

8 Promoting biodiversity in vineyards through agri-environmental schemes and complementary approaches

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Introduction

Vineyards, though often associated with intensive monoculture, hold considerable potential for biodiversity conservation, including rare species. This chapter examines how agri-environmental schemes (AES), when implemented across multiple spatial scales, can transform vineyard landscapes to meet the complementary habitat requirements of specialized or endangered species. Using case studies from an important wine-growing region in Switzerland, it highlights how targeted conservation measures – particularly those tailored to the ecological needs of flagship species – can enhance both habitat quality and ecological connectivity. This chapter also explores the structure and implementation of different types of AES, emphasizing the importance of participatory planning and coordinated spatial strategies. It further critically assesses the limitations of current AES frameworks and proposes innovative, regionally adapted solutions to address them. By aligning policy instruments, market incentives, and ecological expertise, this chapter advocates for a more flexible and integrated approach to vineyard management, one that generates synergies that sustain both viticulture and ecosystems and thus reconciles agricultural productivity with long-term environmental sustainability.

Ecological requirements of species inhabiting vineyards

Vineyards can harbour specialized species and rich biodiversity

Thanks to their strong tie to Mediterranean climates, vineyards present semi-open habitats characterized by dry conditions. Therefore, this permanent crop can harbour species-rich communities of plants and animals, including rare pioneer species or those adapted to arid, steppe-like habitats (Paiola *et al.*, 2020). Although vineyards are not the primary habitat for these specialized species, they can provide structural and microclimatic conditions conducive to their occurrence. As vast areas of semi-open habitats have been converted into anthropogenic landscapes, including vineyards, these now serve as important alternative habitats (Arlettaz *et al.*, 2012; Santos *et al.*, 2023).

Vineyards were not exempt from the agricultural intensification of the past century and have faced an immense increase in mechanization, including ploughing,

mowing, and the excessive use of pesticides and herbicides (Winter *et al.*, 2018; Bosco, Arlettaz & Jacot, 2019). This has been accompanied by a reduction of (semi-) natural structures within and adjacent to vineyards, leading to homogenized landscapes. Vineyard biodiversity therefore usually depends on management intensity, with traditional, extensively managed vineyards typically harbouring a higher biodiversity and a greater number of rare species than conventional, intensively managed ones (Winter *et al.*, 2018; Bosco, Arlettaz & Jacot, 2019; Zielonka *et al.*, 2024). This is partly due to pesticides negatively affecting plant and invertebrate communities (Nascimbene *et al.*, 2013).

As vineyard management is nowadays shifting towards more nature-friendly practices, several studies have shown positive effects of maintaining ground vegetation (Paiola *et al.*, 2020). These include positive impacts on bird diversity, abundance, and breeding success (Buehler *et al.*, 2017; Guyot *et al.*, 2017; Bosco, Arlettaz & Jacot, 2019; Zielonka *et al.*, 2024). Ground vegetation also provides important ecosystem services, as it boosts the abundance and activity of natural enemies that contribute to efficient pest control (Burgio *et al.*, 2016), while also improving soil fertility, limiting erosion, and enhancing microbiological functioning (Steenwerth & Belina, 2008).

Species use vineyards at various scales

As in any other habitat, different species use their environment in different ways depending on their life-history traits. Because vine rows and their inter-rows are often managed differently, vineyards can present a heterogeneous habitat even at small spatial scales (Brambilla & Gatti, 2022). Inter-rows may differ from the soil conditions below the vines, creating a small-scale mosaic of varying soil and, where present, vegetation structure. Such variation in ground vegetation cover may directly influence less mobile species such as ground-dwelling invertebrates (Bosco & Wan *et al.*, 2019). But it likely also indirectly affects species further up the trophic chain, including predatory species. Birds, especially terrestrially feeding insectivores, often prefer habitat mosaics where ground vegetation and bare ground alternate at fine scales (Schaub *et al.*, 2010). Ground vegetation promotes invertebrate prey supply (Bosco, Arlettaz & Jacot, 2019; Bosco & Wan *et al.*, 2019), whereas bare ground increases prey accessibility (Arlettaz *et al.*, 2012).

In general, landscape heterogeneity is beneficial for biodiversity (Priyadarshana *et al.*, 2024). A greater diversity of habitats and structures offers a wider range of resources to support species-rich and abundant communities. Many species – especially mobile ones – require such heterogeneity within their home ranges to fulfil different needs. For birds, this may include nesting locations, foraging areas, perches, and shelters. This ecological principle is known as landscape complementation, where species require resources from different habitat types within their range (Smith *et al.*, 2014). To support species' habitat requirements at all spatial scales, vineyards should therefore provide varied habitat conditions both within and between vineyards (Guyot *et al.*, 2017; Brambilla & Gatti, 2022; Pradervand *et al.*, 2025), that is, inside and outside the production area.

