The Potential for Riparian Zone Restoration to Support Pollinators in Mediterranean Agricultural River Valleys.

Robin Spencer Payne

A Dissertation for the Degree of Master in the

Management of Natural Resources and Conservation

Supervisors: Doutora Manuela Rodrigues Branco Simões

Doutora Patricia María Rodríguez González

Jury

President: Doutora Maria Teresa Marques Ferreira, Professora catedrática do(a) Instituto Superior de Agronomia da Universidade de Lisboa.

Members: Doutora Manuela Rodrigues Branco Simões, Professora associada com agregação do(a) Instituto Superior de Agronomia da Universidade de Lisboa;

Doutor José Carlos Franco Santos Silva, Professor associado do(a) Instituto Superior de Agronomia da Universidade de Lisboa;

Doutora Maria Teresa Ferreira Ramos Nabais Oliveira Rebelo, Professora auxiliar do(a) Faculdade de Ciências da Universidade de Lisboa.

2022

Acknowledgements

The decision to take this masters course, as a part of a search for more meaning in my working life, was one that required deep consideration, and on reflection, I am very glad I took it. Dedicating time to study would have been far harder if I had not had the early, loving support of my parents, Jean and Derek, who showed me the value of peace, patience and lifelong learning.

I am hugely grateful for the constant love, support and encouragement I receive from my sweet partner, Bigui Martins. And I think of my sons Daniel and Lewis; those lights in my life who have been truly inspirational through all of their accomplishments.

It has been a joy to participate in the modules that made up this course and I am indebted to all the wonderful teachers who answered my questions with a profound balance of intelligence, good humour and stoicism, especially when I misunderstood in Portuguese or felt triggered by a particular approach to a natural resources management topic.

In particular, I would like to thank my supervisors for this thesis, Dr. Manuela Branco and Dr. Patricia Rodríguez González, who not only advised me well in this endeavour, but also inspired me in the modules they taught and the way they taught them. With Dr. Patricia, I was privileged to contribute to the publication of a paper on the topic of riparian zone restoration and legislation (Urbanič et al., 2022) and I hope the material in this thesis will lead to two further publications.

And then there are my course colleagues, with whom I was able to enjoy the challenge of scientific debate, join in with rallying cries in defence of the natural world, and partake of a few beers. I will not name them specifically; I regard them all as true friends, I wish them well in all they do, and I hope they will reflect well on the times we had together, if they ever read this statement (I think you know who you are, thank you).

I would like to express gratitude to three people have been additionally supportive during the development of this thesis, Tatiana Moreira who patiently taught me to identify pollinating insects, António Santos with whom I undertook fieldwork in the Sorraia river valley, and André Garcia who ensured we knew where we were going in the field and that we had space to work in the laboratory. I would also like to recognise the hard work of all involved in the project Optimus Prime, from which the pollinator samples came for the case study in this thesis. Particular mention goes to Gonçalo Duarte, Vera Zina, Sonia Duarte and André Fonseca. And I should not forget to mention Fabio Marcolin and Daniel Mameri, who threw me lifelines when I might have sunk beneath R, without a trace.

"What you do makes a difference, and you have to decide what kind of difference you want to make."
Jane Goodall

Abstract

There is a concern that Insect pollinator abundance and diversity is declining world-wide, threatening ecosystem function and hence human food security and wellbeing. This decline may be affecting Mediterranean climatic regions, which are sensitive hotspots of biodiversity. Mediterranean river valleys are areas which have been used for agriculture for thousands of years, and are often in a degraded ecological state. These riparian areas may be suffering a decline in pollinator diversity when they could be providing valuable opportunities for restoration and conservation.

This thesis comprises two parts. The first part is a semi-structured literature review initiated with three questions: 1) What evidence is there that insect pollinator abundance and diversity is declining in Mediterranean regions? 2) What ecological restoration practices offer the most promise of reversing such declines? 3) What contribution might riparian zones make to reversing any decline? The second part is a case study characterising Hymenopteran and Coleopteran pollinators of the Sorraia river valley in Portugal; an example of a Mediterranean agricultural river valley.

