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Fauna as Fieldworkers: An analysis on the use of animals as a form of organic weed and pest management in modern viticulture

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Abstract

Recent data on the current state of pesticide use in global agriculture suggests serious concerns over significant overuse and negative effects on both environmental and human health, and current trends only suggest continued increases in future global pesticide use. Without prompt, large-scale intervention, this global abuse of chemical pesticides spells significant threats of not only continued harm to global health and environmental quality, but also to the long term viability of agricultural lands and the growing threat of pesticide resistant insects and weeds. Various methods have been explored in the realm of integrated pest management (IPM), but a current lack of attention is being given to animal-based biological control, which has been proven both practically effective and ecologically friendly by numerous studies from around the world. Vineyards, due to their frequent status as cultural heritage sites and large-scale monocultures, as well as their rigorous monitoring and control of their agroecology, have an especially high potential for benefiting from an IPM system with animals as central actors. Through a detailed review of various case studies and academic literature and with supplemental information from interviews with two Portuguese vineyards, this study assesses various animals as potential agents for biological control and discusses their benefits and limitations. While current limitations exist for its adoption globally, a shift towards an integrated and less heavily chemical-dependent pest management system is the only viable long-term solution to the growing threat of pesticide resistance and the continued success of global agriculture.

Keywords

Viticulture, vineyards, pesticides, agrochemicals, integrated pest management (IPM), integrated weed management (IWM), integrated crop and livestock system (ICLS), agroecology, biological control, organic agriculture, sustainability, Portugal, pesticide resistance, superpests

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1. Introduction and Literature Review

1.1 Impacts of Pesticide Use in Agriculture

Pesticides, a broad category of chemicals that includes insecticides, herbicides, fungicides, and other compounds, can be an extremely effective tool in managing unwanted biological influences in agriculture, and can give farmers the security of exercising control over some outside factors in their operations (NIH). These toxic agrochemicals are designed and deployed to kill weeds, unwanted insects and other animals, fungi, and bacteria that pose a threat to the healthy growth of agricultural crops (NIH). Over the last three decades, global pesticide use in agriculture has increased nearly twofold, increasing from 1.8 million metric tons in 1990 to 3.54 million metric tons in 2021 (FAO). However, despite their effectiveness as a biocontrol method, chemical pesticides also present a number of negative impacts, including environmental contamination, damage to non-target species, and harm to human health (NIH). This contamination can impact soil, water, and other vegetation; in addition to killing unwanted insects and/or weeds, they can also kill or damage the health of birds, fish, non-target plants, and ecologically beneficial insects and other animals (NIH). Their negative impacts reach not only plant and animal species, but human populations, as well. Notably, chronic exposure to pesticides for workers involved in both their production and their use in agriculture has been connected to a variety of health impacts, including neurological issues, damaged fertility, cardiovascular and respiratory problems, and a number of other concerns (NIH).

This problem is notable in European contexts specifically; in 2020, at least one pesticide was detected above the threshold for risk to human health in 22% of monitoring sites in rivers and lakes across Europe (European Environment Agency). Additionally, one 2019 study of soil pollution in Europe found pesticide residues in 83% of agricultural soil samples collected

(European Environment Agency). Due to uncertainty over the long-term effects of chemical herbicides on environmental and soil quality, workers' health, and food safety, many wine producers, and especially those who produce high-quality wines, have more recently begun to reduce or fully abandon the use of chemical herbicides in their vineyards (Gonçalves et al., 2021). Especially as global demand for wine is expected to continue increasing, the exploration of novel non-chemical-dependent pest and weed management has become a topic of exploration (Niles et al., 2017). As chemical pesticides decline in popularity, European farmers across the region have been experiencing a growing push by environmental advocates and agricultural regulators to explore alternative and particularly organic methods of pest and weed control in their operations, which are not reliant on agrochemicals (European Commission, 2023).

In an effort to find more effective and sustainable land management practices, some farms have begun experimenting with utilizing useful various plants, animals, or bacteria to control unwanted organisms in agriculture, a method of pest management called "biological control" (NIH). Especially in recent years, two of the categories of organisms being more frequently studied for their potential use in biological control projects are insectivorous animals, such as ladybird beetles or bats, and grazing animals, such as sheep or goats, for insect pest control and weed management, respectively (Niles at al., 2017)(Charbonnier et al., 2020).

1.2 Animal Species Being Explored for their Effectiveness in Biological Control

When it comes to biological control agents, the two main categories being explored are grazing animals and insectivorous predators. Grazing animals like sheep have been increasingly a topic of discussion in "integrated weed management", or IWM, for their ability to specifically target and effectively remove small, unwanted plants, especially from an area planted with woody crops like grape vines or fruit trees (Monteiro et al., 2022). Similarly to IPM, or

“integrated pest management”, IWM includes using “a careful combination of grazing animals, conventional biocontrol agents, herbicides, and cultural control” (Popay et al., 1996). IWM aims to increase profit for growers by optimizing crop production using preventative strategies, involved management and monitoring, efficient control techniques, and scientific knowledge of agroecological systems (Monteiro et al., 2022).

Utilizing this systematic approach takes some dependence off of chemical herbicides, and reduces the selection pressure for development of resistance to any one weed control method, creating a more resilient system and causing less harm to ecosystem health, soil health, and farm productivity, as well as reducing any possible impacts of herbicides on the health of consumers, or the farm workers producing it (Monteiro et al., 2022)(Institute for Functional Medicine)(USDA, 2004). With exchange relationships between farms, rental services of livestock from other farmers for weed control, and even farmers buying and keeping livestock of their own, there are a number of options for farmers to explore this form of pest management depending on their circumstances. This approach can be beneficial for livestock as well as for farmers. While much of current meat production is carried out on industrial feedlots or CAFOs and much of agricultural production is carried out without animals, using grazing animals for weed control can present a lower waste, less chemical-dependent, and more humane way to not only grow crops but also raise animals for meat or fiber simultaneously (Popay et al., 1996).

Similarly to grazing animals, insectivorous animals such as bats, birds, and predatory insects are also being explored as options for replacing agrochemicals such as insecticides in organic farms, as parts of an IPM system. Ladybird beetles, also known as ladybugs, are one of the main insects that have been used in IPM systems for their status as natural predators for herbivorous pest insects such as aphids, and have been deployed in numerous countries

worldwide since the 19th century (Rondoni et al., 2020). Similarly to predatory insects, insectivorous bats and birds have been used extensively, serving both the farmers through the removal of insect pests, and the animals through a reduction in habitat destruction on farms and prevention of food scarcity for said animals (Baroja et al., 2019)(University of Évora LabOr). Especially in vineyard systems which are especially vulnerable to arthropods and flying insect pests, bats can be an extremely low-maintenance, low-cost and low-impact tool to control pest populations without the use of, or with reduced use of, chemical pesticides (Baroja et al., 2019). Birds can exercise similar effects to bats on insect pest populations typical of vineyards, especially on insects such as larvae and worms; as the establishment of intensive monocultures such as vineyards frequently displace and destroy habitats for insectivorous birds, the promotion of habitat for these birds may be mutually beneficial for the birds as well as for farmers interested in controlling insect pests (Olmos-Maya et al., 2022). Additionally, because of bird and bat species' capacity as flying predators to travel some distance from their nests in search of food, establishing habitats for these predators can often be done with relative ease and without obstructing the layout of a vineyard. This can be achieved, for example, by creating varied landscapes on the borders of vineyards with hedges, trees, stone walls, and so on, or by creating box nests for bats and birds, which can be done cheaply and easily and without much maintenance by farmers (Baroja et al., 2019)(Olmos-Maya et al., 2022).