Flagship species and evidence-based recommendations to restore biodiversity

Among the specialized species that occur in vineyards, some are particularly emblematic and threatened, which makes them ideal ambassadors for projects that aim at promoting biodiversity. Later in this chapter, we showcase the principles of biodiversity-friendly management practices inside and outside the vineyard production area based on two endangered flagship species of Swiss vineyards: the Woodlark (*Lullula arborea*) and the Iolas Blue (*Iolana iolas*). While the Woodlark is associated with semi-open, dry habitats, including vineyards, the Iolas Blue depends exclusively on the bladder senna (*Colutea arborescens*) as both larval host plant and nectar source, and inhabits sunny, rocky slopes. In Switzerland, both species have strongholds in the southern part of the country, in the vineyards of Valais, where their habitat preferences have been studied.

The ecological requirements of Woodlarks are well known at different spatial scales (Figure 8.1). To forage, Woodlarks favour vineyard parcels with alternating

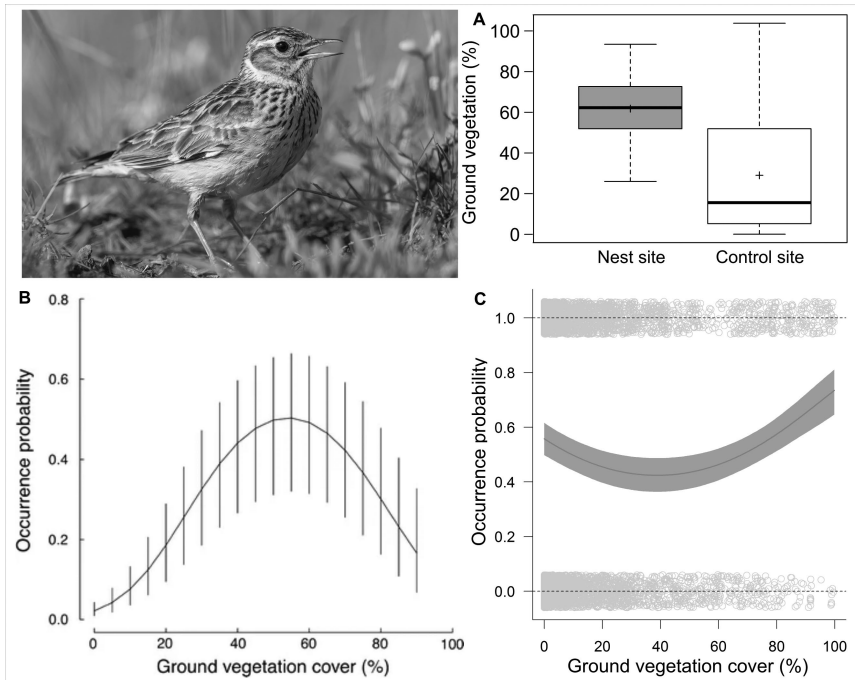


Figure 8.1 Habitat selection of Woodlarks at various spatial scales in vineyards. (A) Selection of nest sites with a higher cover of ground vegetation compared to control sites, at a scale of 1 m²-squares (reproduced from Buehler *et al.*, 2017, copyright © 2026 Elsevier Masson SAS, all rights reserved), (B) selection of foraging patches with intermediate ground vegetation cover of 40%–70%, at a scale of 5 m-radius plots (reproduced from Arlettaz *et al.*, 2012, copyright © 2026 Springer Nature, all rights reserved), (C) selection of areas where mean ground vegetation cover in vineyards exceeds 70%, at a scale of 50 m-radius plots (reproduced from Bosco *et al.*, 2021, copyright © 2026 John Wiley & Sons, Inc., all rights reserved). (Copyright Woodlark picture: Marcel Burkhardt).

vegetated and bare ground patches (Arlettaz *et al.*, 2012), while for breeding, they usually build nests in dense, tall vegetation to enhance concealment (Buehler *et al.*, 2017). At the larger scale of home ranges, Woodlarks select vineyard areas with greater proportions of ground vegetation cover, plant species richness, and wider inter-rows (Bosco, Arlettaz & Jacot, 2019; Bosco *et al.*, 2021) – conditions typically found in mechanized vineyards with less dense vine planting, permitted ground vegetation growth, and reduced or no herbicide use. By contrast, the Iolas Blue is less dependent on conditions within vineyard parcels per se, since its main habitat requirement is the presence and connectivity of bladder senna shrubs (Heer *et al.*, 2013). It exemplifies a species specialized for the dry, sunny, semi-open conditions that prevail in remnants of semi-natural habitats in or around vineyards.