Though relatively few studies of pollinator abundance and diversity in Mediterranean regions were found, there is evidence suggesting there is a decline, mostly due to habitat loss, introduced species and climate change. The impact of agrochemicals hardly featured in the articles reviewed here, and represents one of the opportunities for future investigation. The Sorraia valley case study suggests a marginally higher level of pollinator diversity in riparian areas compared to the agricultural matrix. And that there is a complementary effect, with the riparian species increasing richness at the landscape level.

Overall, there is strong evidence that riparian areas offer an important opportunity for restoration projects through protected area management, ecologically improved riparian woodland and concerted field margin management, improving pollinator diversity and pollination services in cultivated, Mediterranean river valleys.

Keywords: pollinator, abundance, diversity, decline, restoration, riparian

Resumo

Existe a preocupação de que a abundância e diversidade de polinizadores de insectos esteja a diminuir em todo o mundo, ameaçando o funcionamento do ecossistema e, consequentemente, a segurança alimentar e o bem-estar humano. Este declínio pode estar a afectar as regiões climáticas mediterrânicas, que são focos sensíveis de biodiversidade. Os vales fluviais mediterrânicos são áreas que têm sido utilizadas para a agricultura durante milhares de anos, estando frequentemente num estado ecológico degradado. Estas zonas ribeirinhas podem estar a sofrer um declínio na diversidade de polinizadores quando poderiam estar a proporcionar valiosas oportunidades de restauração e conservação.

Esta tese é apresentada em duas partes. Na primeira parte faz-se uma revisão semi-estruturada da literatura iniciada com três questões: 1) Que provas existem de que a abundância e diversidade de polinizadores de insectos está a diminuir nas regiões mediterrânicas? 2) Que práticas de restauração ecológica oferecem a maior oportunidade de reverter tais declínios? 3) Que contribuição podem dar as zonas ribeirinhas para inverter qualquer declínio? A segunda parte é um estudo de caso que caracteriza os polinizadores Hymenoptera e Coleoptera do vale do rio Sorraia em Portugal; um exemplo de um vale de rio agrícola mediterrânico.

Embora tenham sido encontrados relativamente poucos estudos sobre a abundância e diversidade de polinizadores nas regiões mediterrânicas, há provas que sugerem que existe um declínio, principalmente devido à perda de habitat, espécies introduzidas e alterações climáticas. O impacto negativo dos agroquímicos foi escassamente mencionado nos artigos aqui analisados, e representa uma das oportunidades para investigações futuras. O estudo de caso do vale do Sorraia sugere um nível marginalmente mais elevado de diversidade de polinizadores em zonas ribeirinhas, em comparação com a matriz agrícola. Este estudo sugere ainda um efeito complementar entre as infraestruturas ripícolas e a matriz agrícola, permitindo aumentar a riqueza a nível da paisagem.

Globalmente, há fortes indícios de que as áreas ripícolas oferecem uma importante oportunidade para projetos de restauração através da gestão de áreas protegidas, melhoria das matas ripícolas ecologicamente, gestão de concertada das bordaduras nos campos agrícolas, melhorando a diversidade de polinizadores e o serviço de polinização nos vales mediterrânicos cultivados.

Palavras-chave: polinizador, abundância, diversidade, declínio, restauração, ripícola

Extended Abstract

There is concern that Insect pollinator abundance and diversity is declining world-wide. Similarly, this phenomenon may be affecting Mediterranean climatic regions, which are sensitive hotspots of biodiversity. Any decline would represent a significant threat to the resilience of the ecosystems, reduce the productivity of important crops and so threaten human food security and wellbeing. The literature shows pollination is crucial to the productivity and resilience of many agricultural systems characteristic of Mediterranean regions, including those producing fruit, nuts and oil seeds. It is thus critically important to know if insect pollinators are declining in Mediterranean regions and to understand the causes of this decline. This knowledge will allow the identification of ecosystem restoration practices that will reverse such a trend. Mediterranean agricultural landscapes are often a matrix within a river valley. Whilst riparian woodlands are diverse areas of ecological infrastructure, capable of supporting a wide range of ecosystem services (including pollination), Mediterranean river valleys have a long history of anthropogenic disturbance in their middle and lower reaches. After all, they provide mankind with fertile planes where water is easily accessible. Anthropogenic disturbances have included removing trees, channelisation, ploughing close to the water's edge, heavily grazing cattle, introducing invasive species and applying large quantities of agrochemicals. Though some minimal width of riparian zone is expected to be protected under European laws, this expectation has not always been realised and anthropogenic impact has been very significant, frequently leading to the extensive loss of refuge, nesting and foraging habitats for wildlife. Given that river valleys have been used for agricultural purposes for thousands of years, riparian zones are often highly degraded from their natural state. Still, as they are protected from further degradation, they could provide a focus for restoration actions in support of insect pollinators.

