Report

Kent Downs AONB Test and Trials viticulture research project No. 1 - Biodiversity, ecosystem services and sustainable viticulture

Prepared for : Vinescapes

By : Dr Mary Retallack

Date : 26 August 2020

TABLE OF CONTENTS

CHAPTER 1: OVERVIEW ... 10

Introduction ... 13
- Background ... 13
- Scope ... 13
- Brief ... 14
- Deliverables ... 14
- What was done? ... 14

CHAPTER 2: SETTING THE SCENE ... 15

The future for food, farming and the environment ... 15
- Farming for the future and environmental land management ... 15
- The Kent Downs Area of Outstanding Natural Beauty (AONB) ... 15

CHAPTER 3: LITERATURE REVIEW ... 18

Functional biodiversity ... 18
- Landscape simplification ... 18
- The role of ecosystem services ... 19
- Enhancing biodiversity ... 20

Arthropods ... 21
- Functional groups: pests ... 21
- Functional groups: predators ... 23

Higher order predators ... 23
- Predatory birds ... 23
- Insect eating mammals ... 23
- Reptiles ... 25

Insectary plants ... 26
- Native insectary habitat ... 26
- SNAP ... 26
- 'Random' versus directed approaches ... 26
- Introduced insectary species ... 26
- Screening and ranking candidate insectary species ... 27
- Location of insectary plantings ... 28
- Associations between predators and insectary plants ... 28
- Multi-species interactions ... 29
- Seasonal synchrony and overwintering ... 30
- Assumptions about native insectary ... 31
- International examples ... 32

CHAPTER 4: POTENTIAL CANDIDATE NATIVE PLANT SPECIES **35**
Background 35
Kent Downs AONB Vision 35
Overview 35
Context 35
Chalk grassland...36
Meadow grassland 36
Hedgerows 37
Habitat for endangered species 37
International insights on enhancing functional biodiversity 38
Advantages of native ground cover..38
Potential candidate native insectary plant species..39
CHAPTER 5: RECOMMENDATIONS LINKED TO PUBLIC GOODS **44**
ELM scheme 44
Recommendations linked to the public goods..44
Environmental steward programs..53
Sustainable Wines of Great Britain 53
Linking Environment And Farming (LEAF)...55
CHAPTER 6: BEST PRACTICE CASE STUDY FROM AUSTRALIA **56**
Australian native perennial tussock grasses and forbs 56
The Falkenberg Vineyard...56
Biodiversity 58
Cost and benefits 59
PhD research 61
EcoVineyards 62
Insights 63
CHAPTER 7: COSTS AND BENEFITS... **65**
Costs 65
Benefits 65
CHAPTER 8: BARRIERS TO ADOPTION.. **67**
Interview insights...67
Barriers to adoption 67
Drivers for success..67
General comments on ELM focus areas...68
Insights and opportunities 70
CHAPTER 9: RESEARCH GAPS **71**
Further research suggestions...71
CHAPTER 10: NEXT STEPS **72**
Field work 72

RESOURCES **74**
APPENDICES **75**
Appendix 1: Reported host plants of tortricid leafrollers 75
Appendix 2: Potential predatory arthropod species reported in the South Downs National Park 79
Appendix 3a: Native predatory bird species found in Kent and surrounds and their conservation status 83
Appendix 3b: Native insectivorous bird species found in Kent and surrounds and their conservation status 84
Appendix 3c: Native microbat species found in Kent and surrounds and their conservation status 86
Appendix 3d: Native reptile species found in Kent and surrounds and their conservation status 87
Appendix 4: UK vineyard pesticide application and potential pesticide toxicity to predators 75
REFERENCES **91**

LIST OF TABLES

Table 1. Reported associations between insectary plants and predatory arthropods in the UK 29
Table 2. Potential native plants to trial in the UK (pending in-field suitability assessment) 40
Table 3. Demonstrating public goods links to ensuring clean and plentiful water 45
Table 4. Demonstrating public goods links to ensuring clean air...47
Table 5. Demonstrating public goods inc protection from and mitigation of environmental hazards......48
Table 6. Demonstrating public goods links to mitigation of and adaptation to climate change...............49
Table 7. Demonstrating public goods links to thriving plants and wildlife 50
Table 8. Demonstrating public goods links to beauty, heritage and engagement 52
Table 9. Links between Sustainable Wines of GB and functional biodiversity enhancement.................53
Table 10. Cost and benefit of establishing native wallaby grasses in the mid-row................................60
Table 11. Cost and benefit of establishing a 100m long shelterbelt (4m or 10m wide) over 20 years ...66
Table 12. Capacity for functional biodiversity enhancement using native insectary plants. 73

Appendices

Table 1. Reported host plants of grape LBAM, *Epiphyas postvittana* world wide 75
Table 2. Reported host plants of EGVM, *Lobesia botrana* world wide 77
Table 3. Reported host plants of EGBM, *Eupoecilia ambiguella* world wide 78
Table 4. A selection of predatory arthropod species reported in the South Downs AONB 79
Table 5. Native predatory bird species found in Kent and/or surrounds 83
Table 6. Native insectivorous bird species found in Kent and/or surrounds 84
Table 7. Kent microbat distribution table 2018 86
Table 8. Native reptile species found in Kent and surrounds 87

LIST OF FIGURES

Figure 1. Location of Kent Downs AONB, Surrey Hills AONB and South Downs National Park 16

Figure 2. Kent Downs AONB landscape character types...17

Figure 3. Location of vineyards in the Kent Downs AONB..17

Figure 4. 1st or 2nd instar tortricid larva, 5th or 6th instar inside a silk refuge, folded grapevine leaf, the presence of an anal comb is used to identify tortricid larvae to family. 21

Figure 5. Growers can rear larvae to determine the species of tortricid once it emerges as an adult ...22

Figure 6. Barn owl box with raptor perch and microbat box 24

Figure 7. Building bricks tailored to provide habitat for microbats, birds (swifts) and solitary bees 25

Figure 8. The Château d'Yquem vineyard with flowers retained along the drainage area and roses planted adjacent to strainer posts 32

Figure 9. Château Coutet vineyard mid-row biodiversity and VITIROVER in action trimming volunteer grass cover...32

Figure 10. Vignobles Bardet hedgerows along a drain and native camomile insectary.........................32

Figure 11. Domaine Emile Grelier agroforestry and bat boxes agroforestry plants established in the vine row 33

Figure 12. Assessing water quality and arthropod diversity in the vineyard..33

Figure 13. Assessing lichen as an indicator of air quality and wine with the Biodiversity Friend logo ...33

Figure 14. Lavender at the end of rows and a butterfly on lavender 34

Figure 15. Changins cover crop trial and Matteo Mota at Changins 34

Figure 16. Native ground cover, insectary plants establishing in the undervine area and insectary shrubs at the end of strainer posts..34

Figure 17. Dan Falkenberg and wallaby grasses in establishment and fully established 56

Figure 18. Wireweed was sprayed out under vine and in the mid-row prior to the establishment of native grasses. Wireweed persists at the end of strainers, where there is less competition from grasses and wallaby grasses were planted in the mid-row in May 2009 (six months active growth to April 2010).....57

Figure 19. Pelletised wallaby grass ready for seeding, rear view of the seed drill. The rear wheels ensure the seed is firmly bedded into the soil, and wallaby grasses planted to a depth of 0.5 to 1 cm.............58

Figure 20. Wallaby grass seed head, distinctive white fluffy seed heads (middle), and wallaby grasses slashed/strimmed after flowering 59

Figure 21. Transverse ladybird beetle, *Coccinella transversalis*, garden wolf spider, *Tasmanicosa* sp. European earwig, *Forficula auricularia*, brown lacewing larva, *Micromus tasmaniae*............................61

Figure 22. Temporal abundance of predator arthropods found in association with wallaby grasses over a 12-month period. The box plots represent the median (central line), first and third quartiles (grey box), and the whiskers the total range. 61

Figure 23. Mixing the 20 species mix of native grass and forb seeds, the blue devil specialised seeder, sown mid-row area...62

Figure 24. wallaby grasses planted under-vine, in the mid-row, and the biomass produced by the root system...63

APPENDICES

Appendix 1	Recorded host plants of tortricid leafrollers
Appendix 2	Potential predatory arthropod species reported in the South Downs National Park
Appendix 3	a) Native predatory birds found in Kent and/or surrounds and their conservation status
	b) Native insectivorous birds found in Kent and/or surrounds and their conservation status
	c) Native microbats found in Kent and/or surrounds and their conservation status
	d) Native reptiles found in Kent and/or surrounds and their conservation status
Appendix 4	UK vineyard pesticide application and potential pesticide toxicity to predators

Acknowledgements

Project team

With thanks to the project team for their valuable insights and local knowledge:

- Mike Phillips, White Horse Ecology and Viticulture ELMs Project Manager, Kent Downs AONB
- Pippa Palmer, Viticulture Tests and Trials Officer Kent Downs AONB
- Nick Johannsen, Director, Kent Downs AONB Unit
- Alistair Nesbitt, CEO Vinescapes
- Paula Nesbitt, Business and Finance Manager, Vinescapes
- Frances Trappey, Viticulturist, Vinescapes

Contributing vineyard managers

Wine grape growers who contributed via questionnaires (at the time of writing this report) include:

- Kent Downs Area of Outstanding Natural Beauty
  - Tom Berry, Brenley Vineyard
  - Simon Elworthy, Plumford Vineyard
  - Roz Waller, Chartham Vineyard
  - Graham Lark, Gorsley Vineyard
  - Charles McDonald, Tadpole Vineyard
- Surrey Hills Area of Outstanding Natural Beauty
  - Nick Wenman, Albury Vineyard
  - Shaun Page, FWAG, Surrey Hills
- South Downs National Park (SDNP)
  - Cameron Roucher, Rathfinny Vineyard
  - Zam Baring, Grange Estate Vineyard

Acronyms

AMES	Arthropod-mediated ecosystem services
AONB	Area of Outstanding Natural Beauty
BAP	Biodiversity Action Plan
BPS	Basic Payment Scheme
CAP	Common Agricultural Policy
CBC	Conservation biological control
CS	Countryside Stewardship
DEFRA	Department for Environment, Food and Rural Affairs
EI	Ecological infrastructures
ELMs	Environmental Land Management scheme
ELS	Entry Level Stewardship
FAS	Farming Advice Service
HLS	Higher Level Stewardship
NE	Natural England
NVZ	Nitrate Vulnerable Zone
SAC	Special Areas of Conservation
SSSI	Site of Special Scientific Interest
SPA	Special Protection Areas

Interchangeable words

strimming / slashing = cutting grass

Executive summary

This report highlights ecological restoration and functional biodiversity measures that can be employed to help ‘future proof’ the production of vineyards in the UK against the effects of climate change and extreme weather events. These recommendations go hand-in-hand with the proposed Environmental Land Management (ELM) scheme focus areas and provide guidance to landholders who wish to pursue step change in environmental stewardship, while increasing the resilience of their production systems.

This report provides the evidence needed for growers to implement the recommended practices in an informed and scientifically evidenced way.

ELMs focus areas:

1. Ensuring clean and plentiful water,
2. Clean air,
3. Mitigation and adaption to climate change,
4. Protection from and mitigation of environmental hazards,
5. Thriving plants and wildlife, and
6. Beauty, heritage and engagement.

Recommendations

The ten key recommendations of this report and links to the six ELMs focus areas are:

Ecosystem services and functional biodiversity

1. ***Recommendation: Growers are encouraged to adopt ecological restoration measures that preserve and maintain the full functionality of ecosystem services available including biocontrol, weed suppression, erosion control, improved aesthetics, nutrient cycling, soil water retention, soil organic carbon and soil biological activity.***

   Rationale: We are entirely dependent on our natural resources and the ecosystem services they provide. Healthy ecosystems provide services that are the foundation for human wellbeing and it is in our best interest to value and preserve them. Environmental stewardship has the capacity to provide multiple benefits to both land managers and the environment.

   Links to ELMs themes a, b, c, d, e, and f.

2. ***Recommendation: Adopt a fully integrated approach to pest management which includes the use of biocontrol, cultural, and targeted chemical intervention (only if required) to reduce pest insect populations below damaging levels.***

   Rationale: Insect pests cause economic damage in UK vineyards each year. There are a range of biocontrol agents that contribute to their control (predatory insects, spiders, parasitic wasps, microbats, and insectivorous birds). Biocontrol is estimated to provide five to ten times more control of pests than pesticides. It is estimated that 98% of sprayed insecticides and 95% of herbicides miss their intended target species. A reduction in chemical use will reduce off target damage to predators and plants, reduce the likelihood of pest resistance, pollution of waterways and air, contribution of greenhouse gasses through the use of fossil fuels and reduce damage to soils through compaction, erosion and accumulation of chemicals toxic to soil dwelling arthropods and microorganisms.

   Links to ELMs themes a, b, c, d, e, and f.

Conservation biological control and native insectary plants

3. ***Recommendation: Establish locally-adapted, native insectary plants in and around vineyards in strategic locations to provide habitat for predatory species that contribute to the biocontrol of economically damaging insect pests.***

   Rationale: Conservation biological control involves the conservation and augmentation of predator species that are already in place or have the capacity to be readily available in association with production systems. This can be achieved through the incorporation of native insectary plants which provide food, shelter and alternative prey/parasitoid hosts and habitat for higher order predators including microbats, and insectivorous/raptor birds.

   Native grasses provide a valuable complementarity habitat for arthropod species other than those commonly found in association with native woody perennial shrubs and may increase the net number of predator morphospecies by around 27% when planted in association with vineyards. It may be possible to increase the functional diversity of predatory arthropods by more than 3x when native evergreen shrubs are present versus grapevines only.

   Links to ELMs themes a, b, c, d, e, and f.

4. ***Recommendation: Prioritise the use of native insectary plants in preference to introduced species.***

   Rationale: Locally-adapted, native insectary plants are preferred as supplementary flora, as they are naturally adapted to local climatic conditions and are consistently reported as having a low occurrence of pests and a high occurrence of natural enemies. Enhanced functional biodiversity can lead to greater natural biological control, resilience within the system and improved ecosystem services. The resilience of a system describes its capacity to reorganise after local disturbance. The recent 'Plants for Bugs' study also found that the best way to support the presence of invertebrates and promote a healthy ecosystem is to choose plantings biased towards British native plants.

   Links to ELMs themes a, b, c, d, e, and f.

5. ***Recommendation: Incorporate a diversity of native insectary plants to provide functional biodiversity benefits throughout the entire year including ground cover (grasses, forbs, woody prostrate growing plants), shrub, tree and evergreen species to avoid 'resource bottlenecks' from occurring when resources are otherwise limited.***

   Rationale: It is generally regarded that if a greater diversity and species richness are present, then it is less likely that individual weeds or arthropod pest species will dominate. The strategic use of native insectary plantings, both spatially and temporally is important to deliver insectary services when they are needed.

   Links to ELMs themes a, b, c, d, e, and f.

6. ***Recommendation: Incorporate the use of species specific predator perches and/or nesting boxes to support populations of predatory birds (including the endangered honey buzzard and tawny owl).***

   Rationale: Predatory birds such as the barn owl, buzzard, honey buzzard, goshawk, sparrowhawk, hobby, kestrel, long-eared owl, red kite, sparrowhawk, and tawny owl will feed on a range of lower order mammals, birds, lizards and/or insects (Appendix Table 3a). If they are territorial they may patrol the perimeter of the vineyard and help keep fructivorous birds at bay, as well as helping to control rodent pest species

   Links to ELMs themes d, e, and f.

7. ***Recommendation: Incorporate the use of native insectary shrubs, trees and/or species specific nesting boxes that support populations of insectivorous birds (including the endangered swift, nightjar, cuckoo, house martin, pied flycatcher, nightingale, spotted flycatcher, dunnock, wood warbler, and willow warbler).***

   Rationale: Insectivorous birds contribute to the biocontrol of economically damaging insect pests (Appendix Table 3b).

   Links to ELMs themes d, e, and f.

8. ***Recommendation: Incorporate microbat boxes to supplement natural habitat and to boost the presence of microbats (including the endangered barbastelle, Bechsteins' bat, and brown long-eared bat) in and around vineyards.***

   Rationale: Microbats are reported to eat up to half their body weight in insects at night and are able to contribute to the biocontrol of economically damaging insect pests (Appendix Table 3c). Predation on agricultural pests by insectivorous bats may enhance the economic value of agricultural systems by reducing the frequency of required spraying and delaying the ultimate need for new pesticides.

   Links to ELMs themes d, e, and f.

9. ***Recommendation: In-field trials and demonstration sites are needed to verify the suitability of the selected candidate native insectary plants for use in and around vineyards and to help inform grower choices, accelerate practice change and adoption.***

   Rationale: A list of potential candidate native insectary plants has been identified in Table 2 for further investigation. Plants < 30 cm may be suitable for use in the midrow and undervine areas and plants < 2 m may be suitable adjacent to strainer posts. These assumptions need to be verified by local experts and tested in the field.

   Links to ELMs themes a, b, c, d, e, and f.

10. ***Recommendation: Provision is made within the ELMs to provide technical support to growers to plan, implement and maintain new areas of ecological restoration.***

   Rationale: Additional training and support will be required to assist growers to make these suggested changes.

   Links to ELMs themes a, b, c, d, e, and f.

Supporting documentation including links to the underpinning science is presented in the body of this report along with research gaps and suggested next steps.

CHAPTER 1: OVERVIEW

Introduction

Retallack Viticulture Pty Ltd was engaged by Dr Alistair Nesbitt and Paula Nesbitt from Vinescapes to carry out desktop research in partnership with stakeholders to evaluate which native plant species exist within the focal landscapes that could be incorporated for use in and around vineyards, as a part of the 'Kent Downs AONB Test and Trials viticulture research project No. 1 - Biodiversity, ecosystem services and sustainable viticulture'. Consultation for this project and its broader objectives is currently in progress https://www.kentdowns.org.uk/our-projects/environmental-land-management-scheme/

Background

An increasing number of vineyards in the Kent Downs and Surrey Hills Areas of Outstanding Natural Beauty (AONB) and South Downs National Park (SDNP) in the UK are being established on previously arable or pastoral land. It is estimated that there are at least 36 vineyards in the Kent Downs AONB (and surrounds) totalling 685 ha, 10 in the Surrey Hills AONB totalling 122 ha and 51 in the South Downs National Park (SDNP) totalling 436 ha, with a combined total of 700 vineyards and area of 3,500 hectares.

These special areas have lost much of their indigenous ecosystems through the course of human settlement and farming but the diverse habitats that remain are ecologically important. The general desire to protect species and heritage within the AONB and SDNP means that landowners and vineyard managers wish to be empowered with information and incentives to assist in this vital task.

As a result, there is increasing interest by local vineyard managers to do more to protect and enhance functional biodiversity and the environment in which they operate. There is also a commercial opportunity to project a clean, green image for AONB and SDNP wine producers so they can satisfy the demand for these credentials from an increasingly discerning market both in the bottle and in the vineyard. There is a potential win-win situation where research into ecosystem services and enhanced biodiversity in vineyards provides added value, through biocontrol and other environmentally-friendly practices, including reduced reliance on herbicides and pesticides.

In addition, by introducing more and different plant species into a vineyard this has the potential to soften the visual impact by screening trellising and other man-made structures. What some may call 're-wilding' could also provide opportunity for education, and an added attraction for visitors, all whilst linking the older established landscape with newer viticultural enterprises, and providing an opportunity to market improved environmental credential and 'terroir' appeal.

This environmental stewardship focus links closely with the objectives of the UK Government's flagship Environmental Land Management (ELM) scheme which aims to provide a complementary or alternative income stream, to demonstrate how less or 'un-productive' land has value to business and the community, encourage protection of key natural assets and ecosystem services, and make businesses more sustainable, resilient and profitable.

Scope

The focus of this short desk-top research project is to determine the potential for native plants to provide beneficial ecosystem services in vineyards in specific landscapes. They will be determined based on a landscape character assessment, in conjunction with local knowledge. The goal is to provide suitable habitat to support populations of pest predators (arthropods, lizards, microbats insectivorous/raptor bird species), use of persistent ground cover to suppress under-vine weeds and reduce the need for under row cultivation or herbicide use, to increase functional biodiversity, create habitat corridors, and conserve locally endangered or threatened plant, arthropod and animal species. Focus areas include:

- Kent Downs Areas of Outstanding Natural Beauty https://www.kentdowns.org.uk
- Surrey Hills Areas of Outstanding Natural Beauty (AONB) https://www.surreyhills.org
- South Downs National Park (SDNP) https://www.southdowns.gov.uk

Brief

The brief comprises the following aims:

1. To identify native species that could be re-introduced as beneficial to vineyard biodiversity and wider ecosystem services and natural capital in specific landscape types. **This is addressed in Chapter 4.**
2. And would meet the Environmental Land Management (ELM) scheme public goods tests of:
   a. Ensuring clean and plentiful water by reducing spray applications and pesticide loss to ground and buffering against any future irrigation requirements.
   b. Clean air by reducing spray applications and tractor movements as less mowing would also be required.
   c. Mitigation and adaption to climate change by encouraging biodiversity and carbon sink potential within an adaptation setting, also offering shade in extreme conditions and reducing evapotranspiration.
   d. Protection from and mitigation of environmental hazards by reducing pesticide use and promoting biodiversity, also by reducing soil erosion through established ground cover.
   e. Thriving plants and wildlife by encouraging biodiversity and re-introducing native species through vineyard greening which in turn attract birds and insects, natural pest predators and may offer wildlife corridors.
   f. Beauty, heritage and engagement by improving vineyards aesthetic appeal in sensitive landscapes, re-introducing native beneficial species, providing opportunity for a unique story of environmental land management in vineyards which should in turn attract visitors and wider engagement and interest in the work.

   This is addressed in Chapter 5.
3. Calculate the cost-benefit of such an approach to vineyards. **This is addressed in Chapter 7.**

Deliverables

Report into potential native plants and recommendations.

1. Identify native plant species that can be incorporated in and around vineyards as functional supplementary flora. **This is addressed in Chapter 4.**
2. Identify barriers to adoption and required tools to facilitate adoption. **This is addressed in Chapter 8.**
3. Provide recommendations linked to the public goods. **This is addressed in Chapter 5.**
4. Provide a detailed case study of best practice from work you have already undertaken in Australia.. **This is addressed in Chapter 6.**

What was done?

An inception meeting was held on Wednesday 29 July 2020, followed by an update meeting on Friday 7 August and regular correspondence between project team members, Mike Phillips, White Horse Ecology and Viticulture ELMs Project Manager, Kent Downs AONB, Pippa Palmer, Viticulture Tests and Trials Officer Kent Downs AONB, Alistair Nesbitt, CEO Vinescapes, Paula Nesbitt, Business and Finance Manager, Vinescapes and Frances Trappey, Viticulturist, Vinescapes.

A desktop review of available information was conducted and this report was submitted in response to the deliverables. This report is designed to be read in relation to the 'Viticulture impacts and opportunities for Public Goods in the protected landscapes of the South Downs National Park, Kent Downs AONB and Surrey Hills AONB' report other accompanying documents prepared as a part of the broader project.

CHAPTER 2: SETTING THE SCENE

This chapter provides relevant background information on the evolution of farming schemes available to farmers in the past and the vision for the future.

The future for food, farming and the environment

Farming for the future and environmental land management

The EU's Common Agricultural Policy (CAP) has informed how UK farmers manage their land for more than 40 years. The UK's departure from the EU and the CAP provides a unique opportunity to redesign agricultural policies to achieve environmental ambitions while supporting farming sectors.

In England, 69%[1] of the landscape is farmed and with the expansion and intensification of production this has resulted in a decline in the health of the environment. On average there has been a 57%[2] decline in the farmland bird index between 1970 and 2018 and 10% of the UK's overall greenhouse gas emissions also reportedly come from the agricultural sector.[3]

In January 2018, the UK government published an ambitious 25 Year Environment Plan, setting out an intention to be the first generation to leave the environment in a better state than they found it and they subsequently committed to achieving net zero emissions by 2050 to ensure we can mitigate against, and adapt to the effects of climate change. It is recognised that farmers are vital stewards of our natural environment and require support to achieve collective environmentally based targets.

The new proposed Environmental Land Management (ELM) scheme is based on 'public money for public goods'. ELM will provide land managers with an opportunity to secure financial reward in return for delivering environmental benefits.

The public goods ELM will pay for are directly linked to:

- Clean and plentiful water,
- Clean air,
- Protection from and mitigation of environmental hazards,
- Mitigation of and adaptation to climate change,
- Thriving plants and wildlife, and
- Beauty, heritage and engagement.

Given the market does not adequately reward the delivery of environmental public goods, ELM will be an effective way for government to intervene and utilise public funding to deliver them.

This project is part of the tests and trials mechanism which is being used to co-design the ELM scheme with stakeholders and to help refine and improve the policy framework and delivery methods. The National Pilot is due to start in late 2021 and the start of the ELM scheme in 2024.

For more information about the consolation process see https://consult.defra.gov.uk/elm/elmpolicyconsultation/supporting_documents/ELM%20Policy%20Discussion%20Document%20230620.pdf and the Environmental Land management policy discussion visit https://www.gov.uk/ government/consultations/environmental-land-management-policy-discussion-document

---

[1] Department for Environment, Food and Rural Affairs, 2019. June Survey of Agriculture and Horticulture. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/841483/structure-june-eng-series-24oct19.xls

[2] Department for Environment, Food and Rural Affairs, 2018. Wild Bird Populations in England, 1970-2018. https://www.gov.uk/government/statistics/wild-bird-populations-in-the-uk.

[3] Department for Business, Energy and Industrial Strategy, 2020. 2018 UK Greenhouse Gas Emissions, final figures. https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-nationalstatistics-1990-to-2018.

The Kent Downs Area of Outstanding Natural Beauty (AONB)

The Kent AONB is a nationally protected landscape and home to some of the most enchanting countryside in Britain. It covers about a quarter of the County of Kent focusing on the North Downs and the Greensand Ridge, stretching from the White Cliffs of Dover to the Surrey and London borders.

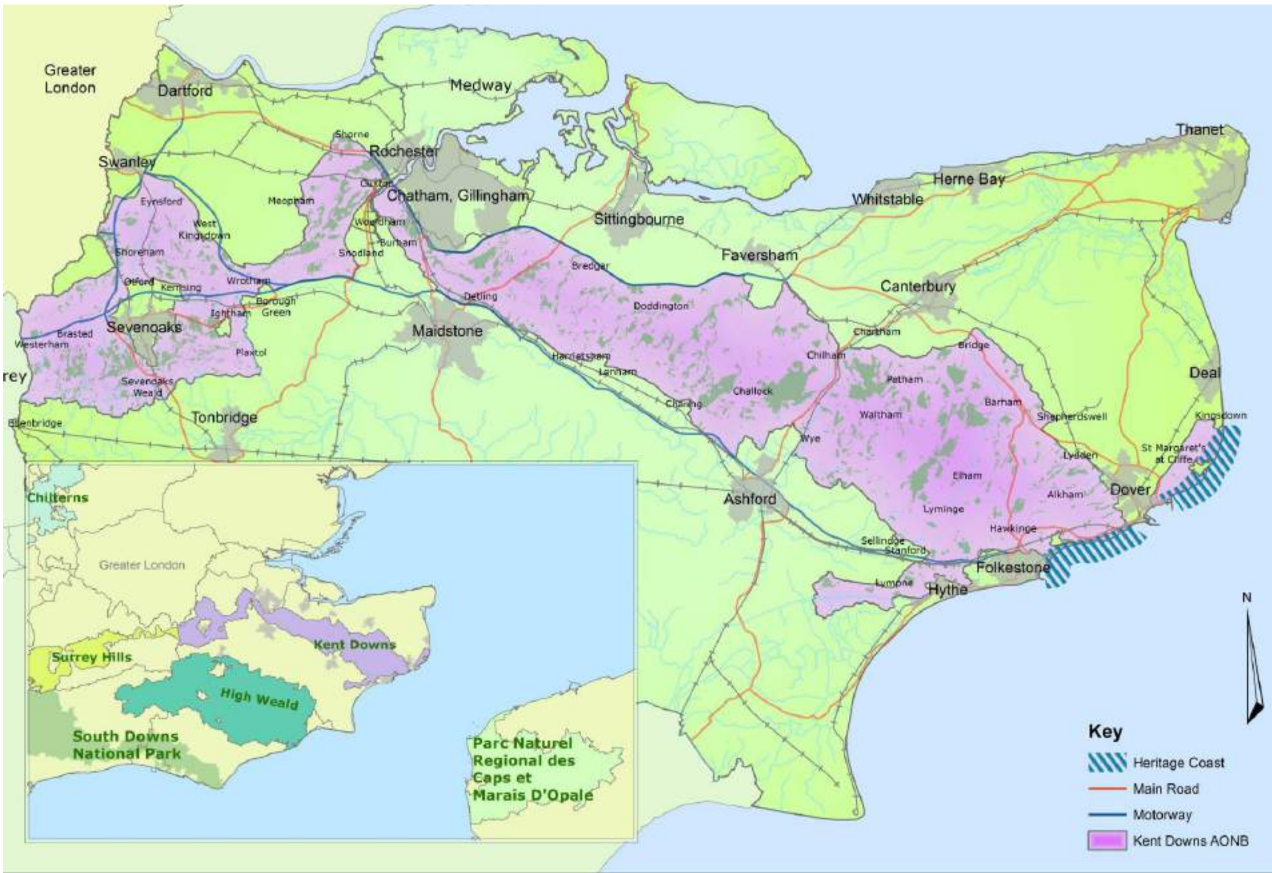

Figure 1. Location of Kent Downs AONB, Surrey Hills AONB and South Downs National Park[4]

The Kent AONB is known for:

- Biodiversity-rich habitats including chalk grassland, woodlands (ancient woodland, veteran trees and wood pasture), traditional orchards and cobnut plats, chalk cliffs and the foreshore, chalk rivers and wet pasture, ponds and heathland (**Figures 2 and 3**).
- Rivers, marshes and ponds are important components of the landscape of the Kent Downs and they also provide valuable habitat for wildlife.
- One of Britain's most wooded landscapes covering over 20% of the AONB (17,579 ha). Almost 70% of the Kent Downs woodlands are ancient woodland, meaning they have been continuously present since at least 1600 AD. The rich ground flora of ancient woodlands include bluebells, wood anemones, ramsons and yellow archangel and the bird song of warblers, nightingale and nightjar.
- It is known for its farmed landscape, tranquillity and remoteness, dramatic views and landform, historical and cultural heritage and vibrant communities.

[4] https://kccconsultations.inconsult.uk/gf2.ti/f/1092162/75945573.1/PDF/-/1._The_Kent_Downs_AONB.pdf

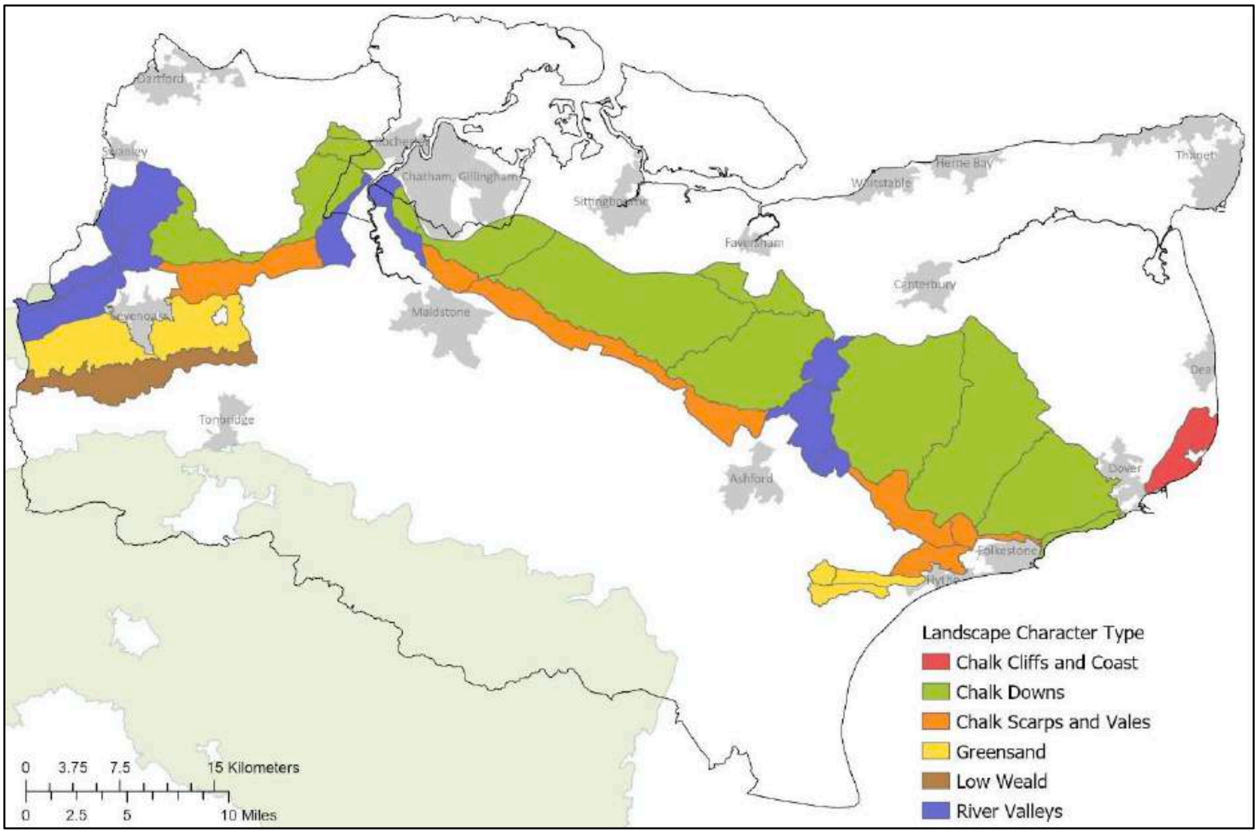

Figure 2. Kent Downs AONB landscape character types[5]

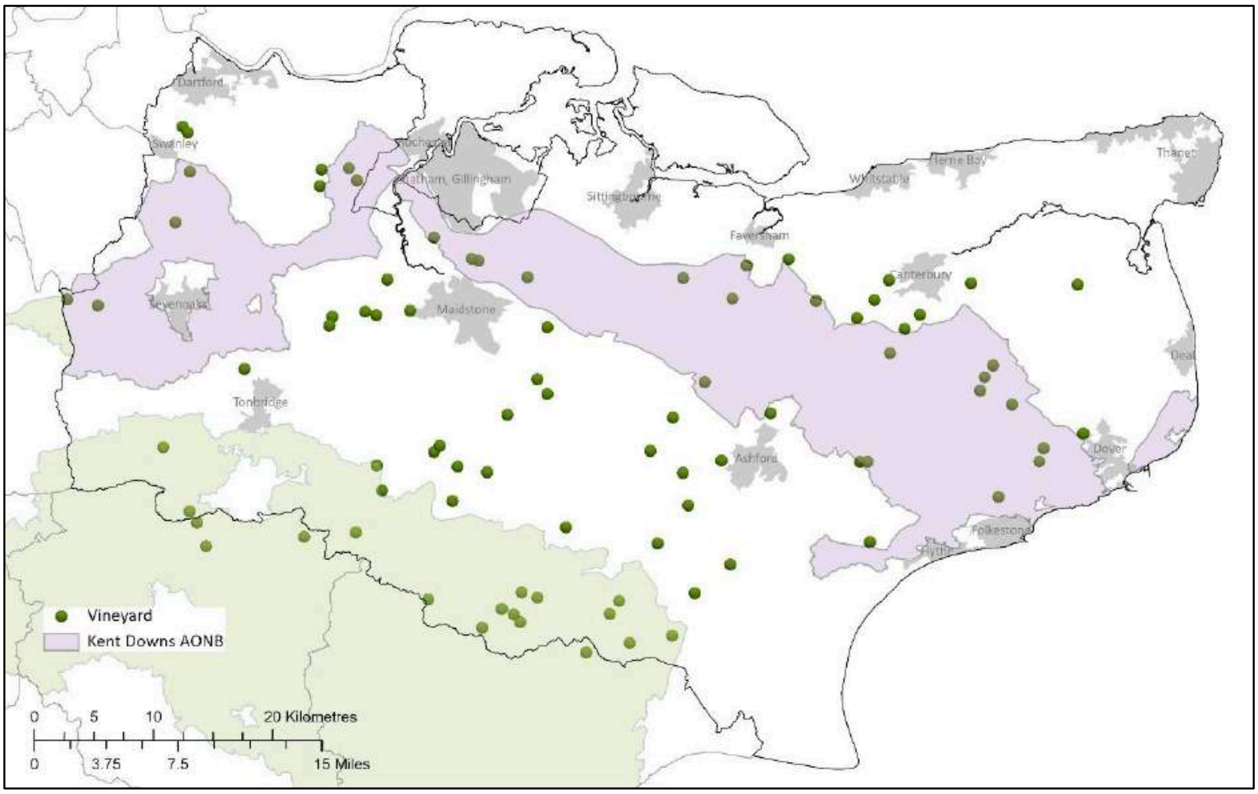

Figure 3. Location of vineyards in the Kent Downs AONB[5]

5 https://kccconsultations.inconsult.uk/consult.ti/kentdowns_aonb/consultationHome

CHAPTER 3: LITERATURE REVIEW

This chapter provides an overview of the literature regarding the importance of functional biodiversity, associated ecosystem services and insights relevant for UK wine grape growers.

