Anna Paiola[1,*], Giacomo Assandri[2,3,*], Mattia Brambilla[2,4,**], Michela Zottini[1], Paolo Pedrini[2], Juri Nascimbene[5]

Exploring the potential of vineyards for biodiversity conservation and delivery of biodiversity-mediated ecosystem services: a global-scale systematic review

[1] University of Padova, Dept. of Biology, Via U. Bassi 58B, I-35131, Padova, Italy

[2] MUSE. Sezione Zoologia dei Vertebrati, Corso del Lavoro e della Scienza 3, I-38123, Trento, Italy.

[3] University of Pavia, Dept. of Earth and Environmental Sciences, Via Adolfo Ferrata 9, I-27100, Pavia, Italy.

[4] Fondazione Lombardia per l'Ambiente, Settore biodiversità e aree protette, Largo 10 luglio 1976 1, I-20822, Seveso (MB), Italy.

[5] University of Bologna Dept. of Biological, Geological and Environmental Sciences, Via Irnerio 42, I-40126 Bologna, Italy.

* Anna Paiola and Giacomo Assandri equally contributed to this work.
** Corresponding author at: brambilla.mattia@gmail.com

Abstract

Vineyards are experiencing a strong expansion and intensification of management worldwide, especially in areas with Mediterranean climate, which are often characterized by high conservation value. This is posing concerns about the environmental impact of vineyards and is fostering research to address biodiversity patterns and ecosystem services in vineyards. With this systematic review, we aimed to provide a global and comprehensive overview of the state-of-the-art research on biodiversity and biodiversity-mediated ecosystem services in vineyards, considering the effects of landscape features and management practices. In this analysis, we considered different organism groups, from microbes to vertebrates, and different spatial scales.

We carried out a systematic literature search on the Web of Science Core Collection Database that was filtered by several selection criteria, resulting in a final collection of 218 papers published between 1995 and 2018.

Results of the studies are often taxon- and scale-dependent, sometimes contrasting and univocal conclusions are hard to derive. However, at least three main points of practical relevance can be retrieved: (i) organic viticulture weakly enhances biodiversity at the landscape scale. Contrasting effects were found at the local scale. (ii) Ground vegetation management by cover cropping and the conservation of native ground cover is crucial for biodiversity. (iii) Habitat heterogeneity at landscape and local scale is a key element for biodiversity. Several studies support the view that improving biodiversity in vineyard-dominated landscapes could also positively affect several ecosystem services.

Our study revealed knowledge gaps that should be filled by future research. In particular: important geographical areas, as well as organism groups are still neglected; studies at the landscape level are scanty, and several ecosystem services still have to be considered.

Keywords - agricultural management; animalia; bacteria; fungi; landscape composition; plantae

1. Introduction

Traditionally, agriculture contributed to shape impressive cultural landscapes, characterized by highly heterogeneous landcover and low-input farming practices, which support species-rich ecosystems (Plieninger, Höchtl, & Spek, 2006). However, in the last decades agriculture expansion and intensification represented one of the main threats to biodiversity (Green, Cornell, Scharlemann, & Balmford, 2005; Tscharntke, Clough, et al., 2012; Foley et al., 2011).

Vineyards, which in several regions are part of the cultural and historical landscape, are emblematic of this situation. This permanent crop is experiencing a strong expansion in the Mediterranean climate regions worldwide (including the so-called New World Mediterranean-NWM: Oceania, South Africa, Chile, California), mainly at the expense of natural and semi-natural habitats (Assandri, Bogliani, Pedrini, & Brambilla, 2019; Streifeneder, Tappeiner, Ruffini, Tappeiner, & Hoffmann, 2007). In parallel, vineyards are experiencing strong intensification of agricultural practices (e.g. increasing fertilizer and pesticide inputs, high level of mechanization, large-scale irrigation) and landscape simplification (e.g. increasing field size, suppression of marginal habitats and landscape infrastructures; Martínez-Casasnovas, Ramos, & Cots-Folch, 2010).

These processes reflect the increasing economic value of vineyards, which now benefit of a higher climatic suitability in previously unsuitable regions, due to climate change (Hannah et al., 2013), and are threatening natural and semi-natural ecosystems and their associated biodiversity and ecosystem services (Viers et al., 2013, Winkler et al., 2017). This trend is increasingly posing concern about the environmental impacts of intensive vineyard management, due to the high conservation value of the Mediterranean Biome, which is characterized by high levels of general biodiversity and endemism (Viers et al., 2013).

In this context, an increasing research activity is addressing biodiversity patterns and ecosystem services (ESs) in vineyards, exploring the effects of local management and landscape features on different organisms, including animals, plants and microorganisms. A crucial topic addressed in many studies is that of exploring under which conditions biodiversity and its associated ecosystem services may be maintained and enhanced, while ensuring productivity.

Even though scientific literature steadily increased in the last two decades, few reviews and meta-analyses addressed specific issues related to biodiversity and/or ESs in vineyards. Katayama et al. (2019) provided an analysis on the trade-off between biodiversity and yield according to different management regimes. Winter et al. (2018) examined the effect of vegetation management intensity. Garcia et al. (2018) focused on the effect of “service crop” management, while Döring et al. (2019) reviewed the effect of organic and biodynamic farming on biodiversity. In this framework, the main aim of our systematic review is that of providing a global and comprehensive overview of the state-of-the-art research on biodiversity and biodiversity-mediated ESs in vineyards. In particular, we aim at summarizing and translating into practical suggestions the available information on the effects of landscape composition, configuration and different management practices on vineyard biodiversity and on biodiversity-mediated ESs. In this analysis, we considered different organism groups, from microbes to vertebrates, and different spatial scales, i.e. the local and the landscape-level scale. Finally, we expect that this summary of available information could effectively help managers and farmers to improve biodiversity and ecosystem services in future vineyard planning and management. We also expect to contribute to highlight gaps of knowledge that should be urgently filled by future research.

2. Material and methods

2.1. Literature search strategy

We carried out a systematic literature search on the Web of Science Core Collection Database (last accessed on October 26, 2018), by entering the following search string: “((VINEYARD* OR VITICULTURE*) AND (BIODIVERSITY OR DIVERSITY OR "SPECIES RICHNESS" OR "ECOSYSTEM SERVICE*" OR RICHNESS OR CONSERVATION))”

No year or country limitations were used. This search provided 1401 results that were first selected by title and abstract according to the following exclusion criteria: i) pure agronomic studies; ii) papers not in English; iii) papers concerning only abandoned vineyards; iv) studies carried out in greenhouses; v) papers regarding individual species genetic diversity. This first selection resulted in 312 papers for full-text reading. Then we retained only papers focusing on biodiversity and biodiversity-mediated ESs in vineyards. For ESs, we considered only papers in which management benefited a specific taxon which, in turn, provides an ES (thus defined as "biodiversity-mediated"). Finally, 218 papers published between 1995 and 2018 were retained. These are listed in Supplementary Information (Appendix S1).