1.3 Increasing Pesticide Resistance & the Danger of Total Dependence on Agrochemicals

When discussing alternative solutions to pest and weed control, it is becoming increasingly important to note the mounting danger of pesticide and herbicide resistance in pest insects and weeds. Due to the process of natural selection, with repeated use of agrochemical pesticides and herbicides, weeds and pests can and have actually become more resistant to them

over time (Pesticide Environmental Stewardship). As successive generations of weeds or insects are subjected to the application of these toxins, the more susceptible genetic variants die off while the more resistant ones survive, meaning that over time and with the proliferation of the resistant variants, pests and weeds can eventually become fully resistant to these toxins (University of Minnesota)(Michigan State University). If current trends of overreliance on agrochemicals continue, we will likely see either the complete failure of pest and weed control and a subsequent agricultural crisis of superpests, or the continued development of more and more potent agrochemical toxins and/or reliance on genetically modified crops meant to be resistant to these toxins, each of which present their own problems (Benbrook, 2012). With growing concerns over the harms of modern agriculture on the environment as well as the effects of climate change on our ability to produce food, drastic changes to current pest and weed control methods are unavoidable. IWM and IPM systems can provide a break in this cycle; when chemical pesticides are only used where other measures fail to sufficiently manage pest populations, there is less exposure among pest populations to chemical pesticides, reducing the rate of their genetic adaptation to become resistant (USDA, 2004). Additionally, as biological control agents like animals can be more selective in their control of pests, they have less of a severe effect on non-target and beneficial species, and may contribute less to the proliferation of pest species that can quickly become dominant after the total destruction of a farm's biodiversity following a large pesticide application (USDA, 2004)(UC Agriculture and Natural Resources).

Through implementing a combination of an IPM and IWM system on their land, farmers attempting to transition to an organic or semi-organic mode of farming can lessen or fully avoid the choice between effective pest control and abusing harmful agrochemicals. The use of animals such as the ones explored in this paper is essential to a properly balanced IPM or IWM system;

especially in systems integrating trees and shrubs in their agriculture, livestock grazing can also provide multiple benefits, such as biodiversity conservation and improved fertility of soil (Monteiro et al., 2022). The numerous benefits of an integrated or wholly organic animal-based pest and weed management system for the health of involved workers, as well as the safety of the environment, are strong arguments in support of moving away from a reliance on chemical pesticides. Further, the use of novel biological controls such as animals may act as a solution for controlling pests which have already become resistant to pesticides, as they present a novel threat (Roberts-McEwen et al., 2022). For Portuguese viticulture, with its typically regular rows of woody plants, sloping terrain and resulting risk of erosion, difficulty of maneuvering heavy machinery, rise of popularity in organic products, and increasing regulations on agrochemicals, this animal-based approach may present a very effective yet cost-efficient, attractive solution for farmers. The goal of this paper is to discuss current efforts at animal-based pest and weed control systems being explored specifically in Portuguese viticulture, as well as more general agricultural examples from around the world, and to analyze the potential for expanding these efforts on the global scale.

1. Research Question and Rationale

Through a review of an array of academic literature on biological control of pests and weeds in agriculture and on the current financial and environmental costs of chemical pesticides, this study explores the benefits, advantages and disadvantages of different animals for either insect or weed control in Portuguese viticulture. This literature review is supported by information from field visits to various vineyards throughout the Alentejo and Douro Valley wine-producing regions of Portugal and to farms in the Alentejo and Extremadura regions of Spain and Portugal. Finally, this study includes an interview with staff members from Casa Clara

vineyard and the Herdade do Freixo do Meio project in the Alentejo region. This study aims to make this information readily available to, and establish a set of recommendations for, grape farmers for the adoption of animal-based pest and weed control in their vineyards.

This study examines the potential of grazing animals, and more specifically sheep, as a partial or full replacement for weed control with chemical herbicides. The potential options for the procurement of animals and implementation by farmers as well as the potential associated costs, as compared to typical chemical herbicides, are also explored in this study. Together with grazing animals, the potential of insectivorous animals of various types, more specifically birds, bats, and ladybird beetles will be assessed as an option for controlling insect pests in vineyards. The financial and labor costs of both IWM and IPM approaches, including their implementation and upkeep, will be assessed, as well as a qualitative analysis of their effectiveness and comparison with the financial, environmental, and human health costs of chemical insecticides. Finally, the study establishes a set of recommendations for potential animals that could be employed in insect and weed management based on each animals' characteristics and needs, and depending on a set of vineyard characteristics. Drawing on information and examples from around the world and various forms of agriculture, this study primarily focuses on Portugal's viticulture as a site for potential integration of animals into weed and insect pest management.

The Alentejo and Douro Valley regions of Portugal are extremely rich in vineyards and wineries (de Almeida Costa et al., 2021). They are also home to numerous species of indigenous and even threatened insectivorous bats and birds, as well as long-standing traditional shepherding practices and silvopasture, and therefore have high availability of animal species that could be effectively put to work in managing weeds and insect pests (Tibério et al., 2014). Increasing pest resistance to chemical herbicides and insecticides poses a significant threat to the

present and future security of agriculture; the development of resistant “superpests” is no longer a future possibility but a growing and increasingly dangerous reality (Benbrook, 2012). Today, more than 600 pest species worldwide have already developed some level of resistance to chemical pesticides (Pesticide Environmental Stewardship). This problem shows no sign of stopping on its own; as genetic modification has allowed for the development of more pesticide-resistant crops, global use of pesticides in agriculture has increased along with them, fighting the immediate threat of resistant pests without actually addressing their root cause (Benbrook, 2012).

Additionally, as pesticide use only continues to increase worldwide, the negative impacts of toxic agrochemicals on humans, ecosystems, and land quality will only continue to rise as well. As vineyards are mostly intensive monocultures and frequently require intense pest and weed control, they offer an excellent opportunity to explore alternative pest management methods such as animal-based biological control. As Portuguese vineyards explore alternative methods of pest management, the increased implementation and use of animals as part of an integrated management system presents a financially, ecologically, and socially beneficial solution and is simultaneously very feasible and functionally appropriate in their geographic, agricultural and cultural context.

2. Methods and Materials

The results and conclusions of this study were obtained through a qualitative analysis based on in-depth readings of academic reports and relevant information on several different species of animals currently being used and/or studied for their potential for use in biological control of agricultural pests and weeds, obtained from websites of various academic and government institutions. The qualitative analysis took into account the advantages and

disadvantages associated with each species being explored as compared with agrochemical pesticides, for further discussion in terms of the ideal strategy for their application. The research herein is supplemented by information from news articles, websites of local vineyards, two ethical, structured interviews with members of the Casa Clara and Herdade do Freixo do Meio vineyard staff, and personal observations from field visits to the Extremadura, Alentejo, and Douro Valley regions of Portugal and Spain. The results are split into sections separated by which type of animal is being discussed and culminate in a table of advantages and disadvantages associated with the use of each animal in agricultural contexts.

3.1 Data Collection

Academic reports and relevant information for this project were found primarily through Google searches for information on the use of the various animals discussed herein in relation to agriculture, integrated pest management, Portugal, viticulture, vineyards, and insect or weed control. Information was also collected using Google on current global pesticide uses, current costs of pesticides in agriculture, environmental and health effects of pesticide use, “superpests”, and pesticide resistance. Additional information and academic articles were found through Google Scholar and through the reference lists of other articles, as well as exploring any websites connected to the articles. This information was supplemented by information from websites connected to government institutions such as the European Union and United States Department of Agriculture, or academic institutions such as universities and research institutions.

Finally, topical supplemental information was collected from news articles from reliable publications such as the New York Times, related NGO webpages, and articles from local publications related to sustainability, wine, and agriculture. Additional background familiarity with the topic of study was established through site visits to local vineyards in the Douro Valley

and Alentejo regions of Portugal as well as farms in the Alentejo and Extremadura regions of Portugal and Spain. For each animal assessed as an option for biological control in this study, case studies of examples of biological control from around the world were carefully selected and analyzed, and connected to the context of Portugal through supplemental information obtained through interviews with two Portuguese vineyards, as summarized in Figure 1 below:

Case Study	**Location**	**Animal of Study**
Ecological and economic benefits of integrating sheep into viticulture production (Niles et al., 2017)	Marlborough, New Zealand	Sheep (*weed management*)
SheepIT, an E-Shepherd System for Weed Control in Vineyards: Experimental Results and Lessons Learned (Gonçalves et al., 2021)	Viseu, Portugal	Sheep (*weed management*)
Pest control services provided by bats in vineyard landscapes (Charbonnier et al., 2020)	Bordeaux, France; Burgundy, France	Bats (*insect pest management*)
Pest consumption in a vineyard system by the lesser horseshoe bat (Rhinolophus hipposideros) (Baroja et al., 2019)	Southwestern Europe	Bats (*insect pest management*)
The use of cavity-nesting wild birds as agents of biological control in vineyards of Central Chile (Olmos-Maya et al., 2022)	Central Chile	Birds (*insect pest management*)
Avian pest control in vineyards is driven by interactions between bird functional diversity and landscape heterogeneity (Barbaro et al., 2017)	Southwestern France	Birds (*insect pest management*)
Uncovering the economic value of natural enemies and true costs of chemical insecticides to cotton farmers in China (Huang et al., 2018)	North China Plain, China	Ladybird beetles (*insect pest management*)
Exotic ladybirds for biological control of herbivorous insects – a review (Rondoni et al., 2020)	Various; USA, Canada, Chile, Europe	Ladybird beetles (*insect pest management*)

Figure 1: Table of Case Studies

Further, the locations of each of the sites assessed in the case studies in a global context can be understood from the following figure, with each animal being represented by its icon. Figure 2 displays a global map for broad context, while Figure 3 displays a focused map on Southwestern Europe to better display overlapping icons, as there were several case studies conducted in regions of close proximity, and this could not be adequately represented in Figure 2, due to limitations related to the application.