Functional biodiversity

Biological diversity refers to the variety of plants, animals and micro-organisms that live and interact within an ecosystem (Cardinale et al., 2012; Wilson and Peter, 1988). They provide valuable ecological services to humans (Pimentel et al., 1992). Biodiversity is typically measured as ‘richness’ (the number of unique life forms), ‘evenness’ (the consistency among life forms) and ‘heterogeneity’ (the dissimilarity among life forms) (Cardinale et al., 2012). A measure of functional diversity is often used to refer to the variety and number of species that fulfil different functional roles (Colwell, 2009) including the biological control of pests by predators. A measure of the richness and abundance of insect predators can be used when collecting data on different plant communities and individual plant species to represent an objective measure of functionality. This will be discussed further below.

Landscape simplification

When diverse natural systems are replaced with a monoculture, this will invariably have a negative impact on biodiversity and species richness (Hooper et al., 2005; Meehan et al., 2011). A simplistic ecological network with fewer connections and low functional biodiversity could lead to instability within a production system (Altieri, 1999; Gurr et al., 2004). Where there is fragmentation of the landscape, there is often an increase in pest pressure on crops and a greater reliance on chemical control options (Meehan et al., 2011; Orre-Gordon et al., 2013). Fragmented landscapes can also have a negative effect on the abundance and diversity of predators (Steffan-Dewenter, 2003) and reduce their capacity to provide biological pest control (Kruess and Tscharntke, 1994). In France, a reduction in semi-natural habitat has also been linked with a reduction of biological pest control in cultivated land by up to 46%, when compared with more complex landscapes (Rusch et al., 2016). The effects of habitat loss and fragmentation on herbivores and predators are contingent on the species and landscape (Tscharntke and Brandl, 2004).

Biodiversity loss

Loss of habitat is regarded as the greatest threat to biodiversity (Brooks et al., 2002). It is generally regarded that as the proportion of suitable habitat in the landscape is reduced to less than 30% of original vegetation cover, that this will cause a loss of biodiversity, that is, a reduction in species numbers and population densities for all fauna (Andren, 1994; Hanski, 2011). Conversely, in structurally complex landscapes predation and parasitism tends to be higher and crop damage lower than in simple landscapes (Marino and Landis, 1996; Thies and Tscharntke, 1999; Tscharntke et al., 2002).

A number of consensus statements are proposed in the literature, which help to sum up the significance of biodiversity loss and its potential impact on humanity (Cardinale et al., 2012):

- There is indisputable evidence that the efficiency of multiple ecosystem functions is reduced as biodiversity is lost.
- Initial losses of biodiversity in complex ecosystems have relatively low impacts on the functioning of ecosystems but both the rate of change within an ecosystem and its capacity to function accelerate as biodiversity loss increases (Cardinale et al., 2006).
- Loss of diversity across trophic levels has the potential to influence ecosystem processes more strongly than diversity loss within trophic levels (Duffy et al., 2007; Estes et al., 2011).
- A reduction in the diversity of functional characteristics of organisms will have large impacts on the extent of ecosystem functions (Laureto et al., 2015; Petchey and Gaston, 2006).
- Conversely, there is growing evidence that as biodiversity increases, so does the stability of ecosystem functions through time (Cottingham et al., 2001; Jiang and Pu, 2009).
- Diverse communities tend to be more productive, as they contain a variety of species with different functional traits that can increase productivity by producing greater biomass (Cardinale et al., 2012).

It is reported that agriculture is the largest contributor to biodiversity loss with expanding impacts due to changing consumption patterns and growing populations (Dudley and Alexander, 2017). However, vineyards may have a greater potential to retain or reintroduce functional biodiversity than arable farming and in some instances the pastoral farming land uses, because the land area that is planted with vines is often only an average of 15 to 20% of the total vineyard area. It is also recognised that agricultural land serves many purposes beyond food production and mechanisms are needed to pay farmers for wider stewardship of land resources. Habitat management involving the manipulation of vegetation in production systems can exert direct suppressive effects on pests and promote predatory arthropods (Gurr et al., 2017). It is not considered that corridors, or revegetation can compensate for the overall loss of habitat provided by original plant cover (Harrison and Bruna, 1999). However, it is possible to implement restorative ecological practices that contribute to bridging this gap, by restoring indigenous plant communities (Altieri, 1999). Stands of native vegetation adjacent to perennial production areas including vineyards, have been associated with increased biodiversity benefits (Thomson and Hoffmann, 2010b).

Ecological Infrastructures

Ecological Infrastructures (EI) are defined as any infrastructure within a radius of the order of 150 m of a farm or vineyard that has an ecological value to the production system and increases the functional biodiversity of the property, such as hedges, grassland, wildflower strips, conservation headlands, stone heaps etc. (Boller et al., 2004). Within a vineyard, existing vegetation structures such as windbreaks, vegetation corridors, mid-row or under-vine ground cover and headland plantings can be enhanced to provide resources for predators that contribute to pest control throughout the year. In Australia, rose bushes planted adjacent to strainers provide no intrinsic value and are being replaced with locally-adapted insectary shrubs and ground cover plants to improve functional benefits (Retallack, 2018).

Other ecological infrastructures include stone walls and raised beetle banks that can provide valuable habitat and connectivity for a range of soil dwelling arthropods (beetles and spiders) and lizards. There are three important aspects of ecological infrastructures and they include large permanent habitats of the fauna, 'stepping stones' or habitats of smaller size allowing the build-up of temporary animal populations and corridor structures to assist animal species in moving between large habitats and small stepping stones (Boller et al., 2004). More work is needed to assess the value of biodiversity corridors and 'stepping stones' between regions (Duelli and Obrist, 2003) for those species not affected by local vegetation but may respond to landscape changes at the regional scale. The optimum surface of EI (including all structures of interest) to maintain an adequate diversity of species is estimated to be close to 15%. According to the International Organization for Biological and Integrated Control (IOBC), a minimum of 5% of farmland is required to be designated as EI (Boller et al., 2004).

The role of ecosystem services

Ecosystem services are the benefits that humans derive from ecosystems (Mace et al., 2012). They are often classified into categories of provisioning, regulating, cultural and supporting services (Close et al., 2009). Enhanced biodiversity is often promoted as an important indicator of vineyard health (Altieri, 1999; Barnes et al., 2010; Gurr et al., 2003; Winter et al., 2018) and non-crop plants may have the capacity to maintain and enhance biodiversity (van Emden, 1965, 2003). There is current interest in biodiversity loss due to crop production and the consequent alteration in ecosystem services provision. The presence of non-crop vegetation including native insectary plants (Schellhorn et al., 2015), may be an important contributor of functional diversity and ecosystem services (Close et al., 2009; Mace et al., 2012). This report focuses on the capacity of native insectary plants to provide 'provisioning' resources, such as food (pollen and nectar), shelter, and alternative prey/hosts (Barnes et al., 2010; Gurr et al., 2017) that nourish predators and extend their presence in a vineyard (Gurr et al., 1998). In turn, predators provide 'regulating' ecosystem services which contributes to biological control of insect pests. Ecological services also include weed suppression, erosion control, aesthetics, nutrient cycling, soil water retention, soil organic carbon and soil biological activity (Fiedler et al., 2008; Gurr et al., 2003; Nicholls and Altieri, 2003), which maintain conditions for life on earth and contribute to human wellbeing.[6]

---

[6] https://www.cbd.int/doc/bioday/2008/ibd-2008-factsheet-01-en.pdf

Biocontrol

Biological control is a key component of arthropod-mediated ecosystem services (AMES), which is used to manage pests in production systems (Isaacs et al., 2009). Biocontrol is estimated to provide five to ten times more control of pests than pesticides (Pimentel et al., 1992).The success of biocontrol if often dependent on the colonisation of vineyards by predatory arthropods each season due to a resource 'bottleneck' which may occur over winter when vines are dormant and resources are limited (Schellhorn et al., 2015). One way to overcome a resource bottleneck is through ecological engineering with a diversity of native species (including evergreens) (Gurr et al., 2004). For example, *Anagrus* spp. an egg parasitoid of the western grape leafhopper, *Erythroneura elegantula* will seek out a range of host plants found adjacent to vineyards during the overwintering period (Wilson et al., 2016), and the seven-spot ladybird beetle, *Coccinella septempunctata* overwinters at ground level insulated in plant material (Nedved, 1993). The benefits of preserving native vegetation near horticultural areas include conservation biological control (CBC) and biodiversity enhancement (Bianchi et al., 2006; Fiedler et al., 2008; Frank et al., 2008; Gurr et al., 2003). Perennial cover crops function as a 'ecological turn-table', which have the capacity to activate and influence key processes and components of the agroecosystem (Altieri, 1999).

Conservation biological control (CBC)

Conservation biological control is defined as the conservation and augmentation of predatory arthropods that are already in place or are readily available (Barbosa, 1998). CBC involves the implementation of practices that protect and enhance the reproduction, survival, and efficacy of natural enemies of pests (Barbosa, 1998; Begg et al., 2017; DeBach, 1974; Fiedler et al., 2008; van Emden, 2003). The success of a CBC strategy is strongly linked to the availability and quality of ecological infrastructures inside and outside the farm limits within a radius of 100 - 200 m (Stefanucci et al., 2018). CBC is one of four strategies of 'biological control' described by Eilenberg et al. (2001), which also include 'classical', 'inoculation', and 'inundation' biocontrol of arthropods. Relatively little work has been done on the use of specific native plant species in vineyards to enhance CBC in the UK. However, this approach could provide innovative, practical and sustainable solutions for local wine grape growers.

Enhancing biodiversity

Enhanced functional biodiversity can lead to greater natural biological control, resilience within the system and improved ecosystem services (Altieri, 1991; Andow, 1991; Stamps and Linit, 1997). The resilience of a system describes its capacity to reorganise after local disturbance (Tscharntke et al., 2005), or in response to environmental changes (Oliver et al., 2015). It is generally regarded that if a greater diversity and species richness are present, then it is less likely that individual weeds or arthropod pest species will dominate (Bianchi et al., 2006). The system may also be better able to recover from disruptions including extreme weather events (Yachi and Loreau, 1999). By adopting optimised management practices and promoting the richness of the natural enemies present, they could reduce the density of herbivorous pests and this may lead to increased yield (Cardinale et al., 2003).

Minimising negative effects

An understanding of the specific attributes insectary plants provide is important. Increasing biodiversity in general is no guarantee of pest suppression (Begg et al., 2017; Gurr et al., 2003), and may have unintended consequences, such as the enhancement of pest populations (Ambrosino et al., 2006; Baggen and Gurr, 1998; Fiedler and Landis, 2007a; Winkler, 2005).

Measuring benefits

Biodiversity enhancement is often promoted as an important indicator of vineyard health. However, the measurement of biodiversity is difficult. Thomson et al. (2007) suggest that a surrogate indicator such as predatory invertebrates, which have a direct impact on pest abundance, can be used as one way to assess the benefits of enhancing biodiversity. Therefore, I suggest focussing on identifying which predators are present on or in association with native vegetation in the UK and are likely to contribute to the control of key vineyard pests.

Arthropods

Functional groups: pests

Family Tortricidae

Tortricidae is a diverse family of moths which have a wide range of host plants (Brown et al., 2010). In the larval stage (**Figure 4a and b**) they are called leafrollers because the caterpillars build protective feeding shelters by folding leaves over their bodies and using silk webbing to secure these structures (**Figure 4c**). Light brown apple moth, *Epiphyas postvittana*, European grapevine moth, *Lobesia botrana* and European grape berry moth, *Eupoecilia ambiguella* are the predominant leafroller pests of grapevines in the UK. Damage to grape skins caused by leafroller moth larvae provide infection sites and may predispose bunches to bunch rots.

Light brown apple moth (LBAM), *Epiphyas postvittana*

LBAM, *Epiphyas postvittana* is an Australian native leafroller. It is a damaging pest of grapevines that has been introduced into England, Ireland, Japan, Sweden and USA (Suckling and Brockerhoff, 2010). Typically, there are three (spring, summer and autumn-winter) LBAM generations (Magarey et al., 1994).

European grapevine moth (EGVM), *Lobesia botrana*

European grapevine moth (EGVM) is a significant pest species in southern Europe. Southern England is a high risk area as EGVM may be blown across from the continent. Adult activity and the highest risk period to grapes is July and August when pest populations in southern Europe are at their highest.

European grape berry moth (EGBM), *Eupoecilia ambiguella*

European grape berry moth (EGBM) is a common pest species in continental Europe but more scarce in the cooler UK. EGBM occurs locally in the south east of England and south Wales. Pheromone monitoring traps are best used to catch adults when they are flying from May to September. This pest of grapevine is able to survive and reproduce on wild berry producing host plants.[7]

There are several morphological characteristics that can be used to identify larvae to the sub-family Tortricinae, including the presence of an anal comb that is used to flick away fecal pellets from their shelters (**Figure 4d**), and is almost always present (Brown, 2011; Gilligan, 2014a; Gilligan, 2014b).

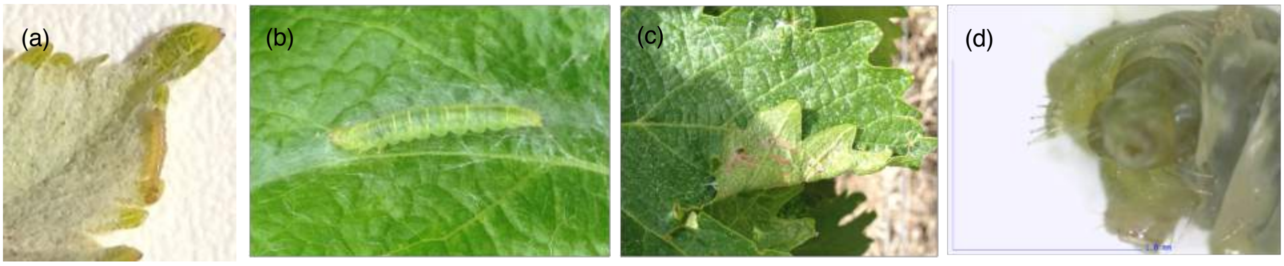

Figure 4. 1st or 2nd instar tortricid larva (a), 5th or 6th instar inside a silk refuge (b), folded grapevine leaf (c), the presence of an anal comb is used to identify tortricid larvae to family (d). Photos: Mary Retallack

However, there are no definitive morphological characters that can be used to identify Tortricidae at the larval stage to species (Whittle et al., 1991). Therefore, molecular methods such as DNA barcoding are required to determine larval stages of species of Tortricidae with confidence (Barr et al., 2011; Barr et al., 2009; Hajibabaei et al., 2006). The specialist knowledge, time and resources required to extract DNA and conduct Sanger sequencing is often not accessible to grape growers.

However, a practical alternative is to rear larvae in containers to adulthood (**Figure 5**). However, specialist knowledge is still required to ensure correct identification of adult moths, and parasitised larvae don't survive to the adult stage.

---

[7] https://www.andermattuk.com/british-grape-growing-pests

Figure 5. Growers can rear larvae to determine the species of tortricid once it emerges as an adult moth. Photos: Mary Retallack

When selecting habitat for predatory arthropods it is important to avoid plant species that may provide breeding sites for pest species. Recorded host plants for each of these leafroller species is presented in **Appendix 1**.

Family: Drosophilidae

Spotted Wing Drosophila (SWD), *Drosophila suzukii*

Spotted wing drosophila is an invasive fruit fly pest which was first recorded in Kent in 2012. It is now found across the major grape growing areas of Kent, Sussex, Hampshire and Surrey in the south of England. It poses a significant risk to numerous fruit crops including wine grapes. SWD differs from other fruit flies because it is able to lay its eggs in green unripe berries. It has also been shown that SWD can increase the spread of *Acetobacter* spp. acetic acid bacteria, which can predispose berries to sour rot.[8]

The spotted wing drosophila typically lays its eggs from March to October and can have up to 13 generations per year. It takes 12 to 79 days from egg to adult stage. Females can lay 7 to 16 eggs/day, and over 300 eggs in its lifetime. Peak in development and activity at 27 °C. They overwinter as adults and can survive cold winters.

Early experience in the UK and from other countries where SWD is prevalent suggests that cherry is the most susceptible UK grown fruit crop followed by cane fruit crops (raspberry, blackberry and hybrid berries), blueberry and strawberry. SWD has also been found in UK grown grapes. Other crops thought to be susceptible are black currant, red currant, white currant, gooseberry, plum, apricot, peach, nectarine and kiwi fruit. Damaged tomatoes are also thought to be at risk.

Apart from fruit crops, other hosts include: wild blackberry, wild cherry, dogwood, elderberry, hawthorn, honeysuckle, mahonia, mountain ash (rowan), mulberry, nightshade, wild raspberry, rose and snowberry. Early and late sugar sources include holly, insect honeydew and ivy. For UK specific insights see https://projectblue.blob.core.windows.net/media/Default/Horticulture/Pests/SWD/Management%20and%20control%20of%20SWD%20(1).pdf

A list of known or suspected host plants for SWD can be viewed here https://www.horticulture.com.au/globalassets/hort-innovation/resource-assets/mt17005-swd-host-list.pdf

Multiple biological control agents target SWD, including predators, parasitoids, nematodes and microorganisms such as fungi and bacteria. Predators ambush and feed on SWD, removing a substantial portion from the production system by targeting larvae, pupae, and/or adults. Their efficacy ranges from less than 15% to more than 90%.[9]

For information on suggested plant protection strategies refer to the WineGB Plant Protection Products Green Book 2020 https://www.winegb.co.uk

8 https://www.andermattuk.com/british-grape-growing-pests

9 https://catalog.extension.oregonstate.edu/em9269/html

Functional groups: predators

Generalist predators feed on a range of host species and are often voracious feeders on eggs, larvae and adult stages. Many predators, like spiders, brown and green lacewings, ladybird beetles and predatory bugs are commonly found in vineyards (Thomson and Hoffmann, 2008; Thomson et al., 2007).

A range of generalist predators contribute to the control of LBAM (Bernard et al., 2006b) and other tortricid moths. The main predators and parasitoids of leafrollers include neuropteran larvae (lacewings), spiders, earwigs, ladybird, carabid and rove beetles, predatory Hemiptera (shield and damsel bugs), predatory Diptera (hover flies and robber flies) and parasitic wasps (Bernard et al., 2006b; Frank et al., 2007; Hogg et al., 2014; Paull, 2007; Thomson and Hoffmann, 2009a; Thomson and Hoffmann, 2010b; Yazdani et al., 2015; Yazdani and Keller, 2017). Some predators feed on leafroller eggs (Danthanarayana, 1980; MacLellan, 1973; Paull and Austin, 2006). It is reported that up to 90% of newly hatched leafroller larvae may be killed by predators in the absence of toxic chemicals (Helson, 1939; Waterhouse and Sands, 2001).

There are at least 25 known parasitoids of eggs, caterpillars and pupae of LBAM (Paull, 2007; Paull and Austin, 2006). *Trichogramma* ssp. (Hymenoptera: Trichogrammatidae) wasps are only able to parasitise LBAM eggs (Glenn et al., 1997; Glenn and Hoffmann, 1997) but no other life stage. This along with low levels of parasitism and late season activity, may naturally limit their ability to control LBAM in isolation (Bernard et al., 2006a). However, young LBAM instars can be parasitised by *Dolichogenidea tasmanica* (Hymenoptera: Braconidae), but parasitism is only possible up to and including the third instar (Yazdani et al., 2015). Whereas, *Gonozius s*sp. (Hymenoptera: Bethylidae), can parasitise third and fourth stage instars (Danthanarayana, 1980).

A list of potential predatory arthropod species reported in the South Downs National Park is presented in **Appendix 2**.

Higher order predators

Predatory birds

Predatory/raptor birds

Predatory birds such as the barn owl, buzzard, honey buzzard, goshawk, sparrowhawk, hobby, kestrel, long-eared owl, red kite, sparrowhawk, and tawny owl will feed on a range of lower order mammals, birds, lizards and/or insects and if they are territorial may patrol the perimeter of the vineyard and help keep fructivorous birds at bay, as well as controlling rodent pest species. They are an important component of the ecological food chain. Examples of predatory bird species of potential interest in and around Kent and surrounding areas including their conservation status are highlighted in **Appendix 3a**.

Insectivorous birds

Insectivorous birds such as long-tailed tit, swift, nightjar, goldfinch, treecreeper, cuckoo, house martin, great spotted woodpecker, pied flycatcher, common chaffinch, nightingale, spotted flycatcher, coal tit, dunnock, common chiffchaff, wood warbler, tree sparrow, willow warbler, and green woodpecker mainly feed on insects, spiders and other invertebrates. Examples of insectivorous bird species of potential interest in and around Kent and surrounding areas including their conservation status are highlighted in **Appendix 3b**.

Insect eating mammals

Microbats

Microbats are 4 to 16 cm long and most species feed on insects. The noctule bat weighs up to 40 grams, while a common pipistrelle may weigh as little as 3 grams. All of the UK's bat species are insectivores, meaning their diet is made up of insects including moths, flies, beetles and mosquitoes. Each bat is capable of eating thousands of insects each night and they play a key role the biocontrol of pest insect species. They are also a good indicator species of ecology health.

In a recent study near Bordeaux up to 70% of bat scats recovered tested positive for the presence of European grapevine moth, *Lobesia botrana* and this demonstrates that they contribute towards the biocontrol of these leafroller pests (Thiery et al., 2018). There are 14 species of microbat potentially found in Kent including the Daubenton's bat, common pipistrelle, soprano pipistrelle, and brown long-eared bat which are all relatively common, along with 10 species which are either in decline or are scarce, rare or elusive to find. Examples of microbat species of potential interest in and around Kent and surrounding areas including their conservation status are highlighted in **Appendix 3c**.

Microbats use a form of biological sonar known as echolocation to help navigate their path. As they fly, they make high frequency calls that are mostly inaudible to the human ear. By listening to the echoes these calls make, bats are able to build a map of their surroundings and locate their prey. Bats have good eyesight but the capacity to use echolocation is a more effective way of flying around and catching small insects at night. Bats will also use linear features such as hedgerows and tree lines to move around. By travelling alongside these features they are less vulnerable to predators like birds of prey, than if they were flying out in the open. Supplementary habitat including manmade bat boxes (and bricks) can also be used and are best positioned at least 4 metres from the ground in close proximity to vegetation and linear features like a hedgerow which bats rely on for navigation and food.

An anabat detector can be used to passively identify different bat species https://www.titley-scientific.com/au/products/anabat-systems?SID=8bdg55uc30uebt0npu9u3sqs51

Creating habitat

Ecological infrastructures also include the use of bird and bat boxes to supplement habitat if natural habitat including tree hollows are lacking. Buzzards have adapted to sit on the abundant telegraph posts, hop poles and fence posts in the district. While combo barn owl perches and nesting boxes are being considered for use in UK vineyards. There are many designs available and a microbat box design has been developed by the Kent Bat Group. For more information see http://www.kentbatgroup.org.uk/kent-bat-box.pdf

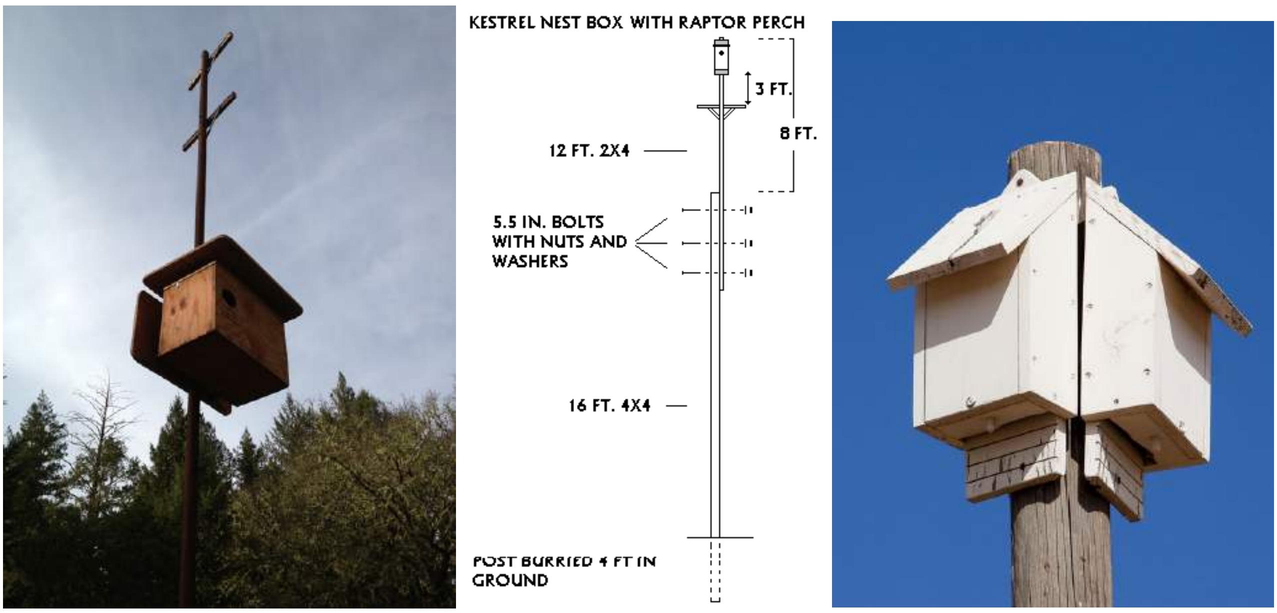

Figure 6. Barn owl box with raptor perch left and middle and microbat box right (Images: left,[10] middle,[11] right[12])

10 https://aj-vineyardsupply.com/gmedia/01-barn_owl_box_with_raptor_perch_id933-jpg/

11 http://tommy51.tripod.com/perch.html

12 https://www.smithsonianmag.com/science-nature/winemakers-are-building-houses-bats-make-vineyards-greener-180956381/

Habitat bricks

There are a range of innovative construction materials available in the UK. They include the microbat brick which is designed to create roosting space for crevice dwelling bats within the framework of new or existing buildings. Microbats play an important role in the environment. The swift box is designed to create nesting space for the declining swift population, which have decreased by over 50% in the last 20 years in the UK due to a loss of habitat. Swifts feeding on a diet of insects and may contribute to biocontrol of insect pests. The solitary bee brick provides a nesting site for red mason and leafcutter bees, and while they are not predatory arthropods, they do provide an alternative source of prey for some of the higher order predators that are important for ecological health and provide a focal point for community interest. Efficacy of use (rate of occupancy) for each brick is yet to be determined.

Figure 7. Building bricks tailored to provide habitat for microbats, birds (swifts) and solitary bees[13]

Badgers

The European badger, *Meles meles* is easy to identify due to their black and white stripes. They are the UKs largest land predator and feed on earthworms, large insects, cereals, fruit and small mammals. Insect prey includes chafers, dung and ground beetles, caterpillars, leatherjackets, and the nests of wasps and bumblebees. They can eat several hundred earthworms a night, are one of the only predators of hedgehogs and can also prey on rabbits. It is nocturnal social, burrowing animal that sleeps during the day. In some areas of intensive agriculture their numbers have reduced due to loss of habitat and in some areas they are considered a pest. Some viticulturists report that badgers may eat entire blocks of grapes in a night and rip through nets. They'll also dig holes under fences and vines on occasion. In England, culling of badger populations is used to reduce the incidence of bovine tuberculosis in cattle. They are protected under the Protection of Badgers Act, 1992, and the Wildlife and Countryside Act, 1981.

Hedgehogs

The European hedgehog, *Erinaceus europaeus* is omnivorous, feeding mainly on invertebrates. Its diet includes slugs, earthworms, beetles, caterpillars and other insects. Britain's hedgehog population has fallen 66 per cent in 20 years. The doubling of the badger population over the same period may have contributed, as they eat hedgehogs and compete for the same insect food. However, hedgehog numbers also dropped in areas without badgers.[14]

Reptiles

There are five reptile species of interest commonly found in the study area including two species of insect eating lizards (sand and common lizard), and three species of snakes that predominantly eat small mammals, birds and reptiles. Examples of reptile species of potential interest in and around Kent and their conservation status are highlighted in **Appendix 3d**.

---

13 https://www.greenandblue.co.uk

14 https://www.newscientist.com/article/2171416-britains-hedgehog-population-has-fallen-66-per-cent-in-20-years/#ixzz6Uht98oqB

Insectary plants

Native insectary habitat

The use of non-crop plants as insectary was reported as early as the mid 1960s (van Emden, 1965). It is well documented that predatory arthropods have the capacity to provide 'regulatory' services such as biological pest control in vineyards (Altieri et al., 2005; Nicholls et al., 2000; Paull, 2007; Simpson et al., 2011; Thomson and Hoffmann, 2009a; Viggiani, 2003; Williams and Martinson, 2000). Many natural enemies that attack crop pests are native (Gagic et al., 2018), and an increase in predator richness and abundance is reported where there are stands of native vegetation adjacent to cropping areas (Landis et al., 2005; Landis et al., 2000; Parry et al., 2015). Native perennial ground covers may provide food and habitat, and be more compatible with crop management than exotic annuals (Daane et al., 2018). For example, the longevity of parasitoid wasps increases up to 3.4x when they are exposed to flowering shoots of *Leptospermum* ssp. when compared to buckwheat (Pandey et al., 2018). The presence of insectary resources to nourish predatory arthropods in vineyards may be a promising way to attract and maintain populations of predators. However, there are still many unknowns and of these, the relationships linking non-crop pants, predators, and levels of pest suppression are also particularly complex (Karp et al., 2018).

SNAP

SNAP is an acronym used to describe arthropod 'provisioning' services - shelter, nectar, alternative prey/hosts and pollen (Barnes et al., 2010; Gurr et al., 2017). These are essential resources required by predators to survive and thrive (Altieri and Nicholls, 2004; Coombes and Sotherton, 1986; Corbett and Plant, 1993; Eubanks and Denno, 1999; Landis et al., 2000; van Emden, 2003). Shelter (Gurr et al., 1998; Nentwig et al., 1998), non-host food (Baggen et al., 1999; Wilkinson and Landis, 2005), including nectar (Gillespie et al., 2016; Heil, 2015; Lavandero et al., 2005; Siekmann et al., 2004; Zemenick et al., 2018), pollen (Andrade et al., 2018; Hickman et al., 1995; Patt et al., 2003; Villenave et al., 2006) and alternative prey/hosts (Agusti et al., 2003; Menalled et al., 1999; van Emden, 2003), all to contribute to sustaining populations of predators. While floral resource availability is important, the provision of structural refuges, alternative prey and other attractive qualities may be critical to support particular predatory functional groups (Hogg and Daane, 2015). By focusing on select perennial insectary plants it may be possible to configure plantings to support particular beneficial taxa (Gareau et al., 2013). Future research is required to elucidate the potential of a broad suite of native insectary plants to extend the richness and abundance of predatory arthropods in UK vineyards.

Introduced insectary species

A small suite of plants has come to dominate the habitat management literature and they are frequently used in areas outside of their native ranges (Fiedler and Landis, 2007b; Fiedler et al., 2008; Shields et al., 2016). For example, New Zealand researchers have focussed on the role of exotic species such as buckwheat, *Fagopyrum esculentum* (Berndt et al., 2000; Berndt et al., 2002; Stephens et al., 1998), alyssum, *Lobularia maritima* (Berndt and Wratten, 2005) and phacelia, *Phacelia tanacetifolia* ((Wratten et al., 2003b). These plants have been trialled in hotter and drier climates with varying degrees of success (Bone et al., 2009; Thomson et al., 2010; Thomson and Penfold, 2012) even though they are recognised for their provisioning services overseas (Ambrosino et al., 2006; Fiedler and Landis, 2007a; Wratten et al., 2003a). In non-native habitats introduced plants may not prove to be as easy to establish and maintain. Hence, locally-adapted native plants are preferred as supplementary flora, as they are naturally adapted to local climatic conditions (Danne et al., 2010; Pandey et al., 2018), are consistently reported as having a low occurrence of pests (Parry et al., 2015), a high occurrence of natural enemies (Gagic et al., 2018; Gurr et al., 2017).

It has also been reported that the presence and longevity of pest species, LBAM may be extended in the presence of buckwheat (Begum et al., 2006) and its fecundity could be enhanced by the availability of nectar plants such as borage, *Borago officinalis*, white clover, *Trifolium repens* and brown mustard, *Brassica juncea* (Begum, et al. 2006). Therefore, it appears that the use of some recognised insectary plant species may be counterproductive in some situations.

‘Random’ versus directed approaches

There are two main ways of incorporating insectary plantings in and around production areas.

1. The first is a ‘random’ approach which involves the planting of a diversity of plant types, or seeds mixes with the assumption that ‘diversity is better’, and will be beneficial to pest control (Gurr et al., 2005).
2. The second, targeted and more directed approach is preferred, which takes into account optimal forms of diversity (Jervis et al., 2004), floral resources (Berndt and Wratten, 2005; Berndt et al., 2002), and community dynamics within food webs (Polis and Strong, 1996)

By employing a rigorous screening and ranking process to identify which species will best attract predators, it is less likely that populations of key insect pests will be increased (Fiedler and Landis, 2007a, b), and provisioning benefits that are favourable to predators can be achieved. Desktop assumptions should always be tested in the field.

Screening and ranking candidate insectary species

Careful screening of candidate insectary plants is required to ensure success. They need to be attractive to predators and be easy to establish and maintain, without actively competing with the crop, or providing habitat for pests. A range of functional attributes is deemed important. As a general rule, it is suggested that growers focus their efforts on selecting insectary plants that provide multiple benefits (Fiedler et al., 2008). While it is not the focus of this study, there may be merit in considering crops as dual use insectary plants with the potential to provide value added benefits as a cash crop.