The complementary habitat requirements of these two species have been used to formulate evidence-based recommendations aimed at promoting biodiversity within vineyards where they both occur. To support Woodlarks, the proportion of ground-vegetated vineyards should be increased, while favouring plant species-rich vegetation over uniform grassy swards. Soil conditions should provide a mosaic of vegetated and bare areas, achieved either by an alternate management of inter-rows or by keeping soil beneath vines bare while inter-rows are vegetated. To establish herb-, flower-rich vegetation, specific seed mixtures based on local ecotypes can be used. These benefit not only Woodlarks and their invertebrate prey (Bosco, Arlettaz & Jacot, 2019) but also pollinators (Biella *et al.*, 2025). Guidelines for restoring Iolas Blue populations are theoretically simple: plant and maintain bladder senna shrubs, the host plant, in and around vineyards to create a well-connected network of suitable microhabitats. In intensively managed agricultural landscapes, these semi-natural habitats also prove vital for a wide range of other species (Guyot *et al.*, 2017; Rösch *et al.*, 2023). In practice, such landscape-level restoration can be challenging, as it requires careful planning and collaboration among vineyard farmers, an aspect discussed further in this chapter.

Biodiversity conservation in vineyards through agri-environmental schemes

Description of agri-environmental schemes

One tool to reestablish habitat heterogeneity and increase biodiversity in vineyards is through the implementation of specific policies, such as AES. These schemes have been introduced by governments of numerous countries worldwide to alleviate the negative environmental impacts of intensive agriculture. In the European Union (EU), most of these schemes were initiated in the 1990s, as they became compulsory for member states (Batáry *et al.*, 2015). While the Common Agricultural Policy sets the framework in the EU (European Commission, 2022), each country has developed an individual scheme with national specificities. Several non-EU countries have designed similar schemes during the same period, including Switzerland (Mack *et al.*, 2020).

AES are typically associated with financial contributions, aiming to compensate a farmer for the potential economic loss associated with the implementation of more nature-friendly agricultural practices (Batáry *et al.*, 2015). Usually, AES have a conditionality component and a facultative component (European Commission, 2022; Homet *et al.*, 2024). In other words, minimal requirements must be fulfilled to be eligible for a subsidized scheme, while other measures can be selected from an existing set of options.

Depending on the country or region, AES address a wider range of negative impacts on the environment and, as emphasized in the new Common Agricultural Policy, on climate (European Commission, 2022). Here, we focus specifically on measures that are directly targeted at biodiversity conservation in vineyards and are qualified as such in the respective schemes. Measures whose primary focus is different, for example, preserve landscape quality, reduce pesticide use, or limit greenhouse gas emissions, are not specifically covered in this chapter.

Characteristics of agri-environmental schemes

Over the years, different types of AES have emerged with the aim to increase their efficiency (Cullen *et al.*, 2018). Initially, most AES were strictly action-based, which means that payments are contingent upon the sole application of a measure. As a result, the success of AES has often been assessed primarily based on participation rates, rather than on measurable environmental outcomes (Burton & Schwarz, 2013). For biodiversity conservation in particular, several studies have cast doubt on the benefits of the applied measures, so-called ‘ecological focus areas’, and the lack of cost-benefit assessments (Kleijn & Sutherland, 2003; Batáry *et al.*, 2015; Pe’er *et al.*, 2017).

From the farmer’s perspective, this approach also presents limitations, as it overlooks the effort required to achieve a certain environmental outcome. Over time, there is a risk that the most straightforward and profitable measures are preferentially adopted, potentially leading to a shift in focus from quality to quantity, hence lowering ecological standards (Pe’er *et al.*, 2017). This assessment has led to the introduction of a new, result-oriented module in some AES. The idea is that farmers are rewarded based on the actual output they achieve on their land allocated to AES (Burton & Schwarz, 2013). This implies a monitoring of the ecological quality, with various approaches applied in different AES. A typical example is the evaluation of plant species richness in certain ecological focus areas in Switzerland, which triggers higher payments once a certain threshold is reached (Schaub *et al.*, 2025), for instance, at least six indicator species in extensively managed meadows (Bundesamt für Landwirtschaft BLW, 2020a).

Nevertheless, this result-based module does not consider the spatial configuration of such measures, a gap that still had to be filled given the importance of a landscape-scale approach to increase habitat connectivity for biodiversity (Meichtry-Stier *et al.*, 2014; Pe’er *et al.*, 2017). Hence, a third module has been developed, with the aim of developing a partnership between neighbouring farmers

and improving the spatial connectivity of biodiversity promotion measures. This approach, referred to as ‘multi-actor-oriented’ in the literature (Cullen *et al.*, 2018; Mack *et al.*, 2020), is, to the best of our knowledge, not yet widespread in the context of vineyards.

