1	0,0
Prunus cerasifera Ehrh.	P	AL	6,75	5,25	4	5	5	0,0	0,2	0,2	0,0	0,0
Rumex crispus L.	H	NTR	5	4	5	X	5	0,0	0,0	0,0	0,1	0,2
Acer monspessulanum L. subsp. monspessulanum	P	QF	4,5	6	2	8	4	0,2	0,0	0,1	0,0	0,0
Acer pseudoplatanus L.	P	QF	3	X	5	X	7	0,0	0,0	0,2	0,0	0,1
Rumex acetosa L.	H	NTR	6	X	X	4	5	0,0	0,0	0,1	0,2	0,0
Polygala nicaeensis subsp. nicaeensis	H	FB	6	4,5	2	7	2	0,2	0,1	0,0	0,0	0,0
Olea europaea L.	P	NTR	8,25	7,5	1	X	2	0,0	0,1	0,0	0,2	0,0
Scilla bifoglia L.	G	Nem_herb	3,75	4,5	5	7	6	0,0	0,0	0,1	0,0	0,2
Agrimonia eupatoria L. subsp. eupatoria	H	TG	5,25	4,5	3	8	4	0,1	0,2	0,0	0,0	0,0
Galanthus nivalis L.	G	QF	3,75	5,25	X	7	7	0,1	0,0	0,0	0,2	0,0
Ajuga reptans L.	H	FB	4,5	X	5	X	6	0,2	0,1	0,0	0,0	0,0
Eupatorium cannabium L.	H	NTR	5,25	5,25	5	5	7	0,0	0,0	0,1	0,2	0,0
Mercurialis perennis L.	G	Nem_herb	1,5	3,75	X	7	7	0,0	0,0	0,2	0,1	0,0
Helleborus foetidus L. subsp. foetidus	Ch	TG	3,75	4,5	3	8	3	0,1	0,0	0,2	0,0	0,0
Allium carinatum L.	G	FB	6,75	5,25	2	6	3	0,0	0,0	0,1	0,1	0,0
Malus sylvestris (L.) Mill.	P	QF	5,25	3,75	4	7	5	0,0	0,1	0,0	0,0	0,2
Rumex obtusifolius L.	H	NTR	5,25	3,75	2	X	9	0,0	0,0	0,2	0,0	0,1
Geranium rotundifolium L.	T	NTR	5,25	6	2	6	3	0,0	0,0	0,0	0,1	0,2
Daucus carota L.	H	NTR	6	4,5	3	5	4	0,0	0,1	0,1	0,0	0,0
Crataegus laevigata (Poir.) DC.	P	RP	4,5	4,5	3,75	5	4	0,0	0,0	0,0	0,1	0,2
Prunus laurocerasus L.	P	AL	6,75	5,25	4	5	5	0,0	0,0	0,1	0,1	0,0
Vinca minor L.	Ch	FB	3	4,5	4	X	6	0,0	0,1	0,0	0,1	0,0
Arundo donax L.	G	NTR	6	6,75	4	5	6	0,0	0,0	0,1	0,1	0,0
Convolvulus sepium L.	H	NTR	6	4,5	5	7	9	0,0	0,0	0,1	0,1	0,0
Melica uniflora Retz.	H	Nem_herb	2,25	3,75	3,75	6	X	0,1	0,1	0,0	0,0	0,0
Helleborus viridis L. subsp. viridis	G	TG	2,25	4,5	4	8	5	0,0	0,1	0,1	0,0	0,0
Euphorbia cyparissias L.	H	FB	5,25	5,25	2,25	5	5	0,1	0,2	0,0	0,0	0,0
Lathyrus sylvestris L. subsp. sylvestris	H	TG	5,25	3,75	3	4	4	0,2	0,1	0,0	0,0	0,0
Lathyrus vernus (L.) Bernh.	G	QF	3	3	3	7	X	0,0	0,1	0,1	0,0	0,0
Asarum europaeum L.	H	Nem_herb	2,25	3,75	5	8	6	0,0	0,0	0,1	0,1	0,0
Erythronium dens-canis L.	G	Nem_herb	3,75	3,75	2,25	6	8	0,0	0,0	0,1	0,0	0,1
Loncomelos brevistylus (Wolfner) Dostál	G	FB	6,75	6	1,5	6	2	0,1	0,1	0,0	0,0	0,0
Asplenium onopteris L.	H	Nem_herb	2,25	6,75	2	5	3	0,1	0,1	0,0	0,0	0,0
Asplenium ceterach L.	H	Al	6,75	5,25	2	7	3	0,1	0,1	0,0	0,0	0,0

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Chapter 6. First syntaxonomical contribution to the invasive *Ailanthus altissima* (Mill.) Swingle forest communities at its southern limit in Europe

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Abstract

Ailanthus altissima (tree of heaven), an invasive alien tree native to China, has become invasive all over the world and in Italy is present in all the administrative regions where it can form dense forest communities. Although there are several ecological studies on this species there is a lack of floristic-vegetational data for southern-Europe. The study presents the results of a floristic vegetational study on *A. altissima* forest communities of central Italy that aims to highlight the possible floristic-vegetational autonomy of these coenoses. The results have allowed the characterization of *A. altissima* coenoses at the ecological, biogeographic, syntaxonomic and landscape levels. These represent first *A. altissima* syntaxa described for the Italian peninsula and for southern-Europe. We propose two new sub-Mediterranean and Mediterranean associations comprised in the recently described alliance *Lauro nobilis-Robinion pseudoaciae*, in the *Chelidonio-Robinietalia* order and the *Robinietea* class*: Asparago acutifolii-Ailanthetum altissimae*: forest community with strat- ified structure and high canopy density on the warmer slopes of the hills in dry soil conditions and low anthropic disturbance and *Aro italici-Ailanthetum altissimae*: paucispecific forest communities with a monolayered structure typically found in agricultural, and peri-urban areas on pelitic, alluvial silty-sandy substrates, in conditions of edaphic humidity and high anthropogenic disturbance. The comparison with literature data highlights the autonomy of these associations of the sub-Mediterranean and Mediterranean alliance *Lauro nobilis-Robinion pseudoacaciae* alliance from the *Balloto nigrae-Ailanthetum altissimae* association of the Central and SE-European *Balloto nigrae-Robinion pseudoacaciae* alliance

6.1. Introduction

The invasion of alien plants is a global process derived from the human–mediated introduction of a species out- side their habitat of origin (Richardson and Pyšek 2006; Van Kleunen et al. 2015). Biological invasions constitute one of the major threats to biodiversity and ecosystem services provided by native ecosystems (Simberloff et al. 2013; Lazzaro et al. 2020; Montecchiari et al. 2020a) causing both ecological, economical and health impacts (Lonsdale 1999; Pimentel et al. 2000; Touza et al. 2008; Vilà and Hulme 2017). *Ailanthus altissima* is one of the most widespread invasive alien species (IAS) in Europe (Lambdon, et al. 2008; Pysek et al. 2009) and was recently added to the list of IAS of Union concern (European commission 2019). It is a tree native to China and introduced in Europe (France) in 1740 (Kowarik and Saumel 2007). It quickly spread in Central and southern Europe in urban and peri–urban areas, but also in the agro–forest environment (Gutte et al. 1987; Udvardy 1998; Howard et al. 2004) due to cultivations for ornamental, productive and erosion control purposes (Hu 1979; Udvardy 1998; Kowarik and Säumel 2007; Badalamenti et al. 2012). Its first record for the Italian territory dates back to 1760 in the Botanical Garden of Padua (Badalamenti et al. 2012). Now is present in all the Italian administrative regions (Galasso et al. 2018) classified as invasive alien species because it can constitute proper forest communities (Montecchiari et al. 2020b; Viciani et al. 2020) capable to impact native ecosystems and Natura 2000 sites (Lazzaro et al. 2020). Moreover, according to the National Forest Inventory (Tabacchi et al. 2007), which classifies in a single category the *A. altissima* and *R. pseudoacacia* and forests, these formations together occupy almost 250000 ha, equal to 2.23% of the total national wooded area.

The efficacy in gamic reproduction and dissemination (Knapp and Canham 2000; Motard et al. 2011), agamic reproduction (Kowarik 1995; Kowarik and Saumel 2007, Von der Lippe et al. 2013) and rapid growth, enable *A. altissima* to form nearly pure stands (Dihoru and Doniţă 1970; Montecchiari et al. 2020b) and to have better competitive ability compared to the forest native species (Arnaboldi et al. 2002; Fotiadis et al. 2011; Höfle et al. 2014; Costàn-Nava et al. 2015). Moreover, the production of an allelopathic compound (Ailanthone) from the bark and leaves, can inhibit the germination of native species (Lawrence et al. 1991; Bostan et al. 2014). It shows a high tolerance to limiting ecological factors such as soil type and drought with several adaptations to water loss (Kowarik and Saumel 2007; Sladonja et al. 2015). *A. altissima* is better adapted to warmer climate regimes, in fact, it shows a high susceptibility to cold that is a limiting factor for the sapling survival (von der Lippe et al. 2005). Badalamenti et al. (2012) reports that *A. altissima* avoids excessively clay soils or soils subject to prolonged water stagnation. Thanks to its highly competitive features *A. altissima* can establish in a wide variety of environmental conditions and is able to form dense forest population that can also impact soil properties and nutrient cycling (Vilà et al. 2006; Gómez-Aparicio et al. 2008; Castro-Díez et al. 2009; Medina-Villar et al. 2015; Motard et al. 2015; Montecchiari et al. 2020b). Despite the many ecological data available and its wide distribution in the Mediterranean and Temperate Europe,

there is an important lack of floristic-vegetational studies on *A. altissima* forests in its meridional range of distribution, in sub-Mediterranean and Mediterranean areas. From a syntaxonomic point of view, in Europe is recognized only one class (with two orders and three alliances) that comprehends alien tree species as characteristic species: the *Robinietea* class. It includes "seral forest-clearing and anthropogenic successional scrub and thickets on nutrient-rich soils of temperate Europe" (Mucina et al. 2016) but it includes also thermophilus and xerophilous communities such as those of the *Euphorbio cyparissiae-Robinietalia* order de- fined as "tortuous and xerophilous Black Locust stands of thermophilus habitats" and on poor soils" (Vitkova and Kolbek 2010). Recently in Allegrezza et al. (2019) was described the *Lauro nobilis-Robinion pseudoacaciae* alliance for the peri-Adriatic sector of Central Italy, that brings together forest and pre–forest coenoses dominated by *R.pseudoacacia* that include forests communities dominated by other invasive alien tree species that have developed in the Mediterranean macroclimate territories of central and southern Italy that also extend into the temperate macroclimate of the sub-Mediterranean variant. Currently, in literature, there is only one *A. altissima* syntaxon, de- scribed for est-Romania by Sîrbu and Oprea (2010) called *Balloto nigrae-Ailanthetum altissimae*. This association is referred to the *Balloto nigrae-Robinion pseudoacaci- ae* alliance, *Chelidonio-Robinietalia pseudoacaciae* order *Robinietea* class. The association comprehend *A. altissima* communities situated between 38 and 265 m a.s.l. near human settlements, along roadsides-railway embankments, in abandoned agricultural areas and on the edge of *Robinia pseudoacacia* plantations that comprehends "heliophilous (sub-heliophilous), moderate thermophilous, xero-mesophilous, neutrophilous and moderate nitrophilous phytocoenoses" (Sirbu and Oprea 2010). Also, *A. altissima* communities of Slovakia were referred to *Balloto nigrae-Ailanthetum* association by Valachovic (2018). For central-Europe, there are other published floristic-vege- tation data of *A. altissima* coenoses but described only at the community level. Those communities have been de- scribed without a clear syntaxonomical classification and referred to syntaxonomic classes other than the *Robinietea* class such as *Sisymbrietea*, *Chenopodietea*, *Artemisietea*, *Agropyretea* or *Urtico-Sambucetea*, *Cratego-Prunetea*, *Quercetea pubescenti–petraeae* classes (Gutte et al. 1987) or described as *Ailanthus*-woods with *R. pseudoacacia* and *Acer* species with a non-clear syntaxonomic attribution (Kowarik and Bocker 1984). Moreover, for the Mediterranean region, Kowarik (1983) reported on the colonization by the *A. altissima* in the French-Mediterranean region classifying the *A. altissima* communities according to the Hemeroby classification system. He reported only one relevè "the only *A. altissima* occurrence in a non-ruderalized *Quercion ilicis* stand is on the northern slope of the mountain range". In literature is also cited *A. altissima* associations with no floristic-vegetational data linked to this syntaxons in literature such as *Ailantho altissimae-Robinietum pseuda- caciae* Julve 2003 referred to *Robinio pseudoacaciae-Ulmion minoris* Julve 1993 alliance, *Pruno avium-Carpinetalia betuli* Gillet 1986 ex Julve 1993 order, *Fraxino excelsioris-Quercetea roboris* Gillet 1986 ex Julve 1993 class and the *Fico-Ailanthetum altissimae* Lov. (1975) 1984 ("*Ailantho-Robinietum*" auct. adriat. Pp non Gutte; Kvarner: "žiròvine"). For the Italian territory, there are only two published papers that describe *A.*

altissima dominated vegetation: Fanelli (2002) described *A. altissima* forest community for the surroundings of the city of Rome and Sciandrello et al. (2017) described a *Rubus ulmifolius* shrub com- munity in Sicily (*Pruno spinosae-Rubion ulmifolii*, *Pyro spinosae-Rubetalia ulmifolii*, *Crataego-Prunetea*) with *A. altissima* having cover–abundance values higher than 3 (Braun-Blanquet scale) in four relevés. In the present paper, we aimed to describe the structure, ecology and syntaxonomy of the *A. altissima* forest communities present in its southern limit of presence in Europe. Specifically, the aims of this syntaxonomic study are to i) extend the poor floristic-vegetational data available for *A. altissima* forests communities in the Italian peninsula; ii) define the *A. altissima* forest vegetational types at the community level and the ecological and landscape context in which they are found; iii) highlight the possible floristic-vegetational autonomy of these coenoses in the context of the *Robinietea* class in comparison with *A. altissima* floristic-vegetational data from Europe.

6.2. Study area

The study was conducted in central Italy (Marche-Abruzzo peri-Adriatic sector) (Figure 13) at altitudes that range from 10 m a.s.l. to 500 m a.s.l on pelitic-arenaceous, arenaceous-pelitic and alluvial lithotypes. The bioclimatic classification sensu Rivas-Martínez et al. (2011) for these territories indicates a Macrobioclimate that ranging from Mediterranean, pluviseasonal oceanic bioclimate and upper meso-Mediterranean thermotype to the Temperate sub-Mediterranean variant, oceanic bioclimate and lower meso-temperate thermotype (Pesaresi et al. 2014) according to the bioclimatic classification. The prevailing land use categories are mostly cops such as heterogeneous
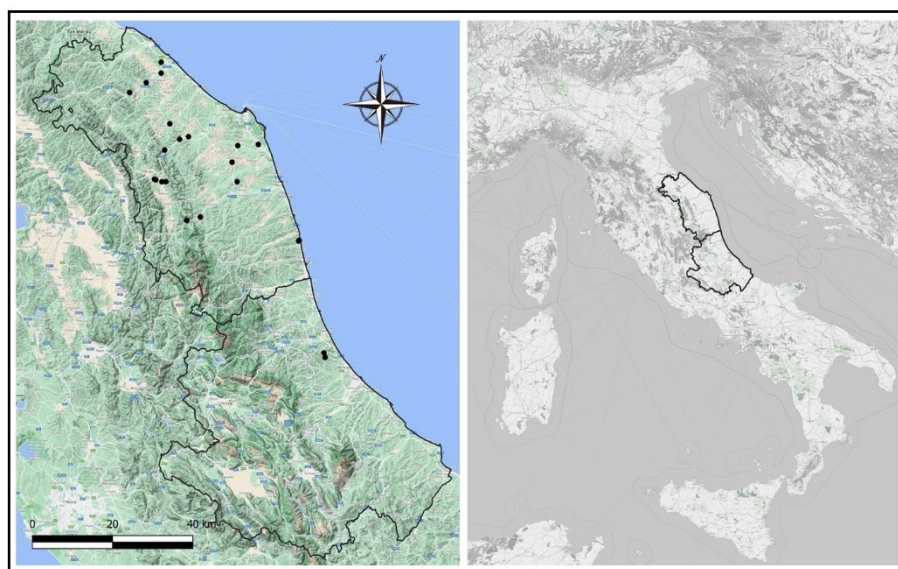
Figure 13 Study area Location of the study area showing the distribution of the unpublished relevés. Each relevè is represented by a single black point.

agricultural areas with complex cultivation patterns and non-irrigated arable land. The native forests vegetation consists of *Quercus pubescens*/*Q. virgiliana* woods on slopes referred to the alliance

Carpinion orientalis (class *Querco roboris-Fagetea sylvaticae*), and riparian woods of *Salix alba* and *Populus nigra* referred to the alliance *Populion albae* (class *Salici purpureae-Populetea nigrae*). The high-shrub pre-forest vegetation is represented by *Ulmus minor* communities of the *Lauro nobilis-Ulmion minoris* alliance (class *Salici purpureae-Populetea nigrae*) (Blasi et al. 2010).