Criteria that were used to guide the process of screening and ranking potential candidate plants (Fiedler and Landis, 2007b; Fiedler et al., 2008; Isaacs et al., 2009; Landis et al., 2000) are presented below:

1) Plant species that are native to the local area, naturally adapted and suitable for use in and around vineyards, with little or no inputs (irrigation, fertiliser) required post establishment.
    a. Use plants that are commercially available, or seed that is easy to source, collect and/or strike.
    b. Plants that can fill flowering gaps to collectively provide floral services throughout the entire year (including evergreen plants that can provide continuity of resources where the focal production crop is dormant as this may create a resource bottleneck).
2) A diversity of different locally-adapted native plants, representing different morphologies and heights.
    a. Flower size - an abundance of smaller flowers is preferred, otherwise bees may deplete the available resources, if only larger flowers are present (Conner and Rush, 1996; Hegland and Totland, 2005).
    b. Flower morphology and accessibility of floral resources - depth and width; some flowers are ‘buzz pollinated’ and their resources can only be accessed by native bees, or the nectar from long, narrow flowers may only be accessed via species with long mouthparts i.e. butterflies (Baggen et al., 1999; Fenster et al., 2004; Houston and Ladd, 2002; Jervis, 1998; Orr and Pleasants, 1996; Patt et al., 2003; Wackers et al., 1996).
    c. Flower colour may impact on attractiveness to different predators and parasitoids. For example, the parasitoid wasp, *Trichogramma carverae* (Oatman and Pinto) (Hymenoptera: Trichogrammatidae) is reported to associate with white flowers of alyssum to a greater extent than to other colours of the same cultivar (Begum et al., 2004).
    d. Flower phenology and synchronicity throughout the year (Long et al., 1998; Rebek et al., 2005; Stephens et al., 1998; Winkler, 2005).
    e. Plants that prolifically produce pollen and/or nectar (Zhao et al., 1992).
3) Attractiveness to predators (Bugg and Wilson, 1989; Maingay et al., 1991; Patt et al., 1997).
    a. The timing of pollen and nectar production coincides with the needs of predators and parasitoids, especially during spring/summer when biocontrol is critical (Colley and Luna, 2000; Jervis et al., 1993; Siekmann et al., 2001).
4) Plants that do not provide resources for herbivorous pests (Ambrosino et al., 2006; Baggen and Gurr, 1998; Fiedler and Landis, 2007a).

Location of insectary plantings

The structure and composition of the adjacent landscape will have an influence on the capacity of the habitat to encourage predatory arthropods into production areas (Colunga-Garcia et al., 1997; Thies et al., 2003). Predatory arthropods will respond differently to the size, location and diversity of insectary plantings (Banks, 2000; Fraser et al., 2008; Tscharntke et al., 2007; Werling and Gratton, 2008). The spatial capacity of predators to prey on pest species will be determined by the distance they disperse into the vineyard from insectary plantings and their movement capabilities (Bugg, 1993; Landis, 1994; Lewis, 1965; Pollard, 1968; Roland and Taylor, 1997). Their migration may also depend on visual preferences and plant volatile cues (Suckling et al., 2012). Local research indicates it may be challenging to encourage certain parasitoid species into the vineyard. Feng et al. (2015) found *Dolichogenidea tasmanica* parasitised the most LBAM larvae in vineyards, while *Therophilus unimaculatus* (Hymenoptera: Braconidae) was most active in adjacent native vegetation.

The spatial area explored by predators during their lifetime may not be sufficient to ensure their movement into the vineyard. 'Islands' of insectary vegetation may be required within production landscapes (Thomas et al., 1991) to facilitate the movement of individuals among the vines. The vineyard floor provides an example of this utility. The mid-row area covers about two thirds of the vineyard area and provides a suitable area to plant native cover crops and facilitate connectivity between patches (Danne et al., 2010; Penfold, 2010; Penfold and McCarthy, 2010; Thomson et al., 2009). It may also be possible to plant low growing insectary plants species that are suited to the undervine area (Penfold, 2018). These plants must be naturally adapted to a site and have a low requirement for water and ongoing maintenance. This is important, so they do not overly compete with grapevines and have a detrimental effect on their vigour.

Spatial movement

Movement between plants enables natural enemies to find floral resources, alternative prey/hosts, and seek refuge from adverse conditions and resource bottlenecks (Schellhorn et al., 2015), which occur when SNAP is less available. Native perennial plants may provide valuable habitat for mobile predators (Letourneau et al., 2012), especially during winter when deciduous plants shed their leaves. Some predators are more mobile than others and have the capacity to colonise areas more quickly (Hogg and Daane, 2018). It is reported that ground beetles move up to 200 m from boundary plantings into adjacent crops, minute pirate bugs and predatory thrips can disperse up to 36 m (Irvin et al., 2018; Nicholls et al., 2001), and parasitoids up to 80 m from buckwheat refuges (Lavandero et al., 2005). Spiderlings are well known for their capacity to passively colonise new areas via aerial dispersal techniques including 'ballooning' which involves moving through the air on silken threads over large distances (Greenstone, 1990; Kevan and Greco, 2001; Simonneau et al., 2016; Venturino et al., 2006). The direction of travel either along or across rows will also be of interest, as this will provide insights to the best location of an insectary. An outstanding issue is the uncertainty that all predators will readily move between native vegetation and vineyards. To build on my research, further work is required to quantify the movement of predators from insectary plants into the vineyard.

Associations between predators and insectary plants

One of the key areas of focus must be to determine when predators are present in the vineyard in relation to abundance of pest species. However there is little information available describing the key relationships between predators in the vineyard and native insectary resources. Wood et al. (2011) found that brown lacewings most likely breed on native wallaby grass, *Rytidosperma bipartitum* and perhaps other grasses. The benefits of planting wallaby grasses are also supported by Thomson and Hoffmann (2009a) who found direct evidence of the effects of the native cover crops in enhancing predators, as predation of LBAM eggs increased when wallaby grasses, *Rytidosperma* ssp. and windmill grass, *Chloris truncata* were present. Danne et al. (2010) found predation levels of sentinel eggs of LBAM were increased in native cover crops, which included species of wallaby grasses, windmill grass, and two species of saltbush, berry saltbush, *Atriplex semibaccata* and sprawling saltbush, *A. suberecta* compared with introduced oats, *Avena sativa*. Similarly, wolf spiders are nocturnal, ground dwelling hunters whose presence is enhanced by grassy understorey, adjacent pasture and woody vegetation (D'Alberto et al., 2012; Thomson and Hoffmann, 2009b; Tsitsilas et al., 2006).

Coccinellid ladybird beetles, which are predators of mealybugs, whiteflies, psyllids, scale, aphids (Hodek and Honek, 2009), lepidopteran (moth) and coleopteran (weevil) immatures (Weber and Lundgren, 2009) and possibly grape phylloxera (Kogel et al., 2013), benefit from nectar and pollen resources (Landis et al., 2000). Thomson and Hoffmann (2006b) found the distribution of spiders, predatory mites, predatory and parasitic flies and parasitoids within a vineyard were positively influenced by native vegetation at the margins. A plant species rich green cover and its appropriate management is also considered as the pre-requisite for a diversified beneficial fauna in the vineyards, as it also causes considerable modifications in the microbiota inhabiting soils (Burns et al., 2016). A number of associations between insectary plants and predatory arthropods have been reported in the UK (**Table 1**).

Table 1. Reported associations between insectary plants and predatory arthropods in the UK[15,16]

Plant		Predatory arthropods and parasitoids found in association
native	field scabious, *Knautia arvensis* fennel, *Foeniculum vulgare* yarrow, *Achillea millefolium*	hornet mimic hoverfly, *Volucella zonaria* hoverflies[17], parasitic wasps (Maingay et al., 1991)
*near native	juniper-leaved thrift, *Armeria juniperifolia*	oak bush cricket, *Meconema thalassinum*
native	possible native substitute sea thrift, *Armeria maritima*	
	not specified	wingless braconid wasp, *Heterospilus hemipterus*[18]
native	Knapweed, *Centaurea* ssp.	hoverfly, *Eristalis* ssp. and *Syrphus* ssp.
native	blackthorn, *Prunus spinosa,* hawthorn, *Crataegus monogyna* ivy, *Hendra helix*	spiders[19]
native	yarrow, *Achillea millefolium* tansy, *Tanacetum vulgare* germander speedwell, *Veronica chamaedrys*	ladybird beetles[20]

* Near native (northern hemisphere excluding UK)

Multi-species interactions

Plant diversification promotes diverse arthropod communities that may provide greater stability of ecosystem provisioning (Lichtenberg et al., 2017). A integrated approach to pest control is needed that embraces a range of predatory arthropods that are either present at the same time, and/or succeed one another (Waterhouse and Sands, 2001). The capacity of multiple species to provide pest control is enhanced by their capacity to attack different life stages of the pest (Cardinale et al., 2003; Holt and Lawton, 1994; Losey and Denno, 1999). These predators may be supported by multiple insectary resources of different strata, located throughout the production landscape. It is also reported that the populations of predators may be more abundant in six year old than one year old insectary plantings (Denys and Tscharntke, 2002). This emphasizes the importance of habitat age for natural enemies and possible biological control. Multi-species interactions will occur between predator and prey.

15 https://www.rhs.org.uk/science/conservation-biodiversity/plants-for-bugs

16 https://www.jstor.org/stable/2260104?read-now=1&seq=3#metadata_info_tab_contents

17 Lavelle, C and M (2009) The illustrated practical guide to wildlife gardening, Anness Publishing, London, UK

18 http://bit.ly/2vIRafI

19 Lavelle, C and M (2009) The illustrated practical guide to wildlife gardening, Anness Publishing, London, UK

20 Lavelle, C and M (2009) The illustrated practical guide to wildlife gardening, Anness Publishing, London, UK

Seasonal synchrony and overwintering

The seasonality of ecosystem services can be extended by planting a range of suitable native perennial plants that provide floral resources at key times. This helps to ensure habitat permanency and synchrony of provisioning services is continual throughout the year (Losey and Denno, 1999). An understanding of the overwintering requirements of predators may be critical to ensuring that their population base is sufficiently large at the start of the following season (Horton and Lewis, 2003; Lorenzon et al., 2015; Nicholls et al., 2001; Schmidt et al., 2005; Sotherton, 1984; Stephens et al., 2006; Thomas et al., 1991). Similarly, access to suitable floral resources and alternative prey via native evergreen shrubs may help to sustain predatory populations throughout the period of grape vine dormancy (Schellhorn et al., 2015).

Manipulating the structure and habit of insectary plantings

It may be possible to manipulate the flowering time, structure and habit of insectary plants. For example, mowing of grass swards can be used to manipulate the timing of flowering and the provision of pollen for predators such as predatory mites (Smith and Papacek, 1991). Mowing of alternative rows can be used to provide habitat and shelter for predators, including spiders that live and reproduce in long grass (Bernard et al., 2006a; Wood et al., 2011). Alternatively, grasses can be slashed to a minimum height of 10 cm to preserve habitat. It may be possible to prune or hedge woody plant species to induce a density of flower clusters or encourage a compact habit. Some species may also provide concurrent flowering over several months. More work is needed on the capacity to manipulate insectary plants to engineer structure and inflorescence production at times that are of benefit to production landscapes.

Drawbacks of using native plants as insectary

There are a number of potential drawbacks of using native perennial plants. For example, the time taken to establish woody plants may take several years. Floral provisions and shelter may be low compared to annuals until perennial plants are well established (Isaacs et al., 2009). It may be difficult to source seeds locally, or native seed of local provenance in commercial quantities, and it may be expensive. Seed may have low germination and viability and should be tested if sourced from a reseller. However, the initial costs can be amortised over the life of the planting and they may provide multiple ecosystem benefits.

Plants for bugs

The 'Plants for Bugs' project identified a suite of native plants and the pollinators found in association in the UK. The research was conducted at RHS Garden Wisley, Surrey just north of the Surrey Hills AONB. The arthropods cited in the study are categorised into different functional groups including those that eat decomposing plant material (detritivores), those whose diet is plant material (herbivores) and those that feed on other invertebrates (predators).

The replicated field study found that the best way to support the presence of invertebrates and promote a healthy ecosystem is to choose plantings biased towards British native plants and encourage dense vegetation. Near-native (northern hemisphere) and exotic (southern hemisphere) plants also have a positive role to play in providing a habitat for invertebrates, offering good evergreen winter cover and supporting pollinators when in flower. There was a greater abundance of total pollinators recorded on native and near-native treatments compared with the exotic plots. For more information visit https://www.rhs.org.uk/science/conservation-biodiversity/plants-for-bugs

Minimising disruption in the vineyard

Pesticide application is often imprecise and it is estimated that 98% of sprayed insecticides and 95% of herbicides miss their intended target species (Miller, 2004). The overuse of pesticides may also result in a range of unintended consequences including the development of resistance in some arthropod pests (Whalon et al., 2008), including mealybugs, scales, moths, and mites. Optimal biological control of economically damaging insect pests in vineyards can be achieved by minimising the use of broad-spectrum insecticides that may kill and often result in collateral damage to predator populations (Bernard et al., 2007). The use of non-selective pesticides should be eliminated if insectary habitat is to be established nearby (Winkler, 2005).

Ideally pest control is achieved using biological control, with the targeted application of selective insecticides used to reduce pest populations to below damaging levels, only if required. Agricultural systems are typically difficult environments for predatory arthropods to thrive because of the high level of disruption.

Greater stability of arthropod populations (Landis et al., 2005; van Emden and Williams, 1974) is likely in vineyards where tillage and chemical inputs are minimised (McLaughlin and Mineau, 1995; Nash et al., 2008) and a greater diversity and complexity of insectary plants is promoted.

There are a range of factors which favour augmented biocontrol of insect pest including cancellation of pesticide registrations, pesticide resistance, and the expansion of organic agriculture (Warner and Getz, 2008). Biological control is one of the most important alternatives to conventional pesticide use in pest management. Biological control is free of many problems associated with pesticide use, such as pest resistance, environmental pollution, and worker health impacts.

There are three simple steps growers can adopt to encourage predator arthropod populations including:

1. Firstly, reduce broad-spectrum pesticide use. Only use targeted application of selective insecticides to reduce pest populations to below damaging levels, if they are required.
2. Secondly, consider adopting a truly integrated approach to pest management, which incorporates cultural and biological control, as a longer-term approach to integrated pest management (IPM). Monitor populations of predatory arthropods and augment with the release of biological control agents if required.
3. Thirdly, incorporate suitable, locally-adapted, native insectary plants boost the presence of predators and parasitoids in and around production systems throughout the entire year.

Information about UK pesticide use and impacts of chemicals on predatory arthropods is presented in **Appendix 4**.

Assumptions about native insectary

Based on the information above, I have made the following assumptions regarding the interactions of arthropods with native insectary plants:

1. Predators will naturally occur in remnant vegetation and vineyards in different abundances and diversities.
2. Natural enemies will benefit from the provision of insectary plantings.
3. Native plant species will vary in their capacity to offer provisioning services to different predatory arthropods.
4. Insectary plantings will attract different natural enemies at different times of the year, and this will depend on their capacity to provide the required provisioning services.
5. The strategic use of native insectary plantings, both spatially and temporally is important to deliver these services when they are needed.
6. Natural enemy abundance will decline with greater distance away from insectary plantings.
7. The capacity of insectary plants to provide provisioning services will increase as they reach maturity.
8. The capacity of natural enemies to control vineyard pests will differ, and will be dependent on host and prey densities.
9. Multi-species interactions will occur between natural enemies and prey species.
10. The biological control provided by generalist predators will differ depending on the resources available, vineyard management practices employed and the seasonal conditions experienced.

International examples

These examples are presented from a travel report of Bordeaux, Verona and Lausanne by the author.[21]

Château d'Yquem: Sauternes appellation, Gironde department, Graves (Left Bank), France

Figure 8. The Château d'Yquem vineyard with flowers retained along the drainage area (left) and roses planted adjacent to strainer posts (right). Photos: Mary Retallack

Château Coutet: Saint-Émilion, Libourne, (Right Bank), France

Figure 9. Château Coutet vineyard mid-row biodiversity (left) and VITIROVER in action trimming volunteer grass cover (right). Photos: Mary Retallack

Vignobles Bardet: Saint-Émilion, Libourne (Right Bank), France

Figure 10. Vignobles Bardet hedgerows along a drain (left) and native camomile insectary (right). Photos: Mary Retallack

[21] https://www.adelaidegreatwinecapital.com.au/blog/blog_posts/a_viticulturist_on_tour

Domaine Emile Grelier: ***Gironde department, Lapouyade (Right Bank), France***

Figure 11. Domaine Emile Grelier agroforestry and bat boxes (left) agroforestry plants established in the vine row (right). Photos: Mary Retallack

World Biodiversity Association: ***Verona, Italy***

Figure 12. Assessing water quality (left) and arthropod diversity in the vineyard (right). Photos: Mary Retallack

Figure 13. Assessing lichen as an indicator of air quality (left) and wine with the Biodiversity Friend logo (right). Photos: Mary Retallack

Fondazione Edmund Mach: ***Veneto, province of Trentino, Italy***

Figure 14. Lavender at the end of rows (left) and a butterfly on lavender (right). Photos: Mary Retallack

HES-SO Ecole d'ingénieurs de Changins: Lausanne, Switzerland

Figure 15. Changins cover crop trial (left) and Matteo Mota at Changins (right). Photos: Mary Retallack

McLaren Vale and Barossa wine regions, South Australia

Figure 16. Native ground cover, insectary plants establishing in the undervine area (left) and insectary shrubs at the end of strainer posts (right). Photos: Mary Retallack

CHAPTER 4: POTENTIAL CANDIDATE NATIVE PLANT SPECIES

This chapter applies the process covered in Chapter 3 for selecting potential candidate native plant species that can be incorporated in and around vineyards as functional supplementary flora.

Background

Kent Downs AONB Vision

The Kent Downs Area of Outstanding Natural Beauty Draft Management Plan 2020 2025 provides clear targets for environmental stewardship and ecological restoration.

> *"By 2030… the distinctive wildlife habitats of the Kent Downs are understood better, enjoyed and celebrated and are in favourable, resilient condition with individual characteristic species flourishing."*

There is also reference to the desire for intended biodiversity net gain. This is in keeping with the functional biodiversity benefits that can be realised via the harnessing of locally-adapted species and their contributions to ecosystem services.

> *"In 2030… the Kent Downs AONB is a place where agriculture takes and is appreciated for a pivotal role in the conservation of natural beauty and landscape qualities and character. Sustainable farming is the predominant land-use of the AONB and is an increasingly important part of the Kent Downs contribution to achieving net zero carbon emissions. Naturally diverse permanent grasslands are well managed. The flourishing number of vineyards are managed in a way that conserves the characteristics and qualities of the AONB. The high quality products of the Kent Downs are commercially successful and high environmental quality is a market advantage."*[22]

Overview

The native vegetation of the Kent Downs AONB is believed to have been broadleaved woodland. This would have been varied in structure and composition, with open glades and patches of grassland and heath created by fallen trees and grazing animals, and chalk grassland refugia found on the exposed cliff tops.[23] This provides a valuable insight to the types of locally-adapted plants and habit that can be used to inform habitat restoration in and around vineyards.

Context

Protected landscape

The Kent Downs AONB is recognised as an IUCN Category V Protected Landscape. The primary objective of Category V status is "To protect and sustain important landscapes and the associated nature conservation and other values created by interactions with humans through traditional management practices." and "Viticulture is a high value, high profile activity, generating relatively high levels of employment when compared with other agricultural uses. Careful vineyard management can present opportunities to create new areas of flower-rich grasslands and species rich hedgerows.*"*[24]

---

[22] https://kccconsultations.inconsult.uk/consult.ti/kentdowns_aonb/consultationHome

[23] https://kccconsultations.inconsult.uk/consult.ti/kentdowns_aonb/consultationHome

[24] https://kccconsultations.inconsult.uk/consult.ti/kentdowns_aonb/consultationHome

Chalk grassland

"There are now only 700 ha of unimproved chalk grassland left within the Kent Downs AONB, of which 60 per cent are designated Sites of Special Scientific Interest (SSSIs). Many of the plants are specifically adapted to survive in the poor alkaline soils, where the porous chalk underneath results in localised drought conditions in the summer."

"As well as the flora, this specialised habitat also supports a wide variety of fauna, especially insects and butterflies. Good chalk grassland management relies on the creation of a mosaic habitat, a patchwork of different habitats is created throughout the sward to ensure that the maximum number of species is encouraged. It should also be recognised that the scrub itself is an integral part of the chalk grassland and benefits many different birds and invertebrates. Scrub should therefore not be completely eradicated from the site, rather a balance sought between the scrub and the chalk grassland to enable a greater range of species to thrive than either vegetation type alone could support."[25]

Grazing

Natural England recommends that chalk grassland be managed by grazing for at least ten weeks in each year without damaging the sward. The aim is to remove last year's growth to achieve an average sward height of 75 mm (3 inches) by the end of the summer. This should be achieved through winter grazing to leave shorter sward, the 3 inches height is the result of spring and summer re growth.

See the 'Chalk grassland in the Kent Downs landscape' fact sheet for more information about managing chalk grasslands, grazing approaches and recommended stocking rates https://s3-eu-west-1.amazonaws.com/explore-kent-bucket/uploads/sites/7/2018/04/18113959/CHALK_GRASSLAND.pdf

Meadow grassland[26]

As a result of the ease in which meadow grassland can be converted for agricultural use, meadow grassland has become a rare and declining landscape feature with 97% being lost in the UK since the 1930s. Meadow grassland accounts for 20% of all semi-natural habitats in Kent but the quality and extent of these vary considerably especially where meadows have become isolated. Grassland is an important habitat for many species of plants and animals ranging from the green-winged orchid and fox sedge to the marsh fritillary butterfly.

It is recommended when cutting to leave an uncut area several metres wide along one edge of the meadow. This acts as a refuge for beneficial insects to repopulate the meadow as the vegetation grows again and important for mammals creating a safe corridor. Alternatively, growers may cut to a minimum of 10 cm in height to retain a stubble habitat area for predatory arthropods. Ideally, grasses will be trimmed after they have flowered and set seed for the following season.

Unimproved and improved meadow grasslands

Meadow grassland falls into one of three categories including:

- **Unimproved' meadow grassland**: is grassland in its natural and original state that has not had significant amounts of fertiliser added. Plant species have adapted to low fertility levels. It is characterised by a colourful mix of finer grasses, wildflowers and herbs.
- **Improved' meadow grassland**: is where the land has been sown for agricultural or recreational purposes and fertilisers have been applied. It normally has a poor variety of species, often dominated by ryegrass, and possesses dominant grass species.
- **Semi-improved grassland**: is in-between improved and unimproved. It may have been ploughed in the past and had some artificial fertiliser added. They have reduced species diversity but retain a number of native grasses and wildflowers and can therefore still be of high conservation value.

---

[25] https://s3-eu-west-1.amazonaws.com/explore-kent-bucket/uploads/sites/7/2018/04/18113959/CHALK_GRASSLAND.pdf

[26] https://s3-eu-west-1.amazonaws.com/explore-kent-bucket/uploads/sites/7/2018/04/18123740/MEADOW_GRASSLAND.pdf

Restoration techniques

Sowing a seed mix suitable for the soil type is essential to obtain the right type of grassland and to get the best establishment. Seeds used should only be from native species and seeds collected from local stock are preferred. Using local seeds will increase the likelihood of successful restoration and maintain the local genetic variation of plants. A common seed rate for wildlife conservation grass and wildflower establishment is grass seed 20 kg/ha, wildflower seed 1 kg/ha, at a ratio of 80% grasses to 20% wildflowers. See the 'Meadow grassland in the Kent Downs landscape' fact sheet for more information on land preparation, restoration techniques and ongoing management https://s3-eu-west-1.amazonaws.com/explore-kent-bucket/uploads/sites/7/2018/04/1812370/MEADOW_GRASSLAND.pdf

Hedgerows[27]

Hedgerows provide valuable habitats for wildlife and the 'traditional' hedge is commonly used to mark field boundary. Where livestock such as sheep are present, it may also provide a barrier sufficient to prevent their escape. A healthy traditional hedge may vary in height considerably and can be anything from 1 m to 2 m and typically comprises between one and up to as many as fifteen native species of plants, but is often dominated by hawthorn.

A shelter hedge is grown in areas where strong winds would otherwise damage valuable crops. Tree species traditionally grown are typically large-leaved, such as beech, poplar or alder, planted in single lines and allowed to grow to 3 m to 4 m tall.

The value of evergreen plants

Seasonal variation may occur between different functional groups of organisms depending on the habitat resources available. Deciduous plants may create a resource bottleneck when they lose their foliage during winter. Endeavour to include evergreen plants in all planting schemes as they provide valuable winter cover. Examples of evergreen plants include native holly, *Ilex aquifolium*, butcher's broom, *Ruscus aculeatus,*[28] common box, *Buxus sempervirens* as well as a selected herbaceous ground cover plants ground pine, *Ajuga chamaepitys,* and glaucous sedge, *Carex flacca*.

Frost

Frost can pose a significant issue to inland wine growing regions in the UK[29] and the strategic use of supplementary flora is warranted to ensure cold air flows away from grapevines. Low growing perennial grasses with slender flower stalk are preferred in high risk areas, so they do not prevent airflow and/or increase the height of cold air near the cordons.

Habitat for endangered species

The Kent Habitat Survey 2012 identified the following endangered or threatened species:[30]

- **Traditional orchards:** The noble chafer beetle, *Gnorimus nobilis*, a rare beetle associated with this habitat type, is the subject of a UK biodiversity species action plan.
- **Lowland calcareous grassland**: Rich invertebrate communities are associated with this type of grassland, with scarce species such as adonis blue, *Polyommatus bellargus* and silver-spotted skipper, *Hesperia comma* requiring the warm, south-facing slopes and specialist vegetation found in calcareous grassland within Kent.

The status of native predatory/insectivorous birds, microbats, and reptiles is highlighted in **Appendix 3.**

27 https://s3-eu-west-1.amazonaws.com/explore-kent-bucket/uploads/sites/7/2018/04/18123740/MEADOW_GRASSLAND.pdf

28 https://www.rhs.org.uk/science/pdf/conservation-and-biodiversity/wildlife/Plants-for-Bugs-Bulletin-3-Gardens-as-habitats-for.pdf

29 http://www.englishwine.com/uk_harvest_report_2017.pdf

30 https://www.kent.gov.uk/__data/assets/pdf_file/0020/95114/Kent-Habitat-Survey-2012-section-5-results-and-habitat-distribution-by-districts.pdf

International insights on enhancing functional biodiversity

Appropriate farming practices and agro-ecosystem planning may play a crucial role in functional biodiversity enhancement (Terres, 2006), for example it is recommended to:

- Plant shrubs at the ends of each row, in places where they do not interfere with work.
- There should be at least 2 x 20-metre hedges per hectare. Hedges constitute biological hotspots, acting as corridors linking up ecological areas.
- The provision of compensatory areas (at least 50 m^2 per hectare) as diversity hotspots both within and on the perimeter of a vineyard.
- The provision of structural elements, such as piles of stones or wood. These provide a habitat for reptiles and insects. The provision of nesting aids for bees, insects and birds. These can be integrated into trellis posts. Perches for birds of prey, which can also keep rodent population in check.

Advantages of native ground cover

Native ground covers provide the following benefits (Stefanucci et al., 2018):

- **Pest control:** The presence of a diversified ground cover increases the abundance of natural enemies of pests (predators and parasitoids), as it provide them natural resources (pollen, nectar, alternative preys, shelter and water).
- **Reduce the risk of erosion and water runoff:** The presence of ground cover reduces the velocity of raindrops before they hit the soil surface, preventing soil from splashing and running off of nutrients.
- **Improvement of soil fertility:** Besides increasing soil nitrogen and organic matter, decomposed cover crops increase the soil cation exchange capacity.
- **Improvement of soil structure and water holding capacity:** Ground cover roots help aggregate soils as fine roots penetrate the soil profile (especially grasses). Large tap roots help to create macropores when the plants die, which greatly assist the movement of air and water into the soil profile. Also organic matter is a food source for macro and micro-organisms. Many of them assist in recycling cover crops into the soil, while improving soil physical qualities. Particularly the increasing of earthworm populations is a good indicator of soil health and improved physical conditions.
- **Improvement of beneficial microbial communities**. Arbuscular mycorrhizal fungi are important to grapevine nutrition. Cover crop strategies can increase the likelihood of fungal colonisation of grapevine roots, facilitating the transfer and uptake of nutrients from cover crops to grapevines. Site characteristics and vineyard management strategies that foster root growth, such as planting vines in soil with adequate texture and structure and irrigating vines during periods of rapid root growth, benefit grapevine roots and mycorrhizal fungi will likely have greater effects on grapevine nutrition than practices that focus solely on enhancing populations of mycorrhizal fungi, such as the application of fungal inoculants to vineyard soil (Baumgartner, 2003).

Advantages of hedgerows

Native hedgerows provide the following benefits (Stefanucci et al., 2018):

- They serve as habitat for beneficial insects, pollinators and another wildlife.
- Protect against rain and erosion, wind and sun.
- Stabilise waterways. Increasing surface water infiltration, reducing non-point source water pollution and groundwater pollution. Regulating soil moisture content.
- Buffer, reducing pesticide drift.
- Act as living fences and boundary lines.
- Provide an aesthetic and aromatic resource (ecotourism, image of the vineyard for the consumer), or can be used as a screening plant to soften the landscape.

Potential candidate native insectary plant species

Considerations

Criteria used to guide the process of screening and ranking candidate plants:

- Select plant species that are native and naturally adapted to the local area. The status of plants was checked using https://www.kentwildlifetrust.org.uk
- Plants that are commercially available, or seed that is easy to source, collect and/or strike.
- Plants that provide floral pollen and/or nectar resources at key periods coinciding with key grapevine phenological periods i.e. in the lead up to flowering (April/May), flowering (June/early July), veraison (August) and harvest (September/October).[31] The corresponding flowering times (and flower colour are presented in the potential candidate insectary plant list.
- Plants that can fill flowering gaps to collectively provide floral services throughout the entire year including evergreen plants that can provide continuity of resources where the focal production crop is dormant to avoid a resource bottleneck.
- A diversity of different locally-adapted native plants, representing different morphologies and height strata. Low growing species < 30 cm may be suitable to trial in the mid-row and/or undervine area if they do not need to be trimmed
- Attractiveness to a range of predators (arthropods, lizards, insectivorous birds, microbats etc.)
- The timing of pollen and nectar production coincides with the needs of predators and parasitoids, especially during spring/summer when biocontrol is critical.
- Plants that do not provide resources for herbivorous pests. NB: Plants listed as potential breeding sites for economically damaging pests have been flagged and may need to be removed from the list if they are regarded as high risk.

Potential candidate native species that could be re-introduced to enhance functional biodiversity and wider ecosystem services (pending in-field suitability assessment) are identified in **Table 2**.

Notes

The following plant list has been compiled from information available in the public domain. Known host plants for tortricid leafrollers[32] and SWD have been highlighted in grey (and can be removed from the list if required). If a plant is a recorded host for an economically damaging insect species, with a diversity of plants this risk may be mitigated in part, as there are likely to be many predators also present that have the capacity to provide biocontrol. This assumption needs to be tested in the field.

Please note this list is not exhaustive and needs to be verified with specialists with local knowledge of these plants and the assumptions tested via field trials to determine their suitability. Some naturalised species with high insectary value are included, as we are working within a modified horticultural landscape and functional benefits are anticipated.

Some plants like deptford pink, *Dianthus armeria*, narrow-fruited cornsalad, *Valerianella dentata,* ground pine, *Ajuga chamaepitys,* wild pansy, *Viola tricolor*, rough poppy, *Papaver hybridum a*re classified as either endangered, nationally threatened or rare on the Vascular Plant Red Data List for Great Britain. Protected in the UK under the Wildlife and Countryside Act, 1981. Priority Species under the UK Post-2010 Biodiversity Framework. It may be possible to source local seed and develop a seed production area similar to the way that hay (from an excellent unimproved meadow) is cut around August or September and broadcast on areas where higher levels of diversity are desired.