Biodiversity promotion measures in vineyards from agri-environmental schemes

Measures from AES that aim at promoting biodiversity in vineyards fall broadly into two categories: the establishment of a vegetative cover (i.e., cover crops) and the integration of semi-natural elements within or adjacent to the vine production area (Paiola *et al.*, 2020; Homet *et al.*, 2024). In the first case, a permanent vegetation cover is achieved between vine rows, either by letting the spontaneous vegetation grow or by sowing specific seed mixtures. This measure is therefore always associated with restrictions on herbicide use or tillage, and sometimes also on the frequency and pattern of mulching or mowing. In Switzerland, this specific AES measure is called ‘vineyards with biodiversity’ (hereafter VB). It consists of vineyards with perennial ground vegetation, where inter-rows must be managed in an alternate manner – those with taller vegetation adjoin those with a short sward or bare ground – resulting in a fine-scale mosaic, particularly beneficial for ground-foraging bird species (Schaub *et al.*, 2010; Arlettaz *et al.*, 2012). Fertilizer and herbicide use is regulated and only permitted under vine rows. VB do not automatically entitle farmers to payments and are therefore less strictly controlled by the authorities. They contribute, however, to fulfilling the conditionality criterion and legal obligation that a minimal vineyard area is designated for biodiversity promotion (i.e., action-based measures). Financial support is only granted if the richness of forbs in the vegetative cover in a VB exceeds a predefined threshold (i.e., result-based criteria) (Bundesamt für Landwirtschaft BLW, 2020b), or if the parcel is enrolled in a multi-actor scheme.

The second category of measures focuses on restoring semi-natural elements within or at the edge of the vine production area. This includes the integration of trees, shrubs, flower strips, and hedgerows, as well as the creation and maintenance of small structures such as stone piles, wood stacks, or dry walls. These features serve as breeding habitats, refuges, and corridors for wildlife and are integral to traditional agricultural landscapes, where they support crucial ecosystem services (Holland *et al.*, 2017; Santos *et al.*, 2023). Yet, they have disappeared from most vineyards in the last decades following agricultural land improvement and the modernization of parcels. Several AES aim to reinstate semi-natural elements in depauperate agroecosystems. In Switzerland, VB may include up to 20% semi-natural elements. The presence, number, and diversity of these elements can also contribute to fulfilling the criteria for result-based (Bundesamt für Landwirtschaft BLW, 2020b) and multi-actor-oriented payments.

As AES typically include measures applicable to other crops, the conversion of vineyard parcels to other cultures (e.g., extensively managed meadows or pastures, traditional high-stem orchards) or to areas temporarily left out of production

(e.g., fallow land) is another way to integrate valuable semi-natural habitats within vineyards and hence to promote biodiversity. This strategy might prove especially valuable in large vineyard areas where crop-type heterogeneity is low. In certain regions where vineyard areas are strictly spatially defined, significant administrative hurdles may limit the application of such measures. However, the evolving socioeconomic landscape, for example, the abandonment or active removal of vines in certain European regions (Bonnier *et al.*, 2024), necessitates the evaluation and integration of such alternative approaches.

Implementation of multi-actor schemes in Swiss vineyards

Swiss vineyards and the Valais region

AES exhibit considerable variation across countries, and even between regions within the same country, which complicates broad generalizations. This section showcases a detailed account of the implementation of biodiversity-focused AES in the wine-producing region of Valais, Switzerland. It constitutes a particularly illustrative case due to the progressive integration of action-based, result-oriented, and multi-actor schemes over time. Furthermore, selected multi-actor programs have benefited from the external support of a non-governmental organization (NGO) to implement specific measures. We present two such cases in greater detail, highlighting their differences and the lessons learned, with the aim of improving current policies and inspiring similar developments in other wine-growing regions.

In Switzerland, vineyards cover approximately 14,500 ha, representing 1.4% of the country's agricultural land. Their distribution is highly concentrated, with only a few regions accounting for most of this area, such as the canton of Valais. This wine-growing region of 4,600 ha in the Western Central Alps is characterized by vineyards cultivated mostly on south-facing slopes above the main valley bottom (Rhône Valley). Since the end of World War II, the vineyard area in Valais has steadily expanded, often at the expense of valuable semi-natural habitats such as dry grasslands and diverse, extensively managed agricultural landscapes (e.g., pastures, orchards, and cereal fields) (Arlettaz *et al.*, 2019; Sierro, 2020). Simultaneously, vineyard management practices became increasingly intensive. Due to the steep terrain, only a limited number of agricultural land improvement projects were feasible, so that small parcel sizes and interspersed semi-natural habitats were preserved in numerous areas. Nevertheless, the inability to mechanize vineyard operations led to the excessive use of herbicides and pesticides, with issues of drift and leaching. Around the turn of the century, the total vineyard area started to decline again in Valais due to a changing economic context and urban sprawl, with a loss of around 650 ha in the last 25 years.