6.3. Materials and Methods

The study of the plant communities was carried out according to the phytosociological methods of the Zurich–Montpellier school (Braun-Blanquet 1928), updated according to the most recent acquisitions (Rivas-Martínez 2005; Allegrezza et al. 2008; Biondi 2011; Blasi and Frondoni 2011). We performed a total of 22 unpublished phytosociological relevés. The surveys were performed on *A. altissima* forests aged >20 years, where the alien tree was clearly dominant and over a minimum homogeneous area of 100 m2. For the characterization of the *A. altissima* forests of the Italian peninsula, the unpublished relevés were analyzed along with 5 relevés from Fanelli (2002) that described *A. altissima* community for the surrounding of Rome, because they have a forest structure, with clearly dominant *A. altissima*, having cover-abundance values higher than 3 (Braun-Blanquet scale) (see Appendix 2). For the comparisons between the Italian peninsula and the European context we selected literature data that have been attributed to a syntaxon that includes *A. altissima* in the name and clearly dominant (cover-abundance values >3). Were used a total of 25 phytosociological relevés referred to the *Balloto nigrae-Ailanthetum altissimae* association respectively 20 from Sirbu and Oprea (2010) 5 from Valachovic (2018). The nomenclature of the species follows the check-list of Italian flora (Bartolucci et al. 2018). The life forms and chorology of the species follow Flora d'Italia (Pignatti et al. 2017–2019). For the Ellenberg indicators values (EIVs) (Ellenberg et al. 1992), we used the indices reformulated for the Mediterranean conditions (Pignatti et al. 2005): L light, T temperatures, C continentality; U soil moisture, R soil reaction, N availability of soil nutrients. The syntaxonomic classification is made according to the Prodrome of the Italian Vegetation (Biondi et al. 2014), as present on the updated site of the Italian Botanical Society (http://www.prodromovegetazioneitalia.org/), with references to that of the European vegetation (Mucina et al. 2016). The status of alien species (specifying between Archeophytes and Neophytes) has been assigned according to Galasso et al. (2018) and information on the national floras for the European data.

6.4. Data analysis

The vegetation data were processed using the "vegan" package (Oksanen et al. 2020) of the R software (R core team 2018). The cover–abundance values of the phytosciological matrix were converted to the Van der Maarel (1979) decimal scale and subjected to multivariate analysis. Before calculations, the ecological variables matrix was undergone at a normalization process using the "decostand" function on the "vegan" package. The numerical classification according to cluster

analysis was carried out by applying the "Ward" link algorithm to the similarity ratio matrix calculated by applying the "Jaccard" index on the vegetation matrix converted in presence/absence values. Life forms of each relevè were weighted on the species abundance values and then averaged at the group level. To compare EIVs of the plots, we used weighted average values. Box plot diagrams were used to illustrate data distribution of Life forms and EIVs. To analyze the variance of the groups and tests for significance we used ANOVA (Appendix 1) ("aov" function of "stats" package). The Shapiro test was used to test the normality of the analyzed data and the Bartlett test for homoscedasticity. For the comparison with the published European data, we create a unique phytosociological matrix, converted to the Van der Maarel (1979) decimal scale and subjected to multivariate analysis. The similarity matrix obtained applying the "Jaccard" index was used to perform non–metric multidimensional (NMDS) ordination diagram. The NMDS ordination diagram is suitable for the analysis of ordinal data such as those of Van der Maarel (Podani 2007) and was used to describe the main trends of the vegetation variations. Percentage weighted presence of chorological types and alien species for each plot was calculated and illustrated by box plots. Then we performed the analysis of variance and tested the significance among the averages of the identified groups.

6.5. Results and Discussion

The dendrogram (Figure 14a) obtained from the classification of phytosociological relevès highlights two main groups (Cluster I and Cluster II) which correspond to the two main structural, ecological and floristic–vegetational characteristics of the *A. altissima* forest communities. The comparison of the statistically significant traits such as functional (life forms) and ecological traits (EIVs), highlights the structural and ecological differences between the two groups. The first group (Cluster I) differs for the higher coverage of phanerophytes (Figure 14b.2) and thermophilous species (Temperature EIV) (Figure 14b.4) while the second group (Cluster II) is characterized by the higher coverage of herbaceous species such as Geophytes and Terophytes (Figure 14b.1 and 14b.3). The processing of the relevès in Table 1 and the comparison with the similar phytocoenoses described for south–est Europe allows us to propose and describe two new associations of *A. altissima* forest vegetation within the sub– Mediterranean alliance *Lauro nobilis-Robinion pseudoacaciae* (order *Chelidonio-Robinietalia pseudoacaciae* and class *Robinietea*): *Asparago acutifolii-Ailanthetum altissimae* (cluster I) and *Aro italici-Ailanthetum altissimae* (Cluster II).

ASPARAGO ACUTIFOLII–AILANTHETUM ALTISSIMAE ass. nova (Cluster I Figure14; *typus* rel. 7 of Tab. 6)

It is a sub-Mediterranean and Mediterranean forest community dominated by *A. altissima* characterized by a stratified structure and high canopy density, with an average height of 13,6 and an average richness of 16 species per relevè. It is typically present on the warmer slopes of the hills (up to 460 m a.s.l.) with arenaceous-pelitic, arenaceous and locally calcareous substrates, in dry soil

conditions and in areas subject to low anthropic disturbance (the surrounding landscape is characterized by the greater presence of forest areas). In the dominated tree and shrub layer are frequent forest species of the *Querco-Fagetea* class such as *Hedera helix*, *Acer campestre*, *Quercus pubescens*, *Fraxinus ornus* and pre-forest and shrub species of the *Rhamno-Prunetea* class such as *Rubus ulmifolius*, *Clematis vitalba*, *Ulmus minor*. Those species indicate that the potential native vegetation for the territory occupied by the *A. altissima* forest of the *Asparago acutifolii-Ailanthetum altissimae* is the Mediterranean and sub-Mediterranean oak forests of the *Carpinion orientalis* alliance, referring to the habitat of community interest 91AA (92/43/ EEC Habitats Directive). Characteristic and differential species of the new association are *A. altissima*, *Hedera helix*, *Acer campestre*, *Quercus pubescens*, *Fraxinus ornus*, *Prunus spinosa*, *Asparagus acutifolius* and *Olea europaea*. The new association refers to the *Lauro nobilis-Robinion pseudoacaciae* alliance because of the presence of characteristic species of this syntaxon such as *Rubus ulmifolius*, *Laurus nobilis*, *Melissa officinalis* subsp. *altissima*, *Rubia peregrina*, *Parietaria diffusa*, *Viola alba* subsp. *dehnhard-tii*, *Ficus carica*, *Ligustrum vulgare*, *Rosa sempervirens*, *Rhamnus alaternus*, *Avena barbata*, etc. The characteristic species of the order *Chelidonio-Robinetalia pseudoacaciae* and *Robinietea* class except for *A. altissima* (*Robinietea* class) are present locally and with low coverage values especially in the xerophilous aspects similarly to what happens for the thermophilous communities of the association *Rubio peregrinae-Robinietum pseudoacaciae* (Allegrezza et al. 2019). However, as highlighted in Allegrezza et al. (2019), the *Lauro nobilis-Robinion pseudoacaciae* alliance includes, in addition to the typically nitrophilous aspects on soils rich in organic matter, also xerophilous and thermophilous communities on dry soils in poorly anthropized contexts (Allegrezza et al. 2019). Compared to the *Rubio peregrinae-Robinietum pseudoacaciae* association described by Allegrezza et al. (2019) for the same study area, the floristic composition of the new association *Asparago acutifolii-Ailanthetum altissimae* essentially differs for the lower species richness and coverage of mesophilous and nitrophilous species such as *Sambucus nigra* denoting for the *A. altissima* forests a stronger thermophilous and xerophilous character, in accordance with what is reported in the literature on the ecology of *A. altissima* (e.g. Sladonja et al. 2015).

ARO ITALICI–AILANTHETUM ALTISSIMAE ass. nova (Cluster II Figure 14; *typus* rel. 22 of Tab. 6).

The new association refers to the *A. altissima* sub-Mediterranean and Mediterranean paucispecific forest communities characterized by a monolayered structure, with a with an average height of 12 m, and an average richness of 13 species per relevè. These forest coenoses are typically found in agricultural areas in correspondence with pelitic, alluvial silty-sandy substrates and peri-urban areas in conditions of edaphic humidity and high anthropogenic disturbance. The shrub layer is poor in species and it consists exclusively of *Rubus ulmifolius* and *Clematis vitalba*, even if locally can be also found *Laurus nobilis* and *Robinia pseudoacacia*. On the other hand, the herbaceous layer is locally rich in species and characterized by geophytes and transgressive hemicriptophytes of the

Galio-Urticetea classes (*Galium aparine*, *Arum italicum*), *Artemisietea* (*Elymus repens*, *Poa trivialis*), *Robinietea* and terophytes of the *Stellarieta mediae* class (*Anisantha diandra*, *Avena barbata*) which highlight the conditions of high and constant anthropogenic disturbance. Characteristic and differential species of the new association are *A. altissima*, *Arum italicum*, *Elymus repens*, *Convolvulus arvensis* and *Poa trivialis*. The new association *Aro italici-Ailanthetum altissimae* that is referred to the *Lauro nobilis-Robinion pseudoacaciae* alliance (*Chelidonio-Robinietalia pseudoacaciae* order and *Robinietea* class) has floristic analogies with the *R. pseudoacacia* association *Melisso altissimae-Robinetum pseudoacaciae* widely present on alluvial plains of the Mediterranean and sub-Mediterranean region. The main differences between these two association are that the *Aro italici-Ailanthetum altissimae* is less common in the study area and has an extremely impoverished tree and shrub components. Furthermore, even if the *Robinia* forest vegetation is also found in the position of the willow groves of *Salix alba* (*Melisso altissimae-Robinietum pseudoacaciae* var. *Carex pendula*), in the investigated territories, the *A. altissima* forest vegetation is almost absent in this landscape context. This confirms what is reported in the literature on the ecology of *A. altissima* that does not tolerate prolonged conditions of soil water stagnation (e.g. Badalamenti et al. 2012).

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Figure 14 Classification of the Italian *A. altissima* forest communities and box plots of the life forms (a) Dendrogram from the phytosociological relevés of the *A. altissima* communities in the study area and published relevés from Fanelli (2002). Cluster I, *Asparago acutifolii–Ailanthetum altissimae*; Cluster II, *Aro italici–Ailanthetum altissimae*. **(b)** Comparison of the significant life form and EIVs of the two *A. altissima* forest associations (AspAil: *Asparago acutifolii–Ailanthetum altissimae* and AroAil: *Aro italici–Ailanthetum altissimae*) through box plots. **(b.1)** Geophytes p-value <0,0001, **(b.2)** Phanerophytes p-value <0,0001; **(b.3)** Terophytes p-value = 0.001; **(b.4)** Temperature EIV p-value =0.04.

Table 6 Mediterranean and sub–Mediterranean *A. altissima* forest communities belong to the alliance *Lauro nobilis–Robinion pseudoacaciae*. *Asparago acutifolii–Ailanthetum altissimae* ass. nova hoc loco (rels. 1–19, typus rel.7); *Aro italici–Ailanthetum altissimae* ass. nova hoc loco (rels. 20–27, typus rel. 22).

Life form		1	2	3	4	5	6	7*	8	9	10	11	12	13	14	15	16	17	18	19	20	22^	21	23	24	25	26	27	Pres.	Freq. Gr. I	Freq. Gr. II
	N° rel.	1	2	3	4	5	6	7*	8	9	10	11	12	13	14	15	16	17	18	19	20	22^	21	23	24	25	26	27			
	N° rel. from dendrogram Figure 2	29	25	20	3	21	5	23	28	18	17	19	4	16	15	22	14	94	8	11	9	10	2	1	97	96	99	95			
	N° cluster from dendrogram Figure 2	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	II	II	II	II	II	II	II	II			
	Altitude [m o.s.l.]	114	38	310	97	462	28	162	80	308	359	268	40	301	140	179	50		152	460	114	97	330	350							
	Aspect	S	SE	S	S	E	NO	NE	E	E	NE	N	SO	NO	SE	NO	SE	SO	NO	O	O	E	SE	S	O	SE	O	NO			
	Slope [°]	30	10	15	30	15	20	25	35	5	15	15	20	15	15	10	10	5	35	40	-	-	5	25	45	2	1	15			
	Area [mq]	200	100	100	90	400	350	250	250	100	100	250	150	100	250	150	300	100	150	120	200	200	100	150	80	80	80	50			
	Total cover [%]	90	90	90	90	85	97	95	90	90	100	95	90	95	99	85	95		98	95	95	50	100	90							
	Tree layer height [m]	8	13	19	8,3	10	19	20	14	11	12	20	9	13	13	8	14	20	15,8	11,4	14	8	10,5	8	15	20	15	7			
	N° species x rel.	17	14	19	18	16	22	23	16	15	12	17	16	25	17	7	13	14	12	17	12	14	15	14	15	11	16	13			
	***Asparago acutifolii-Ailanthetum altissimae* ass. nova**																															
P lian	Hedera helix L.	3.3	1.1			3.3	2.2	4.4	2.2	4.4	5.5	4.4	2.3	+.2	+		3.3	4	+	+	1.2		1.1						18	V	II
P scap	Acer campestre L.			+		+			1.1	2.2	2.2	+	+	+	+	+				1.2									11	III	
P caesp	Quercus pubescens s.l. Willd.	+		+	+		+						+	1.1					2.2	1.2									8	III	
P scap	Fraxinus ornus L.	+		+	1.1		+					+																	5	II	
G rhiz	Asparagus acutifolius L.	1.1	+		2.3	1.1	1.1	+	1.1				+										+				+		10	II	II
P caesp	Prunus spinosa L.				1.1	+	+	+	+	+	+	+					1.1												8	III	
P caesp	Olea europaea L.			+	+.2									+					+	+									5	II	
	***Aro italici-Ailanthetum altissimae* ass. nova**																															
G rhiz	Arum italicum Mill.																		+			1.2	1.2	1.1	3.3	1	+	+	+	9	I	V
G rhiz	Elymus repens (L.) Gould subsp. repens																					1.2	1.2	3.3						3		III
G rhiz	Convolvulus arvensis L.																					+	+		+					3		III
H caesp	Poa trivialis L.					+																					+	+	+	4	I	III
	Lauro nobilis- Robinion pseudoacaciae																															
NP	Rubus ulmifolius Schott	1.1	+		+	2.2	+	2.2	2.2	+	+	1.1	2.3	1.1		5.5	+	+	+		3.3	+.2	+.2		+	+			21	V	IV
P caesp	Laurus nobilis L.	+		+		1.1	+		1.1				+	+	+	2	+				1.2				+				12	III	II

The table below is a phytosociological relevé table. Relevé column numbering is not printed on this page fragment; columns are numbered 1–27 here for reference. The final three columns are: N (number of occurrences) and two constancy classes.