Figure 2: Visualization of Case Study Locations (Global)

Figure 3: Visualization of Case Study Locations (Focused)

3.2 Interviews and Interview Ethics

Interviews for this project were carried out over video call using Zoom in a mostly structured format, with specific questions being predetermined and asked of participants, but with space made for participants to speak about additional topics they considered relevant, where appropriate. Questions were previously reviewed by advisors to ensure their effectiveness, appropriateness, and scope. Interviewees were contacted through Email, and were initially given a description of the project and background information, as well as a timeline for the project and a list of questions to be asked of them prior to the interview. Participants were offered a choice as to which language the interview would be conducted in between English, Spanish and Portuguese based on their level of comfort; following this model, both interviews were conducted in Portuguese. Participants gave consent for the interview to be recorded, and were consulted before any shared information, whether personal or topical, was published in the study. Any translations of interview materials collected in Portuguese were conducted with the supervision and guidance of at least one native speaker in the original language with additionally very high proficiency in English, with help from the project advisor. Interviews were attended

additionally by the project advisor for assistance with any translations or communication errors and for additional note taking and interview depth. All interviews for this study were conducted ethically, with no questions asked about personal or sensitive information, and with adequate information and consent given during the interview process and with consent given to record and store interviews for use in the project. Interviewees reserved the right to decline being recorded, and to not answer any questions they felt uncomfortable responding to as well as to have any quotes omitted from the final paper, as checked for by a communication to the interviewees containing their quoted information prior to the completion of the study. The final study was shared with the interviewees once completed. Notes or recordings from the interview were kept on a password protected device belonging to the researcher or on the researcher's password protected Google Drive account.

3.3 Site Visits

Site visits were carried out as part of academic excursions with the School for International Training, supervised and led by Academic Director Cátia Magro and Program Coordinator Joana Dionisio. Visits were made to the Esporão vineyard and olive grove in Alentejo, and to the Quinta do Bomfim vineyard in the Douro Valley. Visits were also made to two farms where goats and sheep are reared, the first to the Quesería Artesana Carrasco goat farm in the Extremadura region of Spain and the second to a personal farm belonging to one of the program professors, Catarina Roseta-Palma, in Mértola, in the Alentejo region of Portugal. These visits involved a tour of the grounds and some processing facilities, a presentation on the history and operations of the farms and vineyards, and ample opportunities to observe and ask questions about the operations of the farms, such as the processing of grapes and olives, tastings of wine, olive oils, and cheeses, and the collection of milk from and the herding of goats.

Through presentations and speaking with guides, information was shared on various methods used in each of the farms and vineyards that related to the managing of weeds, pests, crops, and animals as part of their operations. These visits not only inspired the topic choice for this study but also informed the research and research questions explored herein.

3.4 Creating a Set of Recommendations

The results of this project culminated in a set of recommendations for the agricultural and ecological contexts in which each of the animal species in question is ideally suited, discussing the advantages and disadvantages associated with each species, as well as recommendations for potential implementation of each species as based on examples from the literature review and/or interviews. This set of advantages and disadvantages is represented in the form of a table. For each species, information was collected on the difficulty associated with their implementation and upkeep, the benefits of their integration into pest and weed management, potential strategies that could be employed to successfully acquire or implement the species, and potential challenges or important considerations that could arise as a result of their implementation on a farm. This information was then organized into a table that can be consulted by farmers for identifying strategies for biological control suitable to their own farms.

3.5 Creation of Images and Figures

The images used in the figures of this study, including the icons used in Figures 2 and 3 as well as the chart in Figure 4, were made using Adobe Photoshop. Figures 2 and 3, which involved the creation of maps, were made using the Google My Map application. Locations of case studies were approximated using the application, and icons created by the researcher in Adobe Photoshop were ascribed to each location to denote which animal was being examined in

each study. For specific cities, such as “Marlborough, New Zealand” or “Viseu, Portugal”, the Google application was allowed to set the location of the icon. For locations that were more general, such as whole countries, as was the case with “USA”, “Canada”, and “Chile, the names of the countries were typed into the Google application and placed in locations approximated by Google. For regions such as “the North China Plain” or “Southwestern Europe”, the researcher chose locations in the approximate centers of these regions for the icons, with the assistance of the Google application by googling specific cities located within those regions.

3. Results and Discussion

4.1 Integrated Crop and Livestock Systems and Sheep as Weed Control Agents

The use of sheep as biological control agents for weeding in vineyards is an ancient and traditional practice, and functions as an environmentally friendly solution to weeds in agriculture, which have always been a major concern for farmers across history (Gonçalves et al., 2021). Grazing sheep in vineyards is one form of integration of livestock onto an agricultural plot, more generally referred to as an “integrated crop and livestock system”, or ICLS (Niles et al., 2017). ICLS is a land-sparing technique, which involves intensification of agricultural production on a small area of land; however, unlike some other land-sparing techniques, ICLS does not necessarily involve increased reliance on agrochemical biocides, synthetic fertilizers, or genetically modified crops (Niles et al., 2017). The potential benefits of ICLS for sustainability are numerous; successful executions of ICLS can result in higher yields, lower rates of pesticide and fertilizer use, reduced greenhouse gas emissions, and increased resistance to drought, making it a key strategy for addressing the issue of pesticide reliance (Niles et al., 2017).

While ICLS was common across history, as agricultural systems grew more technologically advanced and specialized, eventually animals, crops, and pasture became less integrated and eventually fully separate in most cases (Niles et al., 2017). Most current research into ICLS has centered on the grazing of cattle in farmland; however, recent efforts to explore and reintegrate this technique have focused on many different options within the ICLS spectrum. These efforts include integration of crops and animals on farms, but also have manifested in local exchanges beyond and between specialized farms of crop and livestock products, such as the renting or lending of sheep from specialized sheep farms to vineyards for grazing and weed control (Niles et al., 2017).

4.1.1 Integration of Sheep into Vineyard Weed Control - Case Study

New Zealand, the world's 15th largest wine producer, produces 75% of its wine in its Marlborough region, located in the northeastern tip of the South Island (Niles et al., 2017). As viticulture in the area has expanded, 95% of all of the land that has been set aside for new vineyards has come from repurposed pastureland, previously used for grazing livestock (Niles et al., 2017). As a result, an increase in several agricultural inputs has been necessary, such as water use for irrigating crops and herbicides for weed control. This increase in herbicide use has led to harms for the local ecosystem and surrounding communities, and an increased presence of herbicide-resistant grasses and weeds; in fact, rye grass resistant to glyphosate, glufosinate, and amitrole, New Zealand's three most commonly used herbicides, is the first reported weed species confirmed to have developed multiple resistances (Niles et al., 2017). This new introduction of increased herbicides has led researchers and farmers to explore further the integration of sheep into vineyard weed control in the region, and the 2017 New Zealand case study in question

explores the circumstances and strategies involved in the actual integration of sheep, and the perceived costs and benefits they reported following their integration (Niles et al., 2017).