To view pictures of many of the wildflowers listed see https://www.kentwildlifetrust.org.uk/wildlife-explorer/wildflowers or https://wildseed.co.uk/species/category/wild-flowers

[31] http://www.englishwine.com/uk_harvest_report_2017.pdf

[32] http://www.tortricidae.com/foodplantdatabase.asp

Table 2. Potential native plants to trial in the UK (pending in-field suitability assessment)[33,34]

Habit	*Genus*	Species	Common name	Floral resources		Ever-green	Height (m)	Flowering time and colour											
				Pollen	Nectar			J	F	M	A	M	J	J	A	S	O	N	D
Tree	*Acer^1*	*campestre*	field maple	yes	yes		8 to 15												
	Alnus1	*glutinosa*	alder	yes	yes		20												
	*Betula^*	*pendula*	silver birch	yes	yes		25												
	*Carpinus^*	*betulus*	hornbeam	yes	yes		15 to 20												
	*Corylus^*	*avellana*	hazel	yes	no		8 to 10												
	Fagus ^	*sylvatica*	common beech	yes	yes		25 to 35												
	*Fraxinus^*	*excelsior*	ash	yes	no		15 to 35												
	Ilex^2	*aquifolium*	holly	yes	yes	yes	15												
	Populus1	*x canadensis*	hybrid black poplar	yes	yes		30												
	Quercus^1	*petraea*	sessile oak	yes	yes		20 to 40												
	Quercus^1	*robur*	English oak	yes	yes		15 to 20												
	Rhamus^12	*carthartica*	purging buckthorn	yes	yes		10 to 12												
	Sorbus^2	*aria*	common whitebeam	yes	yes		8 to 15												
Shrub	*Buxus^*	*sempervirens*	common box	yes	yes	yes	6												
	Crataegus^12	*laevigata*	midland hawthorn	yes	yes		8 to 12												
	Crataegus^12	*monogyna*	common hawthorn	yes	yes		5 to 14												
	Cornus^12	*sanguinea*	dogwood	yes	yes		2 to 6												
	Cytisus^1	*scoparius*	common broom	yes	yes		3												
	Euonymus^12	*europaeus*	spindle	yes	yes		6 to 9												
	Frangula^12	*alnus*	alder buckthorn	yes	yes		3 to 6												
	Ligustrum^12	*vulgare*	wild privet	yes	yes		3 to 5												
	Prunus^12	*spinosa*	blackthorn	yes	yes		6 to 7												
	Rosa^12	*canina, arvensis, rubiginosa*	sweet briar	yes	yes		1 to 5												
	Ruscus^2	*aculeatus*	butcher's broom	yes	no	yes	1												
	Ulex^1	*europaeus*	common gorse	yes	yes	yes	2 to 3												
	Viburnum^12	*opulus*	guelder-rose	yes	yes	semi	4 to 5												
	Viburnum^12	*lantana*	wayfaring tree	yes	yes	semi	4												
Wildflower	*Achillea**	*millefolium*	yarrow	yes	yes		0.3 to 0.6												
	*Agrimonia**	*eupatoria*	hemp agrimony	yes	yes		1.5												
	*Anthyllis**	*vulneraria*	kidney vetch	yes	yes		0.3												
	*Betonica**	*officinalis*	common hedgenettle	yes	yes		0.3 to 0.6												
	*Blackstonia**	*perfoliata*	yellow-wort	yes	yes		0.1 to 0.2												
	Campanula	*rotundifolia*	harebell	yes	yes		0.4												

33 https://www.rhs.org.uk/Science-Environment/PDF/Conservation-and-biodiversity/Wildlife/Plants-used-Plants-4-Bugs.pdf

34 https://www.kentwildlifetrust.org.uk/

Table 2. Potential native plants to trial in the UK (pending in-field suitability assessment) continued

Habit	*Genus*	Species	Common name	Floral resources		Ever-green	Height (m)	Flowering time and colour											
				Pollen	Nectar			J	F	M	A	M	J	J	A	S	O	N	D
Wildflower	*Centaurea**	*nigra*	common knapweed	yes	yes		0.7												
	*Centaurea**	*scabiosa*	greater knapweed	yes	yes		0.9												
	*Centaurium**	*erythraea*	common centaury	yes	yes		0.3												
	*Chamerion**	*angustifolium*	rosebay willowherb	yes	yes		1.5												
	*Cruciata**	*laevipes*	crosswort	yes	yes		0.5												
	*Daucus**[1]	*carota*	wild carrot	yes	yes		0.8												
	*Dianthus**[1]~	*armeria*	deptford pink	yes	yes		0.6												
	*Echium**	*vulgare*	viper's bugloss	yes	yes		0.3 to 0.8												
	Eupatorium^	*cannabinum*	hemp agrimony	yes	yes		1.5												
	*Filipendula**	*ulmaria*	meadowsweet	yes	yes		1.3												
	*Filipendula**	*vulgaris*	dropwort	yes	yes		0.3												
	*Foeniculum**	*vulgare*	fennel	yes	yes		2												
	Fumaria	*densiflora*	dense-flowered fumitory	yes	yes		0.2 to 0.6												
	*Fumaria**	*officinalis*	common fumitory	yes	yes		0.1												
	*Galium**	*verum*	lady's bedstraw	yes	yes		0.3												
	*Hippocrepis**	*comosa*	horseshoe vetch	yes	yes		0.2												
	*Knautia**	*arvensis*	field scabious	yes	yes		0.8												
	*Lamium**	*album*	white dead-nettle	yes	yes		0.8												
	*Lamium**	*amplexicaule*	henbit dead-nettle	yes	yes		0.3												
	*Lamium**	*purpureum*	red dead-nettle	yes	yes		0.3												
	*Leontodon**	*hispidus*	rough hawkbit	yes	yes		0.1 to 0.4												
	*Leucanthemum**	*vulgare*	oxeye daisy (moon daisy)	yes	yes		0.6												
	*Lotus**	*corniculatus*	common bird's-foot trefoil	yes	yes		0.4												
	*Malva**	*moschata*	musk mallow	yes	yes		0.6 to 0.9												
	*Medicago**[1]	*lupulina*	black medic	yes	yes		0.5												
	*Ononis**	*ripens*	restharrow	yes	yes		0.7												
	*Ononis**	*spinosa*	spiny restharrow	yes	yes		0.1 to 0.8												
	*Origanum**	*vulgare*	wild marjoram	yes	yes		0.5												
	Papaver~	*hybridum*	rough poppy	yes	yes		0.4												
	*Papaver**	*rhoeas*	common poppy	yes	yes		0.8												
	*Phyteuma**	*orbiculare*	round headed rampion	yes	yes		0.5												
	*Plantago**[1]	*media*	hoary plantain	yes	no		0.3												
	*Polygala**[1]	*vulgaris*	common milkwort	yes	yes		0.3												

Table 2. Potential native plants to trial in the UK (pending in-field suitability assessment) continued

Habit	*Genus*	Species	Common name	Floral resources		Ever-green	Height (m)	Flowering time and colour											
				Pollen	Nectar			J	F	M	A	M	J	J	A	S	O	N	D
Wildflower	*Poterium**	*sanguisorba*	salad burnet	yes	no		0.3 to 0.6					purple	purple	purple	purple	purple			
	*Primula**	*veris*	cowslip	yes	yes		0.3				yellow	yellow							
	*Prunella**	*vulgaris*	selfheal	yes	yes		0.2						pink	pink	pink	pink	pink	pink	
	*Ranunculus*1*	*bulbosus*	bulbous buttercup	yes	yes		0.1 to 0.3			yellow	yellow	yellow	yellow						
	*Scabiosa**	*columbaria*	small scabious	yes	yes		0.3 to 0.6						lilac	lilac	lilac	lilac	lilac		
	*Tanacetum*1*	*vulgare*	tansy	yes	yes		0.9							yellow	yellow	yellow	yellow		
	Valerianella~	*dentata*	narrow-fruited cornsalad	yes	yes		0.1 to 0.2						white	white	white				
	*Veronica**	*chamaedrys*	germander speedwell	yes	yes		0.2				blue	blue	blue						
	*Vicia*1*	*hirsuta*	hairy vetch	yes	yes		0.7 to 0.9					yellow	yellow	yellow	yellow				
	Viola~*	*tricolor*	wild pansy	yes	yes		0.2				purple	purple	purple	purple	purple	purple			
Ground cover	*Ajuga*~*	*chamaepitys*	ground pine	yes	yes	yes	0.1 to 0.3				yellow	yellow							
	*Carlina**	*vulgaris*	Carline thistle	yes	yes		0.1 to 0.4							brown	brown	brown			
	*Clinopodium**	*vulgare*	wild basil	yes	yes		0.5							pink	pink	pink			
	*Euphrasia**	*officinalis*	eyebright	yes	yes		0.3					white	white	white	white	white			
	*Helianthemum**	*nummularium*	common rockrose	yes	yes		0.4						yellow	yellow	yellow	yellow			
	*Primula**	*vulgaris*	primrose	yes	yes		0.2	cream	cream	cream									cream
	Reseda1	*lutea*	wild mignonette	yes	yes		0.3 to 0.7						yellow	yellow	yellow	yellow			
	*Rhinanthus**	*minor*	yellow ratttle	yes	yes		0.3 to 0.5				yellow	yellow	yellow	yellow					
	*Thymus**	*serpyllum*	wild thyme	yes	yes		0.02						pink	pink	pink	pink			
	*Trifolium*1*	*pratense*	red clover	yes	yes		0.2 to 0.3					pink	pink	pink	pink	pink	pink		
Grasses	*Avenula**	*pratensis*	sheep's fescue, meadow oat-grass	yes			0.3 to 0.7					cream	cream	cream					
	*Briza**	*media*	quaking grass	yes			0.6 to 0.9						cream	cream	cream				
	*Cynosurus**	*cristatus*	crested dogstail	yes			0.5						cream	cream	cream				
	*Deschampsia**	*cespitosa*	tufted hair grass	yes			1						cream	cream	cream				
	*Festuca**	*ovina*	sheep's fescue	yes			0.1 to 0.4					cream	cream						
	*Festuca**	*rubra*	slender-creeping red-fescue	yes			0.6					cream	cream	cream					
	*Koeleria**	*macrantha*	crested hair-grass	yes			0.5						cream	cream					
	*Phleum**	*bertolonii*	smaller cat's-tail	yes			0.45						pale green	pale green	pale green				
	*Trisetum**	*flavescens*	yellow oat-grass	yes			0.6 to 0.8						pale green	pale green					

Table 2. Potential native plants to trial in the UK (pending in-field suitability assessment) continued

Habit	*Genus*	Species	Common name	Floral resources		Ever-green	Height (m)	Flowering time and colour											
				Pollen	Nectar			J	F	M	A	M	J	J	A	S	O	N	D
Wet areas	*Carex**	*flacca*	glaucous sedge	yes		yes	0.1 to 0.5												
	*Lythrum**	*salicaria*	purple-loosestrife	yes	yes		1.5												
Climber (outside the vineyard)	*Clematis*^[1]	*vitalba*	old man's beard	yes	yes		12												
	Hedera^[1,2]	*helix*	ivy	yes	yes	yes	20 to 30												
	Lonicera^[1,2]	*periclymenum*	common honeysuckle	yes	yes		5												
	*Vicia**[1]	*cracca*	tufted vetch	yes	yes		2												
	*Vicia**[1]	*sativa*	common vetch	yes	yes		0.75												
	*Vicia**[1]	*sepium*	bush vetch	yes	yes		1												

* seed available commercially

^ plants available commercially

~ classified as either endangered, near or nationally threatened on the Vascular Plant Red Data List for Great Britain. Protected in the UK under the Wildlife and Countryside Act, 1981. Priority Species under the UK Post-2010 Biodiversity Framework.

[1] potential host for tortricid leafroller moth larvae (insect pest)

[2] potential host for spotted wing drosophila (insect pest)

CHAPTER 5: RECOMMENDATIONS LINKED TO PUBLIC GOODS

This chapter outlines the links between environmental risks and the mitigation options that are available that demonstrate public good benefits.

ELM scheme

The new ELM scheme will be founded on the principle of 'public money for public goods'. Farmers will be rewarded for actions that deliver public goods such as improved air, water and soil quality, increased biodiversity, climate change mitigation, cultural benefits, and better protection of historic environments following these six themes:

7. Ensuring clean and plentiful water,
8. Clean air,
9. Mitigation and adaption to climate change,
10. Protection from and mitigation of environmental hazards,
11. Thriving plants and wildlife, and
12. Beauty, heritage and engagement.

In multifunctional agricultural systems, functional biodiversity provides important ecological services, such as the improvement of soil fertility and biota, increasing organic matter, improvement of soil structure, storage of carbon, management of undesirable organisms (conservation biological control) and regulation of hydrological cycle and microclimate (Stefanucci et al., 2018).

In addition, genetic diversity of agricultural biodiversity provides species with the ability to adapt to changing environment and evolve, by increasing their tolerance to frost, high temperature, drought and water-logging, as well as their resistance to particular diseases, pests and parasites.[35]

Recommendations linked to the public goods

Measures that grape growers can take to demonstrate public goods against each theme are presented below in **Tables 3 to 8**.

[35] https://www.cbd.int/agro/importance.shtml

Clean and plentiful water

Ensuring clean and plentiful water by reducing spray applications and pesticide loss to ground and buffering against any future irrigation requirements.

Table 3. Demonstrating public goods links to ensuring clean and plentiful water[36]

ELM public goods: Clean and plentiful water				
Key vineyard environmental risks	**Commercially sensible mitigants (normal market conditions)**	**Enhanced public good mitigant**	**Existing scope of Countryside Stewardship mitigation**	**Natural capital (NC) impact**
Pesticide and fertiliser leeching Off target spray drift impacting on water quality Pollution and eutrophication of water bodies **References** Currently about half of the AONB is covered by a Nitrate Vulnerable Zone (NVZ).[37]	Pesticide use best practice (LEREAP / IPM / recycling sprayers / precision viti / washdown chambers) **Reference** The use of recycling sprayers may result in potential chemical savings of up to 90% at the start of the growing season and an average of 30% chemical savings across the season.[38]	Reduce or zero pesticide use • It is anticipated the use of functionally diverse supplementary native flora will enhance biocontrol of economically damaging insect pests and reduce the need for pesticide intervention. • Educate growers about the use of biodegradable or 'softer' pesticides and/or the release of biocontrol agents. • Potentially facilitated by more disease resistant varietals in the longer term.	Watercourse buffer strip and intensive grassland near water as well as items in Annexure 5 of the mid-tier manual.[39]	**References** The NVZ programme aims to reduce nitrate pollution in water through regulation of how and when nitrogen is applied to land, the management and storage of manure and the use of cover crops.[40] Saving just 15% of agricultural water use will more than double the available water for domestic use (FAO, 2017). Freshwater ecosystems cover less than 1% of the planet's surface but support up to 10% of known species (Macadam and Stockan, 2015).

---

36 Building on existing work by Kent Downs AONB and Vinescapes project team

37 https://kccconsultations.inconsult.uk/consult.ti/kentdowns_aonb/consultationHome

38 https://www.fmrgroup.com.au/viticulture/vineyard-sprayers/recycling-sprayer.html

39 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/908238/Countryside_Stewardship_Mid_Tier_2020_v1.0.pdf

40 https://kccconsultations.inconsult.uk/consult.ti/kentdowns_aonb/consultationHome

The groundwater aquifer provides 75% of Kent’s drinking water. The quality and quantity of the ground water aquifer and the surface river water is determined in part by landscape management and other activities.[41] Loss of key indicator species i.e. dragonfly nymphs are sensitive to chemical runoff into waterways, and exposure to copper (Tollett et al., 2009). Dragonfly adults and nymphs are susceptible to broad-spectrum insecticide exposure including pyrethroids (Mian and Mulla, 1992). Less than 1% of the world‘s freshwater resources are usable (70% of that goes to agriculture, 10% domestic, 20% industrial) (FAO, 2017).	A reduction in herbicide use. • Establish select wildflower and/or native grass mixes in the mid-row and under vine areas to reduce the need for herbicide intervention. A reduction in water use. • Enhanced functional biodiversity with locally-adapted plants may improve water infiltration (reduce evaporation), improve soil structure and the water holding capacity of soils.	Vegetative cover of a grassland prevents soil erosion, replenishes ground water and controls flooding by enhancing infiltration and reducing water runoff (Perry, 1994). Functional biodiversity can provide many ‘hidden services’ such as water retention, purification of water (Boller et al., 2004).

[41] https://s3-eu-west-1.amazonaws.com/explore-kent-bucket/uploads/sites/7/2018/04/18113849/KDAONB-Management-Plan.pdf

Clean air

Clean air by reducing spray applications and tractor movements as less mowing would also be required.

Table 4. Demonstrating public goods links to ensuring clean air

ELM public goods: Clean air				
Key vineyard environmental risks	**Commercially sensible mitigants (normal market conditions)**	**Enhanced public good mitigant**	**Existing scope of Countryside Stewardship mitigation**	**Natural capital (NC) impact**
Tractor pollution Frost protection smoke Pruning burning Spray drift **References** Pesticide application is often imprecise and it is estimated that 98% of sprayed insecticides and 95% of herbicides miss their intended target species (Miller, 2004).	Reduced tractor use, e.g. doubling up on operations Electric tractors and ATVs Recycling sprayers and reduced applications – precision viti. Use of automated 'greener' frost protection Mulching prunnings	Reduce or zero pesticide use Vineyard automation The use of low growing wildflower meadows and sheep grazing in the winter will reduce the need for mowing (tractor passes). The use of functionally biodiverse native shelter belts to reduce pesticide drift.	Creating/maintaining woodlands, traditional orchards and fruit trees	**References** Functional biodiversity can provide many 'hidden services' such as purification of air (Boller et al., 2004). The program 'Biodiversity Friend' uses lichen as an indicator of air quality. Lichens are extremely sensitive to atmospheric pollution. The Lichen Biodiversity Index (LBI-bf) evaluates the state of lichen diversity in standard conditions, related to the air pollution of the vineyard. The calculation of the index is based on the epiphytic lichen communities on nearby tree bark (Stefanucci et al., 2018).

Protection from and mitigation of environmental hazards

Protection from and mitigation of environmental hazards by reducing pesticide use and promoting biodiversity, also by reducing soil erosion through established ground cover.

Table 5. Demonstrating public goods including protection from and mitigation of environmental hazards

ELM public goods: Protection from and mitigation of environmental hazards				
Key vineyard environmental risks	**Commercially sensible mitigants (normal market conditions)**	**Enhanced public good mitigant**	**Existing scope of Countryside Stewardship mitigation**	**Natural capital (NC) impact**
Damaging pest species/pesticide use Soil erosion and declining soil health Biodiversity/habitat loss Water course damage **References** Every year we lose 24 billion tons of soil due to erosion (Chemnitz and Weigelt, 2005). Grapevines are grown on 1.86% of the total area cultivated with crops in the EU, but use around 64% of all fungicides, 13% of all insecticides and 5% of all herbicides (Muthmann and Nadin, 2003). There was approximately 32.8 tonnes of pesticide applied to vines in the UK in 2018.[42]	Pesticide best practice – voluntary/good neighbor scheme Cover crops post field prep Reduced tillage (esp. under-vine)	As above Also, undertake Environmental Impact Assessments for all vineyards. Incorporate ecological infrastructure including dry stone walls and perennial ground covers to reduce the risk of erosion on steep slopes.		**References** As biodiversity increases, so does the stability of ecosystem functions through time (Cottingham et al., 2001; Jiang and Pu, 2009). The resilience of a system describes its capacity to reorganise after local disturbance (Tscharntke et al., 2005), or in response to environmental changes (Oliver et al., 2015) including extreme weather events (Yachi and Loreau, 1999). Biodiversity provides many ecosystem services to agricultural production, such, biological pest control, maintenance of soil structure and fertility, nutrient cycling and hydrological services (Stefanucci et al., 2018).

42 https://secure.fera.defra.gov.uk/pusstats/surveys/documents/softfruit2018.pdf

Mitigation of and adaptation to climate change

Mitigation and adaption to climate change by encouraging biodiversity and carbon sink potential within an adaptation setting, also offering shade in extreme conditions and reducing evapotranspiration.

Table 6. Demonstrating public goods links to mitigation of and adaptation to climate change

ELM public goods: Mitigation of and adaption to climate change (CC)

Key vineyard environmental risks	Commercially sensible mitigants (normal market conditions)	Enhanced public good mitigant	Existing scope of Countryside Stewardship mitigation	Natural capital (NC) impact
Carbon (tractor) and nitrous oxide (N_2O via fertilizer) emissions Vines are primarily a carbon sink	Diversification into viticulture (or new varieties) can be classed as CC adaptation Mitigants: see above, also cover crop use	Re-wilding (cover crops) / greening of non-planted areas with indigenous flora and fauna. Encouraging natural pest predators. In-field weather sensor networks to inform/ drive precision viticulture. Understanding projected climate change impacts.	New hedgerows and management of hedgerows Under-vine cover	**Reference** A recent estimate suggests that around one third of the greenhouse gas mitigation required between now and 2030 can be provided by carbon drawdown through Natural Climate Solutions (ecological restoration).[43]

[43] https://www.naturalclimate.solutions/the-science

Thriving plants and wildlife

Thriving plants and wildlife by encouraging biodiversity and re-introducing native species through vineyard greening which in turn attract birds and insects, natural pest predators and may offer wildlife corridors.

Table 7. Demonstrating public goods links to thriving plants and wildlife

ELM public goods: Thriving plants and wildlife				
Key vineyard environmental risks	**Commercially sensible mitigants (normal market conditions)**	**Enhanced public good mitigant**	**Existing scope of Countryside Stewardship mitigation**	**Natural capital (NC) impact**
Lack/loss of biodiversity Habitat fragmentation Failure to meet Biodiversity 2010 targets[44] Pesticide impact (plants, animals, human, insects) Loss of habitat corridors and refugia **References** 97% of meadow grassland has been lost in the UK since the 1930s.[45]	Natural grass cover in non-planted areas Maybe some re-introduction of native species (limited)	As above Preserving species richness is primarily about functional diversity	Grassland: Maintenance, restoration, permanent, species rich. Winter cover crops, nectar flower mix, beetle banks etc.	**References** Stands of native vegetation adjacent to agricultural production areas including perennial/annual horticulture and field cropping systems, have been associated with increased biodiversity benefits (Smith et al., 2015; Taverner et al., 2006; Thomson and Hoffmann, 2010b). Native grasses provide a valuable complementarity habitat for arthropod species other than those commonly found in association with native woody perennial shrubs and may increase the net number of predator morphospecies by around 27% when planted in association with vineyards (Retallack, 2019). It may be possible to increase the functional diversity of predatory arthropods by more than 3x when native evergreen shrubs are present versus grapevines only (Retallack et al., 2019b).

44 https://www.cbd.int/2010-target/

45 https://s3-eu-west-1.amazonaws.com/explore-kent-bucket/uploads/sites/7/2018/04/18123740/MEADOW_GRASSLAND.pdf

The 2019 State of Nature Report shows that, at a national level, the 'UK's wildlife loss continues unabated' with 41% of species in decline since 1970, abundance of wildlife in decline and 15% under threat from extinction.[46]

A reduction in semi-natural habitat has been linked with a reduction of biological pest control in cultivated land by up to 46%, when compared with more complex landscapes (Rusch et al., 2016).

The restoration of grasslands can cost approximately USD $260/ha (GBP £197/ha). The estimated annual benefits from restoration are estimated to be $1,010/ha (GBP £764/ha) resulting in a benefit to cost ratio of 75.1.[47]

Biodiversity and provision of ecosystem services can be improved by at least 20% in vineyards by retaining inter-row vegetation cover in preference to intensive soil tillage and herbicide use (Winter et al., 2018).

Microbats can eat up to half their body weight in insects each night[48] and are a good indicator species of ecology health. They also contribute to the biocontrol of European grapevine moth, *Lobesia botrana* larvae (Thiery et al., 2018).

As the proportion of suitable habitat in the landscape is reduced to less than 30% of original vegetation cover, that this will cause a loss of biodiversity, that is, a reduction in species numbers and population densities for all fauna (Andren, 1994; Hanski, 2011).

Diverse communities tend to be more productive, as they contain a variety of species with different functional traits that can increase productivity via the greater biomass produced (Cardinale et al., 2012).

46 https://kccconsultations.inconsult.uk/consult.ti/kentdowns_aonb/consultationHome

47 https://www.cbd.int/doc/meetings/ecr/cbwecr-sa-01/other/cbwecr-sa-01-iis-en.pdf

48 https://www.abc.net.au/news/2019-02-09/microbats-could-become-natural-pesticide-in-mclaren-vale/10788358

Beauty, heritage and engagement

Beauty, heritage and engagement by improving vineyards aesthetic appeal in sensitive landscapes, re-introducing native beneficial species, providing opportunity for a unique story of environmental land management in vineyards which should in turn attract visitors and wider engagement and interest in the work.

Table 8. Demonstrating public goods links to beauty, heritage and engagement

ELM public goods: Beauty, heritage and engagement				
Key vineyard environmental risks	**Commercially sensible mitigants (normal market conditions)**	**Enhanced public good mitigant**	**Existing scope of Countryside Stewardship mitigation**	**Natural capital (NC) impact**
Visual impacts (rigid lines of metal posts, and plants, fencing, grow tubes, tracks) Vineyard buildings Landscape character changes Lack of vineyard educational visits and vineyard manager education 'Closed' land access	Limited intervention and planning/consideration. Walkways and signage are sometimes provided for 'visitors'. Demonstration of sustainability credentials is increasingly becoming linked to social licence, particularly for the agriculture sector. Agricultural biodiversity is essential to satisfy basic human needs for food and livelihood security.[49]	Mutually beneficial opening of vineyard land Educational access/accreditation Visual impact assessments Closer relationships with AONBs and related farm clusters Cultural services, recreation, tourism, aesthetic/aromatic enjoyment, inspiration and education	Educational access/accreditation See hedgerows above	**References** Utilising native supplementary flora for marketing and education purposes can be used to stand out in a crowded international marketplace and engage with the local community to provide sustainable rural leisure and tourism opportunities The body of evidence firmly establishes the many and diverse benefits of green infrastructure including modification of temperatures and climatic conditions, improved human health and well-being, enhanced community liveability, more effective water management, increased economic prosperity, greater opportunity for biodiversity conservation and more extensive urban food production (Pitman et al., 2015). The aromatic and medicinal properties of wildflowers may be unique driver for community wellbeing.

49 https://www.cbd.int/agro/importance.shtml

Environmental steward programs

Sustainable Wines of Great Britain

Founded in January 2019, the recently launched Sustainable Wines of Great Britain objectives are to:

- Maintain and improve soil health,
- Manage vineyard canopies and yields optimally,
- Reduce (and optimise) pesticide inputs,
- Conserve the vineyard (and surrounding) environment and promote biodiversity, and
- Reduce vineyard energy input, greenhouse gas emissions and carbon footprint per hectare.

The observe/measure/record activity will become the 'minimum standard' for members of the scheme. The results of this activity will generate data that will be benchmarked with that of the other members, to generate standards (or key performance indicators). The first audits were conducted in June 2020 and results have not yet been reported. For more information visit https://www.winegb.co.uk/home-visitors/sustainable-winegb/sustainable-timeline/

The adoption of functional biodiversity practices will help growers meet the guidelines set out in the Wine GB Sustainability program. A summary of the potential synergies are presented in **Table 9**.

Table 9. Links between Sustainable Wines of GB and functional biodiversity enhancement

Sustainable Wines of GB program guideline		**Benefits of functional biodiversity enhancement**
Maintain and improve soil health		
Prohibited	Till (cultivate) the vineyard alleys more than three times a year (in a mature vineyard).	It is anticipated that the use of native perennial grasses will reduce the need for tillage over the medium to long term.
Prohibited	Use of herbicides over 100% of the vineyard area in mature vineyards	It is anticipated that the use of native grasses may reduce the need for herbicides in the undervine and mid-row areas.
Prohibited	Removal of prunings from the vineyard except for composting.	
Minimum standard	Ground cover is present in vineyard inter-row alleys in the winter.	Native grasses and wildflowers can provide a protective and functional ground cover throughout the year.
Minimum standard	For each parcel, carry out a soil survey that includes an assessment of soil fertility and health, which includes evaluating drainage, erosion risk, soil texture and structure, organic matter content, CEC and macronutrient status at least every 3 years.	It is anticipated that the use of native perennial grasses and wildflowers will help to improve long-term soil health metrics.
Best practice	For each parcel, an evaluation of soil health, and a management plan designed to maintain and improve soil health, year on year, particularly focusing on regulating pH, maintaining soil structure, replacing soil nutrients and maintaining organic matter levels.	
Minimum standard	For each parcel, a record of cultural interventions relating to the soil (including cultivations, and fertiliser & herbicide applications) carried out in the vineyard.	It is anticipated that the use of native perennial grasses and shrubs will help to reduce the level of ongoing intervention required in the vineyard, and may result in a saving of both time and resources.
Best practice	A soil intervention management plan that includes an evaluation, from a soil health perspective, of current practices used to manage the vineyard floor, then actions to reduce impact of these interventions on soil health.	

Wine GB Sustainability program guideline		Benefits of functional biodiversity enhancement
Manage vineyard canopies and yields optimally		
Minimum standard	Keep annual records of buds left per hectare at pruning, yields and average bunch size (for each parcel) to help with future crop estimation. These will be benchmarked with other members of the scheme.	
Best practice	A vineyard canopy and yield management plan for each parcel, evaluating the quality of the winter pruning, and of the resulting canopy, then assessing the yield and quality produced on an annual basis, setting new targets and actions to meet these targets.	It is anticipated that the use of native grasses and wildflowers may help to regulate excessive vine growth on high vigour sites.
Reduce (and optimise) pesticide inputs		
Minimum standard	During the growing season, fortnightly monitoring for pests and diseases is undertaken.	It is anticipated the need for pest control intervention could be reduced once functional biodiversity is improved.
Minimum standard	Use biological, cultural, mechanical and physical control methods, in conjunction with chemicals.	Biocontrol can be enhanced through conservation biocontrol principles (provide habitat for good bugs to attract them to the site).
Minimum standard	Pesticide application calibration and service records are kept.	The need for chemical pest control intervention may be reduced once functional biodiversity is improved.
Minimum standard	Records are kept of every spray application and include site, date, target pest, pesticide and quantity, crop stage, harvest date, application method, spray volume, weather observations, and precautions followed.	The need for chemical pest control intervention (as the risk of off target application and the risk of pesticide resistance) may be reduced once functional biodiversity is improved.
Best practice	A sprayer maintenance and calibration plan containing the following components: cleaning, filters, pump, control unit, pressure gauge, nozzles, the boom, the PTO, the boom tube and hoses, and rust prevention.	The need for chemical pest control intervention may be reduced once functional biodiversity is improved.
Best practice	Use weather based forecasting models for disease prediction.	The need for chemical pest and disease control intervention may be reduced once functional biodiversity is improved.
Best practice	The effectiveness of all plant protection measures is evaluated after every growing season, then a plan is drafted, with targets and actions to increase efficiency and effectiveness and reduce and optimise the use of pesticides	
Conserve the vineyard (and surrounding) environment and promote biodiversity		
Minimum standard	Map wildlife habitats and environmental, landscape, archaeological and historical features in the vineyard.	
Minimum standard	Allow vegetation, other than noxious weeds, to grow on headlands.	Functional biodiversity and the benefit of multiple ecosystem, services can potentially be increased by either planting native grasses and/or shrubs and hedgerows in and around the vineyard.
Best practice	Have a long-term plan for both cultivated and non-cultivated land that protects and enhances conservation features, including promoting native plants over invasive species, and developing wildlife habitats, such as nest boxes, wetland areas, beetle banks and hedgerows.	

Wine GB Sustainability program guideline		Benefits of functional biodiversity enhancement
Reduce vineyard energy inputs, greenhouse gas (GHG) emissions and carbon footprint per hectare		
Minimum standard	Use an internationally-recognised system for calculating vineyard energy input, greenhouse gas emissions and carbon footprint per hectare of vineyard.	If native grasses and wildflowers and/or shrubs are grown it is anticipated this will help to reduce the level of ongoing intervention required, and may result in a saving of both time and resources.
Best practice	Particularly for those is the top quartile of members, the vineyard energy input, greenhouse gas emissions and carbon footprint per hectare are evaluated, and a strategy is put in place to reduce these figures and increase carbon sequestration, aiming to become carbon neutral by 2030.	

Linking Environment And Farming (LEAF)

The linking environment and farming (LEAF) marque standard (15.0) is an environmental assurance system recognising more sustainably farmed products.[50] LEAF's Integrated Farm Management (IFM) is a whole farm business approach that delivers more sustainable food and farming.

A farm business managed to IFM principles will demonstrate site-specific and continuous improvement across the whole farm including:

- Organisation and Planning
- **Soil Management and Fertility**
- Crop Health and Protection
- **Pollution Control and By-Product Management**
- Animal Husbandry
- Energy Efficiency
- Water Management
- **Landscape and Nature Conservation**
- Community Engagement

The topics in bold have a direct impact on enhancing biodiversity.

LEAF's Simply Sustainable Biodiversity provides six simple steps to help improve biodiversity on your land including:[51]

Monitoring

- Step 1 Identify habitats
- Step 2 Identify key species

Management

- Step 3 Manage farmland sympathetically
- Step 4 Be pro-active in your management of habitats

Enhancement

- Step 5 Enhance existing habitats and populations
- Step 6 Work with others

---

50 https://leafuk.org/farming/simply-sustainable-series

51 https://s3-eu-west-1.amazonaws.com/leaf-website/LEAF-Sustainable-Biodiversity-36pp-A5.pdf

CHAPTER 6: BEST PRACTICE CASE STUDY FROM AUSTRALIA

Australian native perennial tussock grasses and forbs

The Falkenberg Vineyard

Vineyard owner: Dan Falkenberg

Location: Nuriootpa, Barossa wine region, South Australia

Project: The transition from annual cereal cropping to the establishment of native perennial wallaby grasses in the mid-row in 2009, followed by the over sowing of a 20 multi-species mix of grasses and forbs in winter (June) 2020 as a part of the EcoVineyards project.

The following notes have been collated through conversations with Daniel Falkenberg (right) and his father, Ian Falkenberg over the last 10 years.[52]

Vineyard

- The vineyard was established in 1997 and planted to Shiraz and Grenache on their own roots. The vineyard is approximately 5 hectares in size.
- The topsoil is highly variable grading from grey sand with hard yellow clay underneath, to loamy soil with red clay underneath.

Figure 17. Dan Falkenberg and wallaby grasses in establishment (left) and fully established (right). Photos: Mary Retallack

Weed control

Several weed species were present prior to the establishment of native grasses including salvation jane, *Echium plantagineum*, wireweed, *Polygonum aviculare* and evening primrose, *Oenothera stricta*.

It is important to start weed control in the mid-row nine to twelve months prior to the planting of native perennial grasses to provide adequate time to deplete the existing weed seed bank and start with a clean surface. The site was prepared early in the growing season from spring onwards using Roundup PowerMax spiked with Spotlight. The mid-row was sprayed out twice prior to seeding in autumn to kill the salvation jane and wireweed, and ensure the soil surface was ready for planting the four species mix of wallaby grasses. A week after the seed was planted Roundup was sprayed over the soil surface prior to any seed germination. Wallaby grass seems to tolerate the use of Jaguar to remove broad-leafed weeds early in the growing season.

[52] Paraphrased from the original publication. Retallack, M. J. (2010). Enhancing biodiversity in the vineyard workshop notes - Information for McLaren Vale and Barossa winegrape growers, Adelaide and Mount Lofty Natural Resources Management Board, Adelaide.http://www.viti.com.au/pdf/Enhancing%20Biodiversity%20in%20the%20Vineyard%20-%20Workshop%20Notes.pdf

Figure 18. Wireweed was sprayed out under vine and in the mid-row prior to the establishment of native grasses. Wireweed persists at the end of strainers, where there is less competition from grasses (left) and wallaby grasses were planted in the mid-row in May 2009 (six months active growth to April 2010). Note the absence of weed species where the wallaby grass has established (right).

It is important when planting native grasses to start with minimal weed pressure, as young seedlings don't compete well with established weeds, and to be persistent with weed control during establishment. Once wallaby grasses are established they appears to compete favourably with wireweed.

Seed quality

Native grass seed quality and viability can vary depending on the season and the time of the year the seed is harvested. The mature head can drop seed quickly in late spring/early summer (late November/December in the southern hemisphere). It is important to collect the seed as soon as it is mature, and prior to it falling to the ground. If the seed is collected too early it may not be fully mature which will reduce germination rates. It is important to request the results of seed viability and germination testing prior to purchasing seed from a commercial reseller. This will provide a guide to expected germination percentage for a particular batch.

Sourcing Seed

Seed was sourced commercially from Native Seeds Pty Ltd in Victoria www.nativeseeds.com.au.

A four species mix incorporating the following species of Wallaby grass was used:

- Common wallaby grass, *Rytidosperma caespitosum*
- Wallaby-grass, Rytidosperma racemosum
- Brown-back wallaby grass, *Rytidosperma duttonianum*
- Wallaby-grass, *Rytidosperma fulvum*

Seed treatment

Seed is cleaned and pelletised with a clay covering to provide it with the ballistic properties required to pass through a modified seeder. A third party carries out the pelletising process (separate from the commercial seed reseller). The seed is dyed blue, which is a visual deterrent to birds so they won't eat the seed which appears to work well.

Other native grasses (such as kangaroo and spear grass) can be hard to clean and pelletise due to their physical structure. Kangaroo grass, *Themeda triandra* is considered too vigorous for the vineyard mid-row, and it can be difficult to establish.

Figure 19. Pelletised wallaby grass ready for seeding (left), rear view of the seed drill. The rear wheels ensure the seed is firmly bedded into the soil (middle), and wallaby grasses planted to a depth of 0.5 to 1 cm (right).

Seeding

A specialised seeder was used to plant wallaby grass in the vineyard mid-row in autumn (May 2009), at a rate of 10 kg per sown hectare (mid-rows only). It is possible to reduce this rate to 5 kg per sown hectare but given 20% or more of the seed is likely to be unviable the 10 kg rate seems to be a good balance.

Daniel believes that dry seeding any time from late summer (March in the southern hemisphere) onwards would be beneficial as the seed will be in the soil prior to opening rains while the soil temperature is still warm. The seed can be dry drilled and is unlikely to blow away due to its pelletised clay treatment. It is important not to incorporate DAP or other phosphate fertilisers when planting native seeds, as this will reduce the likelihood of success. The headlands and other vacant areas of the vineyard were also subsequently planted with native grasses.

Germination

Germination of up to 80% is considered a good result. There may be no observable seed germination for the first three months, until the soil starts to warm up in early spring (September). Weeds may need to be brushed with a sponge wiper to knock them back and allow the native grasses below to grow through. Once wallaby grasses are established they will also regenerate from seeds that have fallen near mature plants.

Biodiversity

- A four species wallaby grass mix was used to encourage biodiversity.
- Some species will establish quickly (which is important to compete with weeds quickly) while others will establish more slowly and will be less vigorous.
- The use of multiple species provides the benefit of varying the growth habits of each species, rather than having a disappointing result if only one species is planted and the germination is poor.
- The vineyard is surrounded by peppermint gum grassy woodland, which provides a great habitat for red-capped robins, diamond fire tale finches and a range of other declining woodland bird species. These birds tend to be seed eating and insectivorous rather than fruit eaters, and do not pose a problem in the vineyard.
- Predatory birds such as falcons and hawks also frequent the woodland areas and actively patrol the vineyard border. They are an active deterrent to any pest bird species such as starlings, rosellas and crows that may otherwise flock to the vineyard. Despite native vegetation being in close proximity to the vineyard, fruit loss and damage by pest birds has been insignificant since the vineyard was planted in the 1990's.