LF	Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	N		
H scap	Melissa officinalis subsp. altissima	+					+		+			+		+							1.1	1.2	+.2	2.2				1	10	II	III
P lian	Rubia peregrina L.	+		+	+	2.2			2.2																1				6	II	I
H scap	Parietaria diffusa M. et K.			+					+								+				+.2	+						1	6	I	III
T scap	Anisantha diandra (Roth) Tutin ex Tzvelev	1.1	1.1	+															1.2		1.1								5	I	II
T scap	Avena barbata Potter			+		2.2																	+	1.1		+			5	I	III
H ros	Viola alba Besser subsp. dehnhardtii (Ten.) W.Becker						+		+					+								+.2							4	I	I
P scap	Ficus carica L.																	+.2		1.2		+							3	I	II
NP	Ligustrum vulgare L.							+	2.2				2																3	I	
P caesp	Rhamnus alaternus L.			1.2								1.1													1				3	I	I
H caesp	Brachypodium rupestre (Host) R. et S.			+								+																	2	I	
G bulb	Bellevalia romana (L.) Sweet			+																									1	I	
P scap	Juglans regia L.						+															1.1							2	I	I
NP	Rosa sempervirens L.						+																				+		2	I	I
H bienn	Inula conyzae (Griess.) DC.			+																									1	I	
P scap	Quercus ilex L.				+																								1	I	
G rhiz	Ruscus aculeatus L.						+																						1	I	
G rhiz	Arundo plinii Turra											+.3																	1	I	
G rhiz	Chamaeiris foetidissima (L.) Medik.																+												1	I	
T scap	Sinapis alba L.																	+.2											1		I
Chelidonio-Robinietalia and Robinietea																															
P scap	Ailanthus altissima (Mill.) Swingle	4.4	3.3	3.3	4.4	4.4	5.5	3.3	4.4	4.4	5.5	4.4	4.4	5.5	4.4	4.4	4.4	5	4.4	4.5	4.4	4.4	4.4	4.4	4	5	5	5	27	V	V
P caesp	Sambucus nigra L.					+	+					3.3	+	2.2			+	+	2.2					+					9	III	I
T scap	Galium aparine L.																	+	1.1		+.2		2.2		4	+	+	1	8	I	IV
H scap	Urtica dioica L.											+				+	+	+	+.2	+	+		2						8	II	III
P caesp	Robinia pseudoacacia L.						1.1	+			+	1.1										+	+.2	1					7	II	III
T scap	Chaerophyllum temulum L.				3.3	+					+		+		+			+-2											6	II	
T scap	Anisantha sterilis (L.) Nevski																+	+	+						1		2		5	I	II
H bienn	Alliaria petiolata (M.Bieb.) Cavara & Grande				+											+	+					+							4	I	I
H scap	Lamium maculatum L.								+	+	+		+																4	II	
H caesp	Dactylis glomerata L.		+		+													+.2											3	I	
H scap	Geum urbanum L.				+																								1	I	
T rept	Stellaria media (L.) Vill.																									+			1		I
H scap	Ballota nigra L.																		1.1										1		I

Life form	Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	N		
G rhiz	Bryonia dioica Jacq.																							1					1	I	
T scap	Fallopia convolvulus (L.) Holub																					+							1	I	
H scap	Anthriscus sylvestris (L.) Hoffm.																						+						1	I	

Others

Life form	Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	N		
P lian	Clematis vitalba L.	+		+		+		+	+	+	3.3	+	1.1	1.1	+	+	+	+	3.3	1.2	+.2	+	1.1						19	IV	III
P caesp	Crataegus monogyna Jacq.	+	+					+	+	+	1.1	+	+			+	+			+				+					12	III	II
P scap	Prunus avium (L.) L.							+		+		+		1.1															4	II	
P caesp	Cornus sanguinea L.							+	+	+	1.1	2.2	+	1.1			+		+.2	1.2				+					11	III	II
P caesp	Ulmus minor Miller										+		+	+		2.2	+	2.2	+	1.2					+				9	III	I
P caesp	Euonymus europaeus L.	1.1	+	+		1.1		+		+		1.1				+			+.2										9	III	I
H scap	Clinopodium nepeta (L.) Kuntze		+		+								1.1					+.3											4	II	
P caesp	Paliurus spina christi Miller		1.1	+					+																				3	I	
H scap	Galium album Miller	+	+										+																3	I	
H caesp	Brachypodium sylvaticum (Huds.) Beauv.					5.5			1.1															+					3	I	I
P scap	Cercis siliquastrum L.	+		1.1																									2	I	
NP	Rubus caesius L.	1.1																					+						2	I	I
H scap	Picris hieracioides L.		+										+																2	I	
NP	Osyris alba L.			+		+																							2	I	
T scap	Torilis arvensis (Hudson) Link		1.1											+															2	I	
H scap	Rumex obtusifolius L.																						+	+					2		II
P caesp	Prunus domestica L.						+		+																				2	I	
NP	Rosa canina L.					1.1							+																2	I	
H scap	Cruciata glabra (L.) Ehrend.					+.2							+																2	I	
H ros	Silene italica (L.) Pers.						+									+													2	I	
H caesp	Carex pendula Huds.									+									+										2	I	I
P lian	Lonicera japonica Thunb.											3.2											1						2	I	I
G rhiz	Arundo donax L.						+														+								2	I	I
H bienn	Silene latifolia Poiret												+									+							2	I	I
H scap	Stachys sylvatica L.															+								+					2	I	I
P scap	Populus nigra L.									+									+.2										2	I	I
	Sporadics species	1	1	5	6	4	3	2	-	1	-	-	-	3	4	-	1	2	1	1	-	-	2	-	5	2	2	3			

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6.5.1. Comparison of *A. altissima* communities in Europe and in the Mediterranean and sub– Mediterranean areas

The NMDS ordination plot (Figure 15a) of the *A. altissima* forest coenoses here considered along with those from SE-Europe, highlights the separation into two distinct groups. The first group corresponds to the two new associations here proposed: *Asparago acutifolii–Ailanthetum altissimae* and *Aro italici-Ailanthetum altissimae* of the sub-Mediterranean and Mediterranean alliance *Lauro nobilis-Robinion pseudoacaciae*, while the second group corresponds to the *Balloto nigrae-Ailanthetum altissimae* association of the *Balloto nigrae-Robinion pseudoacaciae* alliance with a south-eastern European range.

Figure 15 Ordination of the Italian and SE–European *A. altissima* forest associations and Box plots of chorological types. (a) NMDS scaling ordination plot (clusters are superimposed to NMDS plot) of the *A. altissima* forest coenoses here considered (dashed line) and *Balloto nigrae–Ailanthetum altissimae* from SE–Europe (continue line). Legend: Circles: *Aro italici–Ailanthetum altissimae*; Squares: *Asparago acutifolii–Ailanthetum altissimae*; Triangles: *Balloto nigrae–Ailanthetum altissimae* . **(b)** Comparison of the significant chorological types (weighted percentage values) between the new Italian *A. altissima* forest associations considered altogether (labelled as 1) and the *Balloto nigrae–Ailathetum altissimae* association (labelled as 2).

(b.1) Mediterranean chorotype p-value=2.84e–11; **(b.2)** Boreal chorotype p-value=3.26e–11; **(b.3)** Wide distribution chorotype p-value=1.95e–05; **(b.4)** Alien species (neophytes and archeophytes) p-value =3.55e–10.

The floristic differentiation between the two groups is mainly determined by the syn-chorology. The statistically significant chorological elements (Figure 15b) were the Mediterranean and Boreal chorotypes and the weighted presence of naturalized (archaeophytes) and invasive (neophytes) species. The Mediterranean chorotype (Figure 15b.1) is linked to the syntaxa of the *Lauro nobilis-Robinion pseudoacaciae* alliance while the Boreal chorotype (Figure 15b.2) and the presence of archeophyte and neophyte alien species (Figure 15b.4) characterize the *Balloto nigrae-Ailanthetum altissimae* association of the *Balloto nigrae-Robinion pseudoacaciae* alliance. As can be seen in the Synoptic table reported in Table 7, the *Lauro nobilis-Robinion pseudoacaciae* alliance recently described for the sub-Mediterranean and Mediterranean forest communities of *Robinia pseudoacacia* confirms its floristic autonomy with respect to the analogous coenoses described for the center and SE–Europe, also for the *A. altissima* forest coenoses present at their southern limit of distribution in Europe. Even if not considered in the data processing of this work (not forest structure), the shrub communities of *A. altissima* and *Rubus ulmifolius* found in Sicily (Sciandrello et al. 2016) can also be referred to the same alliance. The *Lauro nobilis-Robinion pseudoacaciae* alliance could also be extended to *A. altissima* forest communities present in the Mediterranean and sub-Mediterranean areas of France. It can be done thanks to the only phytosociological relevè reported in Kowarik (1983) in which *A. altissima* communities with *Quercus ilex* of the territory of Collies (South France) shows floristic and ecological analogies with the more xerophilic elements of the *Asparago acutifolii-Ailanthetum altissimae* here proposed. At the landscape level, the sub-Mediterranean and Mediterranean *A. altissima* forest communities are mainly found in the forest landscape of the order *Quercetalia pubescentis-petraeae* with the alliances *Carpinion orientalis* and locally with those of *Quercetea ilicis* for the more xerophilic aspects. As regards the relationships with the similar sub-Mediterranean *R. pseudoacacia* of forest coenoses of the *Lauro nobilis-Robinion pseudoacaciae* alliance described above: *Rubio peregrinae-Robinietum pseudoacaciae* and *Melisso altissimae-Robinietum pseudoacaciae*, it is noted that the *A. altissima* forest vegetation is less widespread in the investigated territory but it prevails over *R. pseudoacacia* forests in the more xerophilous slope conditions on dry soil (*Asparago acutifolii-Ailanthetum altissimae*) while the *R. pseudoacacia* forest vegetation is mainly distributed along the river basins, on the recent alluvial loamy-sandy terraces and in the river beds (*Melisso altissimae-Robinietum pseudoacaciae*) where the *A. altissima* forests are almost absent. The distribution of *A. altissima* and *R. pseudoacacia* forests is mainly

Table 7 Synoptic table of *A. altissima* communities in Europe. *Asparago acutifolii–Ailanthetum altissimae* ass. nova hoc loco (column 1); *Aro italici–Ailanthetum altissimae* ass. nova hoc loco (column 2); *Balloto nigrae–Ailanthetum altissimae* (column 3).

Life form	Chorotype	N. columns	1	2	3	Pres.
		N. rels. per column	19	8	25	
		***Asparago acutifolii–Ailanthetum altissimae* ass. nova**				
P lian	Eur./SW–Asiat.	Hedera helix L.	V	II		2
G rhiz	Medit.	Asparagus acutifolius L.	II	II		2
P caesp	S–Eur.	Quercus pubescens Willd.	III			1
P caesp	Medit.	Olea europaea L.	II			1
P scap	S–Eur./W–Asiat.	Fraxinus ornus L.	II			1
P caesp	Eur./W–Asiat.	Prunus spinosa L.	III		I	2
P scap	Eur./W–Asiat.	Acer campestre L.	III		I	2
		***Aro italici–Ailanthetum altissimae* ass. nova**				
G rhiz	Medit.	Arum italicum Miller	I	V		2
G rhiz	Circumbor.	Elymus repens (L.) Gould subsp. repens		III	V	2
G rhiz	S–Eur./W–Asiat.	Convolvulus arvensis L.		III	I	2
H caesp	Eurasiat./N–Am.	Poa trivialis L.	I	III	I	3
		Lauro nobilis–Robinion pseudoacaciae				
NP	Euri–Medit. Eur.	Rubus ulmifolius Schott	V	IV		2
P caesp	Medit.	Laurus nobilis L.	III	II		2
H scap	Steno–Medit.	Melissa officinalis subsp. altissima	II	III		2
P lian	W–Eur./Medit.	Rubia peregrina L.	II	I		2
H scap	W–Eur./Medit.	Parietaria diffusa M. et K.	I	III		2
T scap	Medit.	Anisantha diandra (Roth) Tutin ex Tzvelev	I	II		2
T scap	Medit./SW–Asiat.	Avena barbata Potter	I	III		2
H ros	Medit.	Viola alba Besser subsp. dehnhardtii (Ten.) W.Becker	I	I		2
P scap	Medit./SW–Asiat.	Ficus carica L.	I	II		2
P caesp	Medit.	Rhamnus alaternus L.	I	I		2
NP	Medit.	Rosa sempervirens L.	I	I		2
NP	Eur./W–Asiat.	Ligustrum vulgare L.	I		I	2
H caesp	Eur.	Brachypodium rupestre (Host) R. et S.	I			1
G bulb	Medit.	Bellevalia romana (L.) Sweet	I			1
P scap	SE–Eur./SW–Asiat.	Juglans regia L.	I	I	I	3
H bienn	Eurasiat./N–Afr.	Inula conyzae (Griess.) DC.	I			1
P scap	Medit.	Quercus ilex L.	I			1
G rhiz	Medit.	Ruscus aculeatus L.	I			1
G rhiz	Steno–Medit	Arundo plinii Turra	I			1
G rhiz	SW–Eur.	Chamaeiris foetidissima (L.) Medik.	I			1
T scap	Euri–Medit.	Sinapis alba L.		I	I	2
		Balloto nigrae–Ailanthetum altissimae* and *Balloto nigrae–Robinion pseudoacaciae				
T scap	Medit.	Bromus sterilis L.	I	II	IV	3
H caesp	Eurasiat.	Dactylis glomerata L.	I		I	2
H scap	Medit.	Ballota nigra L.		I	V	2
H bienn	S–Eur.	Lactuca serriola L.			II	1
H caesp	Circumbor.	Poa angustifolia L.			I	1

100

H caesp	Paleotemp.	Arrhenatherum elatius (L.) Presl.		I	1
H caesp	Eurosib.	Calamagrostis epigejos (L.) Roth		I	1
H bienn	Eurasiat.	Cynoglossum officinale L.		I	1
H scap	Circumbor.	Artemisia vulgaris L.		III	1
H bienn	Eurasiat.	Arctium lappa L.		II	1
H scap	A. Nat.	Leonurus cardiaca L.		II	1
Ch rept	Circumbor.	Glechoma hederacea L.		II	1
NP	N. Nat.	Lycium barbarum L.		I	1
Ch suffr	Sub–Cosmop.	Artemisia absinthium L.		II	1
T scap	Circumbor.	Atriplex patula L.		II	1
G rhiz	Medit.	Sambucus ebulus L.		II	1
H scap	Eur.	Parietaria officinalis L.		I	1
H scap	N. Inv.	Solidago canadensis L.		I	1

Chelidonio–Robinietalia pseudoacaciae and **Robinietea**

P scap	N. Inv.	Ailanthus altissima (Mill.) Swingle	V	V	V	3
P caesp	Eur.	Sambucus nigra L.	III	I	I	3
T scap	Eurasiat.	Galium aparine L.	I	IV	III	3
H scap	Subcosmop.	Urtica dioica L.	II	III	III	3
P caesp	N–Am.	Robinia pseudoacacia L.	II	III	II	3
H bienn	Eur./W–Asiat.	Alliaria petiolata (M.Bieb.) Cavara & Grande	I	I	I	3
T scap	Eur.	Chaerophyllum temulum L.	II		I	2
H scap	Eur./W–Asiat.	Lamium maculatum L.	II			1
P lian	Eur.	Humulus lupulus L.			II	1
H scap	Eurasiat.	Geum urbanum L.	I		II	2
T rept	Medit.	Stellaria media (L.) Vill.		I	I	2
T scap	Circumbor.	Fallopia convolvulus (L.) Holub		I	I	2
H scap	Paleotemp.	Anthriscus sylvestris (L.) Hoffm.		I	I	2
H scap	Medit.	Bryonia dioica Jacq.		I		1
G rhiz	N. Inv.	Impatiens parviflora DC.			I	1
H ros	Circumbor.	Taraxacum officinale Weber gr.			I	1
H scap	Eurasiat.	Chelidonium majus L.			I	1
H scap	Eurasiat.	Alkekengi officinarum Moench			I	1
P scap	N. Inv.	Acer negundo L.			I	1
T scap	Eurasiat.	Moehringia trinervia (L.) Clairv.			I	1
T scap	A. Nat.	Anthriscus cerefolium (L.) Hoffm.			I	1
P caesp	N. Nat.	Gleditsia triacanthos L.			I	1
P caesp	A. Nat.	Prunus cerasifera Ehrh.			I	1
H scap	N. Inv.	Solidago gigantea Aiton			I	1