The researchers in the New Zealand study recorded that efforts for integration of sheep by grape farmers in their region of study are primarily carried out during the winter, the period in which vines are dormant, to graze the sheep on vegetation between rows (Niles et al., 2017). Typically, the use of sheep grazing in vineyards is restricted to this time, as most farmers have concerns over the risk of sheep eating or damaging grapes or grape leaves (Niles et al., 2017). However, the researchers did explore integration on short time intervals in which sheep ate leaves from vines to "open up the grape canopy" (Niles et al., 2017). Alternatively, the researchers recorded information on potential year-round integration of sheep by training or fencing sheep to prevent their consumption of the grape leaves, or by using Babydoll sheep, a smaller breed of sheep that cannot reach grape leaves and grapes (Niles et al., 2017). Additionally, they recorded some farmers integrating sheep into the disposal of byproducts such as feeding them grape pomace, or the solids left over from pressing the grapes, following harvests (Niles et al., 2017).

The actual challenge of acquiring sheep was another topic explored with the farmers, with a few different tactics being observed. While some farmers simply rented sheep from local specialized sheep farmers, other farmers took advantage of personal relationships with local sheep farmers in mutually beneficial exchanges where the sheep were able to graze and the grape vines were weeded simultaneously (Niles et al., 2017). Other farmers were recorded buying their own sheep, "fattening" them by grazing them on the weeds in their vineyards and selling them or their meat for profit afterwards (Niles et al., 2017). Another challenge the farmers described was the potential for sheep to damage or break vines, wires, or drip line irrigation; the farmers

explained that most of the breakage occurred when sheep were scared or had to be moved (Niles et al., 2017). However, one farmer stated that the damages of this sort only usually come up to about a half percent of the vines, making for a very small if not negligible portion; additionally, most farmers in the study didn't feel that it was in fact the sheep causing damage to the wires or irrigation lines, but rather rabbits, and that this problem may be partly remedied by burying the drip lines (Niles et al., 2017). Additional challenges were mentioned by the interviewed farmers, such as having to provide water for sheep and monitor them to prevent weed seed transport, construct fencing for their containment, control chemical use on the vineyard in periods prior to slaughter, and monitor the vines to ensure the safety of the grape leaves from overplucking (Niles et al., 2017). The farmers described it as a management issue, and explained that acquiring proper skills and knowledge of the nuances of ICLS is necessary prior to incorporating sheep in their operations (Niles, et al. 2017).

From a set of nine potential benefits, all of the fifteen farmers in the study reported observing at least one; all of the farmers reported benefits from reductions in need for mowing, and most (66%) reported benefits from reduced herbicide use (Niles et al., 2017). One farmer reported on herbicide use that "sheep are as good as herbicides", with the farmers suggesting that sheep were especially well-suited at targeting and removing deep-rooted and woody weeds that herbicides are often unable to kill (Niles et al., 2017). More specifically, sheep were especially good at targeting mallow, the most significant weed identified in the region (Niles et al., 2017). 27% of the farmers in the study reported benefits for reduced nitrogen use and a fifth of the farmers reported beneficial decreases in fuel use (Niles et al., 2017). 27% also reported that, due to the fact that sheep performed better than traditional mowers at cutting the grass to a shorter level at which solar radiation absorption by soil was improved, they even experienced improved

frost protection in their vineyards (Niles et al., 2017). These reports constitute a “quadruple win”, where farmers who reported economic benefits from incorporating sheep into their vineyard weed management experienced reduced mowing, herbicide use, and fuel and labor cost associated with these activities (Niles et al., 2017). According to the wineries involved in the study, the practice was beneficial for farmers whose sheep needed feed during the winter, and was beneficial for them in that the animals could improve nutrient content in soil through the passive application of manure (Niles et al., 2017).

4.1.2 Biological Control of Weeds in Vineyards- Notes from Freixo do Meio Estate

Herdade do Freixo do Meio is a project started in 2011 with the goal of re-establishing in their land an agro-silvo-pastoralist and self-sustenance model of land-use called the Montado, which pertained to the ancient populations of the land it is located on (Herdade do Freixo do Meio). During an interview with a staff member of Herdade do Freixo do Meio estate in the Alentejo region of Portugal, information was collected on the project’s various strategies, philosophies, challenges, and successes related to their use of biological control of pests, primarily focusing on their management of weeds in their operations related to agricultural production. Somewhat surprisingly, when confronted with the question of which methods the estate uses to “control insect pests and weeds”, the staff member being interviewed did not hesitate to correct the wording of the question by stating that Freixo do Meio does not make any attempt to “control” pests, but rather operate within the framework of an “organic and autonomous” ecological system, which does not aim to control nature. According to the staff member, Freixo do Meio does not aim to simply “control” the ecology of their farm, but rather aims to understand and work with it, integrating their operations into the existing ecosystem rather than trying to remake it. As the staff member explained, the project team believes vines

need very little, as they are a pioneer species, and thus they try to maintain the vineyard as a natural system, allowing for insects and weeds to exist as they naturally would. The project team at Freixo do Meio believes there is no need to "overcomplicate things" or to try to outdo nature with intensely automated or technological solutions; if it is clear that a human system is contaminating the environment, "greener and more natural" solutions must be found.

However, when asked about whether the project employs animals as biological control for weeds and insects, the staff member had many examples to share. For the management of weeds, the project does indeed graze sheep during the vines' dormant period to eat weeds; however, the staff member explained that "everything has two faces", and that while the sheep can be very effective for weeding, sheep can compact the soil, making them non-ideal. The use of big animals, according to the staff member, is more suited for when a vineyard has reached a "climax community", the stage of ecological succession when the system has reached a stable state and can handle such an impact. Instead, Freixo do Meio prefers chickens and other birds as agents for weed management, as they are more lightweight and do not compact the soil.

The staff member went on to explain that even outside the use of animals for weed management, the project team prefers to work with mechanical methods to chemical ones when possible. During the interview, reference was made to a machine developed by the Rodale Institute, a non-profit that supports research into organic farming, which simply flattens weeds, protecting the soil against erosion and restoring soil carbon, instead of pulling out the weeds and disturbing the soil. The staff member did explain that although animals can be effective, using a machine that is designed to work in a specific purpose and location may be more effective than animals that aren't adapted to a system; however, using wild animals may be more effective than domestic ones, as they don't need to be artificially brought in or fed.

4.2 Pesticide Resistance and Biological Control of Insect Pests by Insectivorous Predators

Beneficial insects, birds, and bats have long been useful agents in the control of insect pests in agriculture worldwide, both from local, natural predation of insect pests and artificial introduction by farmers for biological control, with some introductions of non-native biological control agents such as exotic ladybugs being employed since the late 19th century (Rondoni et al., 2020). Similarly to chemical herbicides, chemical insecticides have harmful impacts on human and environmental health, and their increased use has led to increased pesticide resistance in insect pest populations worldwide (NIH)(Pesticide Environmental Stewardship). However, somewhat different from chemical herbicides used on weeds, chemical insecticides have the added harm of destroying beneficial non-target species such as pollinators and natural predators (Pesticide Environmental Stewardship). This means that with abuse of chemical insecticides, not only do pest populations grow more resistant, but other preexisting natural sources of pest control are frequently damaged or destroyed, making farmers even more reliant on chemical insecticides to manage pests (Pesticide Environmental Stewardship). Currently and historically, a variety of animals have been essential agents in the fight against insect pests in agriculture, and as the harms of chemical pesticides become more and more known, the importance of biological control and IPM systems becomes more and more apparent (Pesticide Environmental Stewardship). Especially in vineyards, where land and habitats are usually severely altered and biodiversity of local insectivore species is frequently significantly reduced, there is both a need and an opportunity to not only improve the habitat and biodiversity of local ecosystems through the introduction and facilitation of local insectivore populations, but to exercise greater control over insect pests without over-reliance on chemical insecticides (Barbaro et al., 2017). This study

examines case studies on three main types of insectivorous biological control agents: birds, bats, and insects, more specifically ladybird beetles.