During the same period, practices began to shift towards more environmentally friendly approaches, such as the widespread use of mating disruption for pest control and the rise of organic farming (Emery, 2020). This transition was partly due to the introduction in the 1990s of action-based AES at the national level. Those were followed shortly after by result-based and multi-actor-oriented AES (Mack

et al., 2020). It is only in 2014, as financial contributions significantly increased, that multi-actor schemes gained momentum in Valais, with several wine-growing areas integrated in so-called ‘agri-ecological networks’ (Emery, 2020). Currently, approximately 30% of the whole vineyard area in Valais is registered as VB. Of these, about one-third (ca. 10% of the total area) meets the criteria for result-based contributions, while slightly less than half (in total ca. 13%) are enrolled in agri-ecological networks (www.agrarbericht.ch).

Application of multi-actors-oriented schemes: two case studies

Since the early 2000s, the regional office of the Swiss Ornithological Institute (hereafter SOI), an NGO active in applied bird research and conservation, has been a key actor of biodiversity conservation in the Valais vineyards (Arlettaz *et al.*, 2019). The establishment of agri-ecological networks represented a unique opportunity for the large-scale implementation of evidence-based conservation measures, especially for two flagship species with complementary ecological requirements: the Woodlark and the Iolas Blue (see previous section). Acting as a strategic advisor, the SOI has been instrumental in planning, coordinating, and implementing targeted measures to support these two species within the perimeters of two ecological networks where they still occur. Although both selected perimeters have vines as the dominant crop, their landscape characteristics differ significantly. The first network covers the municipalities of Salgesch, Varen, and Leuk (hereafter referred to as SaVaLe), for 380 ha of agricultural land, of which ca. 75% are vineyards. In this perimeter, vineyards are predominantly composed of small parcels interspersed with many small structures, such as dry-stone walls, grassy embankments, groves, and hedges (see Figure 8.2A). The second network covers the municipalities of Chamoson and Leytron (hereafter ChaLey)



Figure 8.2 Two of the perimeters where targeted agri-ecological networks have been implemented. (A) Vineyards of Salgesch within the SaVaLe network, (B) vineyards of Chamoson within the ChaLey network. (Copyright pictures: Swiss Ornithological Institute).

and consists of 790 ha of agricultural land, including ca. 65% of vineyards. In this perimeter, the gentle slope in some areas allows for larger production units compared to the SaVaLe region. These vineyards contain very few semi-natural elements, resulting in a more homogeneous landscape structure (see Figure 8.2B). At the outset, both networks exhibited similar vegetative covers in vineyard parcels, characterized by the widespread use of surface-applied herbicides to suppress ground vegetation.

Both networks were launched around the same time and for a period of eight years. Initially, farmers had to set up an association and commission an environmental consultancy firm to develop a project, which was then validated by the cantonal authorities. For each network, the SOI acted as an external advisor during the development of vineyard-specific measures and provided further support for their spatial planning and implementation, in collaboration with the consultancy firm and the participating winegrowers. One of the main objectives for both networks was to expand the area of ground-vegetated vineyards in favour of the Woodlark through the increase of registered VB. Several additional measures were proposed for the margins of the vine production area to promote species such as the Iolas Blue and the Cirl Bunting (*Emberiza cirrus*), another typical vineyard species which requires interspersed groves and hedges to breed (Arlet-taz *et al.*, 2019).

For SaVaLe, the additional measure focused on planting bladder sennas, as other small structures were already rather widespread throughout the vineyards. Each participating farmer had to plant one such bush for every 0.1 ha of vineyard area reported to the network as VB. The exact location, which could also be outside the production area, was chosen and discussed with the farmer. The SOI, supported by the Pfyn-Finges regional nature park, provided the material and did the planting, while the farmers were responsible for follow-up maintenance, such as watering in the first year, mowing around the plants, and pruning. Over 840 bladder sennas were planted in the network perimeter of SaVaLe during the first year of the project. Moreover, at the end of the eight years, 141 ha (28% of all vineyards) were enrolled in the network project.

For the other case of ChaLey, several additional measures were proposed to compensate for the lack of small structures observed in the perimeter. Participating farmers could choose one of the following five measures: planting groups of bushes (with or without bladder sennas), planting hedgerows, planting isolated fruit trees, building stone piles, or sowing a diverse seed mixture in buffer zones (along roads, paths, watercourses, or hedges). Although no minimum quantity or surface area was specified, each participant was required to implement at least one measure and receive guidance during a field visit with the SOI. During the project period, over 2,500 m of hedgerows, 90 groups of bushes (including bladder sennas) and 240 trees were planted, three stone piles were built, and 2,100 m² flower strips were sown. Most measures were planned and implemented by the SOI, while the participating farmer was responsible for the maintenance. At the end of the eight years, 76 ha (26% of all vineyards) were registered in the network project.