Others

P lian	Eur.	Clematis vitalba L.	IV	III	II	3
P caesp	Eur./W–Asiat.	Crataegus monogyna Jacq.	III	II	I	3
P caesp	Eur.	Cornus sanguinea L.	III	II	I	3
P caesp	Eur.	Ulmus minor Miller	III	I	I	3
P caesp	Eur.	Euonymus europaeus L.	III	I	I	3
H caesp	Eurasiat.	Brachypodium sylvaticum (Huds.) Beauv.	I	I	I	3
NP	Eurasiat.	Rubus caesius L.	I	I	II	3
H scap	Eurosib.	Stachys sylvatica L.	I	I	I	3
H caesp	Eurasiat.	Carex pendula Huds.	I	I		2
P lian	N. Inv.	Lonicera japonica Thunb.	I	I		2

			A	B	C	
G rhiz	A. Inv.	Arundo donax L.	I	I		2
H bienn	Eurasiat.	Silene latifolia Poiret	I	I		2
P scap	Eurasiat.	Populus nigra L.	I	I		2
NP	Eur.	Rosa canina L.	I		II	2
H scap	Eurosib.	Picris hieracioides L.	I		I	2
T scap	Subcosmop.	Torilis arvensis (Hudson) Link	I		I	2
H bienn	Paleotemp.	Daucus carota L.	I		I	2
T scap	N. Inv.	Erigeron canadensis L.	I		I	2
H scap	Medit.	Galium mollugo L.	I		I	2
H scap	Circumbor.	Clinopodium vulgare L.	I		I	2
H scap	Eur.	Rumex obtusifolius L.		II	I	2
H scap	Paleotemp.	Conium maculatum L.		I	II	2
P scap	Eur./W–Asiat.	Prunus avium (L.) L.	II			1
H scap	Medit.	Clinopodium nepeta (L.) Kuntze	II			1
H scap	Subcosmop.	Agrimonia eupatoria L.			II	1
H bienne	Eur.	Carduus acanthoides L.			II	1
T scap	N. Inv.	Erigeron annuus (L.) Desf.			II	1
H scap	Eurasiat.	Tanacetum vulgare L.			II	1
T scap	Sub–Cosmop.	Chenopodium album L.			II	1
		Sporadic species	35	13	98	

connected to the different ecology of the two dominant invasive alien species. As reported in the literature, *A. altissima* is a thermophilous species, adapted to edaphic aridity but it is limited by low temperatures and water stagnation (Kowarik 1983; Trifilò et al. 2004; Kowarik and Saumel 2007). As can be seen from the Table 7, the impoverishment of the species of the order *Chelidonio-Robinietalia* and the *Robinietea* class in the Mediterranean area mainly concerns the *A. altissima* communities present in the most xerophilous areas with low anthropic disturbance. However, this is similar to what happens for the xerophilous and thermophilous communities of the order *Euphorbio cyparissiae-Robinietalia* of the class *Robinietea* shown in Vitkova and Kolbek (2010). Moreover, from an ecological point of view, the differences between *A. altissima* forests and the neighboring native forests were highlighted and proved for both *R. pseudoacacia* (Montecchiari et al. 2020a) and *A. altissima* forests (Montecchiari et al. 2020b). A great effort has been made in Europe to classify alien-dominated forest communities that previously were referred to different orders and classes. Therefore, at the current state of knowledge, the attribution to the *Robinietea* class seems to be the only way forward. Future studies in the Mediterranean area will better clarify the syntaxonomic position of the *A. altissima* communities of the *Lauro nobilis-Robinion pseudoacaciae* alliance currently belonging to the order *Chelidonio-Robinietalia* of the *Robinietea* class and also to better clarify the syntaxonomic framework of the *Robinietea* class in Europe.

Syntaxonomic scheme

ROBINIETEA Jurko ex Hadac et Sofron1980

CHELIDONIO-ROBINIETALIA PSEUDOACACIAE Jurko ex Hadac et Sofron 1980

Lauro nobilis-Robinion pseudoacaciae Allegrezza, Montecchiari, Ottaviani, Pelliccia & Tesei 2019

Asparago acutifolii-Ailanthetum altissimae ass. nova

Aro italici-Ailanthetum altissimae ass. nova

Other syntaxa quoted in the text

Agropyretea repentis Oberdorfer, Muller & Gors in Oberdorfer, Gors, Korneck, Lohmeyer, Muller, Philippi & Seibert 1967; *Ailantho altissimae-Robinietum pseudacaciae* Julve 2003; *Artemisietea vulgaris* Lohmeyer, Preising & Tüxen ex von Rochow 1951; *Balloto nigrae-Ailanthetum altissimae* Sîrbu & Oprea 2010; *Balloto nigrae-Robinion pseudoacaciae* Hadač & Sofron 1980; *Carpinion orientalis* Horvat 1958; *Chenopodietea* Br.-Bl. in Br.- Bl., Roussine & Negre 1952 p.p.; *Cratego-Prunetea* Tuxen 1962; *Euphorbio cyparissiae-Robinietalia* Vítková in Kolbek et al. 2003; *Fico-Ailanthetum altissimae* Lov. (1975) 1984 ("*Ailantho-Robinietum*" auct. adriat. pp non Gutte; Kvarner: "žiròvine"); *Fraxino excelsioris-Quercetea roboris* Gillet 1986 ex Julve 1993 class; *Galio-Urticetea* Passarge ex Kopecky´ 1969; *Lauro nobilis-Ulmion minoris* Biondi, Casavecchia, Gasparri & Pesaresi in Biondi, Allegrezza, Casavecchia, Galdenzi, Gasparri, Pesaresi, Poldini, Sburlino, Vagge & Venanzoni 2015; *Melisso altissimae-Robinetum pseudoacaciae* Allegrezza, Montecchiari, Ottaviani, Pelliccia & Tesei 2019; *Pruno avium-Carpinetalia betuli* Gillet 1986 ex Julve 1993; *Pruno spinosae-Rubion ulmifolii* O. Bolos 1954; *Pyro spinosae-Rubetalia ulmifolii* Biondi, Blasi & Casavecchia in Biondi, Allegrezza, Casavecchia, Galdenzi, Gasparri, Pesaresi, Vagge & Blasi 2014; *Quercetalia pubescentis-petraeae* Klika 1933; *Quercetea pubescenti–petrae* Jakucs 1960; *Quercion ilicis* Br.-Bl. ex Molinier 1934; *Querco roboris-Fagetea sylvaticae* Br.-Bl. & Vlieger in Vlieger 1937; *Rhamno-Prunetea* Rivas Goday & Borja ex Tuxen 1962; *Robinio pseudoacaciae-Ulmion minoris* Julve 1993; *Rubio peregrinae-Robinietum pseudoacaciae* Allegrezza, Montecchiari, Ottaviani, Pelliccia & Tesei 2019; *Salici purpureae-Populetea nigrae* Rivas-Martínez & Cantò ex Rivas-Martínez, Bàscones, T.E. Dìaz, Fernàndez-Gonzàlez & Loidi 2001; *Sisymbrietea* Gutte & Hilbig 1975; *Stellarietea mediae* Tuxen, Lohmeyer & Preising ex Von Rochow 1951; *Urtico-Sambucetea* Passarge & Hofmann 1968.

6.6. Appendices

Appendix 1 Results of ANOVA tests on EIVs and weighted life form percentage values between the two new association here described *Asparago acutifolii–Ailanthetum altissimae* and *Aro italici–Ailanthetum altissimae*. Significative values ($p \leq 0.05$) are highlighted in bold.

	F	p-value
EIV Light	0,98	0,33
EIV Temperature	4,66	**0,04**
EIV Continentality	1,58	0,22

EIV Moisture	1,28	0,26
EIV Reaction	2,27	0,14
EIV Nutrients	0,08	0,77
Chamephytes	1,38	0,25
Geophytes	48,7	**0,0001**
Hemicryptophytes	2,06	0,16
Nanophanerophytes	1,25	0,27
Phanerophytes	20,27	**0,0001**
Therophytes	11,66	**0,001**

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Chapter 7. *Ailanthus altissima* forests determine a shift in herbaceous layer richness: a paired comparison with hardwood native forests in sub-Mediterranean Europe.

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Abstract

Ailanthus altissima is an invasive alien species (IAS) present throughout Europe and included in the list of alien species of Union concern. In sub-Mediterranean areas of central Italy, there is a lack of knowledge about this invasive species and its interactions with the native forest ecosystems. We aim to find what are the main differences in vegetation structure and floristic diversity between *A. altissima* forests and native forests through the assessment of the principal ecological parameters that differ between the forest types. We performed 38 phytosociological relevés and sampling of ecological parameters in *A. altissima* forest communities and neighboring native forests. We analyzed how species richness, diversity, life forms, life strategies, structural characteristics, and ecological parameters changed in *A. altissima* forests compared with native ones. We found that in *A. altissima* forests, there is a shift in herbaceous layer richness, with a higher presence of annual ruderal herbs and the absence of herbaceous species linked to the forest environment. The ecological parameters that diverge from the native forests were total nitrogen, total carbon, and C/N ratio. *A. altissima* forest communities could threaten the biodiversity of the native forest ecosystems in the sub-Mediterranean landscape, favoring ruderal species and inhibiting the presence of typical forest species.

Keywords: *Ailanthus altissima*; invasive alien species; photosynthetic active radiation; nemoral species; soil sampling; paired comparison; community

7.1. Introduction

The worldwide spreading of plant species outside their native range (Van Kleunen et al. 2015) is becoming an expansive phenomenon (Cabra-Rivas et al., 2016; Wagner et al., 2017). Invasive alien species (IAS) are one of the greatest threats to global biodiversity and the sustainable functioning of ecosystems (Perrings et al., 2010) and, for this reason, are subject to a strict policy regulation such as the EU Regulation 1143/2014 on invasive alien species (European Commission, 2014) *Ailanthus*

altissima is one of the most important IAS in Europe, also due to its wide presence (Lambdon et al., 2008) In the recent commission implementing regulation (European Commission, 2019), 2019/1262 of 25 July 2019 the list of IAS of Union concern was updated and *A. altissima* was inserted following a process of risk assessment. This species was first introduced in Europe from China, in the 1740s, in Paris, used as ornamental plants in cities and for afforestation (Hu, 1979) Nowadays, it shows a wide diffusion in urban and peri-urban areas, but also in the agro-forest environment [Gutte et al., 1987; Udvardy, 1998; Howard et al., 2004). In Italy, it appeared in 1760 when it was introduced at the Botanical Garden of Padua (Badalamenti et al., 2012), and now it is considered as invasive in all Italian administrative regions (Galasso et al., 2018; Viciani et al., 2020), exerting an ecological impact on plant communities and Natura 2000 habitats (Lazzaro et al., 2020). The expansions of *A. altissima* is due to its pioneer characteristics such as the efficacy in gamic reproduction and dissemination [Knapp and Canham, 2000; Motard et al., 2011), agamic reproduction with strong sprouting ability also through radical activity (Kowarik, 1995; Kowarik and Säumel, 2007; von der Lippe at al., 2013), and extremely rapid growth (Kowarik and Säumel, 2007) that can easily outcompete the forest native species, e.g., [Fotiadis et al., 2011; Höfle et al., 2014; Costàn-Nava et al., 2015). There is a species-specific mechanism in the invasion of recipient habitats. *A. altissima* colonization probabilities are higher in hardwood forests that are dominated by the trees of the genera *Fraxinus*, *Quercus,* and *Ulmus* in the floodplains and hill positions and in dry conditions (Höfle et al., 2014). Moreover, the production of allelopathic substances (e.g., ailanthone) from the cortex and leaves that accumulate in the soil can inhibit the germination of native species (Lawrence et al., 1991; Bostan et al., 2014). *A. altissima* spontaneous secondary stands also have impacts on soil properties and nutrient cycling, which are fundamental components of ecosystem functioning and processes. *A. altissima* can modify carbon and nitrogen cycling (Vilà et al., 2006; Gómez-Aparicio et al., 2008; Castro-Díez et al., 2009) thanks to the decomposition rates of the leaf litter (Medina-Villar et al., 2015), and alter the soil pH, even though the mechanisms are elusive (Motard et al., 2015). Although its wide distribution all over the Mediterranean and temperate Europe, where it is mainly confined to cities at northern outposts of its range (Kowarik and Säumel, 2007), there is a lack of floristic-vegetational studies along with ecological studies in a paired comparison with the reference forest in its meridional range in sub-Mediterranean and Mediterranean bioclimates. The aims of this study were to compare floristic-vegetational and measured ecological data in mature *A. altissima* forest coenoses and neighbor native forests as reference. Thanks to this comparison, we want to highlight the effects of the alien forests canopy on the herbaceous layer, in terms of diversity and ecological conditions with respect to the native forests. Specifically, we want to (i) identify and investigate floristic-vegetational and ecological parameters of *A. altissima* forest communities in sub-Mediterranean areas of central Italy (ii) investigate light, temperature, and soil parameters that mainly characterize those communities; (iii) investigate differences in species diversity and composition of vegetation layers and differences in habitat conditions through a paired comparison with native forests.

7.2. Materials and Methods

7.2.1. Study area

The forest coenoses were investigated in the sub-Mediterranean region of central Italy (Figure 16) at altitudes between 10 m a.s.l. and 500 m a.s.l, and the prevailing lithotypes are pelitic–arenaceous, arenaceous–pelitic, and alluvial. The study area is characterized by a macrobioclimate that ranges from Mediterranean, pluviseasonal oceanic bioclimate, and upper mesoMediterranean thermotype to the Temperate sub-Mediterranean variant, oceanic bioclimate, and lower meso-temperate thermotype (Pesaresi et al., 2014), according to the bioclimatic classification sensu Rivas-Martınez (Rivas-Martínez et al., 2011). According to the level 3 CORINE Land Cover 2018 (CLC) (Büttner et al., 2017), the principal land-cover/land-use types of forest coenoses, are non-irrigated arable land (code 211) and heterogeneous agricultural areas with complex cultivation patterns (code 242), along with areas occupied by agriculture, significant areas of natural vegetation (code 243) and artificial surfaces (codes 112, 113,141). The plant landscape mainly consists of crops, agro-forest environments, and native forest vegetation, such as oak forests on slopes (*Q. pubescens, Q. virgiliana*) (alliance *Carpinion orientalis*, class *Querco roboris-Fagetea sylvaticae*), riparian woods of *Salix alba* and *P. nigra* (alliance *Populion albae*, class *Salici purpurae-Populetea nigrae*) and *U. minor* communities (alliance *Lauro nobilis-Ulmion minoris*, class *Salici purpurae-Populetea nigrae*) (Blasi, 2010).
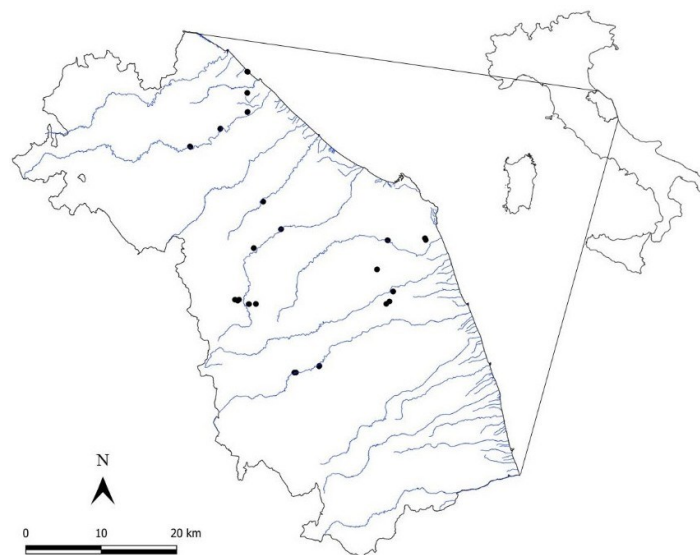
Figure 16 Location of the study area in sub-Mediterranean central Italy, showing the distribution of the paired sampling units. Each pair of sampling is represented by a single black point.