Wallaby grass habitat

- It is important to have a relatively sparse cover of wallaby grass on the ground as this mirrors its habit in nature. A perennial or tussock grass will persist for a number of years and can grow up to 30 cm in diameter.
- A dense groundcover, similar to other mid-row cover crops is not preferred and doesn't appear to be required for the grass to exclude weed species.
- Wallaby grasses have the capacity to regenerate and its natural recruitment will fill some of the gaps. This is preferable rather than aggressively reseeding over the top of existing stands to fill holes.
- The roots of mature grasses may extend down to 30cm and their fibrous root system makes them hardy, and tolerant to drought conditions. Their root system can help to open up the soil and improve soil structure and water infiltration.

Figure 20. Wallaby grass seed head (left), distinctive white fluffy seed heads (middle), and wallaby grasses slashed/strimmed after flowering (right).

Cost and benefits

Sowing rate: 10 kg/ha for pelletised seed covered in clay (mid-row coverage only on a new site)

Seed cost: AUD $75/kg (GBP £40.50/kg)

Cost per seeded area: AUD $750 (£405/ha), plus labour/machine hire (approx. $1,500 or £815 per day).

The Falkenberg vineyard was planted in 1997 and relied on herbicide inputs to manage annual weeds including salvation jane, wireweed and evening primrose. The owner also needed to spray insecticide to control light brown apple moth on an ongoing basis. But with soaring chemical costs and increasing environmental concerns, he made the change to planting a four species wallaby grasses mix.

By 2012, three years after the native grasses were planted the benefits were evident. Dan was able to reach all his goals.

- To use the drought-tolerant and deep-rooted characteristics of native perennial grasses to improve water retention in soil profiles, thereby reducing dependency on irrigation.
- Improve habitat value of degraded pasture areas and surrounding native vegetation for native birds, particularly seed-eating and insectivorous species.
- Achieve a significant reduction in the abundance and distribution of undesirable pest plants (weeds).
- The previous management comprised seeding annual triticale on an annual basis at a cost of $614.50/ha/pa (£331.83/ha/pa[53]) which equates to $1,843.50 (£995.45/ha) over a three year period. The perennial wallaby grasses cost more to establish initially $1,306.65/ha (£705.59/ha) over the first three years but didn't require any inputs thereafter.
- **Dan was able to break even after the third year with a combined saving of $536.85/ha (£289.90/ha) and with ongoing input cost savings of $614.50/ha (£331.83/ha/pa) each year.**

---

53 Assuming an exchange rate of AUD $1 = GBP £0.54 (as at 12 August 2020)

Table 10. Cost and benefit of establishing native wallaby grasses in the mid-row (Arbuckle, 2012) (converted to pounds)

Approximate costs for conventional cover-cropping using a contractor for in field operations. Indicative costings on a per/ha basis.

Task	Rate (per/ha)	1st year preparation	2nd year seeding	3rd year maintenance
Seed				
Triticale	120 kg	£47.79	£47.79	£47.79
Fertiliser	40 kg	£23.76	£23.76	£23.76
Operations				
Seeding		£20.52	£20.52	£20.52
Rotary hoeing		£178.20	£178.20	£178.20
Cultivating		£61.56	£61.56	£61.56
	£/ha	**£331.83**	**£331.83**	**£331.83**
			Total for 3 year period	**£995.49**

Approximate costs to establish native grasses using a contractor for in-field operations. Indicative costings on a per/ha basis.

Task	Rate (per/ha)	1st year preparation	2nd year seeding	3rd year maintenance
4 species mix of *Rytidosperma* ssp.	10 kg		£405.00	
Operations				
Seeding			£97.20	
Spraying		£61.56	£41.04	£20.52
Herbicide mid-row No. of applications		3	2	1
Jaguar	1 L		£19.44	£9.72
Spotlight	250 ml	£32.00		
Roundup	2 L	£19.12		
	£/ha	**£112.67**	**£562.68**	**£30.24**
			Total for 3 year period	**£705.59**
			Difference	**-£289.90**

- In addition, there's been a significant reduction in the abundance and distribution of undesirable pest plants and in the reliance of chemicals for weed control. Before the trial begun, Dan was slashing the volunteer sward of exotic weeds three to four times a year and was applying more irrigation through the summer months. The native perennial grasses are cut only once after they have set seed with a side throw slasher, which applies the cuttings under-vine as a layer of mulch.
- The pest weeds are no longer an issue. Wallaby grasses are able to outcompete them once they are established.
- There is much less intervention required in the vineyard (soil cultivation, sowing, slashing, herbicide inputs).
- The wallaby grasses provide valuable habitat for a range of predatory arthropods (brown lacewings and spiders) and are able to keep light brown apple moth under control using biocontrol without the need for chemical intervention.
- The owner is saving time and resources by not having to intervene as often to manage the mid-row area. The grasses were maintained over a 10 year period without the need for intervention.

PhD research

Predatory arthropods found in association with wallaby grasses

At least 38 types of predatory arthropods were found in association with wallaby grasses, *Rytidosperma* ssp. during a recent study (Retallack, et al. 2019). Wallaby grasses provide a valuable complementarity habitat for arthropod species other than those commonly found in association with native woody perennial shrubs and may increase the net number of predator morphospecies by around 27% when planted in association with vineyards.

Wallaby grasses provide habitat for a diversity of predators with wolf spiders, brown lacewings, earwigs, glossy shield bugs, carabid beetles, parasitoid and predatory wasps (Ichneumonid, Vespoid, and Sphecidae) and carabid beetles found abundantly in South Australian vineyards (Retallack et al., 2019a). It is also reported that predation of LBAM eggs increases when wallaby grasses are present. The difference between predatory and herbivore morphospecies was 2:1 predators: herbivores (Retallack, 2019).

Similarly, when evergreen shrubs were also assessed the richness of predator morphospecies across all plant types was nearly double the number found in association with grapevines. It may be possible to increase the functional diversity of predatory arthropods by more than 3x when native evergreen shrubs are present versus grapevines only (Retallack et al., 2019b).

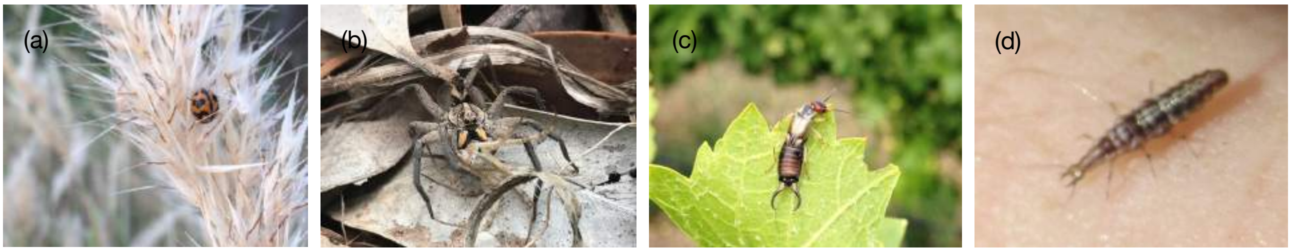

Figure 21. Transverse ladybird beetle, *Coccinella transversalis.* Photo: J Edwards (a), garden wolf spider, *Tasmanicosa* sp. (b) European earwig, *Forficula auricularia* (c), brown lacewing larva, *Micromus tasmaniae* (d). Photos: Mary Retallack

Natural enemies were most abundant from October to December on wallaby grasses. This period coincides with the peak time that predators are needed for crop protection during flowering and in the lead up to harvest. The presence of predatory arthropods reduced as weather conditions became less favourable and access to floral resources diminished.

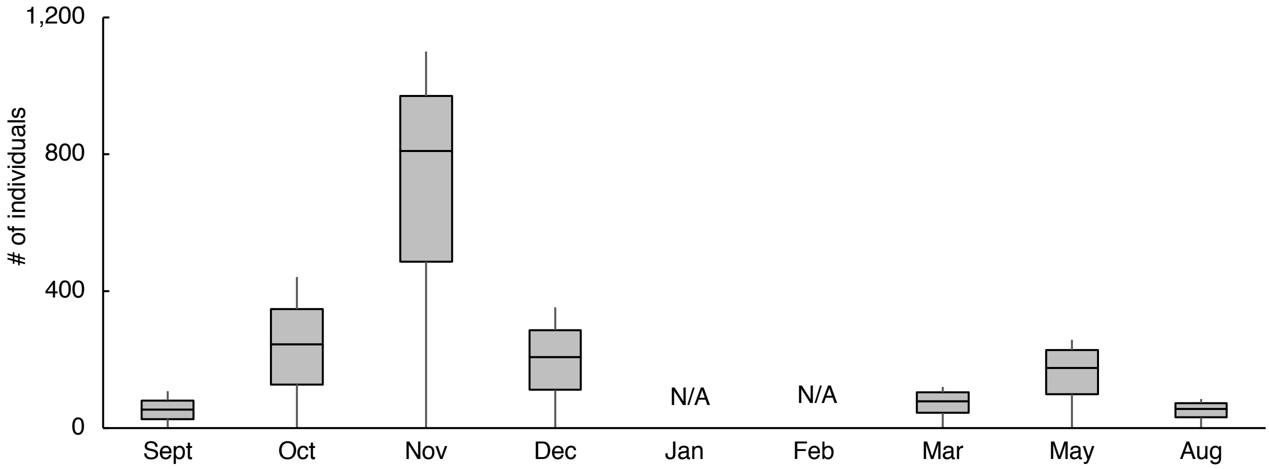

Figure 22. Temporal abundance of predator arthropods found in association with wallaby grasses over a 12-month period. The box plots represent the median (central line), first and third quartiles (grey box), and the whiskers the total range.

EcoVineyards

As a part of the EcoVineyards project https://www.wgcsa.com.au/ecovineyards.html Dan Falkenberg recently (June 2020) over sowed his existing stand of wallaby grasses with a 20 species mix of native Australian grasses and forbs comprising common wheat grass, *Anthosachne scabra,* kneed wallaby grass, *Rytidosperma geniculatum*, small flowered wallaby grass, *Rytidosperma setaceum*, wallaby grass, *Rytidosperma racemosum*, ringed wallaby grass, *Rytidosperma caespitosum,* copper awned wallaby grass, *Rytidosperma fulvum*, curly windmill grass, *Enteropogon acicularis*, windmill grass, *Chloris truncata*, weeping grass, *Microlaena stipoides*, cotton panic grass, *Digitaria brownie*, silky blue grass, *Dichanthium sericeum*, red grass, *Bothriochloa macra*, woolly new holland daisy, *Vittadinia gracilis*, lemon beauty heads, *Calocephalus citreus*, raspwort, *Gonocarpus tetragynus*, blue devil, *Eryngium ovinum*, chocalate lily, *Arthropodium strictum*, button everlasting, *Helichrysum scorpioides*, Australian bindweed, *Convolvulus angustissimus* and traces of other small grassland herbaceous species.

Seeding rate: 6.1 kg/ha over sowing existing mid-row (a standard rate 7.5 kg/ha would be adopted for mid-row coverage on a new site).

Seed cost: AUD $200/kg (GBP £108)

Cost per seeded area: AUD $1,220/ha (GBP £664/ha), plus labour and machine hire (approx. $1,500 or £815 per day).

Figure 23. Mixing the 20 species mix of native grass and forb seeds (a), the blue devil specialised seeder (b), and sown mid-row area (d). Photos: Dan Falkenberg

EcoVineyards is a Wine Grape Council of South Australia and Retallack Viticulture initiative and National Landcare funded project which is underway in South Australia. 25 demonstration sites are in establishment utilising native insectary plants with many of the techniques also relevant for the UK. If you would like to follow the progress of the EcoGrowers visit https://www.wgcsa.com.au/ecovineyards.html

Landline Australia

The Landline program showcased the approach that Dan Falkenberg is taking in a recent program titled 'Native Grasses: Planting native grasses to help deal with drought and bushfire' To watch the 10 minute segment visit https://www.abc.net.au/landline/native-grasses:-planting-native-grasses-to-help/12376990

Related research, native grasses in the undervine area

A team of researchers at the University of Adelaide recently completed a study looking at the use of a low growing kneed wallaby grass, *Rytidosperma geniculatum,* which grows to 30 cm undervine and found that the dormancy trigger normally present is overridden when moisture is available via the dripline. This may render wallaby grass unsuitable when planted undervine on water limited sites, as it may have a detrimental effect on vine vigour. However, on high vigour sites it may provide a good option to reduce vine vigour. Slashing/sttrimming the grass undervine or 'knocking it back' using a contact weedicide may be an alternative way to control the vigour. It is not anticipated wallaby grass will present a vigour problem when planted in the mid-row.

In the first year that wallaby grasses were planted in the undervine area there was a 1.6 t/ha decline (18%) in grapevine yield while they were establishing compared to the control (herbicide strip). In year two there was an increase in grapevine yield by 0.8 t/ha (9%) and in year there was an increase of 1.6 t/ha (26%) compared to the control. Growers should be aware that there may be a short term impact on yield on low vigour sites but this will should come back into equilibrium once they are established with multiple other functional ecosystem service benefits anticipated in the medium to long term.

Figure 24. wallaby grasses planted under-vine. Photo: D Falkenberg (a), in the mid-row (b), and the biomass produced by the root system (c). Photos: Mary J Retallack

Insights

Some key insights include:

- Preparation is critical, it is 90% of the job and indicator of success. Native Australian grasses do not establish well if there is weed pressure. Prepare the site with care and patience. This may take more than one season of weed control to achieve the best outcomes.
- Having access to good quality seed and specialised sowing equipment (if needed) is critical to success. Make sure optimum quality seed is used, appropriate seeding rate for the location (organic sites may need a higher seed rate to offset weed pressure and the lack of herbicide control options), and sowing depth is achieved.
- Seasonal variability can be difficult to foresee. It is better to wait until conditions are optimal rather than sow seed in dry seasons.
- Local knowledge and knowing when the best time to sow seed is important. i.e. dry sowing early just prior to the opening rains in Autumn may be preferable.
- Seed can be expensive and local provenance seed difficult to source. Order early (a season in advance) to ensure the supply of desired seed mixes.
- Some growers are incorporating mycorrhizal fungi and/or biochar formulations at the time of planting.
- Keep careful records of what was sown (varieties and rate), when and where.
- Ongoing weed control may be required until the grasses are established and then they tend to outcompete problem weeds well.
- Record the success, what went well and what would you differently next time.
- There may be a reduction in vine vigour in the first season if you are planting native grasses in the undervine area while the perennial grasses establish but this is normally rectified after the first year. In high vigour sites, it may be a good way to reduce vine vigour. Vine vigour is unlikely to be significantly impacted if grasses are sown in the mid-row.
- Wait until the grasses have set seed before trimming them (if needed). Species like kneed wallaby grass, *Rytidosperma geniculatum* are low growing < 30 cm and may not need trimming.
- A diversity of species is best rather than a monoculture.
- Some Australian native grasses are sensitive to phosphorus and care should be taken not to include high levels of P.

Related articles

Related articles include:

- Native plants could be the key to managing vineyard pests naturally https://www.wineaustralia.com/news/articles/managing-vineyard-pests-naturally
- The evidence supports the value of under-vine crops https://www.wineaustralia.com/news/articles/the-evidence-supports-the-value-of-undervine-crops
- Retallack, M.J., Thomson, L.J, and Keller, M.A. (2019) Native insectary plants support populations of predatory arthropods for Australian vineyards. 42nd Congress of Vine and Wine, International Organisation of Vine and Wine (OIV), Geneva, Switzerland. https://www.bio-conferences.org/articles/bioconf/abs/2019/04/bioconf-oiv2019_01004/bioconf-oiv2019_01004.html
- Retallack, M.J. (2019) The potential functional diversity offered by native insectary plants to support populations of predatory arthropods in Australian vineyards. (PhD Thesis), The University of Adelaide. https://digital.library.adelaide.edu.au/dspace/bitstream/2440/120158/1/Retallack2019_PhD.pdf
- Retallack, M.J., Thomson, L.J, and Keller, M.A. (2019) Predatory arthropods associated with potential insectary plants for Australian vineyards. Australian Journal of Grape and Wine Research, DOI:10.1111/ajgw.12383. https://onlinelibrary.wiley.com/doi/abs/10.1111/ajgw.12383?fbclid=IwAR39klgzRGiVfPTf55GPR9XiqLhwC5dvVjPEyvAHe_XKgxkd_HiEVRSJuIE
- Retallack, M.J. (2019) Ways to monitor arthropod activity on native insectary plants. The Australian and New Zealand Grapegrower and Winemaker. Feb (661), 40-43. https://winetitles.com.au/gwm/articles/february-661/ways-to-monitor-arthropod-activity-on-native-insectary-plants/
- Retallack, M.J. (2019) The functional diversity of predator arthropods in vineyards. The Australian and New Zealand Grapegrower and Winemaker. Jan (660), 23-26. https://winetitles.com.au/gwm/articles/january-660/the-functional-diversity-of-predator-arthropods-in-vineyards/
- Retallack, M.J. (2018) Practical examples of ways to establish native insectary plants in and around vineyards. The Australian and New Zealand Grapegrower and Winemaker. Dec (659), 38-41. https://winetitles.com.au/gwm/articles/december-659/practical-examples-of-ways-to-establish-native-insectary-plants-in-and-around-vineyards/
- Retallack, M.J. (2018) The role of native insectary plants and their contribution to conservation biological control in vineyards. The Australian and New Zealand Grapegrower and Winemaker. Nov (658). https://winetitles.com.au/gwm/articles/november-658/the-role-of-native-insectary-plants-and-their-contribution-to-conservation-biological-control-in-vineyards/
- Retallack, M.J. (2018) The importance of biodiversity and ecosystem services in production landscapes. The Australian and New Zealand Grapegrower and Winemaker. Oct (657), 36 - 43. https://winetitles.com.au/gwm/articles/october-657/the-importance-of-biodiversity-and-ecosystem-services-in-production-landscapes/
- Retallack, M. (2012) Enhancing biodiversity in the vineyard. Adelaide and Mount Lofty Ranges Natural Resources Management Board, Adelaide. http://www.viti.com.au/pdf/Enhancing%20Biodiversity%20in%20the%20Vineyard%20-%20Workshop%20Notes.pdf
- Retallack, M. (2011) Vineyard biodiversity and insect interactions. Grape and Wine Research and Development Corporation, Adelaide. http://www.viti.com.au/pdf/Rmjr0811VineyardBiodiversityandInsectInteractionsBookletFINAL.pdf

CHAPTER 7: COSTS AND BENEFITS

This chapter presents examples of costs and benefits of public good approaches in relation to vineyards.

Restored ecosystems provide a range of goods and services to humanity that in many cases will outweigh the costs of restoration. In general terms, it has been calculated that the restoration of grasslands can cost approximately USD $260/ha (GBP £197/ha). The estimated annual benefits from restoration are estimated to be $1,010/ha (GBP £764/ha) resulting in a benefit to cost ratio of 75.1.[54]

Costs

Grapevines, *Vitis vinifera* in the UK are impacted by varying levels of damage by pest species. European grape berry moth, *Eupoecilia ambiguella,* European grapevine moth, *Lobesia botrana* and light brown apple moth, *Epiphyas postvittana* are the dominant insect pest causing damage to flower clusters and berry skins in UK vineyards. Damaged skins provide infection sites for *Botrytis cinerea* and other bunch moulds, which result in a reduction in fruit quality and yield losses (Ferguson, 1995). Therefore, if it is possible to reduce the damage caused by these tortricid leafroller species it may also be possible to reduce damage caused by botrytis and other bunch rots.

Many of the predators of leafroller moths are also predators of spotted wing drosophila. It has also been shown that SWD can increase the spread of *Acetobacter spp.* acetic acid bacteria, which can predispose berries to sour rot. Similary, if SWD can be controlled using biocontrol options, this may alleviate the need for chemical intervention and the subsequent losses to fruit yield and quality.

Whenever costs and benefits are calculated it is also important to record the downsides of a particular practice in order to fully realise its impact and associated costs. Some of these costs may arise through unintended consequences like collateral damage to predatory arthropods. The use of broad-spectrum insecticides can damage the populations of natural enemies, reducing the cost-effectiveness of insecticide investment if unaccounted for in treatment decisions (Zhang and Swinton, 2009). There are many other costs associated with off target spray events, including soil compaction when the tractor travels along the vine row, the use of fuel, and associated noise, air, water pollution and the time and resources costs associated with intervention.

Benefits

Biological control is a key component of arthropod-mediated ecosystem services, which are used to manage pests in production landscapes (Isaacs et al., 2009). Examples of benefits include:

- Biocontrol is estimated to provide five to ten times more control of pests than pesticides (Pimentel et al., 1992).
- It is reported that up to 90% of newly hatched leafroller larvae may be killed by predators in the absence of toxic chemicals (Helson, 1939; Waterhouse and Sands, 2001).
- It is estimated that the European earwig, *Forficula auricularia* reduces insecticide applications by 2 to 3 per annum in apple orchards and also reduces pest damage (Cross et al., 2015).
- Predation on agricultural pests by insectivorous bats may enhance the economic value of agricultural systems by reducing the frequency of required spraying and delaying the ultimate need for new pesticides (Federico et al., 2008).
- Biodiversity and provision of ecosystem services can be improved by at least 20% in vineyards by retaining inter-row vegetation cover in preference to intensive soil tillage and herbicide use (Winter et al., 2018).
- In some New Zealand vineyards, the use of flowering buckwheat in one row in 10 (every 25 m) reduces leafroller populations to below economic thresholds (Bernard et al., 2006b).

---

54 https://www.cbd.int/doc/meetings/ecr/cbwecr-sa-01/other/cbwecr-sa-01-iis-en.pdf

- Native grasses provide a valuable complementarity habitat for arthropod species other than those commonly found in association with native woody perennial shrubs and may increase the net number of predator morphospecies by around 27% when planted in association with vineyards (Retallack, 2019).
- It may be possible to increase the functional diversity of predatory arthropods by more than 3x when native evergreen shrubs are present versus grapevines only (Retallack et al., 2019b).

Calculating the benefit of natural enemies provided by shelterbelt vegetation

The value of shelterbelt vegetation to pest control adjacent to a vineyard is estimated by calculating the value of the natural enemies provided if they were purchased from commercial suppliers.

The value of adjacent vegetation to the grower is at least $516 to $696 (GBP £279 to £376)[55] for each 100 m of native vegetation shelterbelt of 4 to 10 m in width. The cost of establishing a typical 4 m to 10 m metre wide shelterbelt ranges from $628 to $788 (GBP £339 to £426) per 100 m for a fenced shelterbelt installed by a contractor to $47 to $88 (GBP £25 to £48) for an unfenced shelterbelt put in place through grower provided labour and machinery.

Based on the estimated costs and benefits, there will be a net gain for every year except the first year for a fenced shelterbelt installed by a contractor.

For a shelterbelt lifetime of 20 years, with benefits in terms of natural enemies being derived from conservatively the fifth year, this represents a net gain ranging from $7,462 (GBP £4,029) for the most expensive option (fenced 10 m shelterbelt installed by a contractor), to $8,203 (GBP £4,430) for an unfenced 4 m shelterbelt installed by the grower (Thomson and Hoffmann, 2010a).

Table 11. Cost and benefit of establishing a 100m long shelterbelt (4m or 10m wide) over 20 years (converted to pounds)

Established by	Fenced/ unfenced	Width	Cost (£)	Benefit/year (£)[1]	Net gain first productive year [1]	Net gain over 20 years[2]
Contractor	Fenced	4	£339	£297	-£42	£4,116
		10	£426	£297	-£129	£4,029
	Unfenced	4	£56	£297	£241	£4,399
		10	£117	£297	£180	£4,338
Grower	Fenced	4	£216	£297	£81	£4,239
		10	£275	£297	£22	£4,180
	Unfenced	4	£25	£297	£272	£4,430
		10	£48	£297	£249	£3,867

[1] Mean value based on our measurement in vineyards with shelterbelt widths 4 to 10 m. It is possible that natural enemy abundance will vary with width.

[2] Assuming production of natural enemies at the rate assessed in our studies for 5 to 20 years post establishment with a single establishment cost.

Economic value

Researchers quantified the economic value of two contrasting ecosystem services (biological control of pests and nitrogen mineralisation) provided by non-traded, non-crop species in ten organic and ten conventional arable fields in New Zealand. The economic values of the two selected ecosystem services were greater for the organic systems in all four crops, ranging from US $68 to $200 /ha/yr (GBP £51 to £151 /ha/yr) for biological control of pests and from US $110 to $425 /ha/yr (GBP £83 to £321 /ha/yr) for N mineralisation in the organic systems versus US $0 /ha/yr for biological control of pests and from US $60 to $244 /ha/yr (GBP £45 to £184 /ha/yr) mineralisation in the conventional systems. The total economic value (including market and non-market components) was significantly greater in organic systems, ranging from US $1,750 to $4,536 /ha/yr, (GBP £1,323 to £3,430 /ha/yr) with US $1,585 to $2,560 /ha/yr (GBP £1,32198 to £1,936 /ha/yr) in the conventional systems (Sandhu et al., 2015).

[55] Assuming an exchange rate of AUD $1 = GBP £0.54 (as at 12 August 2020)

CHAPTER 8: BARRIERS TO ADOPTION

This chapter highlights some of the barriers to adoption and the opportunities to overcome some of these barriers.

Interview insights

There were a number of barriers to adoption as well as drivers for success highlighted in the grower interviews conducted by Pippa Palmar, Viticulture Tests and Trials Officer, Kent Downs AONB. I have provided a summary below of information available at the time of writing the report (in the grower's words).

Barriers to adoption

Time

- Too much paperwork needed to access grant scheme incentives.

Cost

- Cost of undertaking additional work without suitable reimbursement. Some of the current grants available do not cover potential lost production.
- Would like more support to market the benefits as recompense for undertaking activities.

Flexibility

- The ELM needs to be flexible with regard to areas you could pick. It could cover row crops, orchard, cane fruit and bush fruit as well.
- Flexibility with in the scheme and to have the scheme where there are bolt on options.

Knowledge gap

- Growers are seeking advice on how to sow native grasses and wildflower strips in the mid-row and undervine areas.
- Biocontrol agents of economically damaging insect pests (leafrollers, SWD, mites etc).
- Greater knowledge and confidence is needed about using biocontrol agents (releasing predatory arthropods) as a part of an integrated approach to pest management. It may be possible to release predatory arthropod via drone if there are local operators available.
- Some growers would like to see machine learning used to develop an app to inform targeted and timely spraying for fungal infections.
- Info on fast growing native species (other than beech, poplar or alder) and/or complementary species that could be planted in association.
- What is the organic matter (and nutrient production) associated with the use of perennial groundcovers.
- A wish to use robotic and drone technology to save on carbon emissions.
- We need to find the right blend of grass or sward mixture under vines so that the height of the sward was controlled.

Drivers for success

- Being paid to enhance the natural habitat for flora and fauna. This is also aesthetically pleasing for the general public.
- ELM's across the whole enterprise including HLS areas adjacent to footpaths and corners which are small but have a large biodiversity level which have not been recognised in CS and Ancient Woodland.
- The desire for as few passes as possible with the tractor and this follows LEAF marque.
- Saving time and resources.

General comments on ELM focus areas

Ensuring clean and plentiful water

Collection

- We could catch water from roof areas.
- We have a bore hole and water from the buildings is all interconnected and could be collected.

Improve soil water holding capacity and reduce runoff

- The headland and rows are covered with sward preventing runoff.
- Plant new vineyards with cover crops to ensure soil cover and to retain soil moisture.
- Plant grass strips between the rows and headlands to dissipate rain water.
- Pulverising prunings improves the quality of the soil.

Water quality

- We have a bio-bed for cleansing the wash down water which we have found to be very effective.
- We treat all waste water and recycle, we have a bore hole which we use for spraying and the winery. We use a bio-bubble. We have a sedum and mixed grasses roof.

Clean air

Reducing emissions

- It would be interesting to see how much carbon we use in extra tractor passes in comparison to pesticides used (herbicides).
- We could measure the amount of fuel we use and reduce the number of passes to be more efficient.
- We would like to use an electric tractor with solar panels to mow and vine trim at the same time.

Alternative power

- Electric tractor with PV's on the roof. Double linkage for machinery.
- Plant more trees and windbreaks to help drawdown carbon dioxide.

Mitigating of and adaptation to climate change

- Crimper roller behind while using the linkage on the front. Electric ATV's for using around the vineyard. Mulching prunings in the row. Reducing spraying using precision viticulture, spraying at point of need rather than preventatively, everybody should be doing this because it is cheaper. Mechanical weeder and glyphosate to scorch the grass rather than kill it.
- No cultivations take place with natural regeneration which is mown tight. Certain chalk grassland wildflowers such as self heal and black medic are better since they are prostrate growers.
- We have a wide headland and strips of regenerated chalk grassland. The chalk is less than 30 cm below the ground and any run off is immediately absorbed through the grass. We also have a hedge at the bottom of the vineyard with also absorbs the runoff if there is any left.

Soil

- Not disturbing the soil by strimming under the vines, so the wildflower meadows are regenerated, grazing in the winter, but needs fencing. Reduces soil compaction using sheep.
- The headland of the new vineyard are planted with a wildflower seed mixture. Seed could be collected from my HLS wildflower meadow and sown as green grass between the rows. This I am very keen on but looking for advice and funding now.
- No fertiliser is used in the vineyard, herbicide (glyphosate) is used once in the year.
- We use fertiliser in the vineyards. I would like to see an increase of organic matter and biodiversity. We don't cultivate but do apply herbicide, an early one and a later one. We only have 20 cm of top soil and don't usually have compaction but we did last year.
- We use chicken pellets and sheep poo as well as mulch the prunings.
- White flints collected from the vineyard are placed undervine to reflect heat and spray when required.
- The vineyard in the winter is grazed by alpacas.
- Minimum amount of fertiliser as possible, we use compost under the rows on one side. We drill the fertiliser in to the soil in the row in the edge of the alley along each side.

Protection from and mitigation of environmental hazards

- Reduced spraying, sward cutting not until August so beautiful wildflowers can express themselves.
- Biological control, traps telling when there is a need to spray.
- We worry about light brown apple moth

Thriving plants and wildlife

- Chalk downland wild flowers are sown round the headlands, debating whether to let them regenerate or not. Collect for higher stewardship meadows and use as green grass.
- We have an owl box on the coast.
- 6 m headland and wind breaks between orchard and vineyard, nectar strip on south side. Areas which are not planted to vines could be wildlife havens with wildflowers, all vineyards have them.
- The headland is 8 - 9 m with chalk grassland species, and meadow of species rich sward for turtle doves close by, the seeds are used to feed the doves.
- Our vineyard sward has been created by regeneration, there are many orchids in the area and sowing a meadow might create more competition for them to establish in the vineyard.
- Vineyards are becoming better at making provision but could be a lot better. They are improving on the understanding of landscape scale. They need to consider the landscape view rather than an ad-hoc attitude.

Wildlife challenges

- Deer have not penetrated so far, badgers are close to the vineyard. Starlings have created severe damage.
- Not officially, fox family has own paddock, lots of hares and more birds around the windbreaks.
- We have our own drone which we use for bird scaring.
- We have ladybirds but we also have a problem with SWD on the pinot noir and use a biological control which is a mix of cheap red wine and cider vinegar and sugar and place 100 pots of these around the vineyard and so far it seems to have worked.
- Hares are the worst, and then deer, roe muntjac and fallow. Badgers are a real problem, we had an electric wire round the bottom of the fence, difficult to maintain. Badgers could make their way under it by digging under the wire, they have now been filled with flints.

Beauty, heritage and engagement

- Opportunity to install interpretive signage for visitors.
- We have information boards and 3 talking posts, one about the vineyard, one about the wildlife and the third about the winery.
- We have planted 6,000 trees so far. We would plant trees in keeping with the landscape but would like funding for them.
- The metal post have less impact than wooden ones and the wooden ones need replacing so often and the cost would be more prohibitive.
- The end posts are concrete and look like wood, they are brown and the rest are brown metal. We chose these so that they are not as intrusive in the landscape.

Insights and opportunities

- Demonstrate the value to a grower of functional biodiversity and ecological restoration.
- ELMs funding to cover fencing to manage sheep during the winter.
- Real time insights for targeting spray application (rather than routine applications).
- Opportunity to create nature corridors for wildlife (at the regional scale).
- Grow organic matter and benefit from slow release of nutrients rather than apply synthetic fertiliser.
- The capacity to use drones to distribute control agents to hot spots of spider mite activity (chemical or biocontrol agents).

Community engagement

- Opportunity to install interpretive signage for visitors.
- Possible educational walks in collaboration with the community if there was and specialist who was interested in undertaking the controlled walk.
- A virtual walk round the vineyard through the seasons as an educational tool.
- Regeneration of natural seed bank using dedicated seed production areas of local provenance.

CHAPTER 9: RESEARCH GAPS

This chapter outlines the research gaps and areas of potential research that may or may not fall within the remit of this project.

Further research suggestions

Recent research has been conducted by the RHS Garden Wisley team (Helen Bostock and Andrew Salisbury) to determine the relationships between native plants and arthropods. Enquire to see if they are able to provide a full list of arthropods found in association with different native plant species.

There are many unanswered, or only partially answered questions about the role of native insectary plants and associated arthropod activity. They include:

- Further research is required to elucidate the potential of broad suite of native insectary plants to support the diversity of predatory arthropods in vineyards throughout the UK.
- Assessment of the optimal size, layout and composition of insectary plantings is required, as well as the anticipated benefit of extending natural biocontrol.
- Recent research titled 'Plants for Bugs' identified a suite of morphospecies present in native vegetation and their temporal abundance throughout the year. An outstanding issue is the uncertainty that all predators will readily move between native vegetation and vineyards. To build on this research further work is required to quantify the movement of predators from insectary plants into the vineyard.
- An integrated approach is required to assess the capacity of predatory arthropods and parasitic wasps to contribute to the biocontrol of insect pests and the individual contributions each makes.
- The cost and benefit of these strategies needs to be included for different plant combinations, as well as an estimation of economic cost of endemic pest and diseases on the UK grape and wine industry.
- The full list of predators of economically damaging pests is incomplete. Further work utilising next generation sequencing of predatory arthropod gut contents provides an exciting opportunity for researchers to make these important connections between predators (including microbat scats) and prey, as new cost effective techniques are now available.
- Multi-species interactions will occur between predator and prey. Further work is required to explore the relationships of different functional arthropod groups, as well as the dynamics of host and prey densities at different times of the year and the dynamics of multi-herbivore species presence.
- All predatory species have the capacity to contribute towards biocontrol, but some are more mobile than others and have the capacity to colonise areas more quickly. More work needs to be done to elucidate the movement capabilities of different natural enemies, their visual cues and volatile signals for different plants.
- More work is also needed to assess the value of biodiversity corridors and 'stepping stones' between regions for those species who are not affected by local vegetation but may respond to landscape changes at the regional scale.
- Progress is needed to capture compelling environmental-economic accounting values of incorporating insectary plants in production landscapes and the associated biodiversity enhancement benefits.
- The full complexity of ecosystem functionality in a production landscape isn't considered here but the provision of floral resources, wetlands and/or roosting perches may also help to support higher trophic groups such as bats (Froidevaux et al., 2017; Sirami et al., 2013; Stahlschmidt et al., 2012) and/or predatory birds (Benayas et al., 2017; Kross et al., 2012; Peisley et al., 2017), which may also have the capacity to contribute either directly or indirectly towards biological control of insect pests (Kelly et al., 2016; Thiery et al., 2018). Future research should consider the complexity of these interactions so components of functionality are not overlooked.
- While it is not the focus of this study, there may be merit in assessing edible UK native insectary plants, with the potential to provide value added benefits as a cash crop or production areas for local provenance seed of endangered or threatened plant species.