This thesis contains a semi-structured literature review, and a case study assessment of the pollinator population in the Sorraia river valley of Portugal. The literature review addresses the questions: 1) What evidence is there that insect pollinator abundance and diversity is declining in Mediterranean regions? 2) What ecological restoration practices offer the most promise of reversing such declines? 3) What contribution might riparian zones make to reversing any decline? The review uncovered only a few long-term studies of pollinator abundance and diversity in Mediterranean regions. Further, the diverse range of methodologies used in those studies makes it hard to compare and combine data sets. This represents a critical information gap that future work needs to fill, ideally in connection with the EU Pollinators Initiative. Still, there is enough evidence in the existing literature to conclude there has been a decline in pollinator abundance and diversity, primarily due to habitat loss. Introduced plant species and climate change are also considered significant threats by some authors. The impact of agrochemicals did not feature specifically in any study in Mediterranean climatic regions and this represents an important opportunity for future investigation. A number of mitigation themes are identified in the existing literature including further protected area management, improved riparian buffer strips, concerted field margin management (specifically the re-establishment of tree, shrub and herb layers of vegetation), grazing management and honeybee (*Apis mellifera* L., 1758) population management.

The case study in this thesis characterises the pollinator population in the Sorraia river valley. It was hypothesised that semi-natural, woody riparian areas in the Sorraia river valley of central Portugal would have a higher diversity of pollinating insects than herbaceous riparian areas, and croplands. There was also an aim to produce an initial characterisation of the assemblage of pollinating insects as part of baseline data for ecological restoration work in the future. Insects were sampled at 31 sites using pan traps and identified to species or equivalent morphotype level using taxonomic keys. The assemblage of pollinating insects was characterised in terms of abundance and diversity and differences in pollinator assemblages according to land cover were analysed by non-metric multidimensional scaling. The influence of pan trap colour on the pollinators captured was also evaluated, as it is recognised that differences between the abundance and diversity of species captured can depend on this factor. The results reveal differences between the pollinator assemblages for land cover types. Riparian woody and riparian herbaceous pollinator communities differed from those of the agricultural crops. Species richness was statistically similar across land-cover types, though the number of species captured in rice fields was relatively low (34) and higher in maize crops (50), with intermediate values between 42 and 43 on the other land-cover types. The diversity of pollinators, as measured by Shannon evenness index was greatest in riparian woody, riparian herbaceous and maize land cover areas 0.81, 0.79 and 0.77, respectively and lower in rice fields (0.63) and mixed crops (0,53). Six genera of pollinating insects were captured in significantly greater numbers than others, contributing approximately 80% of all individuals. These were; *Lasioglossum*, *Panurgus* and *Dasypoda* (amongst the Hymenoptera), and *Anthaxia*, *Oedemera* and *Psilothrix* (amongst the Coleoptera). Capture rates for these genera varied with land cover type, and to some extent it was possible to infer reasons for these differences. The type of vegetation, specific flora-insect associations and nesting resources would justify the observed differences in the assemblage of pollinators and offer clues to measures likely to benefit pollinators in the area. Though the data did provide only slight evidence of a higher diversity of pollinating insects in riparian habitats compared with the agricultural matrix, the communities of species differed substantially, and hence the conservation and restoration of riparian areas is of significant value to agricultural systems in Mediterranean regions.