7.2.2. Sampling design

One method of investigating the effects of alien compared to native stands is to use nearby paired sampling units, invaded and non-invaded. As proven by Bazalova et al. (2018), "the twin plots method proved to be a suitable tool for analyzing the impact of alien trees on understory vegetation". The target forest communities were identified following complementary techniques: the consultation of the

Italian National Forest Inventory (Regione marche, 2001) data on forests type distribution (following the distribution of the category "Robinio-Ailanteti"), photo-interpretation of 2012 geo-referenced images available on the "Geo-portale Nazionale" (http://www.pcn.minambiente.it), expert assessment, Google Street View that provided additional data on the presence of *A. altissima* forests growing along roads (Deus et al., 2016), and reconnaissance days in the study area (in early spring of 2019). The identification was first applied to *A. altissima* forests communities, then, using the same method, we detected native forest communities setting a circular buffer area within a 500 m radius from the detected alien forest community (Sitzia et al., 2012). The native forests communities are *Q. pubescens*, *P. nigra,* and *U. minor* dominated forests and represent the typical spontaneous forest vegetation for the study area. This method assures homogeneity in terms of land-use context and disturbance regime for both alien and native stands. This is important to make comparisons that allow us to understand if and how the presence of *A. altissima* influences the ecological variables under the canopy and the vegetation composition and diversity.

7.2.3. Vegetation survey

We applied a pairwise sampling technique to conduct a comparative study in the southern European limit of this IAS. We identify 19 couples of *A. altissima* dominated forests and native forests (Appendix 3). A total of 38 phytosociological relevés (vegetation plots) were performed in a non-tree-lined row to avoid edge effects and detect only the real influence of the alien species on the understory layer, within an area of at least 100 m^2, with a clear dominance of *A. altissima* or the native forests species (Braun-Blanquet cover-abundance values from 3 to 5), with an average age of at least 20 years assessed by photo-interpretation of 1994, 2000, 2006 geo-referenced images available on the Geo-portale Nazionale (http://www.pcn.minambiente.it/GN/accesso-ai-servizi/servizi-di- visualizzazione-wms). The vegetation survey was conducted according to the phytosociological methods (Braun-Blanquet, 1928). In each plot, for each vascular plant taxa recorded according to the vegetation structure, a cover-abundance value was given, following a seven-grade scale of abundance and dominance (Braun-Blanquet , 1964). The vegetation layers considered were three, defined as tree layer (height >7 m), shrub layer (height 20 cm–7 m), and herb layer (height < 20 cm). The nomenclature of the vascular species follows the check-list of Italian flora (Bartolucci et al., 2018) and the check-list of the vascular flora alien to Italy (Galasso et al., 2018). The life forms of the species follow Flora d'Italia (Pignatti, 1982). Data on Competitive, Stress-Tolerant and Ruderal (CSR) strategies sensu Grime (Grime, 2001) for the herbaceous species were partly available from the online databases BiolFlor (Kühn et al., 2004), database of the Czech flora and vegetation (Pladias database)], and from Hunt et al. (Hunt et al., 2004). For 8 taxa, information on the CSR strategies follows specific literature reference*: Bellevalia romana* (L.) Sweet from Astuti et al. (2019), *Arundo donax* L., *Asparagus acutifolius* L., *Rubia peregrina* L., *Olea europaea* L., *Orobanche minor* Sm., *Pistacia terebinthus* L. from Benhamiche-Hanifi et al. (2012), *Umbilicus horizontalis* (Guss.) DC. from Bocchieri and Iiriti (2006). For the identification of the nemoral species of each relevé, we considered

the syntaxonomic attribution of the species, according to the Prodrome of the Italian Vegetation (Biondi et al., 2014), as present on the updated site of the Italian Botanical Society (http://www.prodromovegetazioneitalia.org/), with references to that of the European vegetation (Mucina et al., 2016). Nemoral species are those herbaceous species that are diagnostic of forest classes according to the syntaxonomic system, e.g: *Querco roboris-Fagetea sylvaticae* class (Appendix 1). Those herbaceous species, expressed in weighted percentage values for each plot, are linked to forest environments and are indicators of environmental quality.

7.2.4. Sampling of the ecological variables

We performed field measurement of a set of ecological variables (Table 8) in both *A. altissima* forests and native forests.

Table 8 Measured variables. Description of the topographic characteristics and ecological variables considered, with the indication of the unit and the respective symbol for each variable.

Topographic and Ecological Variables	Unit	Symbol
Altitude	m a.s.l	Alt
Slope	°	Sl
Northness	°	N
Canopy Cover	%	CC
Canopy Height	m	CH
Photosynthetic active radiation at 1.30 m from the soil	$(\mu mol\, m^{-2}\, s^{-1})$	PAR_chest
Photosynthetic active radiation at the soil level	$(\mu mol\, m^{-2}\, s^{-1})$	PAR_soil
Photosynthetic active radiation in full light condition	$(\mu mol\, m^{-2}\, s^{-1})$	PAR_out
Temperature of the topsoil under forest canopy	°C	T_in
Temperature of the topsoil outside forest canopy	°C	T_out
Temperature of the air	°C	T_air
Difference PAR_out-PAR_chest		Δ PAR_chest
Difference PAR_out-PAR_soil		Δ PAR_soil
Difference T_out-T_in		Δ T soil
Total nitrogen	g/kg	N_tot
Total extractable carbon	g/kg	C_tot
carbon-nitrogen ratio	g/kg	C/N
pH in H2O	pH unit	pH

According to invasion ecology literature (Howard et al., 2004; Vilà et al., 2006; Terwei et al., 2016), we selected those variables that show high explanatory capability. Canopy cover (percentage of the sky covered by leaves) was measured by the mobile application GLAMA (Tichý,2014). Data on canopy cover were measured in the field for all 19 twin vegetation plots. In each plot, one

measurement was taken at the center of the plot of 100 m^2 as representative, at 1.30 m from the soil surface with a hemispherical lens. Photosynthetically active radiation (PAR) was measured in each plot between September and October of 2019 with a photo-radiometer (Delta OHM, HD 2302.0, Milan, Italy). We took four randomly PAR measures per plot, in the Native and *A. altissima* plots, respectively, from 10:00 a.m. to 5:00 p.m. at 1.30 m (PAR30) and 20 cm above the soil surface (PARsoil). We also performed four measurements outside the forest canopy (PARout) in conditions of full light to calculate the ΔPAR (difference from outside full-light conditions and inside forest canopy conditions ΔPAR30 = PARout-PAR30; ΔPARsoil = PARout- PARsoil). The difference between the inside forest and outside were made to minimize the effects of the different light conditions due to the sun height in the sky at different hours on a day. The height of the forest canopy was taken by means of 1 measurement of the dominant tree using an optical height meter (PM-5/360 PC model; Suunto Instrument Co., Helsinki, Finland). The soil was randomly collected from three different subplots and subsequently pooled for each plot. For each sample, surface litter (if present) was removed and the top 20 cm of soil was sampled (from 0 to 20 cm depth). Samples were analyzed for nitrogen (N tot), total extractable carbon (C tot), and pH in H2O. The ratio of total extractable carbon to total nitrogen (C/N) was also calculated as an estimate of soil quality. Soil samples were analyzed by the Marches Region agrochemical analysis and research laboratories according to the methodological standards established by Italian ministerial decree 13/09/99. Total nitrogen was extracted through Kjeldahl mineralization with hydrogen peroxide and determination of total nitrogen by distillation according to Kjeldahl; for the total extractable carbon is followed the extraction, fractionation (by means of solid-phase adsorption chromatography) and determination of organic carbon procedure reported in the ministerial decree; pH in H20 was determined by potentiometric method, after calibration of the measurement system, on suspensions of soil-water." The topsoil temperature was detected using a specific soil thermometer (HANNA Digital thermometer, HI 98501). Three random measurements were performed inside and outside the forest canopy. The measured values were subsequently averaged and used for the calculation of the ΔT, that is, the difference between the average temperatures of the topsoil outside the forest canopy and of the topsoil under the forest canopy.

7.2.5. Data Analysis

The data were processed using the "vegan" package (Oksanen et al., 2018) of the R software (R Development Core Team, 2018). To highlight the pattern of species composition of the two forest coenoses types we merged the vascular plant taxa occurring in more than one layer. In the resulting data set, each species was present once. Before calculations, the ecological variables matrix was undergone at a normalization process using the "decostand" function on the vegan package. To determine if the plot types had different community compositions, we conducted a nonmetric multidimensional scaling (NMDS) analysis with Bray-Curtis distance measure. Indicator species analysis (ISA) (De Cáceres and Legendre, 2009) was performed to identify the indicator species for each group. These species were identified for each group using the indicator value (IndVal) method,

which combines the specificity of a species (uniqueness to a particular sampling unit) and its fidelity (frequency within that sampling unit). For each species, the IndVal ranges from 0 (no indication) to 1 (maximum indication). The statistical significance of the IndVal was tested using a Monte Carlo test, based on 999 randomizations. To highlight differences between vegetation layers of the two forests coenoses we calculated species Richness and Shannon diversity index for the tree, shrub and herb layers of each plot. Then we performed the analysis of variance and tested the significance among the averages of the two groups. The ecological determinants of the species composition and richness of the two forest types were investigated by redundancy analysis (RDA). The RDA allowed the comparison of the forests and the identification of the gradient trajectories for the environmental variables. Only variables that showed a significant difference among *A. altissima* and native forests were used for the model. The redundancy analysis was performed on the Hellinger transformed vegetation matrix. The Monte Carlo permutation test (based on 999 iterations) was performed in order to assess both the significance of the environmental variables and the ordination axes. Box plot diagrams were used to illustrate data distribution of ecological variable and species characteristics. To analyze the variance of the groups and tests for significance we used ANOVA ("aov" function of "stats" package). The Shapiro test was used to test the normality of the analyzed data and the Bartlett test for homoscedasticity.

7.3. Results

7.3.1. Community floristic diversity

From the Nonmetric multidimensional scaling (NMDS) ordination plot (Figure 17), two principal directions of variation, in term of floristic composition, are distinguished that allows us to identify two groups, albeit with very different internal variability (NMDS stress 0.15).
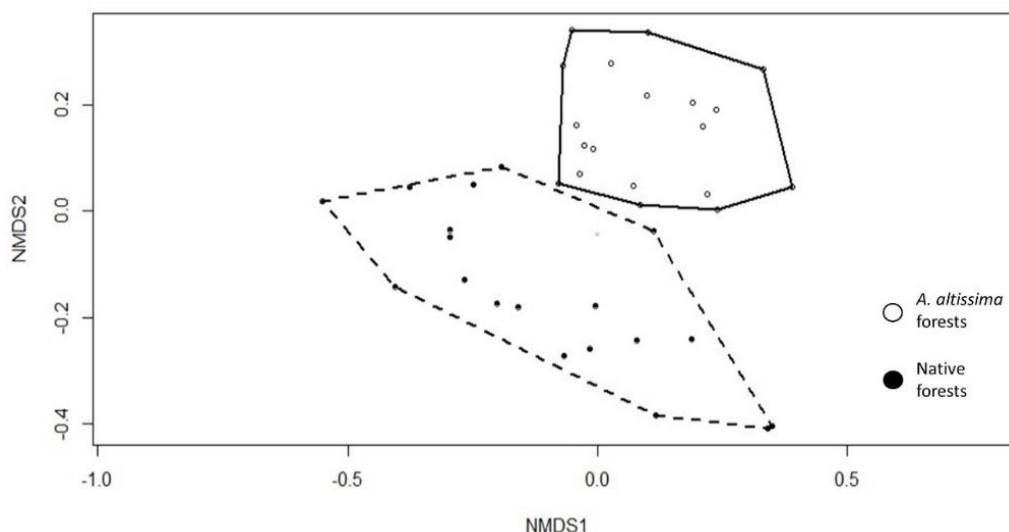
Figure 17 Nonmetric multidimensional scaling (NMDS) ordination diagram (axes NMDS1 and NMDS2) of the *A. altissima* and reference forest plots. The stress value of the ordination is 0.15.

There are two groups, corresponding to the two forest types under study: plots dominated by *A. altissima* (group 1) and plots dominated by *Quercus pubescens*, *Populus nigra,* or *Ulmus minor*, representing the native forests (group 2). Indicator species analysis (IndVal) revealed the species associated with each of the two groups. The indicator species of group 1 are *A. altissima* (Mill.), *Chaerophyllum temulum* L., *Sambucus nigra* L., and those of group 2 are *Q. pubescens* Willd, *Ostrya carpinifolia* Scop, *U. minor* Miller. So, the groups correspond to the different forest coenoses types under study: native forests dominated by the typical forest's species of the study area and the alien *A. altissima* forest communities. Shannon diversity indices of the vegetation layers were compared between the two forest types and resulted in not being significant. Species diversity in terms of the number of species (richness) shows a significant difference only for the herbaceous layer (Table 9). As shown in Figure 18 *A. altissima* forests have higher species richness in the herbaceous layer than native forests.
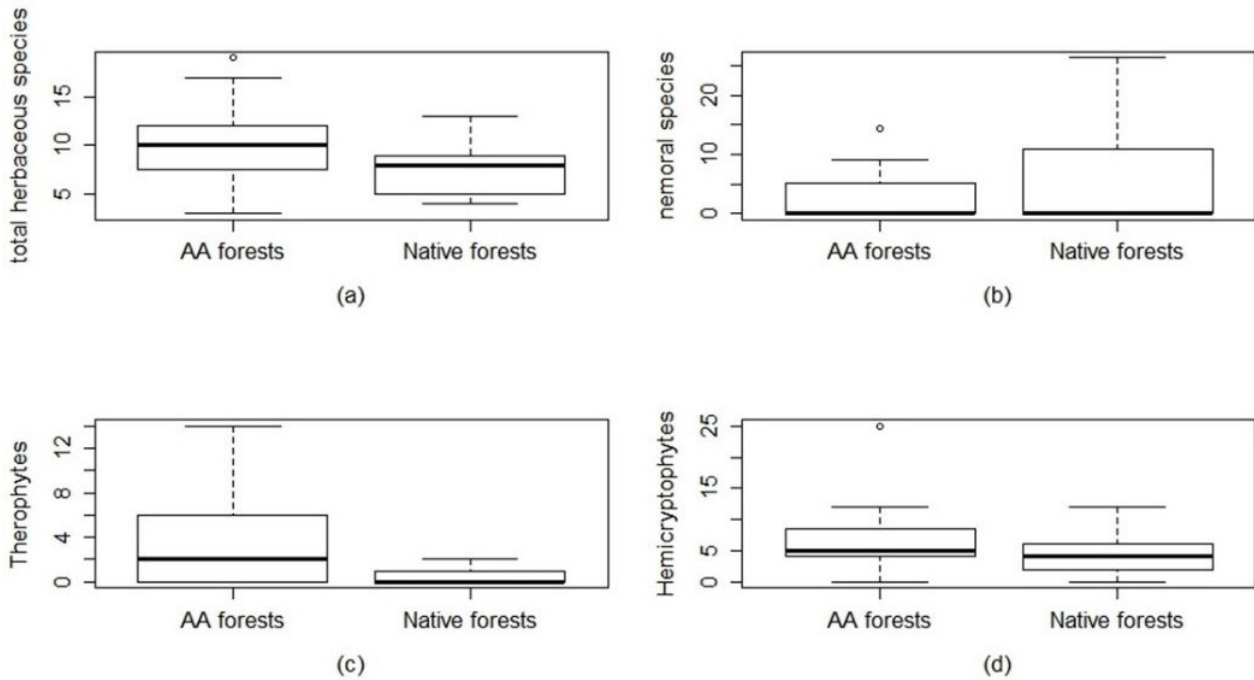
Table 9 Comparison of the vegetation layers. Mean values of the species richness and Shannon diversity index relative to the *A. altissima* and native forests for the tree, shrub, and herbaceous layers. Results from the ANOVA test between the two groups and the significance level is given. Significant values are in bold.