CHAPTER 10: NEXT STEPS

This chapter recommends some of the next steps that will be required to overcome gaps in knowledge.

Field work

There are a number of outstanding questions that would benefit from data collection in the field and the establishment of demonstration sites for practical learning opportunities in vineyards.

Some examples include:

- **RHS Garden Wisley:** Consider reaching out to the RHS Garden Wisley team science@rhs.org.uk (Helen Bostock and Andrew Salisbury)[56] to see if they wish to collaborate on a vineyard based study to determine predatory arthropods found in association with a range of native insectary plants established in association with grapevines. They may be able to provide a full list of arthropods found in association with different native plant species from their existing research.
- Commence monitoring stands of existing unimproved chalk grassland within the Kent Downs AONB throughout the year to determine if they provide breeding sites for economically damaging insect pests including tortricid leafroller months, spotted wing drosophila, and other herbivore pests as well as predatory arthropods and parasitic wasps.
  - Identify which beneficial wildlife species are found in association for the benefit of biocontrol in vineyards as well as the wider community.
  - Investigating the extent to which unimproved stands of native grasses and wildflowers and hedgerows provide provision of food, shelter and alternative prey/parasitoid hosts and habitat for higher order predators including insectivorous/raptor birds and microbats.
  - Identify economically damaging pests and their natural predators (insects and mammals).
  - Highlight the impact of pesticides on non-target species and provide alternative biocontrol options and suggested economic thresholds for intervention.
  - Demonstrate ways of increasing biodiversity through the use of ecological infrastructures in local vineyards so growers can assess the pros and cons in the field.
  - Recommend best practice for vineyard biodiversity and assist growers in developing site specific Biodiversity Action plans (BAPs).
- Seek funding to establish native wildflower meadows, hedgerows, beetle banks and wildlife corridors in and around vineyards for data collection.
- Seek grants for investment into specific equipment which aids monitoring pests for targeted treatments and/or encouragement of natural predators like owls, kestrels, microbats. Also, for equipment that is solely for the purpose of maintaining these areas (non-vineyard equipment).

Some suggested options for functional biodiversity enhancement in and around vineyards are summarised in **Table 12**.

[56] science@rhs.org.uk or RHS Gardening Advice, RHS Garden Wisley, Woking, Surrey GU23 6QB

Table 12. Capacity for functional biodiversity enhancement using native insectary plants.

Existing vineyard infrastructure and layout	Capacity for functional biodiversity enhancement
Linear rows of vines, circa 2 m apart with ground cover (grass or plants) in between the rows.	Establish select wildflower and/or native grass mixes to trial in the mid-row and undervine areas. Establish low growing shrubs adjacent to strainer posts.
End or row headlands (~10–15 m) wide strips of grass.	
Trellising (wooden or metal posts, wires (fruiting and foliage wires), anchors and sundries such as tiebacks, clips and chains) up to 2m height.	
Tutors (thin metal, plastic or wooded tutors/stakes to train the vines; about 1m high).	Repurpose potential waste product into shrub stakes.
Grow tubes / rabbit guards for the first 3–4-years (come in a range of styles and colours).	Repurpose potential waste product into shrub guards. Cut down to size and reuse to reduce waste stream.
Cultivated or sprayed (herbicide) strips of ground (~60–80cm) under vines	Establish select chalk downs grass/wildflower mixes and/or selected herbaceous prostrate growing ground cover plants to trial in the undervine areas to reduce the need for herbicide application.
Deer, rabbit and maybe badger fencing surrounding the vineyards, with access gates.	Establish climbing native insectary plants to help screen and improve the multi-functionality of man-made structures.
Surrounding or/and internal hedges, trees and vegetation	Enhance the biodiversity and functionality of existing shrubs and trees found in association with vineyards by focusing on native and diverse supplementary flora (different flowering times and heights).
Vineyard equipment movements (tractors with sprayers, mowers, cultivators, trimming equipment etcetera).	Reduce the need for vineyard intervention by enhancing the functional biodiversity, ecosystem services and resilience of production systems.
People working in the vineyards.	Reduce the chemical intervention needed by providing habitat for predatory arthropods, microbats, and birds that can contribute to the biocontrol of insect pests and reduce the need for herbicides by planting perennial native plants in the mid and under row areas.
Windbreaks (usually linear rows of trees but could also be plastic meshing)	Enhance the biodiversity and functionality of existing windbreaks by bolstering monoculture plantings with native and diverse supplementary flora. Screen existing windbreaks using native climbing insectary plants.
From mid-March to May some vineyards have frost protection equipment in them. These could be candles/bougies, mobile wind fans, cold air drains or heaters (static or towed).	Reduce air pollution caused by the burning of candles/bougies and replace with more environmentally friendly options. Consider installing rotary frost sprinklers if long term economic damage is likely to be high and there are sufficient water resources available.
Access tracks (grass, hard core, gravel, concrete, tarmac) of varying lengths.	Consider installing raised beetle banks, low growing vegetation corridors and retaining rock piles as habitat for predatory arthropods and to slow the shedding of water (minimise erosion).
Vineyard equipment storage facilities, workshop facilities, welfare facilities, offices, spray tank wash down areas, and maybe public areas – _although these are often ore associated with winery buildings.	Establish climbing native insectary plants to help screen and improve the multifunctionality of man-made structures.

RESOURCES

This section identifies some of the resources that can be utilised to achieve the environmental stewardship vision of the region.

Local information and fact sheets

- Kent Downs management guidance and publications https://www.kentdowns.org.uk/landscape-management/management-publications/ including
  - Chalk grassland management https://s3-eu-west-1.amazonaws.com/explore-kent-bucket/uploads/sites/7/2018/04/18113959/CHALK_GRASSLAND.pdf
  - Meadow grassland management https://s3-eu-west-1.amazonaws.com/explore-kent-bucket/uploads/sites/7/2018/04/18123740/MEADOW_GRASSLAND.pdf
  - Hedgerow management https://s3-eu-west-1.amazonaws.com/explore-kent-bucket/uploads/sites/7/2018/04/18123732/HEDGEROWS.pdf
- Kent Wildlife Trust https://www.kentwildlifetrust.org.uk/cy/wildlife-explorer
- Woodland Trust https://www.woodlandtrust.org.uk
- Microbats http://www.kentbatgroup.org.uk/bats-in-kent/
- Buglife UK https://www.buglife.org.uk

Examples of local nurseries and seed suppliers

- Boston Seeds https://www.bostonseeds.com/?gclid=EAIaIQobChMIqp369tH06gIVQeztCh2UNA63EAAYASAAEgIrt_D_BwE
- British Wildflower Seeds https://britishwildflowermeadowseeds.co.uk
- Cotsolds Seeds https://cotswoldseeds.com
- Enchanted Gardens https://www.enchantedgardenskent.co.uk
- Emorsgate Seeds https://wildseed.co.uk
- John Chambers Wildflowers https://www.johnchamberswildflowers.co.uk
- Wildflowers UK http://www.wildflowersuk.com/products.asp

Best management practices

LEAF: Downloadable guides from the Simply Sustainable Series https://leafuk.org/farming/simply-sustainable-series

Landscape information

- **NBN Atlas** is an online tool that provides species lists based on a particular location including information on mammals, birds, insects, reptiles, and plants https://records.nbnatlas.org
- **Natural England Open Data Geoportal** https://naturalengland-defra.opendata.arcgis.com
- **MAGIC website** provides authoritative geographic information about the natural environment from across government. It is presented in an interactive map which can be explored using various mapping tools that are included. https://magic.defra.gov.uk

Local advisors

- BTF Partnership (land and property experts) https://www.btfpartnership.co.uk/,
- Vinescapes (viticultural experts) https://www.vinescapes.com
- Hutchinsons (agronomists) https://www.hlhltd.co.uk/
- Dr Julien Lecourt at East Malling https://www.emr.ac.uk/commercial-services/uk-vines-for-uk-wines-east-mallings-research-programme-on-grapes/

APPENDICES

Appendix 1: Reported host plants of tortricid leafrollers

Table 13. Reported host plants of grape LBAM, *Epiphyas postvittana* world wide[57]

Family	Genus/species	Common name
Actinidiaceae	*Actinidia* Lindl.	kiwi
Aizoaceae	*Mesembryanthemum* L.	iceplant
Amaranthaceae	*Amaranthus* L.	pigweed
Anacardiaceae	*Mangifera indica* L.	mango
Apiaceae	*Daucus* L.	wild carrot
Apiaceae	*Petroselinum* J. Hill	parsley
Apiaceae	*Platysace* Bunge	
Apocynaceae	*Vinca* L.	periwinkle
Araliaceae	*Hedera* L.	ivy
Asteraceae	*Arctotheca calendula* (L.) Levyns	capeweed
Asteraceae	*Artemisia* L.	sagebrush
Asteraceae	*Aster* L.	aster
Asteraceae	*Baccharis* L.	baccharis
Asteraceae	*Calendula* L.	marigold
Asteraceae	*Chrysanthemum* L.	daisy
Asteraceae	*Dahlia* Cav.	dahlia
Asteraceae	*Erigeron* L.	fleabane
Asteraceae	*Gerbera* J. F. Gmel.	Transvaal daisy
Asteraceae	*Helichrysum* Mill.	strawflower
Asteraceae	*Senecio* L.	ragwort
Asteraceae	*Tithonia* Desf. ex Juss.	tithonia
Betulaceae	*Alnus glutinosa* (L.) Gaertn.	European alder
Bignoniaceae	*Campsis* Lour.	trumpet-vine
Brassicaceae	*Brassica* L.	mustard
Brassicaceae	*Raphanus* L.	radish
Brassicaceae	*Sisymbrium* L.	hedgemustard
Buddlejaceae	*Buddleja* L.	butterflybush
Cannabaceae	*Humulus lupulus* L.	common hop
Caprifoliaceae	*Lonicera* L.	honeysuckle
Caprifoliaceae	*Viburnum* L.	viburnum
Celastraceae	*Euonymus* L.	spindle tree
Chenopodiaceae	*Chenopodium* L.	goosefoot
Clusiaceae	*Hypericum perforatum* L.	common St. Johnswort
Cupressaceae	*Cupressus* L.	cypress
Ebenaceae	*Diospyros kaki* L. f.	Japanese persimmon
Ebenaceae	*Diospyros* L.	diospyros
Epacridaceae	*Monotoca* R. Br.	
Ericaceae	*Arbutus* L.	madrone
Ericaceae	*Vaccinium* L.	blueberry
Escalloniaceae	*Escallonia* Mutis ex L.f.	escallonia
Euphorbiaceae	*Breynia* J.R. Forst. & G. Forst.	breynia
Euphorbiaceae	*Phyllanthus* L.	leafflower
Fabaceae	*Acacia* Mill.	acacia
Fabaceae	*Cassia* L.	cassia
Fabaceae	*Cytisus scoparius* (L.) Link	Scotch broom
Fabaceae	*Genista* L.	broom
Fabaceae	*Hardenbergia* Benth.	

[57] https://www.andermattuk.com/british-grape-growing-pests

Family	Genus/species	Common name
Fabaceae	*Lathyrus* L.	pea
Fabaceae	*Lupinus* L.	lupine
Fabaceae	*Medicago sativa* L.	alfalfa
Fabaceae	*Trifolium* L.	clover
Fabaceae	*Ulex europaeus* L.	common gorse
Fabaceae	*Vicia faba* L.	horsebean
Fagaceae	*Quercus* L.	oak
Geraniaceae	*Pelargonium* L'Her. ex Aiton	geranium
Grossulariaceae	*Ribes* L.	currant
Hydrangeaceae	*Philadelphus* L.	mock orange
Iridaceae	*Crocosmia* Planch.	crocosmia
Juglandaceae	*Juglans* L.	walnut
Juncaginaceae	*Triglochin* L.	arrowgrass
Lamiaceae	*Lavandula* L.	lavender
Lamiaceae	*Mentha* L.	mint
Lamiaceae	*Salvia* L.	sage
Lauraceae	*Persea americana* Mill.	avocado
Loganaceae	*Gelsemium* Juss.	trumpetflower
Magnoliaceae	*Michelia* L.	michelia
Malvaceae	*Sida* L.	fanpetals
Myoporaceae	*Myoporum* Sol. ex G. Forst.	myoporum
Myrtaceae	*Acca sellowiana* (O. Berg.) Burret	feijoa
Myrtaceae	*Astartea* DC.	
Myrtaceae	*Callistemon* R. Br.	bottlebrush
Myrtaceae	*Eucalyptus* L'Her.	gum
Myrtaceae	*Leptospermum* J.R. Forst. & G. Forst.	teatree
Myrtaceae	*Melaleuca* L.	bottlebrush
Oleaceae	*Forsythia* Vahl	fosythia
Oleaceae	*Jasminum* L.	jasmine
Oleaceae	*Ligustrum* L.	privet
Oxalidaceae	*Oxalis* L.	woodsorrel
Pinaceae	*Pinus* L.	pine
Pittosporaceae	*Billardiera* Sm.	
Pittosporaceae	*Bursaria* Cav.	
Pittosporaceae	*Pittosporum* Banks ex Sol.	cheesewood
Plantaginaceae	*Plantago lanceolata* L.	narrowleaf plantain
Polygonaceae	*Polygala* L.	milkwort
Polygonaceae	*Polygonum* L.	knotweed
Polygonaceae	*Rumex* L.	dock
Proteaceae	*Grevillea* R. Br. ex Knight	grevillea
Proteaceae	*Leucadendron* L.	
Proteaceae	*Macadamia integrifolia* Maiden & Betche	macadamia nut
Proteaceae	*Persoonia* Sm.	
Pteridaceae	*Adiantum* L.	maidenhair fern
Pteridaceae	*Pteris* L.	brake fern
Ranunculaceae	*Aquilegia* L.	columbine
Ranunculaceae	*Clematis* L.	leather flower
Ranunculaceae	*Ranunculus* L.	buttercup
Resedaceae	*Reseda* L.	mignonette
Rhamnaceae	*Ceanothus* L.	ceanothus
Rosaceae	*Cotoneaster* Medik.	cotoneaster
Rosaceae	*Crataegus* L.	hawthorn
Rosaceae	*Cydonia oblonga* Mill.	quince
Rosaceae	*Eriobotrya japonica* (Thunb.) Lindl.	loquat
Rosaceae	*Fragaria* L.	strawberry
Rosaceae	*Malus* Mill.	apple

Family	Genus/species	Common name
Rosaceae	*Photinia* Lindl.	chokeberry
Rosaceae	*Prunus armeniaca* L.	apricot
Rosaceae	*Prunus persica* (L.) Batsch	peach
Rosaceae	*Pyracantha* M. Roem.	firethorn
Rosaceae	*Pyrus* L.	pear
Rosaceae	*Rosa* L.	rose
Rosaceae	*Rubus* L.	[various]
Rutaceae	*Boronia* Sm.	boronia
Rutaceae	*Choisya* Kunth	Mexican orange
Rutaceae	*Citrus* L.	citrus
Rutaceae	*Correa* Andrews	Australian fuschia
Rutaceae	*Eriostemon* Sm.	
Rutaceae	*Fortunella* Swingle	kumquat
Salicaceae	*Populus* L.	cottonwood
Salicaceae	*Salix* L.	willow
Sapindaceae	*Dodonaea* Mill.	dodonaea
Sapindaceae	*Litchi chinensis* Sonn.	lychee
Scrophulariaceae	*Hebe* Comm. ex Juss.	hebe
Smilacaceae	*Smilax* L.	greenbrier
Solanaceae	*Datura* L.	jimsonweed
Solanaceae	*Solanum lycopersicum* L. var. *lycopersicum*	garden tomato
Solanaceae	*Solanum tuberosum* L.	Irish potato
Theaceae	*Camellia japonica* L.	
Ulmaceae	*Trema* Lour.	trema
Urticaceae	*Urtica* L.	nettle
Valerianaceae	*Centranthus* Neck. ex Lam. & DC.	fox-brush
Verbenaceae	*Clerodendron* Burm.	
Vitaceae	*Parthenocissus* Planch.	creeper
Vitaceae	*Vitis* L.	grape

Table 14. Reported host plants of EGVM, *Lobesia botrana* world wide [58]

Family	Genus/species	Common name
Actinidiaceae	*Actinidia chinensis* Planch.	kiwi
Araliaceae	*Hedera helix* L.	English ivy
Asteraceae	*Tanacetum vulgare* L.	common tansy
Berberidaceae	*Berberis vulgaris* L.	common barberry
Caprifoliaceae	*Lonicera tatarica* L.	Tatarian honeysuckle
Caprifoliaceae	*Viburnum lantana* L.	wayfaringtree
Caryophyllaceae	*Dianthus* L.	carnation
Cornaceae	*Cornus mas* L.	Cornelian cherry
Cornaceae	*Cornus sanguinea* L.	bloodtwig dogwood
Cornaceae	*Cornus* L.	dogwood
Ebenaceae	*Diospyros kaki* L. f.	Japanese persimmon
Ebenaceae	*Diospyros virginiana* L.	common persimmon
Ericaceae	*Arbutus unedo* L.	strawberry tree
Grossulariaceae	*Ribes nigrum* L.	European black currant
Grossulariaceae	*Ribes rubrum* L.	cultivated currant
Grossulariaceae	*Ribes uva-crispa* L.	European gooseberry
Lamiaceae	*Rosmarinus officinalis* L.	rosemary
Liliaceae	*Urginea maritima* (L.) Baker	red squill
Menispermaceae	*Menispermum canadense* L.	common moonseed

[58] https://www.andermattuk.com/british-grape-growing-pests

Family	Genus/species	Common name
Oleaceae	*Ligustrum vulgare* L.	European privet
Oleaceae	*Olea europaea* L.	olive
Oleaceae	*Syringa vulgaris* L.	common lilac
Punicaceae	*Punica granatum* L.	pomegranate
Ranunculaceae	*Clematis vitalba* L.	evergreen clematis
Rhamnaceae	*Ziziphus jujuba* (L.) Karst.	common jujube
Rosaceae	*Malus pumila* Mill.	apple
Rosaceae	*Prunus avium* (L.) L.	sweet cherry
Rosaceae	*Prunus domestica* L.	European plum
Rosaceae	*Prunus dulcis* (Mill.) D.A. Webb	sweet almond
Rosaceae	*Prunus persica* (L.) Batsch var. *nucipersica* (Suckow) C. K. Schneid.	nectarine
Rosaceae	*Prunus salicina* Lindl.	Japanese plum
Rosaceae	*Prunus spinosa* L.	blackthorn
Rosaceae	*Pyrus communis* L.	common pear
Rosaceae	*Rubus caesius* L.	European dewberry
Rosaceae	*Rubus fruticosus* L.	shrubby blackberry
Rosaceae	*Rubus* L.	raspberry
Thymeleaceae	*Daphne gnidium* L.	flax-leaved daphne
Thymeleaceae	*Thymelaea hirsuta* (L.) Endl.	thymelaea
Vitaceae	*Parthenocissus quinquefolia* (L.) Planch.	Virginia creeper
Vitaceae	*Vitis vinifera* L.	wine grape

Table 15. Reported host plants of EGBM, *Eupoecilia ambiguella* world wide [59]

Family	Genus/species	Common name
Aceraceae	*Acer campestre* L.	hedge maple
Araliaceae	*Eleutherococcus* Maxim.	ginseng
Araliaceae	*Hedera helix* L.	English ivy
Araliaceae	*Hedera* L.	ivy
Caprifoliaceae	*Lonicera* L.	honeysuckle
Caprifoliaceae	*Lonicera periclymenum* L.	European honeysuckle
Caprifoliaceae	*Lonicera ramosissima* Franch. & Sav. ex Maxim.	
Caprifoliaceae	*Symphoricarpos* Dunham.	snowberry
Caprifoliaceae	*Viburnum* L.	viburnum
Cornaceae	*Cornus* L.	dogwood
Cornaceae	*Cornus mas* L.	Cornelian cherry
Cuscutaceae	*Cuscuta* L.	dodder
Cuscutaceae	*Cuscuta reflexa* Roxb.	giant dodder
Grossulariaceae	*Ribes* L.	currant
Oleaceae	*Ligustrum* L.	privet
Oleaceae	*Syringa* X *persica* L.	Persian lilac
Rhamnaceae	*Frangula alnus* Mill.	glossy buckthorn
Rhamnaceae	*Rhamnus* L.	buckthorn
Rosaceae	*Prunus* L.	
Vitaceae	*Parthenocissus quinquefolia* (L.) Planch.	Virginia creeper
Vitaceae	*Vitis vinifera* L.	wine grape

59 https://www.andermattuk.com/british-grape-growing-pests

Appendix 2: Potential predatory arthropod species reported in the South Downs National Park

Table 16. A selection of predatory arthropod species reported in the South Downs AONB[60,61]

Predator taxa	Genus and species	Common name
INSECTA		
ODONATA		
Aeshnidae	*Aeshna affinis*	southern migrant hawker
	Aeshna cyanea	southern hawker dragonfly
	Aeshna grandis	brown hawker dragonfly
	Aeshna juncea	common hawker dragonfly
	Aeshna mixta	migrant hawker dragonfly
	Anax ephippiger	vagrant emperor dragonfly
	Anax imperator	emperor dragonfly
	Anax parthenope	lesser emperor dragonfly
	Brachytron pratense	hairy dragonfly
Calopterygidae	*Calopteryx splendens*	banded demoiselle
	Calopteryx virgo	European damselfly
Coenagrionidae	*Ceriagrion tenellum*	small red damselfly
	Coenagrion puella	azure damselfly
	Coenagrion pulchellum	variable damselfly
	Enallagma cyathigerum	common blue damselfly
	Erythromma najas	red-eyed damselfly
	Erythromma viridulum	small red-eyed damselfly
	Ischnura elegans	blue-tailed damselfly
	Pyrrhosoma nymphula	large-red damselfly
Cordulegastridae	*Cordulegaster boltonii*	golden-ringed dragonfly
Corduliidae	*Cordulia aenea*	downy emerald dragonfly
Gomphidae	*Gomphus vulgatissimus*	common clubtail dragonfly
Lestidae	*Chalcolestes viridis*	willow emerald damselfly
	Lestes barbarus	southern emerald damselfly
	Lestes sponsa	emerald damselfly
Libellulidae	*Libellula depressa*	broad-bodied chaser dragonfly
	Libellula fulva	scarce chaser dragonfly
	Libellula quadrimaculata	four-spotted chaser dragonfly
	Orthetrum cancellatum	black0tailed skimmer dragonfly
	Orthetrum coerulescens	keeled skimmer dragonfly
	Sympetrum danae	black darter dragonfly
	Sympetrum fonscolombii	red-veined darter dragonfly
	Sympetrum sanguineum	ruddy darter dragonfly
	Sympetrum striolatum	common-darter dragonfly
Platycnemididae	*Platycnemis pennipes*	white legged damselfly
DERMAPTERA		
Forficulidae	*Forficula auricularia*	European earwig
MANTODEA		
HEMIPTERA		
Nepidae	*Ranatra linearis*	water scorpion
Nabidae	*Nabis ericetorum*	heath damsel bug
	Nabis ferus	field damsel bug
Pentatomidae	*Picromerus bidens*	spiny shield bug
	Troilus luridus	bronze shield bug
Reduviidae	*Coranus subapterus*	heath assassin bug

[60] Collated from NBN Atlas website at http://www.nbnatlas.org Accessed 09 August 2020

[61] Collated from https://www.kentwildlifetrust.org.uk/wildlife-explorer/invertebrates

Predator taxa	Genus and species	Common name
HYMENOPTERA		
Chrysididae▲	*Chrysis ignita*	ruby-tailed wasp
Crabronidae	*Argogorytes mystaceus*	sand wasp
	Cerceris rybyensis	ornate tailed digger wasp
	Crossocerus podagricus	solitary wasp
	Ectemnius continuus	square-headed wasp
	Ectemnius lituratus	solitary wasp
	Mellinus arvensis	field digger wasp
	Nysson spinosus	large-spurred digger wasp
	Oxybelus uniglumis	square-headed wasp
	Philanthus triangulum	European beewolf
	Tachysphex pompiliformis	square-headed wasp
Tiphiidae	*Methocha articulata*	tiger beetle wasp
Vespidae	*Ancistrocerus gazella*	European potter wasp
	Dolichovespula media	median wasp
	Dolichovespula saxonica	saxon wasp
	Dolichovespula sylvestris	tree wasp
	Eumenes coarctatus	heath potter wasp
	Microdynerus exilis	little mason-wasp
	Symmorphus gracilis	figwort mason-wasp
NEUROPTERA		
Chrysopidae	*Chrysopa pallens*	green lacewing
	Chrysopa perla	green lacewing
	Chrysoperla lucasina	green lacewing
	Chrysotropia ciliata	green lacewing
	Cunctochrysa albolineata	green lacewing
	Dichochrysa flavifrons	green lacewing
	Dichochrysa prasina	green lacewing
	Dichochrysa ventralis	green lacewing
	Nineta flava	green lacewing
	Nineta vittata	green lacewing
Hemerobiidae	*Drepanepteryx phalaenoides*	brown lacewing
	Hemerobius atrifrons	brown lacewing
	Hemerobius contumax	brown lacewing
	Hemerobius humulinus	brown lacewing
	Hemerobius lutescens	brown lacewing
	Hemerobius micans	brown lacewing
	Hemerobius pini	brown lacewing
	Hemerobius simulans	brown lacewing
	Hemerobius stigma	brown lacewing
	Micromus angulatus	brown lacewing
	Micromus paganus	brown lacewing
	Micromus variegatus	brown lacewing
	Psectra diptera	brown lacewing
	Sympherobius elegans	brown lacewing
	Sympherobius fuscescens	brown lacewing
	Wesmaelius concinnus	brown lacewing
	Wesmaelius nervosus	brown lacewing
	Wesmaelius quadrifasciatus	brown lacewing
	Wesmaelius subnebulosus	brown lacewing
Osmylidae	*Osmylus fulvicephalus*	giant lacewing

Predator taxa	Genus and species	Common name
COLEOPTERA		
Coccinellidae	*Adalia decempunctata*	10-spotted ladybird beetle
	Anatis ocellata	eyed ladybird beetle
	Anisosticta novemdecimpunctata	N/A
	Calvia quattuordecimguttata	cream-spot ladybird beetle
	Chilocorus bipustulatus	heather ladybird beetle
	Chilocorus renipustulatus	kidney-spot ladybird beetle
	Coccinella magnifica	scarce seven-spot ladybird
	Coccidula rufa	N/A
	Coccinella septempunctata	seven-spot ladybird beetle
	Exochomus quadripustulatus	pine ladybird beetle
	Halyzia sedecimguttata ⊗	orange ladybird beetle
	Harmonia quadripunctata	4-spot ladybird beetle
	Hippodamia variegata	spotted amber ladybird beetle
	Myzia oblongoguttata	striped ladybird beetle
	Tytthaspis sedecimpunctata ⊗	sixteen-spot ladybird beetle
	Propylea quatuordecimpunctata	14-spotted ladybird beetle
	Psyllobora vigintiduopunctata ⊗	22-spot ladybird beetle
	Rhyzobius litura	N/A
	Rhyzobius lophanthae	scale-eating ladybird beetle
	Subcoccinella vigintiquattuorpunctata ⊗	4-spot ladybird beetle
Endomychidae	*Endomychus coccineus* ⊗	Handsome fungus beetle
DIPTERA		
Asilidae	*Asilus crabroniformis*	hornet robber fly
	Choerades marginatus	robber fly
	Dioctria rufipes	common red-legged robber fly
	Leptarthrus brevirostris	robber fly
	Leptogaster cylindrica	robber fly
	Machimus atricapillus	robber fly
	Machimus rusticus	robber fly
	Machimus cingulatus	robber fly
	Neoitamus cyanurus	common awl robberfly
Rhagionidae	*Chrysopilus asiliformis*	little snipe fly
	Chrysopilus cristatus	black snipe fly
	Rhagio lineola	small fleck-winged snipe fly
	Rhagio scolopaceus	downlooker snipe fly
	Rhagio tringarius	marsh snipe fly
Syrphidae	*Chrysotoxum bicinctum*	two-banded wasp hoverfly
	Chrysotoxum festivum	hook-banded wasp hoverfly
	Episyrphus balteatus	marmalade hoverfly
	Eristalinus sepulchralis	hoverfly
	Eristalis nemorum	stripe-faced dronefly
	Eristalis tenax	dronefly
	Helophilus pendulus	tiger hoverfly
	Platycheirus granditarsus	hoverfly
	Rhingia campestris	common snout-hoverfly
Tachinidae ▲	*Eriothrix rufomaculata*	tachinid fly
	Tachina fera	tachinid fly
Therevidae	*Thereva bipunctata*	twin-spot stiletto fly
MECOPTERA		
Panorpidae	*Panorpa cognata*	scorpion fly
	Panorpa communis	scorpion fly
	Panorpa germanica	scorpion fly
RAPHIDIOPTERA		
Raphidiidae	*Atlantoraphidia maculicollis*	snakefly
PHASMATODEA		
Phasmatidae	*Acanthoxyla prasina*	prickly stick insect
	Clitarchus hookeri	stick insect

Predator taxa	Genus and species	Common name	Behaviour
<u>**ARACHNIDA**</u>			
ACARI	*Phytoseiulus* ssp.	predatory mite	
ARANEAE			
Agelenidae	*Eratigena atrica*	giant house spider	
Araneidae	*Araneus diadematus*	garden spider	web (sedentary
	Argiope bruennichi	orb weaving spider	
	Mangora acalypha	wasp spider	
	Cyclosa conica	orb weaving spider	
	Agalenatea redii	orb weaving spider	
Linyphiidae	*Linyphia triangularis*	money spider	web (sedentary)
Lycosidae	Pardosa amentata	wolf spider	
Phalangiidae	Phalangium opilio	common harvestman	ambush (active)
Philodromidae	*Tibellus oblongus*		
Pisauridae	*Dolomedes fimbriatus*	raft spider	hunter (active
	Pisaura mirabilis	nursery web spider	
Salticidae	*Salticus scenicus*	zebra spider	
Tetragnathidae	*Metellina segmentata*	long-jawed orb-weaver	web (sedentary
	Tetragnatha ssp.	long-jawed orb-weaver	
Thomisidae	*Diaea dorsata*	flower crab spider	ambush (active)
	Misumena vatia	flower crab spider	
Uloboridae	*Hyptiotes paradoxus*	hyptiotes spider	web (sedentary)
Zodariidae			
PSEUDOSCORPIONES			
Chthoniidae	*Cheiridium museorum*	pseudoscorpion	
	Lamprochernes nodosus	pseudoscorpion	
	Pselaphochernes dubius	pseudoscorpion	
	Pselaphochernes scorpioides	pseudoscorpion	
	Dinocheirus panzeri	pseudoscorpion	
	Allochernes powelli	pseudoscorpion	
	Chernes cimicoides	pseudoscorpion	
	Lamprochernes chyzeri	pseudoscorpion	
	Chthonius ischnocheles	pseudoscorpion	
	Chthonius tenuis	pseudoscorpion	
	Chthonius orthodactylus	pseudoscorpion	
		pseudoscorpion	
Neobisiidae	*Neobisium carcinoides*	pseudoscorpion	
	Roncus lubricus	pseudoscorpion	

▲ = parasitoid, ‡ = herbivore, ⊗ = scavenger, omnivore, seed, fungal mould or pollen feeder, ▼= detritivore

Appendix 3a: Native predatory bird species found in Kent and/or surrounds and their conservation status

Table 17. Native predatory bird species found in Kent and/or surrounds[62,63]

Species	Common name	Diet	Habitat	Conservation concern (green, amber, red)[64]
Tyto alba	barn owl	small mammals including mice, shrews, rats and vole	open countryside, roadside verges, farmland	green
Buteo buteo	buzzard	rodents, rabbits, birds and invertebrates	woodland, upland, farmland	green
Pernis apivorus	honey buzzard	bees and wasp larvae	woodland	amber
Accipiter gentilis	goshawk	smaller birds, mammals, amphibians, reptiles	woodland, grassland	green
Accipiter nisus	sparrowhawk	small birds	dense woodland, gardens, cities and suburban area	green
Falco subbuteo	hobby	birds, dragonflies and other flying insects	open woodland, farmland, wetland, grassland	green
Falco tinnunculus	kestrel	voles, mice, shrews, birds and invertebrates	grassland, farmland, upland, urban	amber
Asio otus	long-eared owl	voles, mice, small birds	coniferous or mixed woodland	green
Milvus milvus	red kite	scavenged carrion, small mammals, invertebrates	grassland, woodland, heathland, urban areas	green
Accipiter nisus	sparrowhawk	small birds	dense woodland, gardens, cities and suburban areas	green
Strix aluco	tawny owl	small mammals, birds	woodland, occasionally parks and gardens	amber

For more information visit https://www.kentwildlifetrust.org.uk/wildlife-explorer/birds and https://www.woodlandtrust.org.uk

62 Collated from https://www.woodlandtrust.org.uk/trees-woods-and-wildlife/animals/birds/

63 Collated from https://www.kentwildlifetrust.org.uk/wildlife-explorer/birds/birds-prey

64 Conservation status as per the Birds of Conservation Concern 4: the Red List for Birds (2015). https://britishbirds.co.uk/wp-content/uploads/2014/07/BoCC4.pdf

Appendix 3b: Native insectivorous bird species found in Kent and/or surrounds and their conservation status

Table 18. Native insectivorous bird species found in Kent and/or surrounds[65,66]

Species	Common name	Diet	Habitat	Conservation concern (green, amber, red)[67]
Aegithalos caudatus	long-tailed tit	insects and invertebrates including caterpillars	woodland, farmland, parks and gardens	green
Apus apus	swift	flying insects	grassland, farmland, wetland, urban areas	amber
Caprimulgus europaeus	nightjar	moths, beetles, flies	open conifer woodland, heathland and moorland	amber
Carduelis carduelis	goldfinch	invertebrates and seeds	woodland, farmland, parks and gardens	green
Certhia familiaris	treecreeper	insects and seeds	broadleaf and conifer woodland	green
Cuculus canorus	cuckoo	invertebrates, including hairy caterpillars	woodland edges and grassland	priority species/ vulnerable (red)
Delichon urbicum	house martin	flying insects, aphids	open farmland, open water	amber
Dendrocopos major	great spotted woodpecker	insects, tree seeds, young birds and eggs	woodland, parks and gardens	green
Ficedula hypoleuca	pied flycatcher			red
Fringilla coelebs	common chaffinch	invertebrates, including caterpillars, aphids, earwigs, spiders and beetle larvae.[68]	woodland, farmland, parks and gardens	green
Luscinia megarhynchos	nightingale	invertebrates	scrub and coppice woodland	red
Muscicapa striata	spotted flycatcher	butterflies, damselflies, wasps, bees, moths, craneflies	woodland edges and clearings, parks, gardens	priority species (red)
Passer montanus	coal tit	insects, spiders, nuts, and seeds	conifer or mixed woods, towns and garden	green
Prunella modularis	dunnock	invertebrates and seeds	woodland, farmland, scrub, parks and gardens	amber

[65] Collated from https://www.woodlandtrust.org.uk/trees-woods-and-wildlife/animals/birds/

[66] Collated from https://www.kentwildlifetrust.org.uk/wildlife-explorer/birds/birds-prey

[67] Conservation status as per the Birds of Conservation Concern 4: the Red List for Birds (2015). https://britishbirds.co.uk/wp-content/uploads/2014/07/BoCC4.pdf

[68] Cramp, Stanley, ed. (1994). "Fringilla coelebs Chaffinch". Handbook of the Birds of Europe the Middle East and North Africa. The Birds of the Western Palearctic, Volume 8: Crows to Finches. Oxford: Oxford University Press. pp. 448–473. ISBN 978-0-19-854679-5.