Combining the results of the literature survey and the case study, it is possible to say that riparian zones represent a special case of a protected area, capable of supporting a high level of biodiversity in a relatively small area of land. This would include insect pollinators, which would take advantage of the undisturbed connectivity riparian zones provide, moving between areas of natural and semi-natural habitat, and dispersing into the agricultural matrix. Further, there is often a legal responsibility to maintain good ecological conditions in riparian zones making them an important point of focus for conservation and restoration measures. There is a great opportunity to combine monitoring of restoration in Mediterranean agricultural river valleys like that of the Sorraia river, with the measurement of pollinating insect abundance and diversity across regions. The aim would be to stabilise and increase pollinator abundance and diversity overall, and thereby enhance the resilience of the ecosystem, ensuring the productivity of nearby crops at sustainable levels into the future.

Resumo Alargado

Existe a preocupação de que a abundância e diversidade de polinizadores de insectos esteja a diminuir em todo o mundo. Este fenómeno pode estar a afectar, de igual modo, as regiões climáticas mediterrânicas, que são focos sensíveis de biodiversidade. Qualquer declínio representaria uma ameaça significativa à resiliência do ecossistema, reduziria a produtividade de culturas importantes e, assim, ameaçaria a segurança alimentar e o bem-estar humano. A literatura mostra que a polinização é crucial para a produtividade e resiliência de muitos sistemas agrícolas característicos das regiões mediterrânicas, incluindo os que produzem frutos e sementes oleaginosas. Assim, é extremamente importante saber se os polinizadores de insectos estão a diminuir nas regiões mediterrânicas e compreender as causas deste declínio. Este conhecimento permitirá a identificação de práticas de restauração de ecossistemas que poderão inverter tal tendência. As paisagens agrícolas mediterrânicas são frequentemente uma matriz dentro de um vale de rio. Se por um lado, as florestas ribeirinhas são áreas de infra-estruturas ecológicas de grande diversidade, capazes de suportar uma vasta gama de serviços do ecossistema (incluindo a polinização), os vales fluviais mediterrânicos têm uma longa história de perturbação antropogénica, em particular nos seus troços médio e inferior. Afinal, estes vales proporcionam planícies férteis onde a água é facilmente acessível, tendo sido por isso muito explorados para a agricultura. As perturbações antropogênicas incluíram a remoção de árvores, a lavoura perto da margem da água, o pastoreio intensivo de gado, a introdução de espécies invasoras e a aplicação de grandes quantidades de agroquímicos. Embora se espere que alguma largura mínima da zona ribeirinha seja protegida pelas leis europeias, esta expectativa nem sempre foi concretizada e o impacto antropogênico tem sido muito significativo, levando frequentemente à perda de refúgio, à perda de locais para nidificação e à procura de habitats para a vida selvagem. Dado que os vales fluviais têm sido utilizados para fins agrícolas há milhares de anos, as zonas ribeirinhas estão frequentemente muito degradadas em relação ao seu estado natural. Ainda assim, como estão protegidas de uma maior degradação, poderiam fornecer um foco para ações de restauro em apoio aos polinizadores de insectos.

Esta tese contém uma revisão semi-estruturada da literatura, e uma avaliação de caso de estudo da população de polinizadores no vale do rio Sorraia, em Portugal. A revisão bibliográfica aborda três questões: 1) Que provas existem de que a abundância e diversidade de polinizadores de insectos está a diminuir nas regiões mediterrânicas? 2) Que práticas de restauro ecológico oferecem maior potencial de reverter tais declínios? 3) Que contribuição podem dar as zonas ribeirinhas para inverter qualquer declínio? A revisão revelou apenas alguns estudos a longo prazo sobre a abundância e diversidade de polinizadores nas regiões mediterrânicas. Além disso, a diversidade de metodologias utilizadas nesses estudos torna difícil a comparação e combinação de conjuntos de dados. Isto representa uma lacuna de informação crítica que o trabalho futuro precisa de preencher, idealmente em ligação com a Iniciativa dos Polinizadores da UE. Ainda assim, há provas suficientes na literatura existente para concluir que houve um declínio na abundância e diversidade de polinizadores, principalmente devido à perda de habitat. As espécies vegetais introduzidas e as alterações climáticas são também consideradas ameaças significativas por alguns autores. O impacto dos agroquímicos não foi especificamente mencionado em nenhum estudo nas regiões climáticas mediterrânicas, o que representa uma importante oportunidade para investigações futuras. Vários temas de mitigação são identificados na literatura existente, incluindo uma maior gestão de áreas protegidas, melhores faixas de protecção ribeirinhas, gestão concertada das áreas marginais das culturas (especificamente o restabelecimento de comunidades vegetais com os seus estratos arbóreo, arbustivos e vegetação herbácea nativa), gestão de pastagens e gestão da população de abelhas (*Apis mellifera* L., 1758).