2.2. Data extraction and systematization

From each paper, we extracted information about the year of publication, the geographical location, and the taxonomic group investigated, distinguishing between plants, animals (further split into several taxonomic groups), and microbes (including bacteria, fungi and archaea). Moreover, we systematically collected and organized information on how landscape features (i.e. composition and configuration) in vineyard-dominated landscapes, and vineyard management affect different taxa. For landscape features we considered the following land-cover categories: i) vineyards, ii) other perennial crops, iii) annual crops, iv) grassland v) forest vi) fallow lands, vii) natural remnants (different from forests) and viii) water bodies. We separately considered punctual (i.e. isolated trees or bushes, isolated rural buildings, ponds) and linear (i.e. hedgerows, tree-rows, herbaceous field margins, dry-stone walls, terraces, and riparian corridors) landscape structural elements (Collier, 2012; Declerck et al., 2006; Graham, Gaulton, Gerard, & Staley, 2018; Prevedello, Almeida-Gomes, & Lindenmayer, 2017).

For vineyard management we considered: i) the management regime (i.e. conventional, organic, biodynamic farming); ii) soil management practices, and iii) the trellising system (for details see Table 1).

The studies were further classified according to the spatial scale at which they were carried out. For this purpose, we considered i) the local scale, represented by the vineyard parcel (field level) and the areas adjacent to vineyards (off-field level), and ii) the landscape scale.

In order to identify knowledge gaps and to highlight consistent and contrasting effects of landscape and management on biodiversity and related ESs, we used a standard vote counting procedure (Graham, Gaulton, Gerard, & Staley, 2018; Koricheva, Gurevitch & Mengersen 2013). This procedure is useful to summarize very heterogeneous and often unbalanced data across studies. We separately considered species abundance and species richness (the two most commonly used biodiversity metrics in the literature), and counted significant positive, negative, and non-significant effects of each landscape and management variable for each different taxon, accounting for the two different spatial scales (i.e. local and landscape). Single-species studies were included in the review when matching the inclusion criteria, but not in the vote counting procedure (as they do not consider community richness or abundance).

For papers dealing with biodiversity-mediated ESs, we referred to the four main ES categories defined by the Millennium Ecosystem Assessment (2005), i.e. regulating, provisioning, supporting, and cultural services. From each paper, we summarized information on the management regime, the organism group, and the ES assessed considering if the effect was positive, negative or not significant.

3. Results and discussion

3.1 General Overview

3.1.1 Temporal and geographical distribution of the studies

Studies addressing biodiversity or biodiversity-mediated ESs in vineyards could be clustered into three main groups covering three subsequent periods. Few earlier studies referred to the time span between 1995 and 2000 and were carried out in North America, France and Switzerland. Subsequently, between 2000 and 2009, the number of publications steadily increased mainly due to research carried out in Europe and in the United States (mostly in California). A further notable increase of studies has started since 2010 and included also countries in the NWM, specifically Australia and South Africa. Studies referring to Latin America and Asia were quite recent and scanty (Fig. 1).

Half of the studies were carried out in Europe, with Italy (36 studies), France (21), Spain (20), and Switzerland (14) being the most represented countries. Outside Europe, California (31), South Africa (14), Australia (13) and Canada (12) hold most of the publications (Figure 2).

3.1.2 Taxonomical representation

Animals (i.e. annelids, roundworms, arthropods, amphibians, birds, mammals), with 156 studies, were the most represented organism group, followed by microbes (including bacteria, fungi and archaea; 51 studies), and plants (25). Among animals, arthropods were the most represented taxonomic group (104 studies), followed by birds (47 studies), and mammals (9 studies). We found only one paper on amphibians (Tanadini, Schmidt, Meier, Pellet, & Perrin, 2012), and none on reptiles. Among studies on plants, only one was focused on bryophytes (Zechmeister, Tribsch, Moser, & Wrbka, 2002).

While most studies considered a single taxonomic group, few studies have adopted a multi-taxon approach, often demonstrating that the responses of different taxa were inconsistent among groups. Furthermore, research considering the interaction between different taxonomic groups looks promising. For example, grape yeasts (Belda et al., 2017) were found to disperse using hymenopterans as vectors (Steffanini et al., 2012) and a similar interaction is suspected for bacteria, suggesting a potential role played by biodiversity in transferring beneficial microbial organisms to the grape, thus delivering economic relevant ecosystem services (Mezzasalma et al., 2018).

3.1.3 Spatial scales

Most studies (122) considered the local scale, 56 the landscape scale, and 40 both scales. The considered spatial scale varied according to the taxonomic groups (Figure 3). Most of the studies focusing on bacteria and fungi considered only the local scale, as well as most of the studies concerning invertebrates and plants. In contrast, studies on highly mobile taxa, such as mammals, birds and flying arthropods, mainly considered the landscape scale. However, even if factors acting at the landscape scale are known to be the particularly important for these latter taxa (Assandri et al., 2017; Froidevaux, Louboutin & Jones, 2017; Puig-Montserrat et al., 2017), a few studies stressed the importance of considering the landscape scale also for less mobile taxa (but see Bosco et al. 2019b). The results of such studies (Rusch et al. 2017; Nascimbene et al. 2016) support previous findings suggesting that landscape scale modulate the effect of different local factors on biodiversity in the agroecosystem (Batáry, Báldi, Kleijn, & Tscharntke, 2011; Tscharntke, Tylianakis, et al., 2012).

3.2. Effect of landscape composition and configuration on vineyard biodiversity

A large number of studies addressed the effects of landscape composition on biodiversity in vineyards (table 2 and 3). In contrast, only a few studies focused on landscape configuration (e.g. Hilty, Brooks, Heaton, & Merenlender, 2006; Bosco et al., 2019b).

3.2.1. Landscape composition

Since we found similar effects of landscape composition on both species' abundance and richness, they can be discussed together (Tables 2-3). In general, the increasing cover of vineyards in the landscape negatively affected biodiversity. Only a few studies supported the view that vineyard-dominated landscapes can enhance biodiversity, for example by favouring species related to semi-open-habitats (Arlettaz et al., 2012; Gonçalves et al., 2017), mainly in areas with traditional farming (Assandri, Bogliani, Pedrini, & Brambilla, 2016; Guyot et al. 2017). Moreover, vineyards were considered as surrogate habitats for endemic ants in Australia (Chong, Thomson, & Hoffmann, 2011).

Comparing vineyards with other perennial crops, we found contrasting results according to the crop and the taxa considered. Vineyards seem to provide a better habitat for arthropods as compared to apple orchards (Adu-Acheampong et al., 2016). This could be due to the fact that insecticide treatments are more frequent in apple orchards than in vineyards, determining a lower diversity/biomass of arthropods, and, indirectly, of insectivores (Bouvier, Toubon, Boivin, & Sauphanor, 2005; Brambilla, Assandri, Martino, Bogliani, & Pedrini, 2015). In contrast, olive groves, almond orchards and eucalyptus woodlots were reported to retain a higher diversity of most taxa as compared to vineyards (Cohen et al., 2015; Hadjicharalampous, Kalburtji, & Mamolos, 2002; Sánchez-Moreno, Cano, López-Pérez, & Rey Benayas, 2018). This is likely because vineyards, in particular the wire trellising system, have an overall simpler structure as compared with other wood crops. This is reflected by a lower heterogeneity and thus a lower potential to host animal breeding sites and refuges (Assandri, Giacomazzo, Brambilla, Griggio, & Pedrini, 2017).