Phylloscopus collybita	common chiffchaff	invertebrates, flies, gnats, midges and caterpillars. Requires about one-third of its weight in insects daily.	woodland, scrub, parks and gardens	green
Phylloscopus sibilatrix	wood warbler	insects and spiders	upland oak woods, deciduous woodland	priority species (red)
	tree sparrow	cereals, seeds, insects	woodland, farmland	priority species (red)
Phylloscopus trochilus	willow warbler	invertebrates	woodland, scrub, gardens	amber
Picus viridis	green woodpecker	ants and other invertebrates	woodland, grassland, parks and gardens	green
Regulus regulus	goldcrest	insects and invertebrates	coniferous and mixed woodland, parks and gardens	green
Sitta europaea	nuthatch	insects and invertebrates, seeds and nuts	broadleaved woodland	green
Spinus spinus	siskin	tree seeds and insects	mixed and coniferous woodland	green
Scolopax rusticola	woodcock	invertebrates	deciduous or mixed woodland, heathland	green
Troglodytes troglodytes	wren	insects, spiders	woodland, heathland, farmland, gardens	green

For more information visit https://www.kentwildlifetrust.org.uk/wildlife-explorer/birds and https://www.woodlandtrust.org.uk

Appendix 3c: Native microbat species found in Kent and/or surrounds and their conservation status

Table 19. Kent microbat distribution table 2018[69,70,71,72]

Species	Common name	Diet	Habitat	Kent status	Conservation status
Barbastella barbastellus	barbastelle	moths, midges, beetles	deciduous woodland, wet meadows	not present or very rare	protected/ priority species/near threatened
Eptesicus serotinus	serotine	flies, moths, beetles	woodland, hedgerows, parkland, pastures	widespread but declining	protected
Myotis mystacinus	whiskered bat	midges, moths and other flying insects	open habitats, parks, towns and gardens	Scarce and elusive	protected
Myotis brandtii	Brandt's bat	moths, midges, spiders	woodland, farmland	rare and elusive	protected
Myotis bechsteinii	Bechstein's bat	invertebrates	ancient woodland, deciduous woodland, wet woodland	very rare	protected/ priority species/near threatened
Myotis daubentonii	Daubenton's bat	invertebrates	woodland and grassland close to fresh water	common near water	protected
Myotis nattereri	Natterer's bat	midges, moths, crane flies, beetles, spiders	deciduous woodland, farmland, over sheltered water	scarce	protected
Nyctalus noctula	doctule	Insects	woodland	generally uncommon, declining	protected
Nyctalus leisleri	Leisler's bat	flies, moths, beetles	woodland, farmland	scarce, may be under-recorded	protected
Pipistrellus pipistrellus	common pipistrelle	invertebrates	woodland, farmland, grassland, urban areas	common	protected
Pipistrellus pygmaeus	soprano pipistrelle	flies, moths, midges, mosquitos	woodland, parks and gardens	common	protected
Pipistrellus nathusii	Nathusius' pipistrelle	invertebrates	parkland and light woodland	scarce, often migrant	protected
Plecotus auritus	brown long-eared bat	moths, earwigs, flies, spiders and beetles	woodland	common	protected/ priority
Plecotus austriacus	grey long-eared bat	moths and small lizards	woodland	not present or very rare	protected

69 Collated from http://www.kentbatgroup.org.uk/bats-in-kent/

70 Collated from https://www.woodlandtrust.org.uk/trees-woods-and-wildlife/animals/birds/

71 Collated from https://www.kentwildlifetrust.org.uk/wildlife-explorer/birds/birds-prey

72 Collated from https://jncc.gov.uk/our-work/uk-bap-priority-species/

Appendix 3d: Native reptile species found in Kent and/or surrounds and their conservation status

Table 20. Native reptile species found in Kent and surrounds[73,74]

Species	Common name	Diet	Habitat	Conservation status
Coronella austriaca	smooth snake	smaller animals, especially other reptiles	heathland	priority species
Lacerta agilis	sand lizard	insects and spiders	lowland heathlands and sand dunes	priority species
Natrix helvetica	grass snake	amphibians, fish, small mammals, birds	wetland, woodland, farmland, grassland	priority species
Vipera berus	adder	small mammals, amphibians, birds and reptiles	woodland, grassland, heathland	priority species
Zootoca vivipara	common lizard	insects, spiders and other invertebrates	open woodland, heathland, moorland and sometimes gardens	priority species

For more information visit https://www.woodlandtrust.org.uk/trees-woods-and-wildlife/animals/reptiles-and-amphibians/common-lizard/ and https://www.kentwildlifetrust.org.uk/wildlife-explorer/reptiles

[73] Collated from https://www.woodlandtrust.org.uk/trees-woods-and-wildlife/animals/reptiles-and-amphibians/common-lizard/

[74] Collated from https://www.kentwildlifetrust.org.uk/wildlife-explorer/reptiles

Appendix 4: UK vineyard pesticide application and potential pesticide toxicity to predators

UK vineyard pesticide application 2018

There was approximately 32.8 tonnes of pesticide applied to vines in the UK in 2018. Vines received on average 9 fungicide, 6 sulphur, 2 herbicide and 2 insecticide spray applications. Chardonnay, Pinot Noir and Pinot Meunier were the three main varieties grown.[75]

- **Fungicide**: approximately 16.5 tonnes of fungicide were applied to target control of botrytis, downy mildew, powdery mildew, and phomopsis including:
  - Mancozeb which is potentially highly toxic to fish, and moderately toxic to earthworms[76], it is also regarded as highly toxic to predatory mites and parasitic wasps,
  - Meptyldinocap which is potentially high toxicity to fish and moderate toxicity to honeybees and earthworms.[77]
  - Ametoctradin which potentially has a high acute toxicity and moderate chronic toxicity to fish.[78]
  - Dimethomorph which potentially is moderately toxic to fish, aquatic invertebrates and earthworms.[79]
  - Benthiavalicarb-isopropyl which potentially is moderately toxic to fish and earthworms[80]
  - Cyprodinil which potentially is moderately toxic to birds, fish and earthworms, highly toxic to aquatic invertebrates.[81]
  - Fludioxonil which potentially is highly toxic to aquatic invertebrates, moderately toxic to fish, and earthworms.[82]
  - 15.2 tonnes of sulphur which is toxic to predatory mites and parasitic wasps at rates of 400g/100L.
- **Insecticide:** approximately <0.1 tonnes of insecticide was applied to target control of spotted wing drosophila, general pest control, scale insects and other pests (not specified) including:
  - Spinosad which potentially is highly toxic to aquatic invertebrates, bees and other pollinators, and moderately toxic to fish, and earthworms.[83]
  - Lambda-cyhalothrin which potentially is highly toxic to mammals, fish, aquatic invertebrates, honey, mason and bumble bees and moderately toxic to earthworms.[84]
  - Cyantraniliprole which potentially is highly toxic to aquatic invertebrates, moderately toxic to fish and earthworms.[85]
  - Indoxacarb which potentially is highly toxic to birds honey bees, and bumble bees in acute doses, moderately toxic to fish, aquatic invertebrates and earthworms.[86]
  - Spirotetramat which potentially is potentially toxicity to aquatic invertebrates and fish as well as potential for groundwater contamination[87]

---

75 https://secure.fera.defra.gov.uk/pusstats/surveys/documents/softfruit2018.pdf
76 https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/424.htm
77 https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/439.htm
78 https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/1648.htm
79 https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/245.htm
80 https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/2172.htm
81 https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/199.htm
82 https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/330.htm
83 https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/596.htm
84 https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/415.htm
85 https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/1662.htm
86 https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/399.htm
87 http://pmep.cce.cornell.edu/profiles/insect-mite/propetamphos-zetacyperm/spirotetramat/spirotet_reg_0809.pdf

- **Herbicide:** approximately 1.1 tonnes of herbicide was applied for general weed control (97%), with broad leaf weed control comprising 2% and grass weeds 1%, including:
  - Glyphosate which is potentially moderately toxic to fish and honey bees.[88]
  - Diquat which is potentially moderately toxic to fish, aquatic invertebrates, honey bees and earthworms and is very persistent in the soil. [89]
  - Carfentrazone-ethyl which is potentially moderately toxic to fish and aquatic invertebrates and earthworms.[90]
  - Propyzamide and isoxaben which are both potentially moderately toxic to fish and aquatic invertebrates and earthworms.[91, 92]

Pesticide toxicity to predators

There is growing awareness of the dangers of chemical use. Chemicals may be harmful to the environment and human health if not managed appropriately. Cultural and biological control options can be used to reduce the level of intervention and the volume of chemical use required each season. Off target damage to predatory arthropods can be significant and the cost of unintended consequences should be considered when spraying chemicals.

A summary of sensitivities to sprays for common vineyard predatory arthropods includes:

- Dragonfly nymphs are sensitive to chemical runoff into waterways, and exposure to copper (Tollett et al., 2009). Both adults and nymphs are susceptible to broad-spectrum insecticide exposure including pyrethroids (Mian and Mulla, 1992).
- Damselfly presence on a body of water indicates it is relatively unpolluted. Adults and nymphs are susceptible to broad-spectrum insecticide exposure including pyrethroids (Mian and Mulla, 1992) and fipronil (Sugita et al., 2018).
- Predatory bugs are particularly sensitive to carbaryl, methomyl, fipronil, indoxacarb, organophosphates, pyrethroids, and spinosad (Thomson, 2012). Residues on foliage, or in plant tissues may remain toxic for many months (Biological Services, 2019).
- Ladybird beetles are particularly sensitive to high rates of sulphur (≥400 g/100 litres), carbaryl, methomyl, indoxacarb, organophosphates, and pyrethroids (Thomson, 2012). Growth regulators such buprofezin are also toxic (Thomson et al., 2007).
- Rove beetles are particularly sensitive to methomyl (Sharley et al., 2008), mancozeb (Thomson et al., 2007) and other broad spectrum insecticides, particularly pyrethroids, organophosphates and neonicotinoids.
- Syrphid (hoverfly) populations can be sensitive to some chemicals but their high mobility in vineyards may account for the lack of detectable effects on this group (Thomson and Hoffmann, 2006a). Collateral damage will occur if broad spectrum insecticides are used.
- Parasitoid wasps are particularly sensitive to high rates of sulphur (≥400 g/100 litres), clothianidin, carbaryl, methomyl, fipronil, indoxacarb, organophosphates, pyrethroids, and spinosad (Thomson, 2012). By delaying the release of *Trichogramma* wasps, until 6 days after spraying with sulfur will reduce adverse effects on released organisms (Thomson et al., 2000).
- Ants are sensitive to chlorpyrifos, diazinon and permethrin. They have very high sensitivity to indoxacarb, clothianidin, fipronil, sulfoxaflor and organophosphates and highly sensitive to petroleum spray oil, chlorantraniliprole, spinosad, and methomyl (CRDC, 2019).

---

88 https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/373.htm

89 https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/1541.htm

90 https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/123.htm

91 https://sitem.herts.ac.uk/aeru/iupac/Reports/556.htm

92 https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/411.htm

- Pesticides are toxic to lacewings, and some fungicides may be disruptive. Chlorpyrifos can persist for up to 8 weeks, and along with lime sulphur, high rates of elemental sulphur and mancozeb are particularly damaging to lacewing populations (Thomson and Hoffmann, 2007). Lacewings are very sensitive to carbaryl, methomyl, and pyrethroids, (Thomson, 2012). They have very high sensitivity to chlorantraniliprole and spirotetramat, high sensitivity to sulfoxaflor and clothianidin (CRDC, 2019).
- Predatory mites are particularly sensitive to chemical sprays including active constituents emamectin benzoate, mancozeb (Bernard et al., 2004), spinosad (direct overspray and residue), wettable sulfur (≥400 g/100 litres), and pyrimethanil (Bernard et al., 2010). Chemical residues toxic to predatory mites must have time to degrade before predatory mites are released. Synthetic pyrethroids and some organophosphates may need up to eight weeks to break down (Bugs for bugs, 2019)
- Collateral damage will occur to assassin bug, ground beetle and spider populations if broad spectrum insecticides are used.

REFERENCES

Agusti, N., Shayler, S. P., Harwood, J. D., Vaughan, I. P., Sunderland, K. D., and Symondson, W. O. C. (2003). Collembola as alternative prey sustaining spiders in arable ecosystems: prey detection within predators using molecular markers. *Molecular Ecology* **12**, 3467-3475.

Altieri, M. A. (1991). Increasing biodiversity to improve insect pest-management in agroecosystems. *In* "Biodiversity of microorganisms and invertebrates : its role in sustainable agriculture" (D. L. Hawksworth, ed.), Vol. 4, pp. 165-182. CAB International, Wallingford, UK.

Altieri, M. A. (1999). The ecological role of biodiversity in agroecosystems. *Agriculture Ecosystems and Environment* **74**, 19-31.

Altieri, M. A., and Nicholls, C. I. (2004). "Biodiversity and pest management in agroecosystems," Food Products Press, Binghamton, USA.

Altieri, M. A., Ponti, L., and Nicholls, C. I. (2005). Manipulating vineyard biodiversity for improved insect pest management: case studies from northern California. *International Journal of Biodiversity Science and Management* **1**, 191-203.

Ambrosino, M. D., Luna, J. M., Jepson, P. C., and Wratten, S. D. (2006). Relative frequencies of visits to selected insectary plants by predatory hoverflies (Diptera: Syrphidae), other beneficial insects, and herbivores. *Environmental Entomology* **35**, 394-400.

Andow, D. A. (1991). Vegetational diversity and arthropod population response. *Annual review of entomology* **36**, 561-586.

Andrade, K. A., Aguiar-Menezes, E. L., Goncalves-Esteves, V., Mendonca, C. B. F., Vieira, G. R. M., Melo, S. J., Magalhaes, J. L. A., and Melo, G. J. B. (2018). Pollen ingestion by *Chrysoperla externa* (Hagen) adults in a diversified organic agroecosystem. *Neotropical Entomology* **47**, 118-130.

Andren, H. (1994). Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat - A review. *Oikos* **71**, 355-366.

Arbuckle, K. (2012). Native perennial grasses reap both cost and environmental rewards. *Australian and New Zealand Grapegrower and Winemaker*, 19-22.

Baggen, L. R., and Gurr, G. M. (1998). The influence of food on *Copidosoma koehleri* (Hymenoptera: Encyrtidae), and the use of flowering plants as a habitat management tool to enhance biological control of potato moth, *Phthorimaea operculella* (Lepidoptera: Gelechiidae). *Biological Control* **11**, 9-17.

Baggen, L. R., Gurr, G. M., and Meats, A. (1999). Flowers in tri-trophic systems: mechanisms allowing selective exploitation by insect natural enemies for conservation biological control. *Entomologia Experimentalis Et Applicata* **91**, 155-161.

Banks, J. E. (2000). Natural vegetation in agroecosystems - Pattern and scale of heterogeneity. *Interchanges of Insects between Agricultural and Surrounding Landscapes*, 215-229.

Barbosa, P. (1998). "Agroecosystems and conservation biological control," Academic Press, San Diego.

Barnes, A. M., Wratten, S. D., and Sandhu, H. S. (2010). Harnessing biodiversity to improve vineyard sustainability. *In* "Procedings of the Fourteenth Australian Wine Industry Technical Conference" (R. J. Blair, T. H. Lee and I. S. Pretorius, eds.), pp. 239-243. The Australian Wine Industry Technical Conference, Glen Osmond, SA, Australia.

Barr, N. B., Ledezma, L. A., Farris, R. E., Epstein, M. E., and Gilligan, T. M. (2011). A multiplex real-time polymerase chain reaction assay to diagnose *Epiphyas postvittana* (Lepidoptera: Tortricidae). *Journal of Economic Entomology* **104**, 1706-1719.

Barr, N. B., Ledezma, L. A., Vasquez, J. D., Epstein, M., Kerr, P. H., Kinnee, S., Sage, O., and Gilligan, T. M. (2009). Molecular identification of the light brown apple moth (Lepidoptera: Tortricidae) in California using a polymerase chain reaction assay of the internal transcribed spacer 2 locus. *Journal of Economic Entomology* **102**, 2333-2342.

Baumgartner, K. (2003). Encouraging beneficial AM fungi in vineyard soil. *Practical Winery and Vineyard*, 1 - 3.

Begg, G. S., Cook, S. M., Dye, R., Ferrante, M., Franck, P., Lavigne, C., Lovei, G. L., Mansion-Vaquie, A., Pell, J. K., Petit, S., Quesada, N., Ricci, B., Wratten, S. D., and Birch, A. N. E. (2017). A functional overview of conservation biological control. *Crop Protection* **97**, 145-158.

Begum, M., Gurr, G. M., Wratten, S. D., Hedberg, P. R., and Nicol, H. I. (2006). Using selective food plants to maximize biological control of vineyard pests. *Journal of Applied Ecology* **43**, 547-554.

Begum, M., Gurr, G. M., Wratten, S. D., and Nicol, H. I. (2004). Flower color affects tri-trophic-level biocontrol interactions. *Biological Control* **30**, 584-590.

Benayas, J. M. R., Meltzer, J., de las Heras-Bravo, D., and Cayuela, L. (2017). Potential of pest regulation by insectivorous birds in Mediterranean woody crops. *Plos One* **12**.

Bernard, M., Semerato, L., Carter, V., and Wratten, S. D. (2006a). Beneficial insects in vineyards: Parasitoids of LBAM and grapevine moth in south-east Australia. *The Australian and New Zealand Grapegrower and Winemaker* **513**, 21-28.

Bernard, M., Wainer, J., Carter, V., Semeraro, L., Yen, A. L., and Wratten, S. D. (2006b). Beneficial insects and spiders in vineyards: Predators in south-east Australia. *The Australian and New Zealand Grapegrower and Winemaker* **512**, 37-48.

Bernard, M., Weppler, R., Kourmouzis, T., Yen, A. L., Horne, P. A., Papacek, D., and Jacometti, M. A. (2007). Guidelines for environmentally sustainable winegrape production in Australia: IPM adoption self-assessment guide for growers. *The Australian and New Zealand Grapegrower and Winemaker* **March**, 24-35.

Bernard, M. B., Cole, P., Kobelt, A., Horne, P. A., Altmann, J., Wratten, S. D., and Yen, A. L. (2010). Reducing the impact of pesticides on biological control in Australian vineyards: Pesticide mortality and fecundity effects on an indicator Species, the predatory mite *Euseius victoriensis* (Acari: Phytoseiidae). *Journal of Economic Entomology* **103**, 2061-2071.

Bernard, M. B., Horne, P. A., and Hoffmann, A. A. (2004). Developing an ecotoxicological testing standard for predatory mites in Australia: Acute and sublethal effects of fungicides on *Euseius victoriensis* and *Galendromus occidentalis* (Acarina : Phytoseiidae). *Journal of Economic Entomology* **97**, 891-899.

Berndt, L., Wratten, S., and Frampton, C. (2000). The use of buckwheat flowers to enhance efficiency of leafroller parasitoids in a New Zealand vineyard. *In* "California Conference on Biological Control II, The Historic Mission Inn Riverside, California, USA, 11-12 July, 2000" (M. S. Hoddle, ed.), pp. 121-123.

Berndt, L. A., and Wratten, S. D. (2005). Effects of alyssum flowers on the longevity, fecundity, and sex ratio of the leafroller parasitoid *Dolichogenidea tasmanica*. *Biological Control* **32**, 65-69.

Berndt, L. A., Wratten, S. D., and Hassan, P. G. (2002). Effects of buckwheat flowers on leafroller (Lepidoptera: Tortricidae) parasitoids in a New Zealand vineyard. *Agricultural and Forest Entomology* **4**, 39-45.

Bianchi, F. J. J. A., Booij, C. J. H., and Tscharntke, T. (2006). Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. *Proceedings of the Royal Society B-Biological Sciences* **273**, 1715-1727.

Biological Services (2019). Biological Services website at https://www.biologicalservices.com.au.

Boller, E. F., Häni, F., and Poehling, H. M. (2004). "Ecological infrastructures: ideabook on functional biodiversity at the farm level," Landwirtschaftliche Beratungszentrale Lindau (LBL), Lindau.

Bone, N. J., Thomson, L. J., Ridland, P. M., Cole, P., and Hoffmann, A. A. (2009). Cover crops in Victorian apple orchards: Effects on production, natural enemies and pests across a season. *Crop Protection* **28**, 675-683.

Brooks, T. M., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., Rylands, A. B., Konstant, W. R., Flick, P., Pilgrim, J., Oldfield, S., Magin, G., and Hilton-Taylor, C. (2002). Habitat loss and extinction in the hotspots of biodiversity. *Conservation Biology* **16**, 909-923.

Brown, J. W. (2011). Tools for identifying the larvae of leafrollers (Lepidoptera: Tortricidae) frequently intercepted at U.S. ports of entry. National Museum of Natural History, Washington, DC.

Brown, J. W., Epstein, M. E., Gilligan, T. M., Passoa, S. C., and Powell, J. A. (2010). Biology, identification, and history of the light brown apple moth, *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae: Archipini) in California: an example of the importance of local faunal surveys to document the establishment of exotic insects. *American Entomologist.* **56(1)**, 34-43.

Bugg, R. L. (1993). Habitat manipulation to enhance the effectiveness of aphidophagous hover flies (Diptera: Syrphidae). *Sustainable Agriculture* **5**, 12-15.

Bugg, R. L., and Wilson, L. T. (1989). *Ammi visnaga* (L.) Lamarck (Apiaceae): Associated beneficial insects and implications for biological control, with emphasis on the bell-pepper agroecosystem. *Biological Agriculture and Horticulture* **6**, 241-268.

Bugs for bugs (2019). Bugs for bugs website at https://bugsforbugs.com.au/.

Burns, K. N., Bokulich, N. A., Cantu, D., Greenhut, R. F., Kluepfel, D. A., O'Geen, A. T., Strauss, S. L., and Steenwerth, K. L. (2016). Vineyard soil bacterial diversity and composition revealed by 16S rRNA genes: Differentiation by vineyard management. *Soil Biology & Biochemistry* **103**, 337-348.

Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., Narwani, A., Mace, G. M., Tilman, D., Wardle, D. A., Kinzig, A. P., Daily, G. C., Loreau, M., Grace, J. B., Larigauderie, A., Srivastava, D. S., and Naeem, S. (2012). Biodiversity loss and its impact on humanity. *Nature* **486**, 59-67.

Cardinale, B. J., Harvey, C. T., Gross, K., and Ives, A. R. (2003). Biodiversity and biocontrol: emergent impacts of a multi-enemy assemblage on pest suppression and crop yield in an agroecosystem. *Ecology Letters* **6**, 857-865.

Cardinale, B. J., Srivastava, D. S., Duffy, J. E., Wright, J. P., Downing, A. L., Sankaran, M., and Jouseau, C. (2006). Effects of biodiversity on the functioning of trophic groups and ecosystems. *Nature* **443**, 989-992.

Chemnitz, C., and Weigelt, J. (2005). *In* "Soil atlas: facts and figures about earth, land and fields 2015". Phoenix Print GmbH, Würzburg, Germany.

Close, A., Zammit, C., Boshier, J., Gainer, K., and Mednis, A. (2009). "Ecosystem services: Key concepts and applications, Occasional paper series." Department of the Environment, Water, Heritage and the Arts, Canberra.

Colley, M. R., and Luna, J. M. (2000). Relative attractiveness of potential beneficial insectary plants to aphidophagous hoverflies (Diptera : Syrphidae). *Environmental Entomology* **29**, 1054-1059.

Colunga-Garcia, M., Gage, S. H., and Landis, D. A. (1997). Response of all assemblage of Coccinellidae (Coleoptera) to a diverse agricultural landscape. *Environmental Entomology* **26**, 797-804.

Colwell, R. (2009). Biodiversity: concepts, patterns, and measurement. *In* "The Princeton Guide to Ecology", pp. 257-263. Princeton University Press.

Conner, J. K., and Rush, S. (1996). Effects of flower size and number on pollinator visitation to wild radish, *Raphanus raphanistrum*. *Oecologia* **105**, 509-516.

Coombes, D. S., and Sotherton, N. W. (1986). The dispersal and distribution of polyphagous predatory Coleoptera in cereals. *Annals of Applied Biology* **108**, 461-474.

Corbett, A., and Plant, R. E. (1993). Role of movement in the response of natural enemies to agroecosystem diversification: a theoretical evaluation. *Environmental Entomology* **22**, 519-531.

Cottingham, K. L., Brown, B. L., and Lennon, J. T. (2001). Biodiversity may regulate the temporal variability of ecological systems. *Ecology Letters* **4**, 72-85.

CRDC (2019). Cotton Pest Management Guide 2018–19 at https://cottoninfo.com.au/sites/default/files/documents/CPMG%202018-19%20update%20Dec%202018.pdf.

Cross, J., Fountain, M., Marko, V., and Nagy, C. (2015). Arthropod ecosystem services in apple orchards and their economic benefits. *Ecological Entomology* **40**, 82-96.

D'Alberto, C. F., Hoffmann, A. A., and Thomson, L. J. (2012). Limited benefits of non-crop vegetation on spiders in Australian vineyards: regional or crop differences? *Biocontrol* **57**, 541-552.

Daane, K. M., Hogg, B. N., Wilson, H., and Yokota, G. Y. (2018). Native grass ground covers provide multiple ecosystem services in Californian vineyards. *Journal of Applied Ecology* **55**, 2473-2483.

Danne, A., Thomson, L. J., Sharley, D. J., Penfold, C. M., and Hoffmann, A. A. (2010). Effects of native grass cover crops on beneficial and pest invertebrates in Australian vineyards. *Environmental Entomology* **39**, 970-978.

Danthanarayana, W. (1980). Parasitism of the light brown apple moth, *Epiphyas postvittana* (Walker), by its larval ectoparasite, *Goniozus jacintae* Farrugia (Hymenoptera: Bethylidae), in natural populations in Victoria. *Australian Journal of Zoology* **28**, 685-692.

DeBach, P. (1974). "Biological control by natural enemies," Cambridge University Press, Cambridge, UK.

Denys, C., and Tscharntke, T. (2002). Plant-insect communities and predator-prey ratios in field margin strips, adjacent crop fields, and fallows. *Oecologia* **130**, 315-324.

Dudley, N., and Alexander, S. (2017). Agriculture and biodiversity: a review. *Biodiversity* **18**, 45-49.

Duelli, P., and Obrist, M. K. (2003). Regional biodiversity in an agricultural landscape: the contribution of seminatural habitat islands. *Basic and Applied Ecology* **4**, 129-138.

Duffy, J. E., Cardinale, B. J., France, K. E., McIntyre, P. B., Thebault, E., and Loreau, M. (2007). The functional role of biodiversity in ecosystems: incorporating trophic complexity. *Ecology Letters* **10**, 522-538.

Eilenberg, J., Hajek, A., and Lomer, C. (2001). Suggestions for unifying the terminology in biological control. *Biocontrol* **46**, 387-400.

Estes, J. A., Terborgh, J., Brashares, J. S., Power, M. E., Berger, J., Bond, W. J., Carpenter, S. R., Essington, T. E., Holt, R. D., Jackson, J. B. C., Marquis, R. J., Oksanen, L., Oksanen, T., Paine, R. T., Pikitch, E. K., Ripple, W. J., Sandin, S. A., Scheffer, M., Schoener, T. W., Shurin, J. B., Sinclair, A. R. E., Soule, M. E., Virtanen, R., and Wardle, D. A. (2011). Trophic Downgrading of Planet Earth. *Science* **333**, 301-306.

Eubanks, M. D., and Denno, R. F. (1999). The ecological consequences of variation in plants and prey for an omnivorous insect. *Ecology* **80**, 1253-1266.

FAO (2017). Water for sustainable food and agriculture: a report produced for the G20 presidency of Germany. FAO, Rome.

Federico, P., Hallam, T. G., McCracken, G. F., Purucker, S. T., Grant, W. E., Correa-Sandoval, A. N., Westbrook, J. K., Medellin, R. A., Cleveland, C. J., Sansone, C. G., Lopez, J. D., Betke, M., Moreno-Valdez, A., and Kunz, T. H. (2008). Brazilian free-tailed bats as insect pest regulators in transgenic and conventional cotton crops. *Ecological Applications* **18**, 826-837.

Feng, Y., Wratten, S., Sandhu, H., and Keller, M. (2015). Interspecific competition between two generalist parasitoids that attack the leafroller *Epiphyas postvittana* (Lepidoptera: Tortricidae). *Bulletin of Entomological Research* **105**, 426-433.

Fenster, C. B., Armbruster, W. S., Wilson, P., Dudash, M. R., and Thomson, J. D. (2004). Pollination syndromes and floral specialization. *Annual Review of Ecology Evolution and Systematics* **35**, 375-403.

Ferguson, K. L. (1995). Association of Botrytis bunch rot with light brown apple moth, The University of Adelaide, Adelaide.

Fiedler, A. K., and Landis, D. A. (2007a). Attractiveness of Michigan native plants to arthropod natural enemies and herbivores. *Environmental Entomology*, 751-65.

Fiedler, A. K., and Landis, D. A. (2007b). Plant characteristics associated with natural enemy abundance at Michigan native plants. *Environmental Entomology* **36**, 878-86.

Fiedler, A. K., Landis, D. A., and Wratten, S. D. (2008). Maximizing ecosystem services from conservation biological control: The role of habitat management. *Biological Control* **45**, 254-271.

Frank, S. D., Shrewsbury, P. M., and Esiekpe, O. (2008). Spatial and temporal variation in natural enemy assemblages on Maryland native plant species. *Environmental Entomology* **37**, 478-486.

Frank, S. D., Wratten, S. D., Sandhu, H. S., and Shrewsbury, P. M. (2007). Video analysis to determine how habitat strata affects predator diversity and predation of *Epiphyas postvittana* (Lepidoptera: Tortricidae) in a vineyard. *Biological Control* **41**, 230-236.

Fraser, S. E. M., Dytham, C., and Mayhew, P. J. (2008). Patterns in the abundance and distribution of ichneumonid parasitoids within and across habitat patches. *Ecological Entomology* **33**, 473-483.

Froidevaux, J. S. P., Louboutin, B., and Jones, G. (2017). Does organic farming enhance biodiversity in Mediterranean vineyards? A case study with bats and arachnids. *Agriculture Ecosystems and Environment* **249**, 112-122.

Gagic, V., Paull, C., and Schellhorn, N. A. (2018). Ecosystem service of biological pest control in Australia: the role of non-crop habitats within landscapes. *Austral Entomology* **57**, 194-206.

Gareau, T. L. P., Letourneau, D. K., and Shennan, C. (2013). Relative Densities of Natural Enemy and Pest Insects Within California Hedgerows. *Environmental Entomology* **42**, 688-702.

Gillespie, M. A. K., Gurr, G. M., and Wratten, S. D. (2016). Beyond nectar provision: the other resource requirements of parasitoid biological control agents. *Entomologia Experimentalis Et Applicata* **159**, 207-221.

Gilligan, T. M. (2014a). Key to larval Tortricidae intercepted, or potentially encountered, at U.S. ports of entry.

Gilligan, T. M. a. P., S.C. (2014b). LepIntercept. An identification resource for intercepted Lepidoptera larvae. *In* "Identification Technology Program (ITP), USDA/APHIS/PPQ/SandT", Fort Collins, CO.

Glenn, D. C., Hercus, M. J., and Hoffmann, A. A. (1997). Characterizing *Trichogramma* (Hymenoptera: Trichogrammatidae) species for biocontrol of light brown apple moth (Lepidoptera: Tortricidae) in grapevines in Australia. *Annals of the Entomological Society of America* **90**, 128-137.

Glenn, D. C., and Hoffmann, A. A. (1997). Developing a commercially viable system for biological control of light brown apple moth (Lepidoptera: Tortricidae) in grapes using endemic Trichogramma (Hymenoptera: Trichogrammatidae). *Journal of Economic Entomology* **90**, 370-382.

Greenstone, M. H. (1990). Meterological determinants of spider ballooning - the roles of thermals vs the vertical wind-speed in becoming airborne. *Oecologia* **84**, 164-168.

Gurr, G. M., Scarratt, S. L., Wratten, S. D., Berndt, L., and Irvin, N. (2004). "Ecological engineering, habitat manipulation and pest management," CSIRO, Collingwood, Victoria.

Gurr, G. M., Wratten, S. D., Irvin, N. A., Hossain, Z., Baggen, L. R., Mensah, R. K., and Walker, P. W. (1998). Habitat manipulation in Australasia: recent biological control progress and prospects for adoption. *In* "Pest Management - Future Challenges, Vols 1 and 2, Proceedings" (M. P. Zalucki, R. Drew and G. G. White, eds.), pp. A225-A235. The University of Queensland, Brisbane.

Gurr, G. M., Wratten, S. D., Landis, D. A., and You, M. S. (2017). Habitat management to suppress pest populations: Progress and prospects. *In* "Annual Review of Entomology, Vol 62" (M. R. Berenbaum, ed.), Vol. 62, pp. 91-109.

Gurr, G. M., Wratten, S. D., and Luna, J. M. (2003). Multi-function agricultural biodiversity: pest management and other benefits. *Basic and Applied Ecology* **4**, 107-116.

Gurr, G. M., Wratten, S. D., Tylianakis, J., Kean, J., and Keller, M. (2005). Providing plant foods for natural enemies in farming systems: balancing practicalities and theory. *In* "Plant-Provided Food for Carnivorous Insects: Protective Mutualism and Its Applications", pp. 326-347.

Hajibabaei, M., Janzen, D. H., Burns, J. M., Hallwachs, W., and Hebert, P. D. N. (2006). DNA barcodes distinguish species of tropical Lepidoptera. *Proceedings of the National Academy of Sciences of the United States of America* **103**, 968-971.

Hanski, I. (2011). Habitat loss, the dynamics of biodiversity, and a perspective on conservation. *Ambio* **40**, 248-255.

Harrison, S., and Bruna, E. (1999). Habitat fragmentation and large-scale conservation: what do we know for sure? *Ecography* **22**, 225-232.

Hegland, S. J., and Totland, O. (2005). Relationships between species' floral traits and pollinator visitation in a temperate grassland. *Oecologia* **145**, 586-594.

Heil, M. (2015). Extrafloral nectar at the plant-insect interface: A spotlight on chemical ecology, phenotypic plasticity, and food webs. *In* "Annual Review of Entomology, Vol 60" (M. R. Berenbaum, ed.), Vol. 60, pp. 213-232.

Helson, G. A. H. (1939). "The oriental peach moth (*Cydia molesta* Busck). Investigations in the Goulburn Valley, Victoria. Progress report for the seasons 1935–1938." Council for Scientific and Industrial Research, Australia).

Hickman, J. M., Lovei, G. L., and Wratten, S. D. (1995). Pollen feeding by adults of the hoverfly *Melanostoma fasciatum* (Diptera: Syrphidae). *New Zealand Journal of Zoology* **22**, 387-392.

Hodek, I., and Honek, A. (2009). Scale insects, mealybugs, whiteflies and psyllids (Hemiptera, Sternorrhyncha) as prey of ladybirds. *Biological Control* **51**.

Hogg, B. N., and Daane, K. M. (2015). Impacts of exotic spider spillover on resident arthropod communities in a natural habitat. *Ecological Entomology* **40**, 69-77.

Hogg, B. N., and Daane, K. M. (2018). Aerial dispersal ability does not drive spider success in a crop landscape. *Ecological Entomology* **43**, 683-694.

Hogg, B. N., Wang, X. G., Mills, N. J., and Daane, K. M. (2014). Resident spiders as predators of the recently introduced light brown apple moth, *Epiphyas postvittana*. *Entomologia Experimentalis Et Applicata* **151**, 65-74.

Holt, R. D., and Lawton, J. H. (1994). The ecological consequences of shared natural enemies. *Annual Review of Ecology and Systematics* **25**, 495-520.