O caso de estudo nesta tese caracteriza as populações de polinizadores no vale do rio Sorraia. Foi feita a hipótese de que as zonas ribeirinhas seminaturais e lenhosas no vale do rio Sorraia, no centro de Portugal, teriam uma maior diversidade de insectos polinizadores do que as zonas ribeirinhas herbáceas, e as terras de cultivo. O objectivo era também produzir uma caracterização inicial do conjunto de insectos polinizadores como parte dos dados de base para os trabalhos de restauração ecológica no futuro. Os insetos foram amostrados em 31 locais utilizando armadilhas de prato "pan traps" e identificados a nível de espécie ou morfotipo equivalente, utilizando chaves dicotómicas taxonómicas. O conjunto de insetos polinizadores foi caracterizado em termos de abundância e diversidade e as diferenças de acordo com a cobertura do solo foram analisadas através de métodos de análise estatística não-paramétricos. As diferenças de comunidades foram analisadas através de métodos de análise multidimensional não métricas. Foi também avaliada a influência da cor da armadilha nos polinizadores capturados, uma vez que se reconhece que as diferenças entre a abundância e diversidade das espécies capturadas podem depender deste fator. Os resultados revelam diferenças entre os conjuntos de polinizadores para diferentes tipos de uso do solo. As comunidades de polinizadores nos habitats ripários herbáceos e ripários lenhosos diferiram das comunidades de polinizadores nas culturas agrícolas. A riqueza das espécies foi estatisticamente semelhante entre os tipos de cobertura do solo, embora o número de espécies capturadas nos campos de arroz tenha sido relativamente baixo (34) e mais elevado nas culturas de milho (50), com valores intermédios entre 42 e 43 nos outros tipos de cobertura do solo. Ainda assim, a diversidade de polinizadores, medida pelo índice de equitabilidade de Shannon foi maior nas áreas de habitat ripário lenhosas, ripário herbáceo e milho 0,81, 0,78 e 0,77, respectivamente, e menor nos campos de arroz (0,63) e culturas mistas (0.53). Seis géneros de insectos polinizadores foram capturados em número significativamente maior do que outros, contribuindo aproximadamente para 80% de todos os indivíduos. Estes foram: *Lasioglossum*, *Panurgus* e *Dasypoda* (entre os Hymenoptera), e *Anthaxia*, *Oedemera* e *Psilothrix* (entre os Coleoptera). As taxas de captura para estes géneros variaram com o tipo de uso de solo, sendo possível inferir as razões para estas diferenças. O tipo de vegetação, as associações específicas de flora e insetos e os recursos de nidificação justificariam as diferenças observadas nas comunidades de polinizadores de polinizadores e ofereceram pistas de medidas susceptíveis de beneficiar os polinizadores desta área. Embora os dados tenham fornecido provas modestas de uma maior diversidade de insectos polinizadores em habitats ribeirinhos em comparação com a matriz agrícola, as comunidades de espécies diferiram substancialmente, pelo que a conservação e restauração de zonas ribeirinhas tem um valor significativo para os sistemas agrícolas nas regiões mediterrânicas.

Combinando os resultados do levantamento bibliográfico e do caso de estudo, é possível dizer que as zonas ripícolas representam um caso especial de uma área protegida, capaz de suportar um elevado nível de biodiversidade numa área relativamente pequena ao nível da paisagem. Isto incluiria os polinizadores de insectos, que tirariam partido da conectividade que as zonas ribeirinhas proporcionam sem perturbações, deslocando-se entre áreas de habitat natural e semi-natural, e dispersando-se na matriz agrícola. Além disso, existe frequentemente a responsabilidade legal de manter boas condições ecológicas nas zonas ribeirinhas, tornando-as um importante ponto de enfoque para as medidas de conservação e restauração. Existe uma grande oportunidade de combinar a monitorização da restauração em vales agrícolas mediterrânicos como o do rio Sorraia, com a medição da abundância e diversidade de insectos polinizadores entre regiões. O objectivo seria estabilizar e aumentar a abundância e diversidade de polinizadores em geral, e assim aumentar a resiliência dos ecossistemas, assegurando a produtividade das culturas próximas a níveis sustentáveis no futuro.