4.2.1 Ladybird Beetles in Agricultural Biological Control - Case Study

Exotic ladybird beetles, or ladybugs, have been used across the planet in biological control of agricultural insect pests since the late 19th century, being bought, sold, and released by farmers to control populations of arthropods, and especially aphids, which prey on agricultural crops (Rondoni et al., 2020). While ladybird beetles have proven extremely effective at controlling aphid populations in agriculture, they have also shown a high capacity for spreading out from the initial site of introduction and establishing local populations of exotic species, at times competing with or replacing indigenous species of ladybirds (Rondoni et al., 2020). According to one study on the effectiveness of ladybirds as biological control agents, of the 23 species of ladybird released in Europe, nine of them were exotic in origin; while different species vary in efficacy at controlling insect pest populations, some species are especially effective, with *Harmonia axyridis* even being recorded as "completely controlling" some aphid species in the area of its release (Rondoni et al., 2020). However, while the release of ladybird beetles for biological control was especially common during the majority of the 20th century, new understandings of their impacts on non-target local predators and their capacity for dispersal brought about new hesitations and restrictions on ladybird releases (Rondoni et al., 2020). As ladybirds are released in high numbers, they tend to quickly disperse into surrounding habitats in order to avoid competition for prey and cannibalism by other ladybirds; efforts have been made in different populations in order to prevent this phenomenon and the subsequent effects on local ecosystems with notable success, such as using flightless strains of ladybird species, or using semiochemical lures to attract and keep ladybirds close to crops (Rondoni et al., 2020).

Currently, the European and Mediterranean Plant Protection Organization (EPPO) lists eight exotic species of ladybirds to Europe as successful "augmentative biocontrol" agents, where native or exotic species are continually released as natural enemies to pests; these species have shown no negative environmental effects in at least five years of use in EPPO countries, and have been successful at fighting pest species (Rondoni et al., 2020). However, due to many ladybirds' natures as generalist predators, releases of ladybirds have slowed in the last two decades due to new national regulations requiring risk assessments for their release, which acts as a deterrent for many farmers (Rondoni et al., 2020). Because *H. axyridis* has been recorded spreading to areas and countries other than its location of introduction and competing with local native species, there is reason for concern that the negative ecological impacts of introduction of certain exotic species may outweigh the benefits for biological control. However, some studies find that some species have the capacity to be released with high benefits for biological control and relatively low or near-negligible effects on existing ecosystems, especially when combined with measures such as genetic modification for flightless strains or the use of semiochemical lures or attractive plants to maintain the ladybirds with a specified range (Rondoni et al., 2020).

4.2.2 Insectivorous Bats as Vineyard Pest Control - Case Studies

According to a 2019 study of bats' consumption of insect pests in vineyard systems in Southwestern Europe, the global loss of crops damaged by herbivorous arthropods is estimated between 10-26% (Baroja et al., 2019). According to another study from 2020, global crop yield losses due to pests may be as high as 30-40% (Charbonnier et al., 2020). As global temperatures rise due to climate change, there is evidence to suggest insect pests may benefit, resulting in even higher losses in crop yield in the coming years (Baroja et al., 2019). Of all natural enemies used in biological control of agricultural pests, bats are considered among the most effective and

efficient animals for pest control, limiting damage to crops or yield losses due to pest insects (Charbonnier et al., 2020). Bats, known to be especially successful insect predators, may consume over 70% of their body mass daily in arthropods; this hunger for insects of all types, diurnal or nocturnal, flying or non-flying, and of different sizes, only increases in warmer temperatures (Baroja et al., 2019). The lesser horseshoe bat, which has been commonly reported in vineyard systems in Southwestern Europe, employs a variety of hunting techniques, making it especially good at catching a range of insect pests, including moths and small insects especially harmful in vineyard systems (Baroja et al., 2019).

According to the 2020 study, some species of bats found in Southwestern Europe are known to change their hunting behavior and temporality depending on the temporal changes in activity and availability of prey species such as moths (Charbonnier et al., 2020). This study also confirmed that certain species of pests most common in vineyards, including three especially harmful and common species of grapevine moths, are indeed part of the predatory diet of at least ten species of bats, making bats an excellent choice for the control of vineyard pests. Additionally, according to the 2019 study, the pest species consumed by bats also change by season, making bats an adaptable biological control agent for changes in pests year round (Baroja et al., 2019).

4.2.3 Insectivorous Bats as Vineyard Pest Control - Notes from Casa Clara Vineyard

During an interview with a staff member of Casa Clara vineyard in the Alentejo wine region of Portugal, information was collected on the vineyard's efforts concerning the use of bats for pest control. As reported by the staff member, while the vineyard does not solely rely on bats for insect pest management, they do actively create conditions for the proliferation of bats through the construction of bat boxes, which the staff member claimed is done without much

difficulty using “simple” materials. When asked whether the staff member thought the bats were an effective form of insect control for the vineyard, the answer was given that because bats have no negative effects on production, that “it is always advantageous”; according to this perspective, the simplicity of the efforts to accommodate bats on the vineyard can only bring positive effects, and therefore the staff member felt no additional reasons were needed for the carrying out of the vineyard’s efforts. While the vineyard does not currently do much monitoring of the effects bats have had on its pest populations, they are in collaboration with local researchers and agricultural consultants to see how their efforts can be improved, and have made their land available to scientists to develop sustainable pest control solutions.

4.2.4 Insectivorous Birds as Vineyard Pest Control - Case Studies

According to a 2022 study done of birds as biological control agents in Chilean vineyards, which share a similar Mediterranean climate to many regions of Southern Europe, insectivorous birds are very effective predators of insects that harm grape vines (Olmos-Maya et al., 2022). Insectivorous birds consume annually up to 500 million tons in arthropod insects worldwide, of which an estimated 7% are consumed in agricultural settings; however, one of the main threats to wild bird populations worldwide are the severe changes to land use and chemical pesticide use that come with agricultural intensification (Olmos-Maya et al., 2022). According to one 2016 study on pest control by birds, 50% of birds in farmland predominantly feed on insects, and 75% consume insects and invertebrates at least some of the time (Barbaro et al., 2016).

Species richness of insectivorous birds is usually lower in agroecosystems than in forested settings, as modern farming practices not only reduce the number of viable nesting sites of certain bird species, but also can constitute a barrier to movement and migration of these birds (Olmos-Maya et al., 2022). In an effort to find a solution to this problem, one 2022 study found

that through the establishment of man-made nest boxes in and around vineyards, increases were noted in the population of pre-existing, local insectivorous birds, while increases in frugivorous bird populations were not; this increase in insectivorous bird populations subsequently led to a significant increase in prey removal of harmful insects such as grapevine moths and arthropods by the birds from vineyards (Olmos-Maya et al., 2022). Following the study, it was noted that pest species larvae removal was indeed higher in plots where nest boxes had been set up than in control plots, suggesting that the introduction of nest boxes did have measurable positive effects on biological control of pests by the birds (Olmos-Maya et al., 2022). The study also noted that because only 20.5% of the nest boxes were occupied by bird species that only catch insects while flying and did not target the study's sentinels used to measure insect catches, the results of the study may have even underestimated the role of the birds in flying arthropod consumption (Olmos-Maya et al., 2022).

4.2.5 Biological Control of Weeds in Vineyards- Notes from Freixo do Meio Estate

The interview with Herdade do Freixo do Meio also yielded interesting notes on the use of biological control for management of pest insects, but also for the management of other animal pests such as birds. According to the interviewed staff member, the chickens and birds used in weed control are also effective in controlling insect pests; additionally, they prefer to rely on wild animals to domesticated ones when possible, as they don't require regular feeding, are better adapted to the local ecosystem, and don't need to be artificially introduced. In addition to the control of insect pests however, the staff member also explained that domesticated cats are allowed to roam throughout the fields, reducing the threat of frugivorous birds damaging or eating the grapes or other products; even the cats' presence in the fields are deterrence enough to scare away birds, making for a passive, low-impact, and effective form of pest control.

4.3 Implications of this Research for Portugal

The spatial expansion of intensified agriculture has resulted in some of the most severe threats to global biodiversity, spelling dramatic consequences for bordering ecosystems as well as native species, especially from habitat loss (Olmos-Maya et al., 2022). As farmers worldwide continue to use more and more chemical pesticides annually, these harms to global ecosystems only increase, harming not only the pest species they target but also many of the beneficial secondary and tertiary consumers that may predate on these pests naturally (USDA, 2004). With the overreliance on chemical pesticides by farmers only feeding the growing threat of pesticide resistance and superpests, the importance of exploring and implementing other methods of pest control, such as biological control through the use of natural enemies, has only grown more apparent (Benbrook, 2012). As wine production frequently requires intense control over land and a heavy use of agricultural controls over pests such as weeds, insects, and other "species of economic importance" as they are sometimes described, grape farmers have been some of the most recent and willing actors to take action towards implementing more sustainable pest and weed control (Gonçalves et al., 2021)(Rondoni et al., 2020).