Extensive grassland remnants are key habitats for the conservation of many farmland bird species (Brambilla, Gustin, et al., 2017; Laiolo, 2005; Swolgaard, Reeves, & Bell, 2008), as well as of arthropods (Rosado et al., 2013), and plants (Nascimbene, Marini, & Paoletti, 2012; Nascimbene et al., 2016). Also woodland remnants were reported to host bird species of conservation concern (Sierro, 2001) and richer communities of arthropods (Hogg et al., 2011; Marie-Stephane, Supagro, Kreiter, & Supagro, 2005) as compared to vineyards. Water bodies embedded in vineyard landscapes were found to be fundamental for the persistence of birds (Moreno Mateos et al., 2014), and mammals (Hilty and Merenlender, 2004; Rambaldini and Brigham, 2011; Di Salvo et al., 2009).

In general, natural and semi-natural areas (including woodlands, grasslands and fallows), interspersed within vineyard-dominated landscapes, supported greater richness and abundance of animals and plants as compared to vineyards (Caprio, Nervo, Isaia, Allegro, & Rolando, 2015; Laiolo, 2005; Nascimbene et al., 2016). Often, these remnants are the only heritage of a vanishing traditional landscape experiencing strong intensification and habitat conversion (Assandri, Bogliani, Pedrini, & Brambilla, 2018). For example, even if common bird species associated with semi-open habitats are well supported in vineyards (Assandri et al., 2017a), the most sensitive species rely on natural remnants for their survival, as reported for several cases of declining bird species of vineyard landscapes in California (Jedlicka et al., 2014), Chile (Steel et al., 2017), and Switzerland (Sierro, Arlettaz, Naef-Daenzer, Strebel, & Zbinden, 2001; but see Arlettaz et al., 2012 for an exception). The same pattern was reported for arthropod assemblages inhabiting *fynbos* remnants in South Africa (Gaigher, Pryke, & Samways, 2015) or oak woodlands in Californian vineyards (Hogg, & Daane, 2011). In South Africa, vineyards supported comparable native pollinators and plants as natural vegetation landscape (*fynbos*) (Kehinde and Samways, 2014). However, even if a higher abundance of grasshoppers was found in vineyards as compared to *fynbos*, their species richness and diversity were still higher on *fynbos* remnants. This suggests that vineyards could not support the whole species assemblage of natural habitats (Adu-Acheampong, Bazelet, & Samways, 2016; Magoba & Samways, 2012). Finally, natural habitats interspersed within the vineyard-dominated landscape can mitigate the spread of invasive species (e.g. the alien spider *Cheiracanthium mildei*; Hogg & Daane, 2013;), albeit these benefits appeared to extend only to the vineyard edge (Hogg et al., 2011).

3.2.2 Landscape configuration

Hilty et al. (2006) found that landscape configuration strongly affects mammalian predator distribution and suggested that landscape characterized by isolated vineyards interspersed with well-connected remnants of natural habitats (i.e. a mosaic structure) have a higher probability of occurrence of native predators as compared to those including larger vineyard patches. Similarly to other agricultural landscapes (Fahrig et al., 2015; Fahrig, 2003; Holzschuh, Steffan-Dewenter, & Tscharntke, 2010), landscape configuration is likely to contribute in regulating biodiversity patterns in vineyard-dominated landscapes (e.g. Bosco et al., 2019b).

3.3. Effect of punctual and linear elements on vineyard biodiversity

Studies on the effects of punctual and linear elements in vineyards mostly addressed birds, arthropods, and plants and referred to the landscape scale (table 2 and 3), although several studies on plants and arthropods also referred to the local scale (table 3 and 4).

3.3.1 Linear landscape elements

In vineyard landscapes, hedge and tree rows were found to have a positive influence on birds (Assandri et al., 2016; Assandri, Bogliani, et al., 2017a, 2018; Guyot, Arlettaz, Korner, & Jacot, 2017), arthropods (Duso et al., 2004), and plants (Nascimbene et al., 2012). Similarly, riparian corridors are considered fundamental for mammal conservation, as they provide sheltering and breeding opportunities and increase connectivity in fragmented agricultural landscapes. However, riparian areas may fail to fully mitigate the impact of fragmentation on more sensitive mammals (Hilty & Merenlender, 2004).

The establishment and/or the maintenance of herbaceous field margins within vineyards strongly enhanced the abundance and richness of arthropods (Pérez-Bote & Romero, 2012; Rosas-Ramos et al., 2018), birds (Assandri, Bogliani, Pedrini, & Brambilla, 2017b), and plants (Mania, Isocrono, Pedullà, & Guidoni, 2015).

The width and species composition of vegetated linear elements are important features in determining their role for conservation. For example, woody margins were found to contribute more than any other margin type to plant conservation (Mania et al., 2015). On the other hand, herbaceous field margin width was demonstrated to mitigate insecticide drift, with grasshopper densities like those of grasslands only when vineyard field margins exceeded 9 m in width (Bundschuh, Schmitz, Bundschuh, & Brühl, 2012). Additionally, natural hedgerows have been reported to accommodate higher phytoseiid mite densities as compared to secondary (i.e. planted) hedgerows, likely due to differences in their pollen availability (Duso et al., 2004).

Despite the fact that in agricultural landscapes dry stone walls may play a crucial role for biodiversity (Manenti, 2014), their influence was poorly investigated in vineyards. However, a positive effect of dry stone walls was found for birds, due to increased habitat heterogeneity and availability of potential breeding sites (Assandri, Bogliani, et al., 2017a, 2018). Similarly, dry stone walls were shown to be refuges for rich assemblages of xerothermophilic spiders (Košulič, Michalko, & Hula, 2014).

3.3.2 Punctual landscape elements

Small water bodies were found to favour bat activity, since they provide better foraging opportunities for more species as compared to vineyards (Di Salvo, Russo, & Sarà, 2009). Accordingly, Stahlschmidt et al. (2012) demonstrated that the creation of artificial wetlands (i.e. retention ponds) could provide foraging islands for bats in vineyards-dominated landscapes, where the decrease of insect abundance due to management intensification seems to be one of the main drivers of bat decline (Stahlschmidt & Brühl, 2012). The effect of isolated trees and isolated rural buildings was assessed on birds, highlighting their role in providing nesting sites within homogeneous vineyard landscapes. However, although the presence of these punctual elements has been reported to favour some species (Assandri, Bogliani, et al., 2017b), they seem less influential for bird biodiversity as compared to hedge and tree rows (Assandri et al., 2016; Guyot et al., 2017).

3.4. Effect of management on vineyard biodiversity

Studies on the impacts of management practices on vineyard biodiversity were carried out both at the landscape (Tables 2 and 3) and the local scale (Tables 4 and 5).