|	*Ailanthus* Forests	Native Forests	*Ailanthus* Vs. Native	
	Mean	Mean	Mean sq	*p*-Value
Species richness tree layer	2.42	2.95	2.63	0.18
Species richness shrub layer	7.16	8.84	13.92	0.25
Species richness herb-layer	8.16	7.74	50.95	0.05
Shannon index tree layer	0.68	0.89	0.41	0.18
Shannon index shrub layer	1.81	2.00	0.34	0.19
Shannon index herb-layer	2.13	1.91	0.45	0.16

7.3.2. Herbaceous layer: species diversity, life forms, and Grime strategies

The species diversity analysis performed for each vegetation layer suggests that the main differences are at the level of the herbaceous layer. The life form distribution (Figure 18) shows that there are more geophytes in the native forests (data not shown) such as *Teucrium chamaedrys* L., *Cyclamen hederifolium* Aiton, *Cyclamen repandum* Sm., *Carex flacca* Schreber, *Helleborus bocconei* Ten. *A. altissima* forests communities show a greater presence of hemicryptophytes and therophytes (annual herbaceous species) with respective *p*-values of 0.08 and < 0.01 (Figure 18). Specifically, in *A. altissima* herbaceous layer, the hemicryptophytes species represent almost 43% of the *A. altissima* forests herbaceous layer. Those species are biennial or perennial, frequently linked to open environment or nemoral/forest edge species, linked to forest environments (Appendix 1). Therophytes are heliophilous annual species that represent almost 35% of the *A. altissima* forests' herbaceous layer (Appendix 1). From the total herbaceous species, we analyzed the nemoral component (Figure 18). In terms of weighted percentage cover, the nemoral component is linked to

the native forest and is statistically significant (*p*-value = 0.1) (Figure 18 and Appendix 1). Regarding the Grime life strategies (Figure 19) in the herbaceous layer, the *A. altissima* community shows a greater presence of species with a competitive-ruderal strategy (CR, $p = 0.008$) that are species adapted to disturbances as well as species having a competitive strategy (C, $p = 0.1$). In the native forests, it was found a greater presence of species having a competitive-stress tolerant strategy (CS, $p = 0.005$).

Figure 18 Comparison of the herbaceous layer diversity and life forms between *A. altissima* (AA forests) and Native forests. (**a**) total herbaceous species diversity (p-value = **0.05***), (**b**) nemoral species diversity (p-value = 0.065), (**c**) therophyte species (p-value = **0.006****), (**d**) hemicryptophyte species (p-value = 0.085). *p* level: *** p <0.001; ** p <0.01; * p ≤0.05. Significant values are in bold.
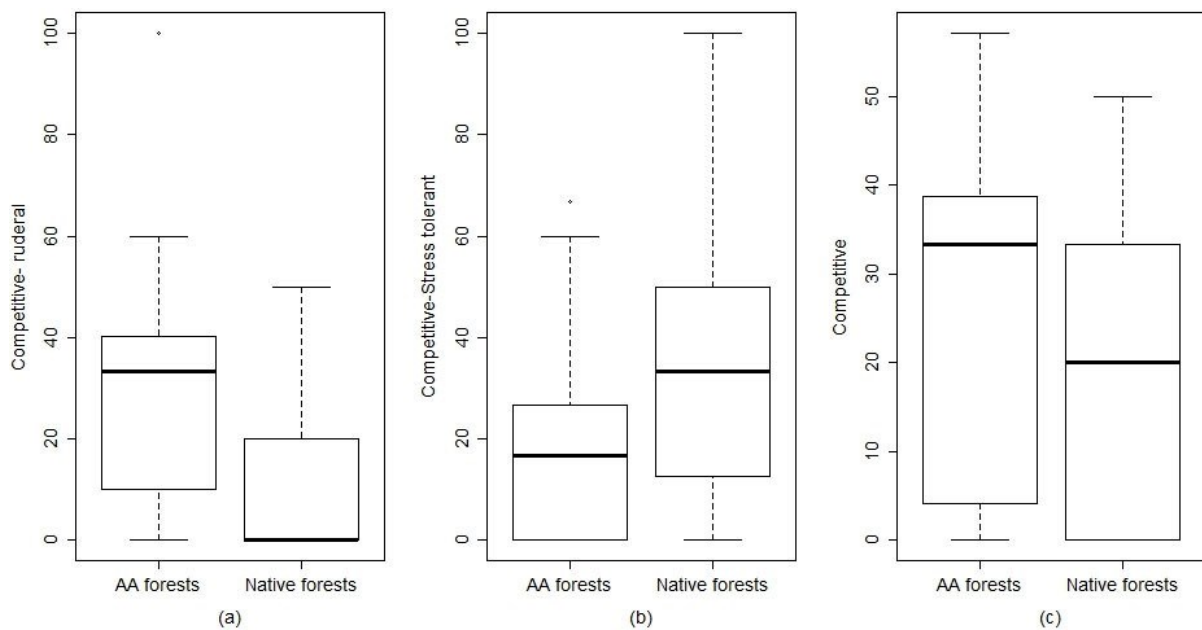
Figure 19 Comparison of the significant Grime strategies between *A. altissima* (AA forests) and native forests. (a) Competitive-ruderal p-value=**0.008****; (b) Competitive-stress tolerant p-value = **0.005 ****; (c) Competitive *p* = 0.1). *p* level: *** *p* <0.001; ** *p* <0.01; * *p* ≤0.05. Significant values are in bold.

7.3.3. Ecological variables

In order to identify the trends of environmental variables in relation to the two forest vegetation types, an RDA was performed (Figure 20). The results of the RDA reveal, among the set of environmental variables, that canopy height, Δ T soil, C tot, and N tot are significant variables (Table 10, Appendix 2). This proves that those factors are the main environmental variables shaping the plant community. The total model shows a significance level of *p* = 0.001, the constrained variation represents 24% of the total variation. The cumulative amount of variance expressed as proportions of the total explained variance (24%) by RDA1 axes is 39.7% and RDA2 axes 19.02% (total of 59.02%) To better observe the variation of environmental variables in relation to the two groups and test their statistical significance, box plots were generated. The difference between the averages of measured environmental values such as Canopy height, canopy cover, ΔPAR, and ΔT were all non-significant in the comparison between the two forest types. A slight trend between a narrow range of values can be observed in the ΔPAR as well as the canopy- cover, that shows higher average values in the *A. altissima* forests (Appendix 2).
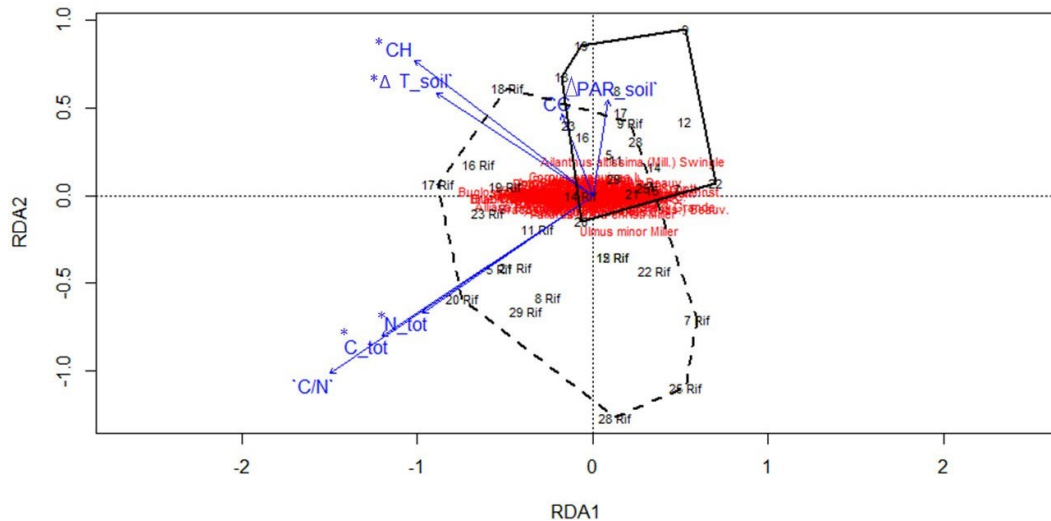

Figure 20 RDA Ordination diagram of vegetation plots and species in relation to the considered environmental variables. *A. altissima* forests are within the dashed line. Native forests are within the continuous line. Significant variables (at p-value ≤0.05) are reported with asterisks. RDA1 explains 39.1% of the cumulative amount of variance expressed as proportions of the total explained variance and RDA2 axes as 19.02%. For abbreviations of the variables, see Table 8.

In the first case, this means the presence of a greater difference between the radiation recorded outside (full light) and the one recorded below the forest canopy. The comparison of the measured edaphic characteristics is shown in Figure 21. The pH values were not different between the groups. Total nitrogen, total carbon and C/N ratio were significantly different between the two groups (pH *p* = 0.1; N tot *p* = 0.025 *; C tot *p* = 0.007 **; C/N *p* = 0.0033 **) with *A. altissima* forests having lower values

for all three variables considered.

Table 10 Redundancy analysis**.** Ordination parameters of redundancy analysis (RDA). Significance of the environmental factors. *p* level: ******p* <0.001; *** p* <0.01; ** p* ≤0.05.

Ecological Variables	df	Variance	F	*p*	
N_tot	1	0.02694	1.69	0.012	*
C_tot	1	0.03234	2.03	0.001	***
C/N	1	0.01138	0.72	0.896	
CC	1	0.01431	0.90	0.596	
CH	1	0.03037	1.91	0.005	**
ΔPAR_soil	1	0.01163	0.73	0.891	
ΔT_soil	1	0.02625	1.65	0.020	*
Residual	30	0.47722			
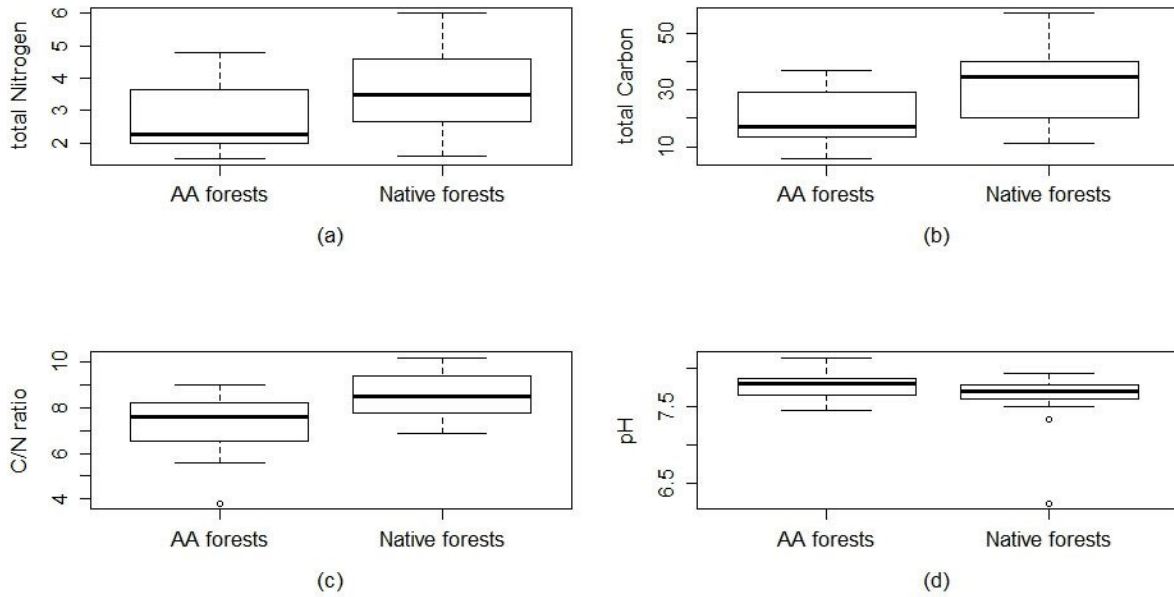
Figure 21 Comparison of the soil chemical parameters measured for the *A. altissima* and native forests through box plots. (**a**) Total nitrogen, p-value = **0.025***; (**b**) Total carbon, p-value = **0.007 ****; (**c**) carbon/nitrogen ratio, p-value= **0.003 ****; (**d**) reaction expressed in pH in H2O, p-value = 0.1. *p* level: **** p* <0.001; *** p* <0.01; ** p* ≤0.05. Significant values are in bold.

7.4. Discussion

7.4.1. Species diversity, life forms, Grime strategies

The results show that *A. altissima* forests host a pool of species that diverge from the target species of the compared native forests. In opposition to a recent study on other alien forest species (Allegrezza et al., 2019), we found a lack of species linked to nutrient-rich conditions. The species richness of the tree and shrub layers seems to not determine a significant differentiation of the two coenoses. In accordance with several other studies in invasion ecology, the main effect is found in

the herbaceous layer (e.g. Motard et al., 2015; Terwei et al., 2016). Floristic diversity (Richness) was higher in *A. altissima* forests in comparison to the native forest coenoses. Even if Constan Nava et al. (2008), Motard et al., (2011), Vilà et al. (2006) reported a reduced species richness in plant communities dominated by this alien species, our result is consistent with the findings of Fotidias et al. (2011). The latter research reports a reduced species diversity in the herb layer in *A. altissima* coenoses in comparison with *Q. pubescens* dominated forest vegetation in a Mediterranean environment. Our result indicates that this alien species invades different environments with a human-mediated process, from seminatural and ruderal habitats to abandoned arable land. Its wide tolerance in different habitat types favored the presence of perennial and annual grass species (hemicryptophytes and therophytes) in the invaded forests. Ruderal species are those species that thrive on high disturbance levels and do not tolerate a high level of stress (Grime, 2001). This ecological strategy group comprehends mainly hemicryptophytes (perennial) and therophytes (annual) life forms. The significant higher presence of annual and perennial herbaceous species, along with ruderal species in *A. altissima* plots, can be explained by the presence of altered vegetative conditions. Both of those elements are reliable indicators of disturbed conditions (Montecchiari et al., 2020). In *A. altissima* forests coenoses, there is the total absence of the herbaceous nemoral species characteristics of the native forest ecosystems of the study area. We found that *A. altissima* could change the species composition of the herb layer, through direct competition for resources and modification in local environmental conditions. The presence of the herbaceous nemoral component is known to be an important element for habitat identification and quality assessment compared to invaded ecosystems, e.g., (Gentili et al., 2019). Its total absence, even if in suitable environmental and landscape conditions, could be due to the presence of phytotoxic substances (ailanthone) contained in *A. altissima* leaves and bark, which can accumulate in the soil (Bostan et al., 2014). It was demonstrated that the spontaneous herbaceous species, more specifically nemoral species that are frequent under the native forest canopy, are susceptible to the presence of allelopathic compounds (Motard et al., 2011) The presence of these phytotoxic substances leads to a reduction of germination success of the spontaneous nemoral species (Lawrence et al., 1991) and if this toxic compound accumulates for a long period, it could have a strong impact on the resident plant community.