Lessons learned and policy outlook

After an initial phase of eight years, we can draw important lessons from the two networks and the contrasting approaches that were applied. Thanks to effective group counselling and the appeal of additional payments, around a quarter of all vineyard plots were successfully enrolled in both networks. This contributed to a substantial expansion in the total area of registered VB (SaVaLe: +80%, ChaLey: +180%), that is, ground-vegetated vineyards with alternate management. In the network of SaVaLe, 63.6% (48.2 ha) of these VB fulfilled the vegetation quality criteria, while only 24.8% (35.1 ha) did so in ChaLey. Regarding the additional measures, only 30% of the planted bladder sennas in SaVaLe were found to be in good condition by the end of the project's first phase. In contrast, it was estimated that more than three-quarters of the plantations remained intact in ChaLey, although no systematic sampling was carried out. Several notable initiatives were also implemented in this perimeter, such as new plantations of tree alleys and hedgerows along the edges of large parcels. While the environmental consultancy firm monitored Iolas Blues and Woodlarks in both perimeters, the available data were too limited to determine a trend.

It is not an easy task to identify the exact factors behind these different trajectories. While the initial sociological and landscape context (see Figure 8.2) undoubtedly played a role, we believe that the involvement of farmers in the process was a key factor. In SaVaLe, a rather top-down approach was adopted, partly due to the lower initial engagement of farmers within the network. A minimum threshold was set based on each participating farmer's land area, and their role was limited to selecting the locations for the plantations of bladder sennas. Most of these were planted independently, which led to a lack of ownership: maintenance responsibilities were either neglected or entirely forgotten. In contrast, ChaLey followed a participatory model: each farmer had to actively contact the SOI and select their preferred measures. This bottom-up process fostered engagement, as the measures were discussed during field visits with the SOI, and, in many cases, the farmers were directly involved in their implementation. Unlike SaVaLe, measures were implemented not only in the first year but throughout the project period, with requests for new measures even extending beyond the eight years of the initial phase of the project.

Despite the mixed results, we believe that the multi-actor-oriented approach presented here is key for promoting biodiversity in vineyards. First, it enables mobilizing many winegrowers simultaneously and creates a positive dynamic and sense of emulation in the implementation of biodiversity-promoting measures. Besides the additional financial support associated with this module, farmers benefit from advisory services that simplify the whole process and help them to understand the purpose of the implemented measures (Cullen *et al.*, 2018). From the biodiversity conservation perspective, this approach enabled coordinated action at the regional and, therefore, landscape level, which proves crucial for rare species such as the Iolas Blue and the Woodlark (see first section). Furthermore, it allows for targeted, region-specific measures and ultimately accelerates the implementation

process. The example presented here shows that an NGO's involvement can be key in supporting the realization of measures by providing additional human and financial resources. The main challenge lies in striking the right balance between a bottom-up approach, which allows for the direct involvement of farmers and brings flexibility to decision-making, and a more top-down approach, which ensures that minimum quantitative thresholds are met and that the implemented measures are spatially coherent, effective, and managed accordingly in the long term.

Limitations of AES in viticulture and pathways towards complementary approaches

Barriers to achieving efficient biodiversity outcomes in AES

Despite their recognised potential to enhance biodiversity and promote more sustainable vineyard management, AES have drawbacks and limitations that can reduce their effectiveness. First, due to price volatility and the high production costs, it remains difficult to set payments that adequately compensate for the immediate economic losses and additional workload linked to biodiversity promotion measures in vineyards (Galati *et al.*, 2015). In addition, AES depend on the reform cycles of agricultural policies and the corresponding national or regional programs, which typically undergo substantial revisions every few years. This temporal instability creates planning uncertainty, especially for the cultivation of perennial crops, such as vines. Practices such as the establishment of hedgerows, costly restoration of dry-stone terraces, or transition to reduced-input management require long-term commitments and investments, whereas financial incentives may be discontinued or altered within a short timeframe. As a result, vineyard farmers may be reluctant to adopt specific biodiversity-friendly measures whose economic viability is not guaranteed (Muzzillo *et al.*, 2024). The mismatch between policy timelines and ecological processes undermines the long-term effectiveness of AES, especially when farmers must weigh environmental commitments against the immediate economic viability of their operations.

Beyond these structural and temporal barriers, a further challenge lies in the knowledge base underpinning AES and the degree to which recommendations reflect the ecological complexity of viticultural landscapes. Viticulture is highly diverse, shaped by local climate and geo-topography, which in turn determine species composition and the occurrence of priority species. Measures that are ecologically effective in one viticultural area may be poorly adapted in another (Santos *et al.*, 2023). This potential lack of regional tailoring, specifically to regionally endangered priority species, complicates the implementation of result-based schemes, which require measurable and context-specific indicators of success. However, recommendations that focus too narrowly on individual target species risk neglecting broader biodiversity objectives. Effective conservation in vineyard landscapes requires measures that integrate multiple taxa and ecological functions, ensuring that biodiversity promotion does not simply favour a limited set of species but strengthens the resilience of entire ecosystems (Simberloff, 1998; Tälle

et al., 2023). Even where measures are ecologically appropriate, their effectiveness ultimately depends on how and where they are implemented across the landscape (Meichtry-Stier *et al.*, 2014). This again points to the importance of multi-actor schemes, which can help coordinate actions across different holdings (Meier *et al.*, 2024) and select appropriate target species whose conservation can act as a lever for wider biodiversity gains and the maintenance of diverse ecosystem functions.