3.4.1 Organic vs conventional farming

In general, the expected positive effect of organic farming on biodiversity as compared to conventional management was often weak and inconsistent across taxa or trophic levels (Bruggisser, Schmidt-Entling, & Bacher, 2010; Kehinde, Temitope & Samways, 2012; Puig-Montserrat et al., 2017). At the landscape level, only birds were considered: because of their high mobility, birds are expected to respond to management practices mainly at the landscape scale (Winqvist, Ahnström, & Bengtsson, 2012). Birds were positively affected by organic farming in very intensive vineyard-dominated landscapes (Rollan, Hernández-Matías, & Real, 2019), while it was not more beneficial than conventional farming in extensive landscapes (Assandri et al., 2016). This pattern could be due to the relatively comparable regime of disturbance on birds between organic and conventional farming (Assandri, Giacomazzo, et al., 2017). In addition, the isolation of few organic farms in the a landscape matrix dominated by conventional fields could hamper the potential effect of organic management for biodiversity (Assandri, Bogliani, et al., 2017a, 2017b; Hole et al., 2005).

At the local scale, comparisons between organic and conventional farming were mostly tested on arthropods, fungi, plants, and less frequently on mammals, birds, roundworms, and Annelida. These studies found contrasting effects on biodiversity, although organic farming was positively related to plant (Nascimbene et al., 2012; Puig-Montserrat et al., 2017) and fungal richness (Freitas, Yano-Melo, da Silva, de Melo, & Maia, 2011; Kernaghan, Mayerhofer, & Griffin, 2017; Tello, Cordero-Bueso, Aporta, Cabellos, & Arroyo, 2011), as well as to arthropod richness and abundance (Gaigher & Samways, 2010; Masoni et al., 2017). This could be due to the fact that organic farming prevents the use of synthetic herbicides and insecticides. However, the non-targeted pyrethrin insecticide used in organic farming was found to impact arthropod communities (Wolfenbarger, Naranjo, Lundgren, Bitzer, & Watrud, 2008).

The effects of biodynamic farming were investigated only on microbes (i.e. fungi, bacteria, and archaea) and results mainly support the view that this management regime may be more effective for them as compared with conventional and organic farming (Burns et al., 2016).

3.4.2 Ground cover management

In recent years, the need to balance the trade-off between vine-weed competition and soil degradation and erosion led researchers and practitioners to experiment different ground cover management (Rodrigo-Comino, 2018). A variety of studies have highlighted the multiple benefits for biodiversity of establishing a ground vegetation cover by cover crops or the maintenance of native vegetation in vineyard inter-rows. Most of these studies referred to the local scale. Ground vegetated vineyards were reported to host higher species richness and abundance of arthropods as compared to non-vegetated vineyards, especially when ground cover is provided by native vegetation (Danne et al. 2010; Pétremand et al., 2017; Bosco et al., 2019b). In contrast, bare soil was found to harbour few arthropods, especially when maintained by herbicides (Masoni et al., 2017; Sanguankeo & León, 2011). A positive influence of ground cover was reported also for fungal communities, especially in the case of mutualistic species (e.g. arbuscular mycorrhizal fungi) (Lumini, Orgiazzi, Borriello, Bonfante, & Bianciotto, 2010; Oehl & Koch, 2018), and for bacteria (López-Piñeiro, Muñoz, Zamora, & Ramírez, 2013).

Studies on the effect of soil management practices on birds mostly considered the impact on foraging habitat selection and breeding behaviour (autoecological studies are not included in the Tables 2-5, but discussed below), indicating that vegetated vineyards had mixed effects on birds, depending on species-specific ecological requirements (Luther et al., 2008). Specifically, granivorous birds preferentially forage on bare ground (Rollan et al., 2019). In contrast, ground-foraging insectivorous birds, such as hoopoe (*Upupa epops*), wryneck (*Jynx torquilla*), woodlark

(*Lullula arborea*) and common redstart (*Phoenicurus phoenicurus*), typically prefer to forage on vegetated habitats with patches of bare ground (with an optimum of 40-60% of bare ground) (Arlettaz et al., 2012; Barbaro et al., 2016; Coudrain, Arlettaz, & Schaub, 2010; Schaub et al., 2010; Tagmann-Ioset, Schaub, Reichlin, Weisshaupt, & Arlettaz, 2012), and generally on low to medium height grass (<20 cm) (Assandri, Bogliani, et al., 2017b). This because ground-feeding insectivorous birds benefit from the so called "kitchen-dining room" system (Vickery & Arlettaz, 2012), according to which arthropod preys are more abundant in tall grass, but are detectable by ground feeding birds only if patches of low or sparse grass (or bare ground) are available. Additionally, Buehler, Bosco, Arlettaz, & Jacot (2017) found that the woodlarks breeding in Swiss vineyards also require a dense and high vegetation cover for nesting. Thus, an active ground vegetation management, resulting in heterogeneous sward structures, is fundamental to meet the habitat requirements of several species of conservation concern (Bosco et al. 2019a; Guyot et al., 2017).

In general, ground management has strong impacts on most taxa, specifically when intensive practices, such as tillage and the use of herbicides, are used. Chemical weeding was reported to be particularly harmful for arthropods (Pétremand, Speight, Fleury, Castella, & Delabays, 2017; Renaud, Poinsot-Balaguer, Cortet, & Le Petit, 2004; Sanguankeo & León, 2011), whereas tillage appeared as highly detrimental for several groups, such as arthropods (including pollinators), fungi, bacteria, and plant abundance and richness (Bruggisser et al., 2010; Gago, Cabaleiro, & García, 2007; Kratschmer et al., 2018). The mechanical mowing of ground cover less severely impacted on biodiversity (e.g. Duarte, Farfán, Fa, & Vargas, 2014; Rollan et al., 2019) and allowed to prevent an excessive competition between vines and weeds (Bruggisser et al., 2010; Gago et al., 2007). However, frequent mowing, in particular on steep slopes, had negative effects on plants (Nascimbene et al., 2016).

Finally, mulching was found to benefit most taxa, including arthropods (Addison, Baauw, & Groenewald, 2013; Thomson, Sharley, & Hoffmann, 2007), plants (Lososová, Danihelka, & Chytry, 2003), bacterial and fungal abundance and richness (Longa et al., 2017).

3.4.2 Trellising systems

Few studies addressed the potential of different trellising systems in affecting biodiversity and all of them were focused on birds. Results suggested that traditional systems are generally more beneficial than modern wire systems (Assandri, Bernardi, et al., 2018; Assandri et al., 2016; Assandri, Bogliani, et al., 2017a). *Pergola*, a traditional system occurring in northern Italy, favoured bird nesting attempts and breeding success as compared to wire systems, due to its complex and tree-like structure providing more niches (Assandri, Giacomazzo, et al., 2017). *Gobelet*, the traditional system in Valais (Switzerland), was reported to positively affect woodlark foraging habitat selection as compared to the wire system (Arlettaz et al., 2012).