However, it is this precise control and capacity for monitoring of their land that makes vineyards an excellent opportunity for case studies and innovation in biological control and IPM efforts, and Portugal is no exception. Portugal's rich wine growing history, various wine regions of note, and its widespread traditions in silvopasture and sheep and goat husbandry, as well as its recent efforts for sustainability following trends across the EU, additionally make it an excellent candidate for leadership in efforts to reduce agricultural dependence on agrochemical toxins (de Almeida Costa et al., 2021)(Tibério et al., 2014). In fact, in the last two decades, pesticide use in Portugal has actually decreased, with more and more farmers making efforts to comply with new

EU agricultural regulations on pesticide use, receiving financial incentives from both government and private actors to reduce their pesticide use and adopt measures such as IPM or organic farming (OF)(Amaro da Costa et al., 2017). As knowledge of the harms of chemical pesticides becomes more widespread and regulations and financial incentives for OF methods grow in scope, Portuguese farmers will need to adopt strategies to keep up, and due to the high availability of sheep and other biological control agents in Portugal, more farmers should begin to explore the ways animal agents can be employed in IPM and IWM systems on their land.

4.3.1 Integration of Biological Control Agents into Portuguese Vineyards

Fortunately, many of Portugal's established wine regions, such as the Douro Valley and Alentejo, overlap or are in near proximity to areas where animal husbandry and sheep farming are commonplace (de Almeida Costa et al., 2021)(Tibério et al., 2014). This sort of technique is already being employed in certain vineyards in Alentejo, as reported during field visits to a number of Portuguese vineyards. With individual producers taking initiative or with government facilitation of inter-farm cooperation, it is certainly not outside the realm of possibility for wine and sheep farmers in the various areas of overlap to engage in mutually beneficial animal exchanges for the implementation of grazing as part of an IWM system, as has been observed in New Zealand (Niles et al., 2017). With a proper management system of animals that takes into account seasonality, use of breeds of sheep that may be more well suited to vineyard grazing (such as miniature or short-legged breeds), or technological advancements, the use of sheep in IWM may be used to great effect in Portugal (Niles et al., 2017)(Conrad et al. 2022).

Recent advances in technology may prove helpful to improving the effectiveness of sheep grazing on weeds in vineyards. According to one 2021 study done in the Dão wine producing region of Portugal, researchers explored SheepIT, an automatic shepherding technology being

designed to improve the efficiency of sheep grazing as a control for weeds in vineyards through monitoring and posture conditioning of sheep with the use of a smart collar (Gonçalves et al., 2021). While not all farmers currently have access to this sort of technology, and it may not be ideally suited to every location, advances like this suggest future improvements to current biological control methods, and may aid in its increased adoption by farmers looking into organic forms of weed management.

As confirmed by the interview carried out with Casa Clara staff, the introduction of bats into a vineyard can actually be quite simple, with the creation of bat boxes, set up at various points in the vineyard, being enough to attract bat populations and give them a habitat. Similarly to bats, the introduction of birds can be rather passive, with either the setting up of nest boxes, perches, or varied rural structures such as rock walls, thatches, and other places for birds to set up nests (Barbaro et al., 2016). If farmers are to integrate birds or bats into their pest management systems, special attention should be given to the birds and bats being of indigenous varieties when possible to avoid competition of exotic species with native ones; fortunately, as confirmed by the case study from Chile, the construction of nest boxes in a vineyard will not significantly change the species that occupy a region but rather will allow for the greater presence of existing species, which means the indigenous varieties need not be altered by efforts to create additional habitats (Olmos-Maya et al., 2022). Seeing as Southern Europe indeed has numerous native insectivorous bird and bat species, the attraction of at least some of these species to habitat boxes should not present a significant challenge (Charbonnier et al., 2016). However, as mentioned by the staff member from Casa Clara, because these insectivorous species do not cause any harm to the farmers or their crops, there really is no harm in introducing them regardless of benefits, especially when it requires very little labor and/or materials.

Even more so than with birds and bats, ladybird species for are a well-studied, time-tested and adaptable agent for the biological control of insect pests; because of the simple nature of their integration via single or multiple releases, and because they are relatively simple to buy, transport, and release, ladybirds are an affordable and effective option for pest control (Rondoni et al., 2020). Additionally, there is myriad research suggesting that certain ladybird species can be introduced to the benefit of farmers without the danger of becoming a serious ecological threat, with eight exotic ladybirds being recognized by the EPPO as being effective agents for pest control without causing negative effects on the local ecosystem (Rondoni et al., 2020). This may have larger financial implications than commonly believed; according to research from one 2018 study done on cotton plantations in China, doubling the current average density of 13,500 ladybirds per hectare could increase farmers' income by nearly 94 USD per hectare, even with current pesticide use (Huang et al., 2018). Additionally, decreasing insecticide use in farms could actually be beneficial as well; by cutting current excesses in insecticide use by 75 percent, the marginal value of the ladybird beetles per hectare would increasingly rise over two and a half times, from 6.98 to 17.6 USD annually (Huang et al., 2018). This sort of financial benefit is significant, and could be essential to the adoption of biological control by not only small farmers, but also by large-scale, industrial producers such as the ones examined in the Chinese study.

4.3.2 Limitations of Biological Control in Vineyards

While sheep may be beneficial agents for biological control of weeds, it is important to acknowledge that the introduction of sheep, as with most other biological control agents, requires an often significant amount of labor for the management of the sheep, such as proper rotation, transportation, monitoring and caring for sheep health, construction and maintenance of appropriate fencing and protection from predators (Monteiro et al., 2021). Biological control

using sheep is also typically reserved to certain parts of the year where the grape vines are dormant or the trees are not fruiting, as many farmers have concerns over sheep damaging or eating leaves from the vines, however varying sources argue that this is not as serious of a concern as some farmers might believe (Niles et al., 2017). Additionally, farmers are constrained by their location, financial standing, the spatial composition of their farms, and their relationships with neighboring farms; while some farmers may be able to keep and use their own sheep and others may be able to rent or borrow sheep, these just may not be realistic options for some farmers, in which case farmers could potentially explore their options with private or government funding to support their efforts (Niles et al., 2017). In some cases, integrated systems are simply not as profitable due to their higher labor requirements and typically smaller size, forcing some farmers to choose between profits and sustainability (Niles et al., 2017).

In terms of controlling insects, the risks of a release of any ladybird species should be heavily assessed prior to its execution, which is already the case due to newer EU regulations (Rondoni et al., 2020). Exotic ladybirds especially have the well-studied capacity to spread beyond their site of release, and while this can be mediated through the use of varying scientific or management strategies, the possibility of damaging local ecosystems should be weighed against the potential benefits they might bring for biological control. If farmers intend to rely heavily on birds or bats for biological control, monitoring should be carried out to measure the effectiveness of these animals at managing pests, including how many birds or bat colonies or nests are in an area, what sorts of insects they are in fact consuming, and the general health of colonies or populations, all of which would require additional labor and knowledge, as is the case with all biological controls. Additionally, while insectivorous birds and bats are far easier to introduce due to the simplicity of setting up habitats and the fact that they don’t cause any threats

to productiveness, their presence does require added attention to the timing, intensity, and frequency of pesticide applications, similarly as with sheep, as their ingestion of chemical pesticides or herbicides may have very negative consequences on their health (Niles et al., 2017). The knowledge necessary to properly balance both systems is unfortunately just currently not available to many farmers, highlighting the need for better communication between the scientific and agricultural communities, as well as improved information campaigns from the EU and the private sector in their efforts to promote agricultural sustainability.

4.3.3 Obstacles to Implementing Biological Control - Notes from Freixo do Meio Interview

Biological control and sustainable pest control measures have clearly met their fair share of resistance from the global farming community for various reasons, whether commercial, financial, cultural, or structural. However, according to the staff member from Herdade do Freixo do Meio, the biggest obstacle is cultural; it's difficult to convince people that it works. When proponents of this kind of strategy say that "agricultural methods should be systematic and ecological as well as productive", it becomes a difficult point to sell. As put by the staff member, many consider agroecology and other forms of traditional agriculture as "returning to the cave", as if they are primitive and can't be as effective as modern methods. Freixo do Meio's team wants to bring credibility to agroecology; until more institutions and larger producers start to really embrace agroecology, the movement will remain small and dispersed, relying on a lot of outside funding to be effective, whether government, institutional, or private.