An additional key limitation of current AES lies in the spatial allocation of biodiversity-promoting areas. Farmers typically decide where to place ecological surfaces, often opting for marginal or hard-to-manage plots rather than locations that would optimize ecological networks and connectivity. This weakens the potential of AES to create coherent biodiversity-friendly landscapes. Even within multi-actor approaches, the voluntary approach and lack of binding rules on landscape composition and configuration remain crucial shortcomings (Batáry *et al.*, 2015). Moreover, this flexibility risks fulfilling only the formal criteria of result-based AES without achieving their intended ecological outcomes across larger spatial scales (Burton & Schwarz, 2013). To circumvent this limitation, it is essential to define in-crop measures directly linked to vineyard management, ensuring that biodiversity practices are also implemented within viticultural surfaces themselves rather than confined to peripheral or marginal areas.

Alternative approaches and opportunities beyond agri-environmental schemes in viticulture

While AES in Switzerland and across Europe have been instrumental in encouraging biodiversity-friendly practices, their scope often limits innovation. To fully align viticulture with sustainable land use and biodiversity objectives, complementary approaches and tools are needed. Strict rules on minimal planting densities, for instance, constrain experimentation with alternative crop mixtures or vitiforestry systems that might enhance resilience and biodiversity. Meanwhile, regulations sometimes allow herbicide use under conditions of severe water stress, even though these practices can undermine long-term soil health and biodiversity goals (Galati *et al.*, 2015). Such rules often stem from a need to ensure a profitable crop while limiting production costs. Yet, under rapid climate change, evolving consumer preferences, and the need for adaptive management, rigid and short-sighted regulations can prove counterproductive. Introducing flexibility – through pilot projects, derogations for biodiversity-promoting approaches, or adaptive regulations – could unlock new pathways for sustainable viticulture.

An emerging concern for vineyard landscapes in several European regions is the gradual abandonment of certain parcels (Bonnier *et al.*, 2024). This trend is particularly noticeable in areas with steep slopes, where mechanization tends to be limited or economically challenging. This structural problem is compounded by an unfavourable market situation where per capita wine consumption is declining, resulting in reduced demand. Consequently, profitability is constrained, and landowners often face limited economic perspectives. These abandoned parcels present both risks and opportunities for biodiversity (Bonnier *et al.*, 2024). Rewilding through

natural succession can provide substantial biodiversity benefits. The development of semi-natural habitats and vegetation corridors may reconnect fragmented landscapes, enhancing ecological connectivity for biodiversity. In addition, such processes contribute to soil stabilization in steep areas and carbon sequestration. At the same time, abandonment can also facilitate the spread of invasive species and lead to a loss of heterogeneity in semi-natural structures among vineyards.

An alternative to uncontrolled land abandonment is the deliberate recultivation or ecological restoration of such parcels. Besides the introduction of alternative crops such as olives, almonds, figs, or aromatic plants, these areas also present a unique opportunity to establish biodiversity-friendly structures. Extensive dry meadows, which thrive particularly well on such sites, can promote pollinators, ground-nesting birds, and a wide range of invertebrates, many of which have suffered habitat loss with the historical expansion of vineyards (Sierro, 2020). However, the establishment of such biodiversity-oriented land uses is only the first step; their long-term management represents a major challenge. Extensive meadows require periodic mowing or grazing to maintain species-rich vegetation, and traditional orchards depend on regular maintenance to preserve both productivity and habitat quality. Ensuring the long-term continuity of these practices requires robust financial incentive mechanisms, among which certification schemes could represent a promising alternative pathway towards sustainability.

Labels can help promote biodiversity in viticulture beyond AES, and they can serve as an option to achieve specific goals in result-based approaches. Examples such as *Delinat* (Delinat, 2023), *IP-Suisse* (Jenny *et al.*, 2024), or smaller local labels demonstrate how private certification schemes can encourage measures that go further than public policy requirements. Both *IP-Suisse* and *Delinat* require winegrowers to limit pesticide use, establish a ground vegetation cover in all parcels, and integrate biodiversity-promoting structures in their vineyards. Such schemes build a bridge between producer practices and consumer awareness. In parallel, platforms that bring together winegrowers with shared values – whether linked to labels or operating independently – can foster innovation and facilitate knowledge transfer, helping producers navigate agronomical challenges. However, economic barriers remain, as certification involves direct costs and management changes that may reduce short-term yields (Merot & Smits, 2020). Since AES rarely support participation in private certification, producers must rely on market recognition to justify these efforts. Yet, evidence suggests that consumers – particularly in local or niche markets – are increasingly willing to pay higher prices for wines that carry credible biodiversity or sustainability labels (Valenzuela *et al.*, 2022). Greater alignment between policy frameworks and market-based schemes, for example, through co-funding of certification or cross-recognition of standards, could accelerate their adoption and amplify their ecological impact.