3.5. Biodiversity-mediated ecosystem services in vineyards

In agroecosystems, biodiversity sustains multiple ESs (Brussaard, de Ruiter, & Brown, 2007; Gurr, Wratten, & Michael Luna, 2003). In this framework, vineyard landscapes were reported to provide a wide array of ESs that benefit human activities (Winkler, Viers, & Nicholas, 2017). However, evidences of direct relationships between management, biodiversity enhancement and consequent provisioning of biodiversity-mediated ESs in vineyards are still scanty (see Table 6). Among the categories of ESs, regulating services are the most represented (24 studies), followed by supporting services (4). We found no specific study on biodiversity-mediated cultural ESs in vineyards. Additionally, we found poor evidence of practices determining biodiversity-mediated provisioning services in vineyards (not reported in Table 6), but it is likely that these services are associated with other ESs such as supporting and regulating services (Garcia et al., 2018). For example, Daane et al. (2018) showed that the preservation of native ground cover enhanced pest control and increased soil quality and fertility without affecting grape yield and wine quality. Similarly, cover crop proved to be useful to control weeds, without creating competition with vines (Baumgartner et al. 2008). However, Irvin et al. (2016) found a negative effect of irrigated cover crops on grape quality (due to reduced sugar content and pest damages).

3.5.1. *Regulating biodiversity-mediated ecosystem services in vineyards*

Pest control received much attention because of its high economic importance in viticulture. Management practices that enhance invertebrate or vertebrate predators or parasitoids, which are natural enemies of pests, have a clear potential to increase biological control and thus to support crop yield, while benefiting biodiversity.

Birds can be valuable pest controllers in vineyards. Habitat heterogeneity at both local (achieved through active sward management) and landscape (maintaining high proportions of semi-natural areas such as woodlands and grasslands) scale was reported to positively affect insectivorous birds-mediated pest control services (Barbaro et al., 2016). Similarly, Rusch et al. (2017) found that landscape heterogeneity positively affects bird predation in partially ground-vegetated vineyards. However, the latter relationship was observed only in spring, highlighting the importance of considering temporal variation when assessing biodiversity-mediated ESs. In Californian vineyards located in heterogeneous landscapes that include remnants and woody riparian vegetation, nest-boxes provisioning was reported to enhance avian insectivorous species richness and this in turn was shown to promote pest control services (Jedlicka, Greenberg, & Letourneau, 2011; Jedlicka, Letourneau, & Cornelisse, 2014). Similar results were found in Mediterranean vineyards, though the installation of nest boxes was not sufficient to replace the effects of conventional control of arthropod pests (Rey Benayas, Meltzer, De Las Heras-Bravo, & Cayuela, 2017). In New Zealand, the threatened *Falco novaeseelandiae* was successfully reintroduced into vineyards and this determined a reduction of the abundance of allochthonous pest passerine birds and a 95% reduction in the number of grapes removed relative to vineyards without falcons (Kross, Tylianakis, & Nelson, 2012).

Considering arthropod-mediated biological control, the maintenance or re-creation of natural edges and vegetated corridors besides vineyards, which provide alternative food and refuge for predators and parasitoids, were reported to improve biological control (Nicholls, Parrella, & Altieri, 2001; Ponti, Ricci, Veronesi, & Torricelli, 2005; Thomson & Hoffmann, 2013). Additionally, the type of edge influenced the assemblages of natural enemies. In fact, they were enhanced by woody margins, while pasture margins had no or negative effect (Thomson et al., 2010; Thomson & Hoffmann, 2009).

The importance of habitat heterogeneity and traditional way of vine growing for pest control was corroborated by the results of Altieri and Nicholls (2002), which found that the traditional vineyard-based agroforestry systems (i.e. vineyards composed of host trees, vines, annual crops, and pastures) exhibited higher diversity and abundance of natural enemies, lower densities of leafhopper nymphs, and lower proportion of vine inflorescences infested by the tortricid moth *Lobesia botrana* larvae, as compared with modern monocultures.

At the local scale, increasing vineyards heterogeneity and complexity was shown to enhance the abundance of beneficial arthropod predators, resulting in higher predation rates compared to vineyards with bare soil. This can be obtained by establishing cover crops (English-Loeb, Rhainds, Martinson, & Ugine, 2003; Sanguankeo & León, 2011). Notably, Danne et al. (2010) demonstrated the better performance of native cover instead of exotic cover crops in favouring predators and parasitoids, which, in turn, increased pest control in vineyards. Shields et al. (2016) noted that the inclusion of native plant species within vineyards enhances biological control. Similarly, Daane et al. (2018) demonstrated that the use of native grass as ground cover resulted in higher parasitism rates and lower leafhoppers nymph densities compared to bare ground treatment.

Also the vineyard management regime was found to affect biological control. Contrary to expectations, organic farming decreased parasitism rates of tortricid moths by their parasitoids, suggesting that also organic-certified agrochemicals could have negative impacts on natural enemies and related ESs (Rusch, Delbac, Muneret, & Thiéry, 2015). A similar negative effect of sulphur (a common fungicide used in both organic and conventional vineyards) on beneficial arthropods was reported by Nash et al. (2010) in South Australia, while copper was shown to negatively affect earthworms (Eijsackers, Beneke, Maboeta, Louw, & Reinecke, 2005). A further strategy which resulted in a significant increase of natural arthropods enemies, with consequent increased level of biological control, was the release of a herbivore-induced plant volatile (methyl salicylate, which is naturally produced by plants when attacked by herbivores) through controlled-release dispensers of this phenolic compound artificially synthesized for this scope (James & Price, 2004). The practice of mulching, which is targeted at increasing soil quality while reducing chemical inputs and augmenting soil organic matter, was additionally reported to enhance natural enemy communities but not pest control (Addison et al., 2013; Thomson & Hoffmann, 2007). Only one study assessed the potential as pest controller of entomopathogenic fungi, concluding that landscape heterogeneity negatively affected the rate of attacks by fungi on moth pests during winter (Rusch et al., 2017).

A further regulating ES mediated by vineyard biodiversity is weed suppression. In fact, cover crops can prevent weed growth through diverse mechanisms, as direct competition, or the release of radical exudates such as allelochemicals or nutrients that foster microorganisms harmful to certain weeds (Schonbeck, 2015). Non-chemical weed control through cover crops establishment represents an interesting alternative strategy to the use of herbicides in vineyards (Baumgartner, Steenwerth, & Veilleux, 2008; Gago et al., 2007; Shields et al., 2016). Further, the preservation of native ground cover was reported to have a comparable efficiency for the same reasons described for cover crop (Monteiro, Caetano, Vasconcelos, & Lopes, 2012).

3.5.2. Supporting biodiversity-mediated ecosystem services in vineyards

Biodiversity-mediated supporting services were poorly represented in the reviewed papers. The preservation of native ground vegetation, as compared to tillage, was reported to improve the quality and fertility of vineyard soil, increasing the soil organic carbon content, which contributes to improve many soil properties (e.g. water-soluble organic carbon, water content, total N, available P and K). It also decreased the soil penetration resistance, and enhanced soil micro-organisms (Daane et al., 2018; López-Piñeiro et al., 2013). Similar effects were reported also for the creation of cover crop with endemic plant species (Shields et al., 2016), although Baumgartner et al. (2008) failed to detect such an effect.