Table of Contents

List of Figures

List of Tables

List of Appendices

List of Abbreviations

b, w, y	Blue, white, yellow
H/C	Ration of *Hymenoptera* to *Coleoptera*
IPAD	Insect Pollinator Abundance and Diversity
NMDS	Non-metric Multidimensional Scaling
PCA	Principal Component Analysis
REI	Riparian Ecological Infrastructure
RH	Riparian Herbaceous
RW	Riparian Woody
S.E.	Standard Error
SEI	Shannon Evenness Index

1. This Thesis: Motivation, Structure and Goals

As will be described in more detail below, insect pollinators are a key element in the reproduction of many Angiospermae and consequently to the functioning of most terrestrial ecosystems. This thesis was motivated by a wish to understand better, the part wild insect pollinators are playing in the ecological and agricultural systems of riparian areas, and how this might be conserved.

The most important groups of pollinators are, most bees (Hymenoptera) and butterflies (Lepidoptera), and some flies (Diptera) and beetles (Coleoptera). In recent decades, studies have shown that a significant proportion of bees and butterfly species in Europe and North America are facing extinction or are in decline (Hallmann et al., 2017; Wagner, 2020). A number of measures beneficial to pollinators have been proposed, including for example, the protection of their natural habitats through EU nature legislation (EU, 1992). Wetlands and riparian zones are habitats that are poorly studied for pollinators but they may have a significant role to play in pollinator conservation (Cole et al., 2015a and b; McKergow et al., 2016; Brito et al., 2017). The work reported here is aimed at clarifying the relevance of these riparian habitats for the conservation of pollinators, and examining the way restoration actions could be taken in a particular case of a Mediterranean, agricultural river valley.

This thesis is structured in two related parts, each of which it is hoped will develop into a future paper. The first part is a literature review ("Perspectives on Insect Pollinator Abundance and Diversity in Mediterranean Agricultural Landscapes", Section 2), which introduces the topic and was conducted to:

a). Summarise the scientific literature providing evidence about a decline in insect pollinator abundance and diversity (IPAD) in Mediterranean agricultural landscapes;
b). Understand what restoration approaches have been or could be used to support IPAD in these regions;
c). Explore the part riparian zones might play for the conservation of pollinator species;
d). Identify any apparent knowledge gaps and hence potential topics for future investigation

A semi-systematic method of reviewing the literature was applied (Snyder, 2019), with search strings related to three specific questions, as shown in Section 2.2.

The second part of this thesis reports on a practical case study ("Pollinators of the Sorraia River Valley", Section 3), conducted to characterise IPAD in the Sorraia river valley of Portugal (which is very much a Mediterranean agricultural area), and to use data about a sampled community to:

e). Characterise the insect pollinator community of the Sorraia river valley, providing a 'baseline' set of data in line with good practice in ecological restoration (González et al., 2017; Optimus Prime project, Fonseca et al., 2021);
f). Test the hypothesis that IPAD was higher in riparian woody areas of the valley than herbaceous riparian areas or crop fields;

g). Infer ways in which IPAD could best be supported in this particular area;
h). Make suggestions for future work relevant to a real-world situation.

In combination the literature review and the case study investigate the likelihood that there has been a decline in IPAD in Mediterranean agricultural areas and establish how such a trend could be reversed.