Hooper, D. U., Chapin, F. S., Ewel, J. J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J. H., Lodge, D. M., Loreau, M., Naeem, S., Schmid, B., Setala, H., Symstad, A. J., Vandermeer, J., and Wardle, D. A. (2005). Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. *Ecological Monographs* **75**, 3-35.

Horton, D. R., and Lewis, T. M. (2003). Numbers and types of arthropods overwintering on common mullein, Verbascum thapsus L. (Scrophulariaceae), in a central Washington fruit-growing region. *Journal of the Entomological Society of British Columbia* **100**, 79-87.

Houston, T. F., and Ladd, P. G. (2002). Buzz pollination in the Epacridaceae. *Australian Journal of Botany* **50**, 83-91.

Irvin, N. A., Hagler, J. R., and Hoddle, M. S. (2018). Measuring natural enemy dispersal from cover crops in a California vineyard. *Biological Control* **126**, 15-25.

Isaacs, R., Tuell, J. K., Fiedler, A. K., Gardiner, M., and Landis, D. A. (2009). Maximizing arthropod-mediated ecosystem services in agricultural landscapes: the role of native plants. *Frontiers in Ecology and the Environment* **7**, 196-203.

Jervis, M. A. (1998). Functional and evolutionary aspects of mouthpart structure in parasitoid wasps. *Biological Journal of the Linnean Society* **63**, 461-493.

Jervis, M. A., Kidd, N. A. C., Fitton, M. G., Huddleston, T., and Dawah, H. A. (1993). Flower-visiting by hymenopteran parasitoids. *Journal of Natural History* **27**, 67-105.

Jervis, M. A., Lee, J. C., and Heimpel, G. E. (2004). Use of behavioural and life-history studies to understand the effects of habitat manipulation. *In* "Ecological engineering for pest management: Advances in habitat manipulation for arthropods " (G. M. Gurr, S. D. Wratten and M. A. Altieri, eds.), pp. 65-100. CSIRO, Collingwood VIC, Australia.

Jiang, L., and Pu, Z. C. (2009). Different Effects of Species Diversity on Temporal Stability in Single-Trophic and Multitrophic Communities. *American Naturalist* **174**, 651-659.

Karp, D. S., Chaplin-Kramer, R., Meehan, T. D., Martin, E. A., DeClerck, F., Grab, H., Gratton, C., Hunt, L., Larsen, A. E., Martínez-Salinas, A., O'Rourke, M. E., Rusch, A., Poveda, K., Jonsson, M., Rosenheim, J. A., Schellhorn, N. A., Tscharntke, T., Wratten, S. D., Zhang, W., Iverson, A. L., Adler, L. S., Albrecht, M., Alignier, A., Angelella, G. M., Zubair Anjum, M., Avelino, J., Batáry, P., Baveco, J. M., Bianchi, F. J. J. A., Birkhofer, K., Bohnenblust, E. W., Bommarco, R., Brewer, M. J., Caballero-López, B., Carrière, Y., Carvalheiro, L. G., Cayuela, L., Centrella, M., Ćetković, A., Henri, D. C., Chabert, A., Costamagna, A. C., De la Mora, A., de Kraker, J., Desneux, N., Diehl, E., Diekötter, T., Dormann, C.

F., Eckberg, J. O., Entling, M. H., Fiedler, D., Franck, P., Frank van Veen, F. J., Frank, T., Gagic, V., Garratt, M. P. D., Getachew, A., Gonthier, D. J., Goodell, P. B., Graziosi, I., Groves, R. L., Gurr, G. M., Hajian-Forooshani, Z., Heimpel, G. E., Herrmann, J. D., Huseth, A. S., Inclán, D. J., Ingrao, A. J., Iv, P., Jacot, K., Johnson, G. A., Jones, L., Kaiser, M., Kaser, J. M., Keasar, T., Kim, T. N., Kishinevsky, M., Landis, D. A., Lavandero, B., Lavigne, C., Le Ralec, A., Lemessa, D., Letourneau, D. K., Liere, H., Lu, Y., Lubin, Y., Luttermoser, T., Maas, B., Mace, K., Madeira, F., Mader, V., Cortesero, A. M., Marini, L., Martinez, E., Martinson, H. M., Menozzi, P., Mitchell, M. G. E., Miyashita, T., Molina, G. A. R., Molina-Montenegro, M. A., et al. (2018). Crop pests and predators exhibit inconsistent responses to surrounding landscape composition. *Proceedings of the National Academy of Sciences of the United States of America* **115**, E7863-E7870.

Kelly, R. M., Kitzes, J., Wilson, H., and Merenlender, A. (2016). Habitat diversity promotes bat activity in a vineyard landscape. *Agriculture Ecosystems and Environment* **223**, 175-181.

Kevan, P. G., and Greco, C. F. (2001). Contrasting patch choice behaviour by immature ambush predators, a spider (*Misumena vatia*) and an insect (*Phymata americana*). *Ecological Entomology* **26**, 148-153.

Kogel, S., Schieler, M., and Hoffmann, C. (2013). The ladybird beetle *Harmonia axyridis* (Coleoptera: Coccinellidae) as a possible predator of grape phylloxera *Daktulosphaira vitifoliae* (Hemiptera: Phylloxeridae). *European Journal of Entomology* **110**, 123-128.

Kross, S. M., Tylianakis, J. M., and Nelson, X. J. (2012). Effects of introducing threatened falcons into vineyards on abundance of Passeriformes and bird damage to grapes. *Conservation Biology* **26**, 142-149.

Kruess, A., and Tscharntke, T. (1994). Habitat fragmentation, species loss, and biological control. *Science* **264**, 1581-1584.

Landis, D. A. (1994). "Arthropod sampling in agricultural landscapes: Ecological considerations."

Landis, D. A., Menalled, F. D., Costamagna, A. C., and Wilkinson, T. K. (2005). Manipulating plant resources to enhance beneficial arthropods in agricultural landscapes. *Weed Science* **53**, 902-908.

Landis, D. A., Wratten, S. D., and Gurr, G. M. (2000). Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annual review of entomology* **45**, 175-201.

Laureto, L. M. O., Cianciaruso, M. V., and Samia, D. S. M. (2015). Functional diversity: an overview of its history and applicability. *Natureza and Conservação* **13**, 112-116.

Lavandero, B., Wratten, S., Shishehbor, P., and Worner, S. (2005). Enhancing the effectiveness of the parasitoid *Diadegma semiclausum* (Helen): Movement after use of nectar in the field. *Biological Control* **34**, 152-158.

Letourneau, D. K., Allen, S. G. B., and Stireman, J. O. (2012). Perennial habitat fragments, parasitoid diversity and parasitism in ephemeral crops. *Journal of Applied Ecology* **49**, 1405-1416.

Lewis, T. (1965). The effects of shelter on the distribution of insect pests of crops: a review. *Scientific Horticulture* **17**, 74-84.

Lichtenberg, E. M., Kennedy, C. M., Kremen, C., Batary, P., Berendse, F., Bommarco, R., Bosque-Perez, N. A., Carvalheiro, L. G., Snyder, W. E., Williams, N. M., Winfree, R., Klatt, B. K., Astrom, S., Benjamin, F., Brittain, C., Chaplin-Kramer, R., Clough, Y., Danforth, B., Diekotter, T., Eigenbrode, S. D., Ekroos, J., Elle, E., Freitas, B. M., Fukuda, Y., Gaines-Day, H. R., Grab, H., Gratton, C., Holzschuh, A., Isaacs, R., Isaia, M., Jha, S., Jonason, D., Jones, V. P., Klein, A. M., Krauss, J., Letourneau, D. K., Macfadyen, S., Mallinger, R. E., Martin, E. A., Martinez, E., Memmott, J., Morandin, L., Neame, L., Otieno, M., Park, M. G., Pfiffner, L., Pocock, M. J. O., Ponce, C., Potts, S. G., Poveda, K., Ramos, M., Rosenheim, J. A., Rundlof, M., Sardinas, H., Saunders, M. E., Schon, N. L., Sciligo, A. R., Sidhu, C. S., Steffan-Dewenter, I., Tscharntke, T., Vesely, M., Weisser, W. W., Wilson, J. K., and Crowder, D. W. (2017). A global synthesis of the effects of diversified farming systems on arthropod diversity within fields and across agricultural landscapes. *Glob Chang Biol*.

Long, R. F., Corbett, A., Lamb, C., Reberg-Horton, C., Chandler, J., and Stimmann, M. (1998). Beneficial insects move from flowering plants to nearby crops. *California Agriculture* **52**, 23-26.

Lorenzon, M., Pozzebon, A., and Duso, C. (2015). Feeding habits of overwintered predatory mites inhabiting European vineyards. *Biocontrol* **60**, 605-615.

Losey, J. E., and Denno, R. F. (1999). Factors facilitating synergistic predation: The central role of synchrony. *Ecological Applications* **9**, 378-386.

Macadam, C. R., and Stockan, J. A. (2015). More than just fish food: ecosystem services provided by freshwater insects. *Ecological Entomology* **40**, 113-123.

Mace, G. M., Norris, K., and Fitter, A. H. (2012). Biodiversity and ecosystem services: a multilayered relationship. *Trends in Ecology and Evolution* **27**, 19-26.

MacLellan, C. R. (1973). Natural enemies of the light brown apple moth, *Epiphyas postvittana*, in the Australian Capital Territory. *Canadian Entomologist* **105**, 681-700.

Magarey, P. A., Nicholas, P. R., and Wachtel, M. F. (1994). Control of the diseases of grapes in Australia and New Zealand. *Wine Industry Journal* **9**, 197–225.

Maingay, H. M., Bugg, R. L., Carlson, R. W., and Davidson, N. A. (1991). Predatory and parasitic wasps (Hymenoptera) feeding at flowers of sweet fennel (*Foeniculum vulgare* Miller var. dulce Battandier and Trabut , Apiaceae) and spearmint (*Mentha spicata* L.. Lamiaceae) in Massachusetts. *Biological Agriculture and Horticulture* **7**, 363-383.

Marino, P. C., and Landis, D. A. (1996). Effect of landscape structure on parasitoid diversity and parasitism in agroecosystems. *Ecological Applications* **6**, 276-284.

McLaughlin, A., and Mineau, P. (1995). The impact of agricultural practices on biodiversity. *Agriculture Ecosystems & Environment* **55**, 201-212.

Meehan, T. D., Werling, B. P., Landis, D. A., and Gratton, C. (2011). Agricultural landscape simplification and insecticide use in the Midwestern United States. *PNAS Early Edition*.

Menalled, F. D., Marino, P. C., Gage, S. H., and Landis, D. A. (1999). Does agricultural landscape structure affect parasitism and parasitoid diversity? *Ecological Applications* **9**, 634-641.

Mian, L. S., and Mulla, M. S. (1992). Effects of pyrethroid insecticides on non-target invertebrates in aquatic ecosystems. *Journal of Agricultural Entomology* **9**, 73-98.

Miller, G. T. (2004). " Sustaining the earth: an integrated approach," 6/Ed. Brooks/Cole.

Muthmann, R., and Nadin, P. (2003). The use of plant protection products in the European Union. European Communities, Luxembourg.

Nash, M. A., Thomson, L. J., and Hoffmann, A. A. (2008). Effect of remnant vegetation, pesticides, and farm management on abundance of the beneficial predator Notonomus gravis (Chaudoir) (Coleoptera : Carabidae). *Biological Control* **46**, 83-93.

Nedved, O. (1993). COMPARISON OF COLD-HARDINESS IN 2 LADYBIRD BEETLES (COLEOPTERA, COCCINELLIDAE) WITH CONTRASTING HIBERNATION BEHAVIOR. *European Journal of Entomology* **90**, 465-470.

Nentwig, W., Frank, T., and Lethmayer, C. (1998). "Sown weed strips: artificial ecological compensation areas as an important tool in conservation biological control," Academic Press, San Diego.

Nicholls, C. I., and Altieri, M. A. (2003). "Agroecological bases of ecological engineering for pest management."

Nicholls, C. I., Parrella, M., and Altieri, M. A. (2001). The effects of a vegetational corridor on the abundance and dispersal of insect biodiversity within a northern California organic vineyard. *Landscape Ecology* **16**, 133-146.

Nicholls, C. I., Parrella, M. P., and Altieri, M. A. (2000). Reducing the abundance of leafhoppers and thrips in a northern California organic vineyard through maintenance of full season floral diversity with summer cover crops. *Agricultural and Forest Entomology* **2**, 107-113.

Oliver, T. H., Heard, M. S., Isaac, N. J. B., Roy, D. B., Procter, D., Eigenbrod, F., Freckleton, R., Hector, A., Orme, D. L., Petchey, O. L., Proenca, V., Raffaelli, D., Suttle, K. B., Mace, G. M., Martin-Lopez, B., Woodcock, B. A., and Bullock, J. M. (2015). Biodiversity and resilience of ecosystem functions. *Trends in Ecology and Evolution* **30**, 673-684.

Orr, D. B., and Pleasants, J. M. (1996). The potential of native prairie plant species to enhance the effectiveness of the *Ostrinia nubilalis* parasitoid *Macrocentrus grandii*. *Journal of the Kansas Entomological Society* **69**, 133-143.

Orre-Gordon, S., Jacometti, M., Tomkins, J., and Wratten, S. (2013). Viticulture can be modified to provide multiple ecosystem services. *In* "Ecosystem services in agricultural and urban landscapes" (S. Wratten, H. Sandhu, R. Cullen and R. Costanza, eds.), pp. 45-57. John Wiley & Sons, Ltd, West Sussex, UK.

Pandey, S., Rahman, A., and Gurr, G. M. (2018). Australian native flowering plants enhance the longevity of three parasitoids of brassica pests. *Entomologia Experimentalis Et Applicata* **166**, 265-276.

Parry, H. R., Macfadyen, S., Hopkinson, J. E., Bianchi, F., Zalucki, M. P., Bourne, A., and Schellhorn, N. A. (2015). Plant composition modulates arthropod pest and predator abundance: Evidence for culling exotics and planting natives. *Basic and Applied Ecology* **16**, 531-543.

Patt, J. M., Hamilton, G. C., and Lashomb, J. H. (1997). Impact of strip-insectary intercropping with flowers on conservation biological control of the Colorado potato beetle. *Advances in Horticultural Science* **11**, 175-181.

Patt, J. M., Wainright, S. C., Hamilton, G. C., Whittinghill, D., Bosley, K., Dietrick, J., and Lashomb, J. H. (2003). Assimilation of carbon and nitrogen from pollen and nectar by a predaceous larva and its effects on growth and development. *Ecological Entomology* **28**, 717-728.

Paull, C. (2007). The ecology of key arthropods for the management of *Epiphyas postvittana* (Walker) (Lepidoptera: Torticidae) in Coonawarra vineyards, South Australia. PhD, Adelaide University, Adelaide.

Paull, C., and Austin, A. D. (2006). The hymenopteran parasitoids of light brown apple moth, *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae) in Australia. *Australian Journal of Entomology* **45**, 142-156.

Peisley, R. K., Saunders, M. E., and Luck, G. W. (2017). Providing perches for predatory and aggressive birds appears to reduce the negative impact of frugivorous birds in vineyards. *Wildlife Research* **44**, 334-342.

Penfold, C. M. (2010). Native grass cover crops. *Australian and New Zealand Grapegrower and Winemaker*, 48-50.

Penfold, C. M. (2018). "Development of a low-input under-vine floor management system which improves profitability without compromising yield or quality (UA 1303)." Wine Australia, Adelaide.

Penfold, C. M., and McCarthy, M. (2010). "Soil management for yield and quality' - Sub-project 'Pursuing sustainability – the role of native ground cover species'." Grape and Wine Research and Development Corporation, Adelaide.

Perry, D. A. (1994). "Forest ecosystems," Johns Hopkins University Press, Baltimore. MD.

Petchey, O. L., and Gaston, K. J. (2006). Functional diversity: back to basics and looking forward. *Ecology Letters* **9**, 741-758.

Pimentel, D., Stachow, U., Takacs, D. A., Brubaker, H. W., Dumas, A. R., Meaney, J. J., Oneil, J. A. S., Onsi, D. E., and Corzilius, D. B. (1992). Conserving biological diversity in agricultural forestry systems - most biological diversity exists in human managed ecosystems. *Bioscience* **42**, 354-362.

Pitman, S. D., Daniels, C. B., and Ely, M. E. (2015). Green infrastructure as life support: urban nature and climate change. *Transactions of the Royal Society of South Australia* **139**, 97-112.

Polis, G. A., and Strong, D. R. (1996). Food web complexity and community dynamics. *American Naturalist* **147**, 813-846.

Pollard, E. (1968). Hedges. IV. A comparison between the Carabidae of a hedge and field site and those of a woodland glade. *Journal of Applied Ecology* **5**, 649-657.

Rebek, E. J., Sadof, C. S., and Hanks, L. M. (2005). Manipulating the abundance of natural enemies in ornamental landscapes with floral resource plants. *Biological Control* **33**, 203-216.

Retallack, M. J. (2018). Practical examples of ways to establish native insectary plants in and around vineyards. *The Australian and New Zealand Grapegrower and Winemaker*, 38-41.

Retallack, M. J. (2019). The potential functional diversity offered by native insectary plants to support populations of predatory arthropods in Australian vineyards, PhD Thesis, University of Adelaide, Adelaide.

Retallack, M. J., Keller, M. A., and Thomson, L. J. (2019a). Predatory arthropods associated with potential native insectary plants for Australian vineyards. *Australian Journal of Grape and Wine Research* **25**, 233-242.

Retallack, M. J., Thomson, L. J., and Keller, M. A. (2019b). Native insectary plants support populations of predatory arthropods for Australian vineyards. *In* "42nd Congress of Vine and Wine, International Organisation of Vine and Wine". International Organisation of Vine and Wine, Geneva.

Roland, J., and Taylor, P. D. (1997). Insect parasitoid species respond to forest structure at different spatial scales. *Nature* **386**, 710-713.

Rusch, A., Chaplin-Kramer, R., Gardiner, M. M., Hawro, V., Holland, J., Landis, D., Thies, C., Tscharntke, T., Weisser, W. W., Winqvist, C., Woltz, M., and Bommarco, R. (2016). Agricultural landscape simplification reduces natural pest control: A quantitative synthesis. *Agriculture Ecosystems & Environment* **221**, 198-204.

Sandhu, H., Wratten, S., Costanza, R., Pretty, J., Porter, J. R., and Reganold, J. (2015). Significance and value of non-traded ecosystem services on farmland. *Peerj* **3**.

Schellhorn, N. A., Gagic, V., and Bommarco, R. (2015). Time will tell: resource continuity bolsters ecosystem services. *Trends in Ecology and Evolution* **30**, 524-530.

Schmidt, M. H., Roschewitz, I., Thies, C., and Tscharntke, T. (2005). Differential effects of landscape and management on diversity and density of ground-dwelling farmland spiders. *Journal of Applied Ecology* **42**, 281-287.

Sharley, D. J., Hoffmann, A. A., and Thomson, L. J. (2008). The effects of soil tillage on beneficial invertebrates within the vineyard. *Agricultural and Forest Entomology* **10**, 233-243.

Shields, M. W., Tompkins, J. M., Saville, D. J., Meurk, C. D., and Wratten, S. (2016). Potential ecosystem service delivery by endemic plants in New Zealand vineyards: successes and prospects. *Peerj* **4**.

Siekmann, G., Keller, M. A., and Tenhumberg, B. (2004). The sweet tooth of adult parasitoid *Cotesia rubecula*: Ignoring hosts for nectar? *Journal of Insect Behavior* **17**, 459-476.

Siekmann, G., Tenhumberg, B., and Keller, M. A. (2001). Feeding and survival in parasitic wasps: sugar concentration and timing matter. *Oikos* **95**, 425-430.

Simonneau, M., Courtial, C., and Petillon, J. (2016). Phenological and meteorological determinants of spider ballooning in an agricultural landscape. *Comptes Rendus Biologies* **339**, 408-416.

Simpson, M., Gurr, G. M., Simmons, A. T., Wratten, S. D., James, D. G., Leeson, G., Nicol, H. I., and Orre, G. U. S. (2011). Field evaluation of the 'attract and reward' biological control approach in vineyards. *Annals of Applied Biology* **159**, 69-78.

Sirami, C., Jacobs, D. S., and Cumming, G. S. (2013). Artificial wetlands and surrounding habitats provide important foraging habitat for bats in agricultural landscapes in the Western Cape, South Africa. *Biological Conservation* **164**, 30-38.

Smith, D., and Papacek, D. F. (1991). Studies of the predatory mite *Amblyseius victoriensis* (Acarina: Phytoseiidae) in citrus orchards in south-east Queensland: control of *Tegolophus australis* and *Phyllocoptruta oleivora* (Acarina: Eriophyidae), effect of pesticides, alternative host plants and augmentative release. *Experimental and Applied Acarology* **12**, 195-217.

Smith, I. M., Hoffmann, A. A., and Thomson, L. J. (2015). Ground cover and floral resources in shelterbelts increase the abundance of beneficial hymenopteran families. *Agricultural and Forest Entomology* **17**, 120-128.

Sotherton, N. W. (1984). The distribution and abundance of predatory arthropods overwintering on farmland. *Annals of Applied Biology* **105**, 423-429.

Stahlschmidt, P., Patzold, A., Ressl, L., Schulz, R., and Bruhl, C. A. (2012). Constructed wetlands support bats in agricultural landscapes. *Basic and Applied Ecology* **13**, 196-203.

Stamps, W. T., and Linit, M. J. (1997). Plant diversity and arthropod communities: Implications for temperate agroforestry. *Agroforestry Systems* **39**, 73-89.

Stefanucci, S., Graça, A., Novello, V., Belda, I., Carlos, C., and Gautier, J. (2018). "Functional biodiversity in the vineyard." OIV - International Organisation of Vine and Wine, Paris, France.

Steffan-Dewenter, I. (2003). Importance of habitat area and landscape context for species richness of bees and wasps in fragmented orchard meadows. *Conservation Biology* **17**, 1036-1044.

Stephens, C. J., Schellhorn, N. A., Wood, G. M., and Austin, A. D. (2006). Parasitic wasp assemblages associated with native and weedy plant species in an agricultural landscape. *Australian Journal of Entomology* **45**, 176-184.

Stephens, M. J., France, C. M., Wratten, S. D., and Frampton, C. (1998). Enhancing biological control of leafrollers (Lepidoptera: Tortricidae) by sowing buckwheat (*Fagopyrum esculentum*) in an orchard. *Biocontrol Science and Technology* **8**, 547-558.

Suckling, D. M., and Brockerhoff, E. G. (2010). Invasion biology, ecology, and management of the light brown apple moth (Tortricidae). *In* "Annual review of entomology", Vol. 55, pp. 285-306.

Suckling, D. M., Twidle, A. M., Gibb, A. R., Manning, L. M., Mitchell, V. J., Sullivan, T. E. S., Wee, S. L., and El-Sayed, A. M. (2012). Volatiles from apple trees Infested with light crown apple moth larvae attract the parasitoid *Dolichogenidia tasmanica*. *Journal of Agricultural and Food Chemistry* **60**, 9562-9566.

Sugita, N., Agemori, H., and Goka, K. (2018). Acute toxicity of neonicotinoids and some insecticides to first instar nymphs of a non-target damselfly, Ischnura senegalensis (Odonata: Coenagrionidae), in Japanese paddy fields. *Applied Entomology and Zoology* **53**, 519-524.

Taverner, P., Wood, G., Jevremov, D., and Doyle, B. (2006). "Revegetation by design guidebook: A guide to using selected native plants to reduce pests and diseases in the horticulture region of the Northern Adelaide plains." SARDI, Adelaide.

Terres, K. M. (2006). "Biodiversty serving agriculture. The example of Conservation Biological Control (CBC)."

Thiery, D., Louapre, P., Muneret, L., Rusch, A., Sentenac, G., Vogelweith, F., Iltis, C., and Moreau, J. (2018). Biological protection against grape berry moths. A review. *Agronomy for Sustainable Development* **38**.

Thies, C., Steffan-Dewenter, I., and Tscharntke, T. (2003). Effects of landscape context on herbivory and parasitism at different spatial scales. *Oikos* **101**, 18-25.

Thies, C., and Tscharntke, T. (1999). Landscape structure and biological control in agroecosystems. *Science* **285**, 893-895.

Thomas, M. B., Wratten, S. D., and Sotherton, N. W. (1991). Creation of 'island' habitats in farmland to manipulate populations of beneficial arthropods: predator densities and emigration. *Journal of Applied Ecology* **28**, 906-917.

Thomson, L. J. (2012). Pesticide impacts on beneficial species at http://www.mvwi.com.au/items/511/2012-05-FS-Pesticide-Impacts2.pdf. GWRDC, Adelaide.

Thomson, L. J., Danne, A., Sharley, D. J., Nash, M. A., Penfold, C. M., and Hoffmann, A. A. (2009). Native grass cover crops can contribute to pest control in vineyards. *Australian Viticulture* **13**.

Thomson, L. J., Glenn, D. C., and Hoffmann, A. A. (2000). Effects of sulfur on Trichogramma egg parasitoids in vineyards: measuring toxic effects and establishing release windows. *Australian Journal of Experimental Agriculture* **40**, 1165-1171.

Thomson, L. J., and Hoffmann, A. A. (2006a). Field validation of laboratory-derived IOBC toxicity ratings for natural enemies in commercial vineyards. *Biological Control* **39**, 507-515.

Thomson, L. J., and Hoffmann, A. A. (2006b). The influence of adjacent vegetation on the abundance and distribution of natural enemies in vineyards. *The Australian and New Zealand Grapegrower and Winemaker*, 36-42.

Thomson, L. J., and Hoffmann, A. A. (2007). Ecologically sustainable chemical recommendations for agricultural pest control? *Journal of Economic Entomology* **100**, 1741-1750.

Thomson, L. J., and Hoffmann, A. A. (2008). Vegetation increases abundance of natural enemies of common pests in vineyards. *The Australian and New Zealand Grapegrower and Winemaker*, 34-37.

Thomson, L. J., and Hoffmann, A. A. (2009a). "Sustainable viticulture 2010 and beyond: Vineyard management to maximize beneficial invertebrates to increase the bottom line," Rep. No. MU 06/01. Grape and Wine Research and Development Corporation, Adelaide.

Thomson, L. J., and Hoffmann, A. A. (2009b). Vegetation increases the abundance of natural enemies in vineyards. *Biological Control* **49**, 259-269.

Thomson, L. J., and Hoffmann, A. A. (2010a). Cost benefit analysis of shelterbelt establishment: Natural enemies can add real value to shelterbelts. *The Australian and New Zealand Grapegrower and Winemaker*, 38-44.

Thomson, L. J., and Hoffmann, A. A. (2010b). Natural enemy responses and pest control: Importance of local vegetation. *Biological Control* **52**, 160-166.

Thomson, L. J., Macfadyen, S., and Hoffmann, A. A. (2010). Predicting the effects of climate change on natural enemies of agricultural pests. *Biological Control* **52**, 296-306.

Thomson, L. J., and Penfold, C. M. (2012). Cover crops and vineyard biodiversity. Grape and Wine Research and Development Corporation, Adelaide.

Thomson, L. J., Sharley, D. J., and Hoffmann, A. A. (2007). Beneficial organisms as bioindicators for environmental sustainability in the grape industry in Australia. *Australian Journal of Experimental Agriculture* **47**, 404-411.

Tollett, V. D., Benvenutti, E. L., Deer, L. A., and Rice, T. M. (2009). Differential Toxicity to Cd, Pb, and Cu in Dragonfly Larvae (Insecta: Odonata). *Archives of Environmental Contamination and Toxicology* **56**, 77-84.

Tscharntke, T., Bommarco, R., Clough, Y., Crist, T. O., Kleijn, D., Rand, T. A., Tylianakis, J. M., van Nouhuys, S., and Vidal, S. (2007). Conservation biological control and enemy diversity on a landscape scale. *Biological Control* **43**, 294-309.

Tscharntke, T., and Brandl, R. (2004). Plant-insect interactions in fragmented landscapes. *Annual Review of Entomology* **49**, 405-430.

Tscharntke, T., Klein, A. M., Kruess, A., Steffan-Dewenter, I., and Thies, C. (2005). Landscape perspectives on agricultural intensification and biodiversity - ecosystem service management. *Ecology Letters* **8**, 857-874.

Tscharntke, T., Steffan-Dewenter, I., Kruess, A., and Thies, C. (2002). Contribution of small habitat fragments to conservation of insect communities of grassland-cropland landscapes. *Ecological Applications* **12**, 354-363.

Tsitsilas, A., Stuckey, S., Hoffmann, A. A., and Thomson, L. J. (2006). Shelterbelts in agricultural landscapes suppress invertebrate pests. *Australian Journal of Experimental Agriculture* **46**, 1379–1388.

van Emden, H. F. (1965). The role of uncultivated land in the biology of crop pests and beneficial insects a review. *Scientific Horticulture* **17**, 121-136.

van Emden, H. F. (2003). Conservation biological control: from theory to practice. . *In* "Proceedings of the 1st International Symposium on Biological Control of Arthropods, Honolulu, Hawaii, 14-18 January 2002" (R. G. van Driesche, ed.), pp. 199-208.

van Emden, H. F., and Williams, G. F. (1974). Insect stability and diversity in agro-ecosystems. *Annual review of entomology. Volume 19.*, 455-475.

Venturino, E., Isaia, M., Bona, F., Issoglio, E., Triolo, V., and Badino, G. (2006). Modelling the spiders ballooning effect on the vineyard ecology. *Mathematical Modelling of Natural Phenomena* **1**, 133-155.

Viggiani, G. (2003). Functional biodiversity for the vineyard agroecosystem: Aspects of the farm and landscape management in Southern Italy. *Bulletin OILB/SROP* **26**, 197-202.

Villenave, J., Deutsch, B., Lode, T., and Rat-Morris, E. (2006). Pollen preference of the Chrysoperla species (Neuroptera: Chrysopidae) occurring in the crop environment in western France. *European Journal of Entomology* **103**, 771-777.

Wackers, F. L., Bjornsen, A., and Dorn, S. (1996). A comparison of flowering herbs with respect to their nectar accessibility for the parasitoid *Pimpla turionellae*. *Proceedings of the Section Experimental and Applied Entomology of the Netherlands Entomological Society (N.E.V.)* **7**, 177-182.

Warner, K. D., and Getz, C. (2008). A socio-economic analysis of the North American commercial natural enemy industry and implications for augmentative biological control. *Biolocical Control* **45**, 1-10.

Waterhouse, D. F., and Sands, D. P. A. (2001). "Classical biological control of arthropods in Australia," CSIRO Entomology, Canberra, ACT.

Weber, D. C., and Lundgren, J. G. (2009). Assessing the trophic ecology of the Coccinellidae: Their roles as predators and as prey. *Biological Control* **51**, 199-214.

Werling, B. P., and Gratton, C. (2008). Influence of field margins and landscape context on ground beetle diversity in Wisconsin (USA) potato fields. *Agriculture Ecosystems and Environment* **128**, 104-108.

Whalon, M. E., Mota-Sanchez, D., and Hollingworth, R. M. (2008). "Global pesticide resistance in arthropods," Oxford University Press, Oxford, UK.

Whittle, C. P., Bellas, T. E., and Bishop, A. L. (1991). Sex pheromone of lucerne leafroller, *Merophyas divulsana* (Walker) (Lepidoptera: Tortricidae) - evidence for two distinct populations. *Journal of Chemical Ecology* **17**, 1883-1895.

Wilkinson, T. K., and Landis, D. A. (2005). Habitat diversification in biological control: the role of plant resources. *Plant-Provided Food for Carnivorous Insects: Protective Mutualism and Its Applications*, 305-325.

Williams, L., and Martinson, T. E. (2000). Colonization of New York vineyards by *Anagrus* spp. (Hymenoptera: Mymaridae): Overwintering biology, within-vineyard distribution of wasps, and parasitism of grape leafhopper, *Erythroneura* spp. (Homoptera: Cicadellidae), eggs. *Biological Control* **18**, 136-146.

Wilson, E. O., and Peter, F. M. (1988). "Biodiversity," The National Academies Press, Washington, DC.

Wilson, H., Miles, A. F., Daane, K. M., and Altieri, M. A. (2016). Host Plant Associations of Anagrus spp. (Hymenoptera: Mymaridae) and Erythroneura elegantula (Hemiptera: Cicadellidae) in Northern California. *Environmental Entomology* **45**, 602-615.

Winkler, K. (2005). Assessing the risks and benefits of flowering field edges: strategic use of nectar sources to boost biological control, Wageningen University.

Winter, S., Bauer, T., Strauss, P., Kratschmer, S., Paredes, D., Popescu, D., Landa, B., Guzman, G., Gomez, J. A., Guernion, M., Zaller, J. G., and Batary, P. (2018). Effects of vegetation management intensity on biodiversity and ecosystem services in vineyards: A meta-analysis. *Journal of Applied Ecology* **55**, 2484-2495.

Wood, G., Glatz, R., DeGraaf, H., Siekmann, G., and Stephens, C. (2011). "Revegetation by design - Promoting the 'on farm' use of native vegetation as agents of 'natural pest control' ". RIRDC, Canberra.

Wratten, S., Berndt, L., Gurr, G., Tylianakis, J., Fernando, P., Didham, R., and Forest Health Technology Enterprise, T. (2003a). Adding floral diversity to enhance parasitoid fitness and efficacy. *In* "1st International Symposium on Biological Control of Arthropods, January 14-18, 2002", pp. 211-214, Honolulu, Hawaii, USA,.

Wratten, S. D., Bowie, M. H., Hickman, J. M., Evans, A. M., Sedcole, J. R., and Tylianakis, J. M. (2003b). Field boundaries as barriers to movement of hover flies (Diptera: Syrphidae) in cultivated land. *Oecologia* **134**, 605-611.

Yachi, S., and Loreau, M. (1999). Biodiversity and ecosystem productivity in a fluctuating environment: The insurance hypothesis. *Proceedings of the National Academy of Sciences of the United States of America* **96**, 1463-1468.

Yazdani, M., Feng, Y., Glatz, R., and Keller, M. A. (2015). Host stage preference of *Dolichogenidea tasmanica* (Cameron, 1912) (Hymenoptera: Braconidae), a parasitoid of *Epiphyas postvittana* (Walker, 1863) (Lepidoptera: Tortricidae). *Austral Entomology* **54**, 325-331.

Yazdani, M., and Keller, M. (2017). Tackling grapegrowers' number one insect pest. *The Australian and New Zealand Grapegrower and Winemaker Journal*.

Zemenick, A. T., Kula, R. R., Russo, L., and Tooker, J. F. (2018). A network approach reveals parasitoid wasps to be generalized nectar foragers. *Arthropod-Plant Interactions***, in press**, 1-13.

Zhang, W., and Swinton, S. M. (2009). Incorporating natural enemies in an economic threshold for dynamically optimal pest management. *Ecological Modelling* **220**, 1315-1324.

Zhao, J. Z., Ayers, G. S., Grafius, E. J., and Stehr, F. W. (1992). Effects of neighboring nectar-producing plants on populations of pest Lepidoptera and their parasitoids in broccoli plantings. *Great Lakes Entomologist* **25**, 253-258.

/Users/RetallackViti 1/Library/Mobile Documents/com~apple~CloudDocs/Documents/Documents - MacBook Pro/Retallack Viticulture/RV Clients/Vinscapes/Rmjr260820KentDownsAONBRetallackViticultureFINAL.docx

retallack
viticulture
wine growing for the future

Retallack Viticulture Pty Ltd

ABN 161 3501 6232

125 Sheoak Road,
CRAFERS WEST South
Australia 5152

Mob: +61 (0) 408 393 324
Tel: +61 8 8339 3324
Fax: +61 8 8339 4331

mary@viti.com.au
www.viti.com.au