4. Conclusions and perspectives

Most reviewed studies tested the effects of different agricultural practices on vineyard biodiversity. Results are often taxon- and scale-dependent, sometimes contrasting and not straightforward to be summarized. However, at least three main points of practical relevance can be clearly retrieved: (i) organic (or biodynamic) farming weakly enhances biodiversity at the landscape scale, although all the reviewed studies focused on birds. This is in accordance with previous meta-analyses suggesting that, at the landscape scale, the positive effects of organic management on biodiversity are weak, and that the landscape structure and composition are much more relevant (Batáry et al., 2011; Tuck et al., 2014). Mixed effects were found at the local scale, with the partial exception of arthropods, which are quite consistently positively affected by organic farming in vineyards. In this perspective, our results are less optimistic on the potential of organic farming for benefiting biodiversity in viticulture than those reported by Döring et al. (2019). In general, the sympathetic management of semi-natural remnants and landscape elements in organic farms could be crucial to amplify the positive effect of organic farming on biodiversity. (ii) Ground vegetation management by cover cropping and the conservation of native ground cover is pivotal for biodiversity in vineyards and does not impact vines. In contrast, intensive ground management, such as tillage and chemical weeding, were confirmed to be detrimental for most taxa. Cover cropping and the conservation of native ground cover were further reported to sustain many biodiversity-mediated ESs. (iii) Similarly to other agricultural systems (Benton, Vickery, & Wilson, 2003; Fahrig et al., 2015), habitat heterogeneity at landscape and local scale is a key element for improving vineyard biodiversity, since different species inhabiting vineyards greatly differ in their ecological requirements. In addition to the positive effects at the community level, heterogeneity appears as an essential habitat characteristic for several individual species. In vineyard agroecosystems, habitat heterogeneity could be achieved through the maintenance of a mosaic of different land-cover types, including natural and semi-natural habitats and structural elements, as well as field margins. At the local scale, mechanical sward and partial ground management allow to increase within-field habitat heterogeneity.

Several studies support the view that improving biodiversity in vineyard-dominated landscapes could also positively affect several biodiversity-mediated ESs. However, most of the available literature is still focused on a restricted range of services of agronomic relevance, i.e. regulating services, as in the case of pest control and weed suppression, thus lacking information on other services.

Actually, our study revealed several knowledge gaps that could be filled by future research on this increasingly important crop system. These can be summarized in four main points:

1) effort should be devoted to cover poorly investigated geographical areas, especially those where vineyards are rapidly expanding at the expenses of valuable natural habitats, as in Latin America and Asia. This point is crucial since management practices, protocols and regulations dramatically vary among regions;
2) several components of the vineyard biota are scarcely -or not at all- represented in the available literature (e.g. reptiles or many groups of invertebrates of scarce agronomic importance). In this perspective, multi-taxon studies should be encouraged, as they are promising for exploring the

simultaneous responses of different organisms to the same drivers and to clarify the role of biological interactions;

3) as studies mostly focused on the local scale, effort should be devoted to better explore the role of the landscape features. Interactive effects between the local and the landscape scale are almost unexplored, as well as the landscape-level effects of organic farming. Studies should include country-specific contrasts between organic vs conventional management and potential time-lags between organic conversion and response to biodiversity;
4) research on supporting, provisioning, and cultural biodiversity-mediated ESs is scanty, and therefore the potential of vineyards to simultaneously provide different ESs should be better investigated and clarified.

In conclusion, information summarized in this study suggests that vineyards have a potential for biodiversity conservation and consequent delivery of biodiversity-mediated ESs. The actual expression of such a potential depends on the adoption of sustainable management practices (*sensu* Tscharntke, Clough, et al., 2012), both at the local and landscape scale. However, even under these circumstances more sensitive species (e.g. endemics or habitat specialists) exclusively rely on natural and semi-natural habitat fragments, that are therefore crucial in preserving biodiversity in vineyard-dominated landscapes.

In addition, recent evidences suggest the potential of integrated conservation strategies in vineyards, aiming at synergistically enhance both biodiversity conservation and ES delivery (Assandri et al., 2018; Brambilla et al., 2017; James et al., 2015). We believe that approaches of this kind could greatly help reconcile an expanding and often intensive agricultural system, which is devoted to the production of a very sought after product, with urgent sustainability targets (including nature conservation). This could also benefit product marketing, resulting in a win-win strategy.

Supplementary Information

Appendix S1. List of papers analysed in the review.

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Table 1: Management variables considered in the review.

Management regimes		
Conventional: allows the use of a broad-spectrum of synthetic pesticides (e.g. herbicides, insecticides, fungicides) and inorganic fertilizers.		
Organic: does not allow the use of synthetic pesticides, but allows organic and mineral products (e.g. copper, sulphur, pyrethrines).		
Biodynamic: very similar to the organic regime in terms of chemicals allowed.		
Soil management		
Ground vegetation cover	*Cover type*	*Ground management*
Bare	**Native vegetation**	**Tillage**
Partial	**Cover crop**	**Mowing**
High		**Chemical weeding**
		Mulching
Trellising system		
***Wire systems (spalliera)*:** low vines supported by wires held between wood or concrete poles. Although there are dozens of variants, this is the most typical system worldwide.		
***Pergola*:** tall vines that grow into a dense leaf “roof” supported by a robust structure of poles and beams (mostly found in several areas of Northern Italy).		
***Gobelet*:** small vines not arranged around wires but left free standing. Mainly found in windy areas, e.g. in Valais (Switzerland) or Mediterranean Islands.		

Table 2. Landscape-scale effect of landcover, structural elements and management practices on the abundance of different taxonomic groups (+: significant positive effect; -: significant negative effect; ns: not significant effect). When more than three positive/negative results are available, the number of positive/negative results is reported in square brackets.

Taxa	Mammalia	Aves	Arthropoda	Nematoda	Annelida	Fungi	Bacteria	Plantae	Total
Landcover									
Vineyards		+ + + - - -	+ + + [10 -]	- -			ns	-	6+; 16-; 1ns
Other perennials		+	- -	+				-	2+; 3-
Annual crops		- -							2-
Grasslands			+ + -						2+; 1-
Forest		+ + + -	+ +						5+; 1-
Fallows		+	+ + - -					+	4+; 2-
Natural remnants		+	[8 +] - ns ns	+			ns	+	11+; 1-; 3ns
Water bodies	+ +	+							3+
Structural elements									
Punctual		+ + +	+						4+
Linear		[6 +]	+ + +					+	10+
Management regime									
Organic		+ - - ns ns							1+; 2-; 2ns
Conventional		-							1-
Ground vegetation cover									
High		-							1-
Partial									
Bare									
Cover type									
Native		ns							1ns
Cover crops		ns							1ns
Trellising system									
Pergola		[5 +]							5+
Spalliera		[5 -]							5-

Table 3. Landscape scale effect of landcover, structural elements and management practice on the species richness of different taxonomic groups (+: significant positive effect; -: significant negative effect; ns: not significant effect). When more than three positive/negative results are available, the number of positive/negative results is reported in square brackets.