7.4.2. Ecological variables

The strongest difference between the two forests communities was found for the topsoil parameters. Specifically, the results of the edaphic characteristics consistently indicated the capability of this invasive species to alter some soil properties. Our results are inconsistent with other studies relating to the effects of *A. altissima* on the soil in the Mediterranean environment (Vilà et al., 2006; Gómez-Aparicio and Canham, 2008). According to Medina-Villar et al. (2016) and Castro-Díez et al. (2009, 2012), we found lower total nitrogen and carbon and C/N ratio in *A. altissima* plots. Castro-Dìez et al. (2009) observed that the lower presence of total nitrogen and C/N ratio in *A. altissima*

forests is in correspondence to the maximum nitrogen mineralization activity in the same period of the year in which our survey was carried out. It was demonstrated that in invaded ecosystems, the net N mineralization and nitrification rates were almost 50% higher than in the native ones. This modification is due to the quality of the alien species litter that can alter the decomposition rates, accelerating the ecosystem nutrient cycling processes (Liao et al., 2008). In accordance with Lazzaro et al. (2014), a lower C/N ratio in invaded ecosystems could be linked to the quality of organic matter under *A. altissima* canopy and a consequent shift in soil bacterial community. A high C/N ratio means high litter quality with topsoil rich in organic matter. The main driver in C/N ratio levels is tree species, and Mediterranean oak forests have higher C/N values with respect to other invasive species forests (Cools et al., 2014). *A. altissima* forests showed no significant impact on soil pH, in accordance with Vilà et al. (2006) and Castro-Díez et al. (2009). Regarding the other environmental variables, we found that canopy height significantly contributes to explaining part of the species compositions of the two forests coenoses, in fact, this variable is linked to forest permanence. Moreover, we can assume that there are altered light conditions under *A. altissima* forests canopy. We found higher Δ PAR under *A. altissima* forest canopy than in native forests, mainly due to the presence of a dense layer of *A. altissima* renovation. *A. altissima* is known to be a species adapted to full light conditions (Kowarik and Säumel, 2007), but on the contrary to what is assumed for invasive alien species, it has been demonstrated that even in low light conditions, *A. altissima* is able to reproduce with good survival rates (Knüsel et al., 2017). These factors lead to the alteration of the herbaceous layer species composition and diversity under the alien species canopy. In the present study, we highlighted the principal floristic and environmental differences between *A. altissima* forests coenoses and native forests typical of the hilly landscape of sub-Mediterranean bioclimate in southern Europe. This work is the first contribution to a specific characterization of *A. altissima* forest coenoses in Italy and, from a broader point of view, for southern Europe. In the light of the recent introduction of *A. altissima* in the list of invasive alien species of European Union concern (European Commission, 2019), a better understanding of the ecological behavior of this species is essential.

7.5. Conclusions

The alien forest communities were located between 10 and 500 m above the sea level, with an average age >20 years, an area ranging from 300 m2 up to 3000 m2, and an average canopy height of 12 m. The comparison of the floristic composition, diversity, and environmental factors between *A. altissima* coenoses and native forest coenoses, highlighted that the main differences were present at the level of the herbaceous layer. Interestingly, *A. altissima* forests are characterized by higher species richness in the herbaceous layer, constituted by annual and perennial herbaceous species (therophytes and hemicryptophytes), with ruderal strategy and linked to disturbed conditions. Moreover, there is a total absence of a pool of nemoral species found in the native forests that are an indicator of habitat quality. The difference detected in species richness could be linked to changes in environmental

variables, in fact, *A. altissima* coenoses showed lower total nitrogen and carbon and C/N ratio values due to an accelerated nutrient cycling process. Our findings highlight that immediate management plans are needed to protect the native plant communities. Further analysis is needed to better understand the below-ground processes and the effect of the litter layer and allelopathy related to this invasive species on the resident plant community.

7.6. Appendices

Appendix 1 A list of species recorded in the study area. Indication of percentage frequency values for each species present respectively in the *A. altissima* forest plots (%AIL) and native forest plots (%NAT), life form, Grime life strategy, and indication of nemoral status (nem_herb). At the end of the table are indicated percentage frequencies of seedlings and saplings recorded in *A. altissima* forests and Native forests. Nomenclature follows Bartolucci et al.,2018.

Species	%AIL	%NAT	Life Form	Grime Strategy	Nemoral Status
Acer campestre L.	52,6	63,2	P scap	C	
Acer pseudoplatanus L.	5,3		P scap	C	
Aegonychon purpurocaeruleum (L.) Holub		10,5	H scap	CS	Nem_herb
Ailanthus altissima (Mill.) Swingle	100,0	15,8	P scap	C	
Alliaria petiolata (M.Bieb.) Cavara & Grande	15,8	15,8	H scap	CR	
Allium sp.	5,3				
Anisantha sterilis (L.) Nevski	31,6	5,3	T scap	CR	
Artemisia campestris L.	5,3		Ch suffr	CS	
Arum italicum Mill. subsp. *italicum*	5,3	10,5	G rhiz	SR	
Arundo donax L.	5,3	10,5	G rhiz	SR	
Asparagus acutifolius L.	26,3	31,6	G rhiz	CS	
Avena barbata Pott ex Link	5,3		T scap	SR	
Ballota nigra L. subsp. *nigra*		5,3	H scap	C	
Bellevalia romana (L.) Sweet	5,3		G bulb	CS	
Brachypodium rupestre (Host) Roem. & Schult.	10,5	26,3	H caesp	CS	
Brachypodium sylvaticum (Huds.) P.Beauv.	15,8	21,1	H caesp	CS	
Bunium bulbocastanum L.	5,3		G bulb	CSR	
Campanula trachelium L. subsp. *trachelium*		5,3	H scap	CS	Nem_herb
Carex flacca Schreb. subsp. *flacca*		10,5	G rhiz	CSR	
Carex pendula Huds.	5,3	5,3	H caesp	CS	Nem_herb
Celtis australis L. subsp. *australis*		5,3	P scap	CSR	
Cercis siliquastrum L. subsp. *siliquastrum*	10,5	5,3	P scap	CSR	
Chaerophyllum temulum L.	31,6		T scap	CR	
Clematis vitalba L.	78,9	52,6	P lian	C	
Clinopodium nepeta (L.) Kuntze	15,8	5,3	H scap	C	
Clinopodium vulgare L. subsp. *vulgare*	5,3		H scap	CS	
Convolvulus arvensis L.	5,3		G rhiz	CR	
Cornus sanguinea L.	47,4	36,8	P caesp	C	
Corylus avellana L.	5,3		P caesp	C	
Crataegus laevigata (Poir.) DC.		10,5	P caesp	C	
Crataegus monogyna Jacq.	57,9	68,4	P caesp	C	
Cruciata glabra (L.) C.Bauhin ex Opiz	10,5	5,3	H scap	CSR	
Cruciata laevipes Opiz	5,3		H scap	CSR	
Cyclamen hederifolium Aiton		10,5	G bulb	CSR	Nem_herb
Cyclamen repandum Sm. subsp. *repandum*		5,3	G bulb	CSR	Nem_herb
Cytisophyllum sessilifolium (L.) O.Lang		5,3	P caesp	CSR	
Dactylis glomerata L. subsp. *glomerata*	10,5	5,3	H caesp	C	
Daucus carota L. subsp. *carota*	5,3		H bien	CR	
Dioscorea communis (L.) Caddick & Wilkin	5,3	5,3	G rad	C	
Elymus repens (L.) Gould subsp. *repens*	5,3	10,5	G rhiz	S	
Emerus major Mill. subsp. *emeroides* (Boiss. & Spruner) Soldano & F.Conti		10,5	Np	CS	

Euonymus europaeus L.	47,4	47,4	P caesp	C	
Ficus carica L.	5,3	10,5	P scap	CS	
Fraxinus ornus L. subsp. *ornus*	26,3	36,8	P scap	C	
Galium album Mill. subsp. *album*	15,8	10,5	H scap	C	
Galium aparine L.	21,1	5,3	T scap	CR	
Galium mollugo L.	5,3		H scap	C	Nem_herb
Geranium dissectum L.	5,3		T scap	CR	
Geranium robertianum L.		5,3	T scap	CSR	Nem_herb
Geranium sp. pl.	5,3				
Geum urbanum L.	5,3		H scap	CSR	
Hedera helix L. subsp. *helix*	84,2	89,5	P lian	CS	
Helleborus foetidus L. subsp. *foetidus*	5,3		Ch suffr	CS	
Helleborus viridis L. subsp. *bocconei* (Ten.) Peruzzi		5,3	G rhiz	CS	Nem_herb
Inula conyzae (Griess.) DC.	5,3		H bien	CS	
Iris germanica L. s.l.	5,3		G rhiz	C	Nem_herb
Juglans regia L.	5,3	10,5	P scap	C	
Lamium maculatum L.	5,3		H scap	CSR	
Lamium sp.	15,8	15,8			
Lapsana communis L. subsp. *communis*	5,3		T scap	CR	
Laurus nobilis L.	52,6	47,4	P caesp	C	
Ligustrum lucidum W.T.Aiton	5,3	10,5	Np	CS	
Ligustrum vulgare L.	15,8	36,8	Np	C	
Lonicera caprifolium L.	5,3	5,3	P lian	C	
Lonicera etrusca Santi		21,1	P lian	C	
Lunaria annua L.	5,3	5,3	H scap	CR	
Malus sp.	5,3		P csesp		
Melica uniflora Retz.		5,3	H caesp	C	Nem_herb
Melissa officinalis L. s.l.	47,4	15,8	H scap	C	
Mentha spicata L.	5,3		H scap	C	
Narcissus sp.	5,3				
Olea europaea L.	21,1	5,3	P caesp	CS	
Origanum vulgare L. subsp. *vulgare*	5,3		H scap	CSR	
Orobanche minor Sm.		10,5	T scap	SC	Nem_herb
Ostrya carpinifolia Scop.		31,6	P caesp	C	
Osyris alba L.	10,5	15,8	Np	SR	
Paliurus spina-christi Mill.	15,8	10,5	P caesp	CS	
Parietaria judaica L.	5,3		H scap	CSR	
Petrosedum rupestre (L.) P.V.Heath		5,3	Ch succ	SR	
Phillyrea latifolia L.		10,5	P caesp	CS	
Picris hieracioides L. subsp. *hieracioides*	10,5		H scap	CSR	
Pistacia terebinthus L. subsp. *terebinthus*		5,3	P caesp	CS	
Poa trivialis L.	15,8		H caesp	CSR	
Populus alba L.	5,3		P scap	C	
Populus canescens (Aiton) Sm.		5,3	P scap	C	
Populus nigra L. subsp. *nigra*	10,5	5,3	P scap	C	
Primula vulgaris Huds. subsp. *vulgaris*		10,5	H ros	CSR	Nem_herb
Prunus avium (L.) L.	21,1	36,8	P scap	C	
Prunus domestica L.	10,5	5,3	P caesp	C	
Prunus spinosa L. subsp. *spinosa*	42,1	15,8	P caesp	C	
Pseudoturritis turrita (L.) Al-Shehbaz	5,3	15,8	H bien	CR	
Pyrus communis L. subsp. *pyraster* (L.) Ehrh.	5,3	5,3	P scap	C	
Quercus cerris L.		10,5	P scap	C	
Quercus ilex L. subsp. *ilex*	5,3	10,5	P scap	C	
Quercus pubescens Willd. subsp. *pubescens*	36,8	63,2	P caesp	C	
Rhus coriaria L.		5,3	P caesp	C	
Robinia pseudoacacia L.	15,8	36,8	P caesp	C	
Rosa canina L.	10,5	15,8	Np	CRS	
Rosa sempervirens L.	5,3		Np	C	
Rosa sp.		5,3	Np		
Rubia peregrina L.	26,3	36,8	P lian	CS	
Rubus caesius L.	5,3	5,3	Np	C	
Rubus ulmifolius Schott	84,2	68,4	Np	CS	
Rumex sanguineus L.	5,3		H scap	CS	
Ruscus aculeatus L.	5,3	10,5	Ch frut	S	Nem_herb
Sambucus nigra L.	42,1	15,8	P caesp	C	

Silene italica (L.) Pers.	10,5	5,3	H ros	C	
Silene latifolia Poir.	5,3		H bien	C	
Sonchus asper (L.) Hill subsp. *asper*	5,3		T scap	CR	
Sorbus domestica L.		5,3	P scap	C	
Spartium junceum L.	5,3		P caesp	CR	
Stachys sylvatica L.	5,3	5,3	H scap	CS	
Stellaria media (L.) Vill. subsp. *media*	10,5		T rept	CR	
Symphyotrichum squamatum (Spreng.) G.L.Nesom	5,3		T scap	CS	
Teucrium chamaedrys L. subsp. *chamaedrys*		5,3	Ch suffr	CSR	
Torilis arvensis (Huds.) Link subsp. *arvensis*	21,1		T scap	CR	
Ulmus minor Mill. subsp. *minor*	36,8	52,6	P caesp	C	
Umbilicus horizontalis (Guss.) DC.	5,3		G bulb	SR	
Urtica dioica L. subsp. *dioica*	26,3	5,3	H scap	C	
Verbascum thapsus L. subsp. *thapsus*	5,3		H bien	C	
Viburnum tinus L. subsp. *tinus*	5,3	10,5	P caesp	CSR	
Viola alba Besser subsp. *dehnhardtii* (Ten.) W.Becker	15,8	21,1	H ros	CSR	Nem herb
Vitis vinifera L.		10,5	P lian	C	
Seedlengs and Saplings					
Ailanthus altissima (Mill.) Swingle pl	73,7	5,3			
Laurus nobilis L. pl	31,6	31,6			
Quercus pubescens Willd. pl	26,3	47,4			
Acer campestre L. pl	21,1	36,8			
Ulmus minor Miller pl	5,3	21,1			
Fraxinus ornus L. pl	5,3	15,8			
Ligustrum vulgare L. pl	5,3	10,5			
Pyrus communis L. pl	5,3	5,3			
Quercus ilex L. pl	5,3	5,3			
Sambucus nigra L. pl	15,8	5,3			
Crataegus monogyna Jacq. pl	21,1				
Euonymus europaeus L. pl	15,8				
Ligustrum lucidum W.T.Aiton pl	5,3				
Populus alba L. pl	5,3				
Cercis siliquastrum L. pl		5,3			
Cornus sanguinea L. pl		5,3			
Ostrya carpinifolia Scop. pl		5,3			
Populus canescens (Aiton) Sm. pl		5,3			
Prunus avium (L.) L. pl		5,3			
Quercus cerris L. pl		5,3			
Rosa canina L. pl.		5,3			
Sorbus domestica L. pl.		5,3			
Viburnum tinus L. pl		5,3			

Appendix 2 Minimum, average and maximum values of the topographic characteristics and ecological variables surveyed in the *A. altissima* forests and native forests.

	Ailanthus Forests			Native Forests		
	Min	Average	Max	Min	Average	Max
Alt (m slm)	9	194	462	18,89	192	463
Slope (°)	1	10	23	0	10	33
Northness	-1	0	1	-1	0	1
Sup (m2)	215	833	3045	-	>2000	-
Canopy_cover (%)	74	88	94	61	88	97
Canopy_height (m)	7,4	13,4	21,6	6	14,5	24,8
PAR_chest (µmol m-2s-1)	3,2	25,8	97,1	7,3	28,2	64,4
PAR_soil (µmol m-2s-1)	2,2	21,4	125,5	6,1	19,8	49,8
PAR_out (µmol m-2s-1)	83,1	1349,2	1906,8	83,1	1213,1	1863,3
T_in (°C)	15,7	18,9	22,3	15,8	18,4	20,2
T_out (°C)	18,1	21,7	25,6	17,4	21,2	29,2
T_air (°C)	19,2	25,8	29,5	19	25,4	32,3
Δ PAR_chest	61,2	1292,7	1875,3	71,1	1184,9	1854,5
Δ PAR_soil	66,2	1297,1	1874,1	75,5	1193,3	1856
Δ T	-0,5	2,7	7,9	-0,7	2,8	9,5
N_tot (g/Kg)	1,5	2,8	4,8	1,6	3,7	6
C_tot (g/Kg)	5,7	20,8	36,9	11,1	32,2	56,9
C/N (g/Kg)	3,8	7,3	9	6,9	8,5	10,2
pH	7,4	7,8	8,1	6,2	7,6	7,9

Appendix 3 Geographical coordinates of the vegetation plots. Coordinates system WGS84-UTM33.