While market-based incentives like certification can support biodiversity-friendly practices, other trends in viticulture risk undermining these gains by favouring large-scale, homogeneous production systems. Viticulture modernization is often framed as a solution to the challenges of small-scale agriculture and difficult market conditions. A central aspect of this shift involves restructuring vineyards into larger,

mechanizable units to cut production costs and increase profitability. However, this shift from historically heterogeneous, small-scale landscapes with diverse management practices towards large-scale, homogeneous vineyard systems is widely expected to contribute to biodiversity loss (Priyadarshana *et al.*, 2024). At the same time, modernization can also present opportunities to integrate biodiversity considerations into production systems. When planned carefully, vineyard restructuring can support both production and ecological functions. Biodiversity-friendly areas can be integrated within vineyards – through hedgerows, vegetated embankments, or grassed inter-rows – and in the surrounding landscape, including meadows, orchards, or fallow land, creating landscape-scale networks that enhance habitat connectivity and support biodiversity. By embedding such features during vineyard redesign, production efficiency and ecological heterogeneity need not be mutually exclusive. Realizing these benefits requires a shift in perspective: areas designated for biodiversity should not be considered ‘lost land’, but rather as functional infrastructure delivering key ecosystem services, including natural pest regulation, soil stabilization, and enhanced soil fertility. An improved collaboration among governing authorities is particularly essential to more effectively reconcile economic imperatives with sustainable agricultural practices.

Conclusion and outlook

In Europe, biodiversity conservation in vineyards stands at crossroads, especially as climate change and socioeconomic shifts are reshaping agricultural landscapes. Vineyards, as permanent crops mostly cultivated in monocultural systems, are managed intensively. Yet, they may represent important alternative habitats for specialized and endangered species (Paiola *et al.*, 2020). This dichotomy means that the current changes contain both challenges and opportunities for biodiversity. To successfully navigate this transition, it is essential to translate scientific research into practical, field-level conservation measures. Local organizations active in nature conservation may play a crucial role in this process. Their engagement might prove particularly important within the framework of AES, notably through their advisory services at different levels, from farmers to local authorities (Pe’er *et al.*, 2017; Cullen *et al.*, 2018). One efficient strategy is the careful selection of target species, which can both serve as indicators of ecosystem health and help guide management decisions in a way that resonates with cultural values.

The different types of AES – whether action-oriented, result-based, or multi-actor programs – offer a powerful toolkit to promote biodiversity at the landscape level (Cullen *et al.*, 2018; Mack *et al.*, 2020). However, the implementation of these schemes requires flexibility to adapt to local contexts while also ensuring appropriate spatio-temporal planning across regions. In Switzerland, the anticipated fusion of biodiversity-targeted multi-actor schemes with landscape quality programs could enhance planning coherence and foster more integrated conservation efforts. Yet, this shift also poses risks, particularly the potential dismantling of advisory services and existing multi-actor structures due to reduced financial resources. Such elements are critical for translating policy into practice and

ensuring that farmers and land managers receive the support they need to implement biodiversity-friendly measures effectively (Cullen *et al.*, 2018).

AES remain a cornerstone of biodiversity promotion in viticulture (Homet *et al.*, 2024), integrating nature-based solutions that contribute to the sustainability of agro-ecosystems. These schemes not only support ecological functions but also deliver long-term socioeconomic benefits, such as improved soil health, reduced erosion, pest control, and enhanced landscape aesthetics that can boost tourism and local economies (Holland *et al.*, 2017; Pe'er *et al.*, 2017). Nevertheless, these schemes alone are insufficient to meet the full spectrum of sustainability goals. Complementary strategies are essential to create a more resilient and multifunctional viticultural landscape. These include a revision of rigid regulatory frameworks, alternative land use of abandoned parcels, development of sustainability labels, and integration of biodiversity into land improvement projects.

Importantly, these approaches demonstrate that viticulture does not need to choose between production and biodiversity. With innovative practices and adequate incentives, both can coexist and even reinforce one another. The challenge ahead lies in aligning policy frameworks, market mechanisms, and landscape-level decisions to generate synergies that sustain both viticulture and ecosystems. Policy recommendations should therefore focus on enhancing the coherence and flexibility of conservation programs, securing long-term funding for advisory services, and promoting participatory planning processes that involve local stakeholders. Additionally, integrating biodiversity goals into broader land-use and rural development strategies will be crucial to ensure that conservation efforts are not isolated but embedded within a holistic vision for sustainable agriculture.

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