2. Introduction: Perspectives on the Conservation of Insect Pollinator Abundance and Diversity in Mediterranean Agricultural Landscapes

Pollination regulates flower fertilisation in most Angiospermae and hence plant reproduction in natural and semi-natural ecosystems, as well as productivity in many agricultural landscapes (Klein et al., 2007; Harrison et al., 2010; Meehan et al., 2013; Kumar et al., 2018; Balasubramanian, 2019; Kowalska et al., 2021; Raji et al., 2021; Papa et al., 2022). Around 87% of wild plants and 78% of domesticated crops depend on animal pollinators (Ollerton et al, 2011; Ollerton, 2017), many of which are insects in the orders of Hymenoptera (bees and wasps), Coleoptera (beetles), Diptera (flies) and Lepidoptera (butterflies and moths). The economic value of insect-pollinated crops in Europe has been estimated at €15 billion (Harrison et al., 2010). Mediterranean areas in Southern Europe are typically considered hotspots of biodiversity, rich in entomophilous floral species (particularly in the families Brassicaceae, Asteraceae, Ericaceae, Boraginaceae, Fabacea and Lamiaceae), and consequently are also rich in pollinators (Cowling et al., 1996; Porqueddu et al., 2016). For example, the diversity of bees in regions like the Portuguese territory of the Iberian Peninsula can be very high, featuring over 700 species to our knowledge (Baldock et al., 2018). However, there is a concern that these areas, rich in flora and pollinators, might be threatened by global trends in biodiversity loss and the consequential reduction in ecosystem resilience (Hallmann et al., 2017; Wagner, 2020).

Beyond the ecological consequences of pollinator decline, Mediterranean areas might be at an elevated risk of adverse crop productivity effects when compared to other parts of the world. In Southern Europe in particular, there is a high economic dependency on fruit and nut production, and such crops need insect pollinators. As a result, countries around the Mediterranean Sea are highly dependent on high levels of pollination; yet there is a risk the extent of this dependency may not be well understood and go unacted upon (Gallai et al., 2009; Harrison et al., 2010; Leonhardt et al., 2013). It is also worth noting, though it seems often buried under economic and food security priorities, that humans benefit from connection with a diverse, fully functioning ecosystem for an enhanced quality of life and wellbeing (Keesing et al., 2010; Riis et al., 2020).

Though managed pollinators like honeybees and bumblebees can provide a significant pollination service, wild pollinators are more effective for certain crops, (Dikmen 2007; Garibaldi et al., 2013; Pardo & Borges, 2020). One species will not necessarily substitute for others as species differ in their modes of pollination (Dikmen 2007; Danforth et al., 2019; Pardo and Borges, 2020). This makes the diversity of pollinators, as well as the abundance of certain species important if pollination services are going to be complete at the ecosystem level. And in all likelihood, an integrated approach to species and habitat environment management is needed to successfully conserve biodiversity and enhance pollination as a service (Garibaldi et al, 2014 and 2017). Critically, the diversity of pollinators shows a positive correlation with the diversity of flowering plant species (Kline & Joshi, 2020). And importantly for human food security, pollinator diversity correlates with the inter-annual stability, quantity and quality of fruit and seed set (Senapathi et al, 2015 and 2021; Loy & Brosi, 2022).

The most strongly voiced concerns that insect abundance and diversity is declining, suggest Lepidoptera, Hymenoptera and Coleoptera being amongst the taxa most affected (Burkle et al., 2013; Vanbergen, 2013). The main drivers of decline are widely recognised as: i) habitat loss through agricultural intensification and urbanisation; ii) pollution (particularly from synthetic pesticides and fertilisers); iii) pathogens; iv) introduced species; and v) climate change (Hines & Hendrix, 2005; Kleijn et al., 2009; Ollerton et al., 2014; Cole et al., 2017; Sánchez-Bayo & Wyckhuys, 2019). Mediterranean climatic areas are typically hot and dry in the Summer, with mild, wet winters, and this has contributed over time to their richness of flowering plants and insect pollinators (Baldock et al., 2018; Sanchez et al., 2019). However, this richness is highly sensitive to all of the drivers of decline listed above, so it seems likely IPAD is lower in these regions now than it was in the past.

Some of the most highly pressurised Mediterranean ecosystems exist in the mid- to lower reaches of river valleys, where water has been easily accessed, and the land is flat and fertile, and so readily cultivated. As a result, these agricultural valleys are often seen to be severely degraded ecologically, though their ecological function is relatively little studied (Rodríguez-González et al., 2022). In some countries, riparian zones are protected by law, with the purpose of preserving their good ecological status sustaining ecosystem services (Riis et al 2020; Langhans et al., 2022), as protected riparian zones are expected to reduce the level of pollution entering rivers, provide supportive habitats for wildlife and areas of recreation and connection with nature for humans. Fully functioning riparian zones are able to provide these 'ecosystem services' because they feature strong ecological gradients and dynamics. As a result, they can support high levels of biodiversity in a relatively small geographic area. They are relatively continuous habitats, or 'ecological infrastructures', crossing and connecting a range of other natural and semi-natural environments (Stella et al., 2013), so they can act as corridors along which wildlife disperses finding refuge, food and nesting sites (Brito et al., 2017; Santos et al., 2018; Proesmans et al., 2019).