Taxa	Mammalia	Aves	Arthropoda	Nematoda	Annelida	Fungi	Bacteria	Plantae	Total
Landcover									
Vineyards	-	+ [4 -]	++ [10 -]	- -			+ +	+ - - -	6+; 20-
Other perennials	-	+	+ - -	+				+ -	4+; 4-
Annual crops	-	+	-						1+; 2-
Grasslands			+ +					-	2+; 1-
Forest		+ + -	+ + -					-	4+; 3-
Fallows		+	+ + -					+ +	5+; 1-
Natural remnants	+ +	+ +	[11 +] ns	+				+ +	18+; 1ns
Water bodies	+								1+
Structural elements									
Punctual		+ ns							1+; 1ns
Linear		+ + +	+ +						5+
Management regime									
Organic		+ ns ns							1+; 2ns
Conventional		-							1-
Ground vegetation cover									
High		+							1+
Partial									
Bare									
Cover type									
Native		ns							1ns
Cover crops		ns							1ns
Trellising system									
Pergola		+							1+
Wires		-							1-

Table 4: Local effect of vineyard management practices and structural elements on taxa abundance (+: significant positive effect; -: significant negative effect; ns: not significant effect). When more than three positive/negative results are available, the number of positive/negative results is reported in square brackets.

Taxa	Mammalia	Aves	Arthropoda	Nematoda	Annelida	Fungi	Bacteria	Plantae	Total
Management regime									
Organic	ns	ns ns	[6+] - [4ns]	+ ns	-	+ - -	ns	+ ns ns	9+; 4-; 11ns
Conventional	ns		[6 -] + [4ns]	- ns	+	+ - ns	ns	- ns ns	3+; 9-; 10ns
Biodynamic						ns	ns		2ns
Ground vegetation cover									
High		+	[6 +] ns ns			+			8+; 2ns
Partial			+ + ns						2+; 1ns
Bare		-	[6 -] ns			-			8-; 1ns
Cover type									
Native		+	[6 +] ns -				+		8+; 1-; 1ns
Cover crops			+ + + - - ns ns			+	-	+ +	6+; 3-; 2ns
Ground management									
Tillage		-	- ns		ns ns	-		-	4-; 3ns
Mowing		+						+	2+
Chemical		-	- - -					-	5-
Mulching			+ + ns					+	3+; 1ns
Structural elements									
Punctual									
Linear			+ + + +						4+

Table 5: Local effect of vineyard management practices and structural elements on species richness. (+: significant positive effect; -: significant negative effect; ns: not significant). When more than three positive/negative results are available, the number of positive/negative results is reported in square brackets.

Taxa	Mammalia	Aves	Arthropoda	Nematoda	Annelida	Fungi	Bacteria	Plantae	Total
Management regime									
Organic			[7 +] - - - [1 ns]	ns		[4+] [4 ns]	+ - ns ns	+ + + - [4 ns]	15+; 5-; 19 ns
Conventional			+ [9 -] [6 ns]	ns		[6-] [2 ns]	- ns	+ - - - [4 ns]	2+; 19-; 14ns
Biodynamic						+ + [4 ns]	+ + ns ns		4+; 6ns
Ground vegetation cover									
High		+	[4 +] ns ns ns			[4 +]	+		10+; 3ns
Partial			+ ns			-			1+; 1-; 1ns
Bare		-	- - - ns ns			- - -	-		8-; 2ns
Cover type									
Native		+	[4 +] - ns			+ +	+	+	9+; 1-; 1ns
Cover crops			+ + - ns			+ + +	+	+	7+; 1-; 1ns
Ground management									
Tillage		-	ns		ns	- - -	- -	- -	8-; 2ns
Mowing		+						- - ns	1+; 2-; 1ns
Chemical		-	- - -					-	5-
Mulching			+			+	+	+	4+
Structural elements									
Punctual									
Linear								[4+]	4+

Table 6. Relationships between the adoption of management/biodiversity friendly practices in viticulture and the provisioning of biodiversity-mediated ecosystem services by different taxa. Each taxon should be considered as "benefited" by the practice, whereas the effect on the ES could be the enhancement (+), depletion (-), or not significant (ns). Several studies simultaneously investigated more than one category of ESs.

Agricultural management or biodiversity-friendly practices applied	*Taxonomic group benefited*	*Ecosystem service provided*	*Type of effect*	*References*
Regulating Ecosystem Services				
favour landscape and local heterogeneity	birds	pest control	+ +	Barbaro et al., 2016; Rusch et al., 2017
nest-box provisioning	birds	pest control	+ + +	Jedlicka et al., 2011, 2014; Rey Benayas et al., 2017
reintroduction of species of conservation concern	birds	pest control	+ +	Kross et al., 2012, 2013
favour landscape and local heterogeneity	fungi	pest control	-	Rusch et al., 2017
natural edges, marginal habitats and corridors preservation	arthropods	pest control	+ + +	Thomson and Hoffmann, 2009; Nicholls et al., 2001; Ponti et al. 2005
vineyard-based agroforestry systems	arthropods	pest control	+	Altieri and Nicholls, 2002
preservation of native ground cover	arthropods	pest control	+	Daane et al., 2018
establishment of cover crops	arthropods	pest control	+ + + + + ns	Danne et al., 2010; Shields et al., 2016; Hanna et al., 2003; Sanguankeo and León, 2011; English-Loeb et al., 2003
mulching	arthropods	pest control	ns ns	Addison et al., 2013; Thomson et al., 2007
use of methyl salicylate (MeSA)	arthropods	pest control	+	James and Price, 2004
organic regime	arthropods	pest control	-	Rusch et al., 2015
preservation of native ground cover	plants	weed control	+	Monteiro et al., 2012
establishment of cover crops	plants	weed control	+ + +	Shields et al., 2016; Baumgartner et al., 2008; Gago et al., 2007
Supporting Ecosystem Services				
preservation of native ground cover	plants	soil quality and fertility	+	López-Piñeiro et al., 2013; Daane et al., 2018
instauration of cover crops	plants	soil quality and fertility	ns +	Baumgartner et al., 2008; Shields et al., 2016