Even then, according to the staff member, the challenges of agroecology are not so much a problem for small farmers in some senses as they are for large ones, such as corporate industrial projects. Because corporate and other large sellers are heavily bound by the demand for a uniform and replicable product, they are more bound by the need to control every aspect of

production and recreate the same ecological conditions across space and time in their farms, restricting them from experimenting, and encouraging them to rely on specially designed tools like chemical pesticides and monocultures. Small producers, who likely sell more locally or do not have such a wide distribution plan, have more flexibility in the products they grow year to year, allowing them to overlook differences in the final product and lessening the pressure to exercise strict control over their land, opening their options with the agricultural strategies they employ. However, it is worth noting that while Freixo do Meio does produce grapes for commercial purposes, the majority of their revenue is not in fact from wine production but rather from the production of grape juices, and more importantly, from the sale of grape leaves for medicinal and other production, distinguishing them from other vineyards in the area.

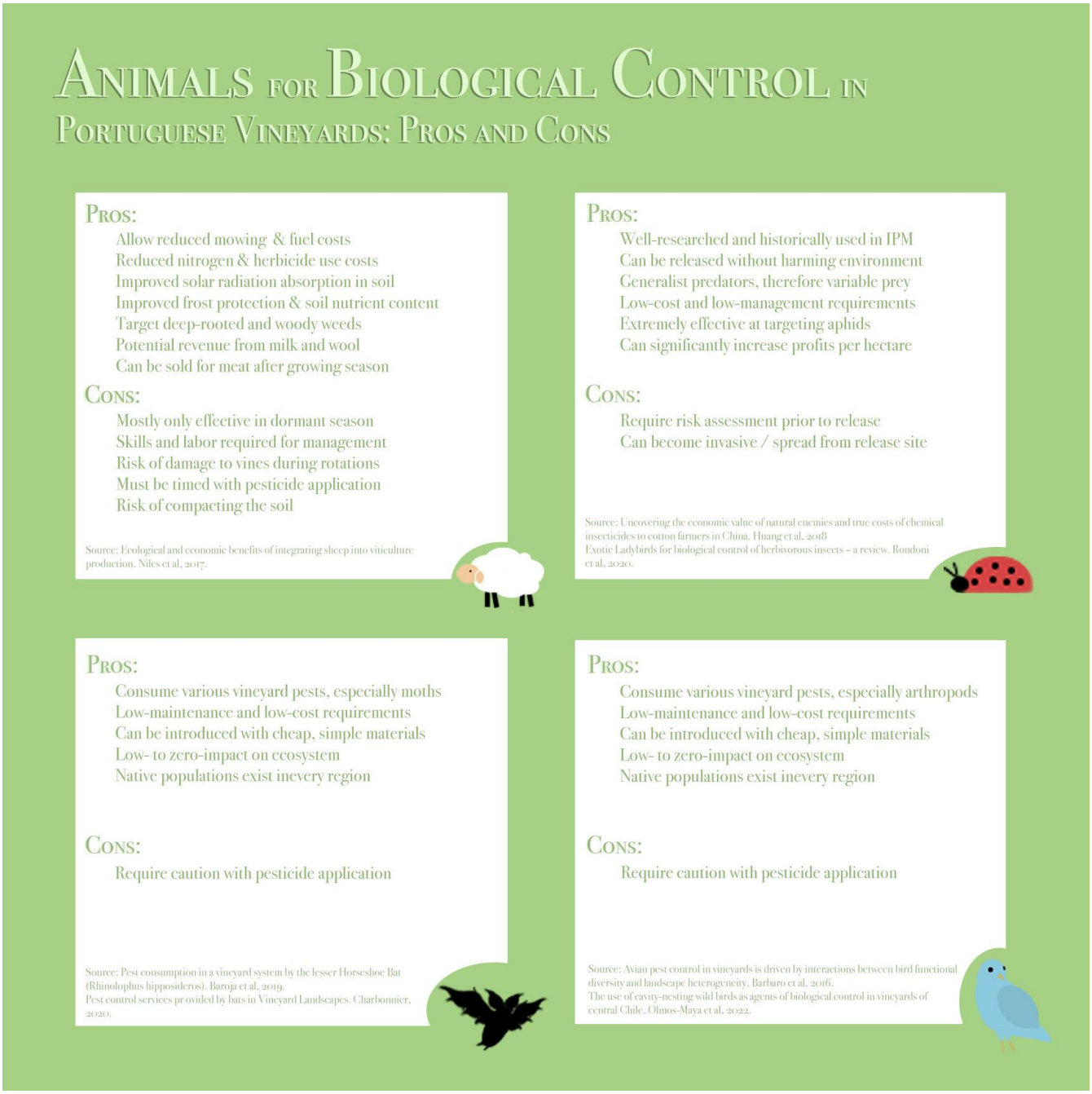

Figure 4: Animals for BC in Portuguese Vineyards: Pros and Cons

4. Conclusion

If ever doubts existed of the dangers of the overuse of chemical pesticides in agriculture, recent data on the current state of global pesticide use and its effects on the health of both the environment and of human populations such as the information discussed in this study have

surely dispelled any uncertainty. The research explored herein into the viability of biological control and the use of animals was carried out in numerous corners of the planet, on different forms of agriculture and using a variety of different animal agents; the results of this research show clear support for the effectiveness and possibility of an integrated system, if not a wholly pesticide-free system alone. With their frequent status as cultural heritage sites and large-scale monocultures, as well as their rigorous monitoring and control of their ecology, vineyards have an especially high potential to experiment with and benefit from an integrated pest management system with animals as central actors. While undeniable limitations exist for its adoption worldwide, and different strategies surely have varying levels of success in different financial, ecological, cultural, and agricultural contexts, a shift towards an integrated and less heavily chemical-dependent pest management system is the only viable long-term solution to the growing threat of pesticide resistance and the continued success of global agriculture. This study then suggests that the question of integrating animals as biological control agents into an integrated pest management system is, therefore, no longer one of whether it is possible or economically viable, but rather one of willingness by farmers to adapt and plan for a more sustainable, secure, and ecologically conscious future. This study was limited by a short time frame and is limited in its assessment of the quantitative financial costs and benefits of the strategies discussed and how they compare to those associated with pesticide use in vineyards. Additionally, this research does not adequately discuss the potential effects on living organisms of combining pesticide use on farms with biological control. Future research should explore the ways these two systems may interact and how animal agents may be affected by exposure to chemical pesticides in an IPM system.

5. References

Aktar, Md. W., Sengupta, D., & Chowdhury, A. (2009, March). *Impact of pesticides use in agriculture: Their benefits and Hazards*. Interdisciplinary toxicology. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2984095/#:~:text=Impact%20on%20environment,%2C%20and%20non%2Dtarget%20plants

Amaro da Costa, C., do Godinho, M., Santos, J. L., Mexia, A., & Amaro, P. (2017). Integrated Pest Management in Portugal: From policies to practices. *International Journal of Environment, Agriculture and Biotechnology*, *2*(5), 2524–2533. https://doi.org/10.22161/ijeab/2.5.33

Bale, J. S., van Lenteren, J. C., & Bigler, F. (2008, February 27). *Biological Control and Sustainable Food Production*. Philosophical transactions of the Royal Society of London. Series B, Biological sciences. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2610108/

Barbaro, L., Rusch, A., Muiruri, E. W., Gravellier, B., Thiery, D., & Castagneyrol, B. (2016). Avian pest control in vineyards is driven by interactions between bird functional diversity and landscape heterogeneity. *Journal of Applied Ecology*, *54*(2), 500–508. https://doi.org/10.1111/1365-2664.12740

Baroja, U., Garin, I., Aihartza, J., Arrizabalaga-Escudero, A., Vallejo, N., Aldasoro, M., & Goiti, U. (2019). Pest consumption in a vineyard system by the lesser Horseshoe Bat (Rhinolophus hipposideros). *PLOS ONE*, *14*(7). https://doi.org/10.1371/journal.pone.0219265

Benbrook, C. M. (2012). Impacts of genetically engineered crops on pesticide use in the U.S. -- the first sixteen years. *Environmental Sciences Europe*, *24*(1). https://doi.org/10.1186/2190-4715-24-24