ID	East	North
5	385604	4814288
7	376931	4799761
8	375047	4796378
9	346354	4816786
11	339474	4796335
12	337269	4859623
14	375354	4813757
15	372499	4805753
16	337494	4796349
17	334511	4797268
18	333757	4797518
19	356709	4779328
20	349941	4777643
21	338904	4811611
22	341462	4824278
23	337132	4853921
25	337141	4848681
28	329718	4844106
29	321483	4839316
5 Nat	385786	4813831
7 Nat	376900	4799729
8 Nat	375913	4797043
9 Nat	346288	4816722
11 Nat	334511	4797268
12 Nat	337061	4859794
14 Nat	375487	4813711
15 Nat	372552	485785
16 Nat	337596	4796311
17 Nat	334874	4797533
18 Nat	333769	4797522

ID	East	North
19 Nat	356776	4779481
20 Nat	350414	4777647
21 Nat	338860	4811557
22 Nat	341453	4824259
23 Nat	337092	4853935
25 Nat	337222	4848771
28 Nat	329777	4844203
29 Nat	321615	4839182

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Chapter 8. *R. pseudoacacia* and *A. altissima* forest vegetation in central Italy: comparative considerations on the floristic-vegetational and ecological characteristics

The alien forest coenoses identified and described in this thesis for southern Europe have several analogies due to the invasive character of the two dominant species but also differences caused by a certain level of divergence in ecological requirements. A preliminary multivariate analysis was performed to assess the demonstrated autonomy level of the four alien forest vegetation considered as a whole. Thanks to the classification analysis ("Ward" algorithm performed on similarity matrix, calculated by applying the "Bray-Curtis" index) have been identified four groups that show floristic-vegetational analogies and differences (data not shown). The same groups are highlighted in the non-metric multidimensional (NMDS) scaling ordination plot (figure 22). All four associations are clearly separated in the ordination plot thus confirming the belonging to characteristic contexts. The four coenoses are referred to the same newly described alliance *Lauro nobilis-Robinion pseudoacaciae* given the correspondence with the elements present in the diagnostic description of the alliance, in fact, *Lauro nobilis-Robinion pseudoacaciae* alliance brings together the naturalized and invasive alien neoformation forests and pre-forest that are dominated by *R. pseudoacacia* and have developed in the Mediterranean territories of the Adriatic sector of central Italy. The characteristic and differential species of the alliance are present with high cover-abundance values in the described associations and are: *R. pseudoacacia, Ailanthus altissima, Laurus nobilis, Rubus ulmifolius, Fraxinus ornus, Melissa officinalis subsp. altissima, M. officinalis subsp. officinalis, Arum italicum, Chamaeiris foetidissima, Vitis vinifera, Ligustrum vulgare, Arundo plinii, Lonicera etrusca, Asparagus acutifolius, Rubia peregrina, Rosa sempervirens, Inula conyzae, Anisantha diandra, Symphytum tuberosum subsp. angustifolium, Sinapis alba, Bellevalia romana, Parietaria judaica, Brachypodium rupestre, Viola alba subsp. dehnhardtii, Juglans regia, Ficus carica, Ruscus aculeatus, Viburnum tinus, Rhamnus alaternus, Cyclamen hederifolium, Petasites pyrenaicus*. The optimum for the communities of this alliance is on alluvial plains and low-slopes morphology, on humid soils that are rich in organic matter, and in areas subjected to anthropic disturbance (Typus: *Melisso altissimae-Robinietum pseudoacaciae*). The inclusion of the *A. altissima* forests in this alliance is also because the *Lauro nobilis-Robinion pseudoacaciae* can be extended to include the neoformation forests dominated by the naturalized and invasive alien tree species that have developed in the Mediterranean macroclimate territories of central and southern Italy. In both *Ailanthus* and *Robinia* forests types, we identified two aspects, a more mature and xerophilous one and a disturbed, nitrophilous and humid one. For the xerophilous aspect, the *Asparago acutifolii-Ailanthetum altissimae* association shows an ecological and floristic affinity with the *Rubio peregrinae-Robinietum pseudoacaciae* association. The low coverage values of the characteristic species of the order *Chelidonio-Robinetalia pseudoacaciae* and *Robinietea* class except for *A. altissima* (*Robinietea* class) especially in the xerophilous aspects of the association reflect what happens for the thermophilous communities of the *Rubio peregrinae-Robinietum pseudoacaciae*. However, the *Lauro nobilis-Robinion pseudoacaciae* alliance includes, in addition to the typically nitrophilous aspects on soils

rich in organic matter, also xerophilous and thermophilous communities on dry soils in poorly anthropized contexts. The *Asparago acutifolii-Ailanthetum altissimae*, compared to the *Rubio peregrinae-Robinietum pseudoacaciae* association, has the lower species richness and coverage of mesophilous and nitrophilous species, such as *Sambucus nigra*, denoting for the *A. altissima* forests a stronger thermophilous and xerophilous character. For nitrophilous and humid aspect the *Aro italici-Ailanthetum altissimae* has floristic and ecological analogies with the *R. pseudoacacia* association *Melisso altissimae-Robinetum pseudoacaciae* that is widely present on alluvial plains of the Mediterranean and sub-Mediterranean region. The main differences between these two association are that, in the study area, the *Aro italici-Ailanthetum altissimae* has extremely impoverished tree and shrub layers and is less frequent. The *Robinia* forest vegetation of the *Melisso altissimae-Robinietum pseudoacaciae* var. *Carex pendula* is also found in the position of the willow groves of *Salix alba* but in the investigated territories, the *A. altissima* forest vegetation is almost absent in this landscape context. In fact, in *Aro italici-Ailanthetum altissimae* we found lower cover-abundance values and the total absence of species like *Carex pendula, Lamium maculatum, Chamaeiris foetidissima, Symphytum tuberosum subsp. angustifolium, Bellevalia romana* that are characteristic of the *Melisso altissimae-Robinietum pseudoacaciae* association. This because *A. altissima* is a species with a xerophilous character, that does not tolerate prolonged conditions of soil water stagnation.
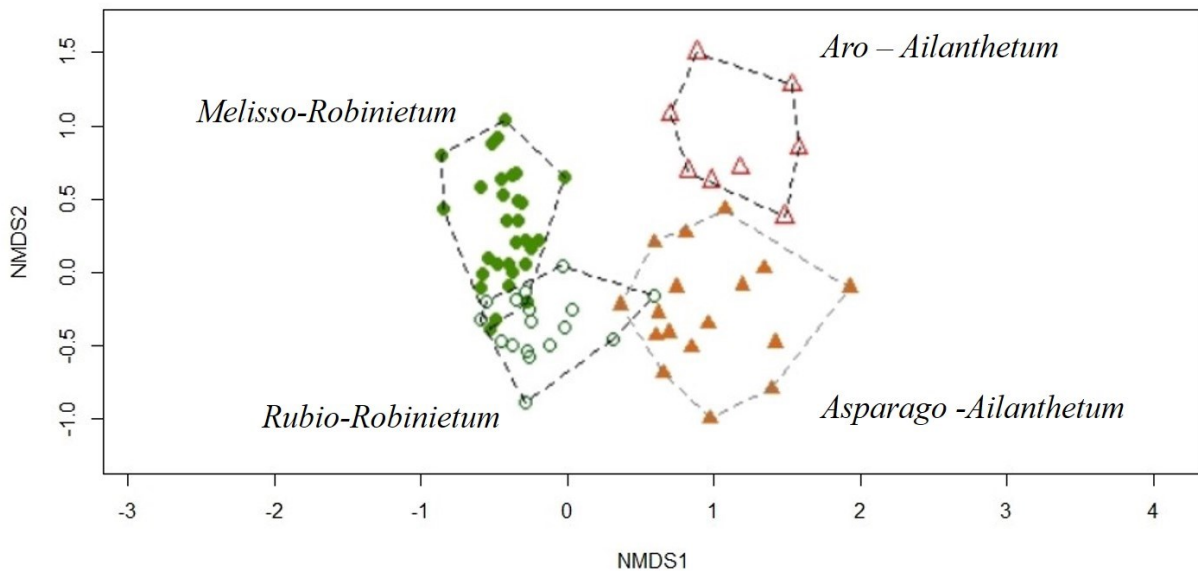
Figure 22 NMDS scaling ordination plot (clusters are superimposed to NMDS plot) of the *R. pseudoacacia* and *A. altissima* forest association newly described. Legend: Green circles: *R. pseudoacacia* coenoses (full colored *Melisso-Robinietum*; empty *Rubio-Robinietum*). Orange triangles *A. altissima* coenoses (full colored *Asparago-Ailanthetum*; empty *Aro – Ailanthetum*). NMDS Stress level:0.1.

So, it can be argued that the synecology of the described forest communities reflects the ecological requirements of the two dominant species. In fact, *R. pseudoacacia* is a nitrophilous species adapted to humid conditions and *A. altissima* having a more xerophilous character. For these reasons, the *R. pseudoacacia* communities are more diffuse and frequent in the study area along

alluvial basins and along watercourses, than *A. altissima* communities that can be found only on more xeric aspects. It is possible to predict that by expanding the floristic-vegetational investigations in the Mediterranean climate areas of southern Italy and in general in southern Europe, the *A. altissima* forest communities belonging to the *Lauro-Robinion* alliance will be very widespread and take advantage of the climate change underway.

Part IV Conclusions

Chapter 9. Concluding Remarks

9.1. Conclusions

Biological invasions by alien plant taxa are one of the main characteristics of the actual geological era (Anthropocene). It is an increasing phenomenon caused mainly by human activities and disturbances. Invasive alien species cause a high amount of damages not only on the native species, ecosystems or protected habitats but also on ecosystem services, human health and economy. We identified two invasive alien tree species, that are widely distributed in Europe and reaches in Italy the southern limit of distribution with a high potential of diffusion: *A. altissima* and *R.pseudoacacia.* Even if there are some ecological studies in continental Europe, ecological and floristic-vegetational studies of syntaxonomical nature on forest communities dominated by these two alien tree species, are still insufficient. The research allowed the identification, classification and characterizations of the forest communities dominated by *A. altissima* and *R.pseudoacacia* in southern Europe in the Mediterranean and sub-Mediterranean climate areas (Chapter 1 and 3). The application of ecological and syntaxonomical approaches let us analyze these communities considering different aspects (Chapter 2). Thanks to the processing of the collected data and the comparison with existing literature data on analogous communities and syntaxa we described a new alliance, the *Lauro nobilis-Robinion pseudoacaciae* that includes four new associations (*Melisso altissimae-Robinietum pseudoacaciae, Rubio peregrinae-Robinietum pseudoacaciae, Asparago acutifolii-Ailanthetum altissimae, and Aro italici-Ailanthetum altissimae*). The new alliance *Lauro nobilis-Robinion pseudoacaciae*, is the southernmost syntaxa of the class *Robinietea* that have been currently described for the Italian peninsula and the first syntaxonomic contribution of this class in Europe for the Mediterranean biogeographical region. It brings together the naturalized and invasive alien neoformation forests and pre-forest that are dominated by *R. pseudoacacia* (and other alien tree species such as *A. altissima*) developed in the Mediterranean territories of the Adriatic sector of central Italy and extends into the temperate macroclimate of the sub-Mediterranean variant. The research focused on precise target vegetation selected by the application of strict selection criteria which excluded non-spontaneous forests, in different succession stages, and managed. We selected from an initial database of over 200 relevés only of *Robinia/Ailanthus* dominated forests that result spontaneous, not in a juvenile stage, inserted in a precise plant landscape and pure. The description of the floristic-vegetational, structural and landscaped characteristics of these syntaxa highlight their autonomy in the invaded

areas (Chapter 4 and 6) and the different responses in respect to biotic and abiotic variables (Chapter 8).

Moreover, we also assessed their ecological characteristics through measurements in the field and considering ecological traits. We assessed altered floristic-vegetational and ecological characteristics in paired comparison with native forests. In fact, for *R. pseudoacacia* we assessed that already low cover-abundance levels of *R. pseudoacacia* indicate an initial negative effect on the target community (e.g. *Q.pubescens* forests of the habitat 91AA*). In this sense, we observed how the presence of species linked to forest conditions (nemoral species defined as target species of the 91AA* habitat according to the Italian Habitat interpretation manual) are although still present but with a decreasing coverage trend until they disappear (at least the most sensitive ones) in groups with black locust dominance (Chapter 5). For *A. altissima* we highlighted that there is a clear floristic separation between *A. altissima* and hardwood native forests in the study area mainly at the level of the herbaceous layer that is sensitive to the canopy changes and disturbances. In respect to the native forests, *A. altissima* forests a higher presence of annual and ruderal herbs, the absence of herbaceous species linked to the forest environment and lower total nitrogen, total carbon, and C/N ratio. *A. altissima* forest communities could threaten the biodiversity of the native forest ecosystems in the sub-Mediterranean landscape, favoring ruderal species and inhibiting the presence of typical forest species (Chapter 7).

The main strengths of this research project rely both on the fact that this is the first scientific contribution on the identification, classification and characterization of these two main invasive tree species in southern Europe in the Mediterranean and sub-Mediterranean areas and on the use of an integrated approach between the ecological and floristic-vegetational methods. The application of floristic-vegetational analysis of the phytosociological/syntaxonomical approach strictly integrated with ecological investigations of measured in field biotic and abiotic characteristics represent a strength because is not so diffuse in vegetation studies and researches.

The characterization of these alien coenoses at the ecological, bio-geographic, syntaxonomical, ecological and landscape levels is an important starting point to understand. The important insights produced are essential to start to understand these alien forest ecosystems and implement proper planning and managing decisions.

9.2. Future perspectives

The future objectives of this research are several and aim to better understand the ecology of the invasive alien tree species and to apply the same methodology to similar new forest formation dominated by native species. In the near future the point to be developed are:

1) The extension of the study area in other Mediterranean areas of southern Italy area in order to better clarify the syntaxonomic position *Lauro nobilis-Robinion pseudoacaciae* alliance in the *Chelidonio-Robinietalia* order in a deeper analysis in the broader European context. Moreover, this will contribute to providing further information on *R. pseudoacacia* and *A. altissima* communities distribution and ecological behavior.

2) The application of a landscape analysis on these two alien forest communities to highlight possible land-cover type gradients that acts like corridors for the spread of invasive alien species. A possible analysis could be done according to the Corine Land Cover categories in urban–peri-urban–rural gradient (e.g. Wagner et al., 2020).

3) The use of remote sensing data (e.g. identification of the spectral sign or a phenological pattern) for the detection, discrimination and mapping of *R. pseudoacacia* and *A. altissima* forests over a large area (e.g. Kopec et al., 2019; Tarantino et al., 2019; Vaz et al., 2018). Under the light of the last Italian forest inventory (Tabacchi et al., 2005), the *R. pseudoacacia* and *A. altissima* vegetation are classified under the same category, namely "Robinio-Ailanteti", and this makes almost impossible the application of separate measurements for the two species (of which only *A. altissima* is in the list of IAS of Union concern).

4) Highlight ecological relations between these two alien tree species in the study area. It can be done only by planning to expand the study to those forest areas co-dominated by both species and collect florist-vegetational and ecological data.

5) Perform other kinds of measurement on these forest coenoses (e.g. dendrometric-structural measures) to produce useful data for management purposes.

6) Extend the same research protocol to other invasive alien tree species e.g.: *Acer negundo*, *Prunus serotina*, *Quercus rubra* etc. (e.g. Campagnaro et al. 2018; Dyderski and Jagodziński, 2021).

7) Apply the same methodology to similar new forest formation dominated by native species in the context of the vegetation dynamics and disturbance ecology.

9.3. References

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