Total			24+; 2-; 4ns	

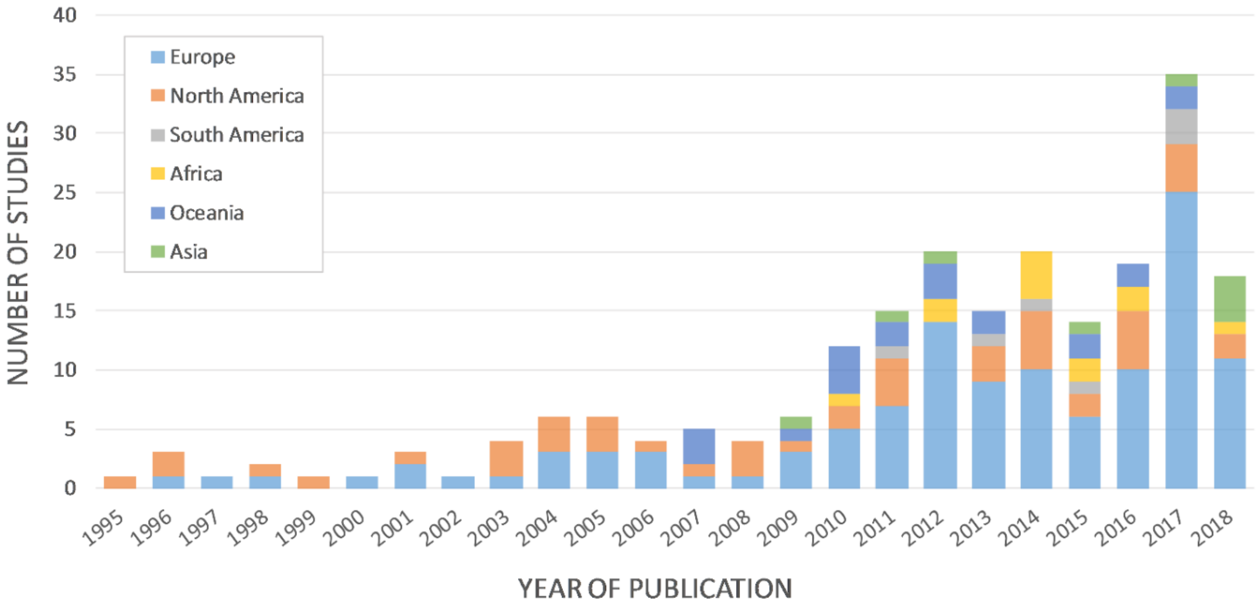

Figure 1. Number of studies on biodiversity and biodiversity-mediated ecosystem services in vineyard landscapes according to continent and year of publication. N=218.

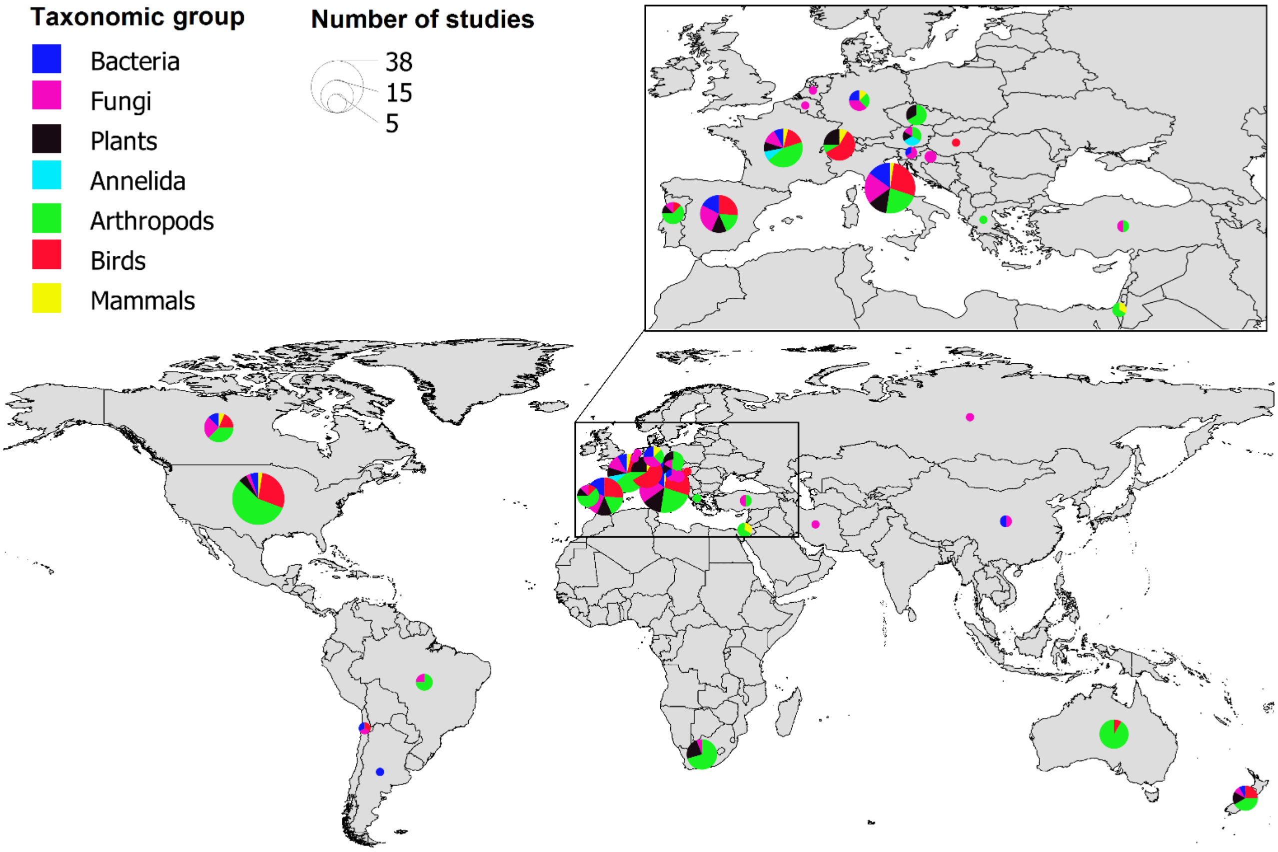

Figure 2. Number of studies on biodiversity and biodiversity-mediated ecosystem services in vineyards according to country. Archea, Nematoda and Amphibia are not represented due to scarce representation. Studies considering together more than one taxon are duplicated. N=252.

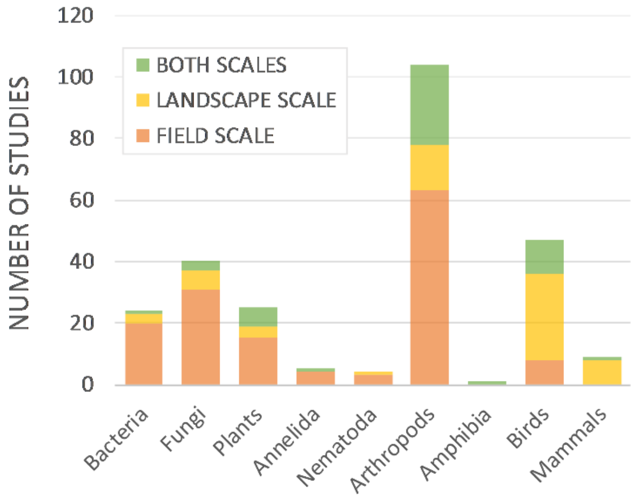

Figure 3. Number of studies on biodiversity and biodiversity-mediated ecosystem services in vineyards according to different taxonomic groups and two spatial scales (local and landscape). Studies considering together more than one taxon are duplicated. N=259