Charbonnier, Y., Papura, D., Touzot, O., Rhouy, N., Sentenac, G., & Rusch, A. (2020). Pest control services pr ovided by bats in Vineyard Landscapes. *Agriculture, Ecosystems & Environment*, *306*, 107207. https://doi.org/10.1016/j.agee.2020.107207

Conrad, L., Hörl, J., Henke, M., Luick, R., & Schoof, N. (2022). Sheep in the vineyard: Suitability of different breeds and potential breeding objectives. *Animals*, *12*(19). https://doi.org/10.3390/ani12192575

de Almeida Costa, A. I., Marano-Marcolini, C., Malfeito-Ferreira, M., & Loureiro, V. (2021, April 29). *Historical wines of Portugal: The classification, Consumer Associations and Marketing Implications*. MDPI: Foods. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8146683/

Directorate-General for Agriculture and Rural Development. (2023, January 18). *Organic farming in the EU: A Decade of growth*. Agriculture and rural development. https://agriculture.ec.europa.eu/news/organic-farming-eu-decade-growth-2023-01-18_en#:~:text=By%20producing%20high%20quality%20food,food%20system%20for%20the%20EU.

European Commission. (n.d.). *Sustainable Development Goals*. International Partnerships. https://international-partnerships.ec.europa.eu/policies/sustainable-development-goals_en

European Union. (2023, October 10). Agriculture and Food System. European Environment Agency. https://www.eea.europa.eu/en/topics/in-depth/agriculture-and-food?activeTab=07e50b68-8bf2-4641-ba6b-eda1afd544be

Exposure to pesticides, herbicides, & Insecticides: Human Health Effects. The Institute for Functional Medicine. (2023, September 22). https://www.ifm.org/news-insights/exposure-pesticides-herbicides-insecticides-human-health-effects/

Food and Agriculture Organization of the United Nations. (n.d.). *Pesticides Use*. FAOSTAT. https://www.fao.org/faostat/en/#data/RP/visualize

Garthwaite, J. (2012, October 5). *Superweeds, superpests: The Legacy of Pesticides*. The New York Times. https://archive.nytimes.com/green.blogs.nytimes.com/2012/10/05/the-legacy-of-pesticides-superweeds-and-superpests/

Gonçalves, P., Nóbrega, L., Monteiro, A., Pedreiras, P., Rodrigues, P., & Esteves, F. (2021). Sheepit, an E-shepherd system for weed control in vineyards: Experimental results and lessons learned. *Animals*, *11*(9). https://doi.org/10.3390/ani11092625

Gunsolus, J. (n.d.). *Herbicide-resistant weeds*. Extension at the University of Minnesota. https://extension.umn.edu/herbicide-resistance-management/herbicide-resistant-weeds#:~:text=When%20an%20herbicide%20is%20applied,the%20herbicide%20(Figure%204).

Huang, J., Zhou, K., Zhang, W., Deng, X., van der Werf, W., Lu, Y., Wu, K., & Rosegrant, M. W. (2018). Uncovering the economic value of natural enemies and true costs of chemical insecticides to cotton farmers in China. *Environmental Research Letters*, *13*(6). https://doi.org/10.1088/1748-9326/aabfb0

Laboratório de Ornitologia. (n.d.). *Vineyard characteristics influence the potential of*

birds as allies in ... LabOr. https://www.labor.uevora.pt/en/vineyard-characteristics-influence-the-potential-of-birds-as-allies-in-pest-control/

Michigan State University. (n.d.). *How pesticide resistance develops*. MSU Extension. https://www.canr.msu.edu/grapes/integrated_pest_management/how-pesticide-resistance-develops#:~:text=With%20each%20pesticide%20application%2C%20those,that%20pesticide%20eventually%20becomes%20ineffective.

Monteiro, A., & Santos, S. (2022). Sustainable approach to weed management: The role of Precision Weed Management. *Agronomy*, *12*(1). https://doi.org/10.3390/agronomy12010118

Niles, M. T., Garrett, R. D., & Walsh, D. (2017). Ecological and economic benefits of integrating sheep into viticulture production. *Agronomy for Sustainable Development*, *38*(1). https://doi.org/10.1007/s13593-017-0478-y

Olmos-Moya, N., Díaz-Siefer, P., Pozo, R. A., Fontúrbel, F. E., Lavandero, B., Abades, S., & Celis-Diez, J. L. (2022). The use of cavity-nesting wild birds as agents of biological control in vineyards of central Chile. *Agriculture, Ecosystems & Environment*, *334*. https://doi.org/10.1016/j.agee.2022.107975

Popay, I., & Field, R. (1996). Grazing animals as weed control agents. *Weed Technology*, *10*(1), 217–231. https://doi.org/10.1017/s0890037x00045942

Roberts-McEwen, T. A., Deutsch, E. K., Mowery, M. A., & Grinsted, L. (2022). Group-living spider *cyrtophora citricola* as a potential novel biological control agent of the tomato pest *tuta absoluta*. *Insects*, *14*(1), 14–34. https://doi.org/10.3390/insects14010034

Rondoni, G., Borges, I., Collatz, J., Conti, E., Costamagna, A. C., Dumont, F., Evans, E. W., Grez, A. A., Howe, A. G., Lucas, E., Maisonhaute, J., Onofre Soares, A., Zaviezo, T., & Cock, M. J. W. (2020). Exotic Ladybirds for biological control of herbivorous insects – a review. *Entomologia Experimentalis et Applicata*, *169*(1), 6–27. https://doi.org/10.1111/eea.12963

Tiberio, M. L., & Diniz, F. (2014). Sheep and goat production in Portugal: A dynamic view. *Modern Economy*, *05*(06), 703–722. https://doi.org/10.4236/me.2014.56066

Understanding Resistance. Pesticide Environmental Stewardship. (n.d.). https://pesticidestewardship.org/resistance/understanding-resistance/

University of California Agriculture and Natural Resources. (n.d.). *Managing pesticide resistance*. UC IPM. https://ipm.ucanr.edu/agriculture/floriculture-and-ornamental-nurseries/managing-pesticide-r

esistance/#:~:text=Pesticide%20resistance%20can%20develop%20over,at%20the%20formerly%20effective%20rate

US Department of Agriculture. (2004, April). Integrated Pest Management (IPM) and Wildlife. https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=18487.wba

U.S. Department of Health and Human Services. (n.d.). *Pesticides*. National Institute of Environmental Health Sciences. https://www.niehs.nih.gov/health/topics/agents/pesticides/index.cfm

7. Appendix

7.1 Interview Questions

(Questions asked during the interview were worded in Portuguese. The questions below are the original questions, in English, initially sent to interviewees, and were faithfully translated during the interview to Portuguese once interviewees chose their preferred language.)

- *What is the current system in place for pest and weed control at this vineyard?*
- *Are there currently any animals or insects involved in the control of pests/weeds? Which are they, and why?*
    - *If there are, has this been a successful method?*
- *Do you have thoughts on the viability of animals as a pest/weed control method?*
    - *Do you think it depends on the climate and landscape? Does it work for viticulture?*
- *What are the challenges that come to mind when implementing such a system?*
    - *Is there a labor or financial constraint? Or problems surrounding UNESCO restrictions?*
- *Are you concerned by the possibility of superpests in the future? If you are, do you think this vineyard is contributing to a solution? Is there more other vineyards could do?*
- *If you're knowledgeable on the topic, do you think using animals might be able to remedy or slow down this problem?*

7.2 Interview Consent Forms

(Consent forms were delivered in Portuguese. The questions below are faithful translations.)

Please, choose an answer after each statement listed below.

1. A response of “YES” indicates that you understand the statement and are at least 18 years of age, and that you agree to participate. Indicating “NO” would result in your responses in this study not being used.

   (YES / NO)

2. I understand the potential risks associated with participating in this study. I also understand that while the researcher will maintain my responses confidential, communications over Email or Zoom are not secure.

   (YES / NO)

3. I am at least 18 years of age.

   (YES / NO)

4. I agree to this interview being recorded, stored, and used for research in this project. I agree to the use of quotes of my statements from this interview.

   (YES / NO)

5. I agree with the use of the name of (the vineyard) in the final study.

   (YES / NO)