Despite positive legal requirements, it has proven difficult to coordinate policy and practice in protecting riparian zones (Urbanič et al., 2022). Still, their legal status and potential for high biodiversity indicates that riparian zones represent important opportunities for conservation and restoration action. Indeed, it has been observed that the conservation of semi-natural areas such as wetlands may be the single most generally effective action for bumblebee conservation (Whitehorn et al., 2022). And if bumblebees benefit from the conservation of wetlands and riparian zones, other pollinators are likely to benefit too.

This review provides a compilation of existing information on the temporal trends of IPAD in the Mediterranean areas, with emphasis on the river valleys. In particular, the goals were to:

a). Summarise the scientific literature providing evidence about a decline in insect pollinator abundance and diversity (IPAD) in Mediterranean agricultural landscapes;

b). Understand what restoration approaches have been or could be used to support IPAD in these regions;

c). Explore the part riparian zones might play for the conservation of pollinator species;

d). Identify any significant knowledge gaps and hence potential topics for future investigation.

2.1. Materials and Methods

A literature search was conducted using the database ISI Web of Knowledge (http://pcs.isiknowledge.com). Three separate searches were undertaken using keyword strings aligned with the three main questions of this review, as shown in Table 1. Searches were applied across all content fields of the database. No time constraints were used, and the searches led to some duplicates, which were removed to leave each article associated with the question for which it had the highest relevance. A significant number of additional articles were reviewed through cross-referencing, increasing the number of perspectives covered in this review.

Table 1: The questions and corresponding search strings used in the literature review.

Question	Search String
1) What evidence is there that IPAD is declining in Mediterranean regions?	1) pollinator* AND Mediterranean AND (abundance OR diversity) AND (threat* OR decline)
2) What ecological restoration practices offer most promise of conserving or reversing any decline in IPAD in Mediterranean agricultural landscapes?	2) pollinator* AND Mediterranean AND (abundance OR diversity) AND (“habitat management” OR restoration)
3) What contribution might riparian zones make to conserving or reversing any decline in IPAD in these landscapes?	3) pollinator* AND (abundance OR diversity) AND riparian

The results of article review are summarised in Appendix 1, indicating: Reference, Country/Climate, Habitat, Taxa, Years (study period), Method, Main Observation, Threat, Mitigation, Factor Analysed and IPAD Effect.

2.2. Results and Discussion

In total 76 articles were identified relating to the three main questions after removal of duplicates (Appendix 1). Of these, 39 (51%) were associated with the question of IPAD decline in Mediterranean regions. Though many of these only referred to decline as a globally recognised issue in their introduction, some information specific to decline in Mediterranean regions was found amongst the global perspectives. Combining evidence from the 13 studies (17%) directly related to restoration practices in Mediterranean agricultural landscapes with information across all articles, enabled the identification of a number of 'Threats' to IPAD and in response to these, a number of 'Mitigations'. 24 articles (32%) were found specifically relating to the role riparian zones might play in restoration.

2.2.1. Evidence that IPAD is Declining in Mediterranean Regions

To quantify a change in IPAD with statistical confidence, Potts et al. (2020) have shown studies need to apply a consistent methodology over a period of of the order of, or greater than ten years. However, approximately 80% of the articles identified here covered a study period of three years or less and the majority of studies were completed within one year, typically using areas with different levels of degradation or agricultural intensification to infer impact (Figure 1). Of those that covered longer periods, data was typically collected irregularly over time or from disparate studies that used different techniques to acquire data, making it difficult to identify any trends in abundance and diversity. Still, it is possible to find some indications of a decline in IPAD in Mediterranean regions in 7 articles reviewed. The following three paragraphs discuss the observations made in these articles.

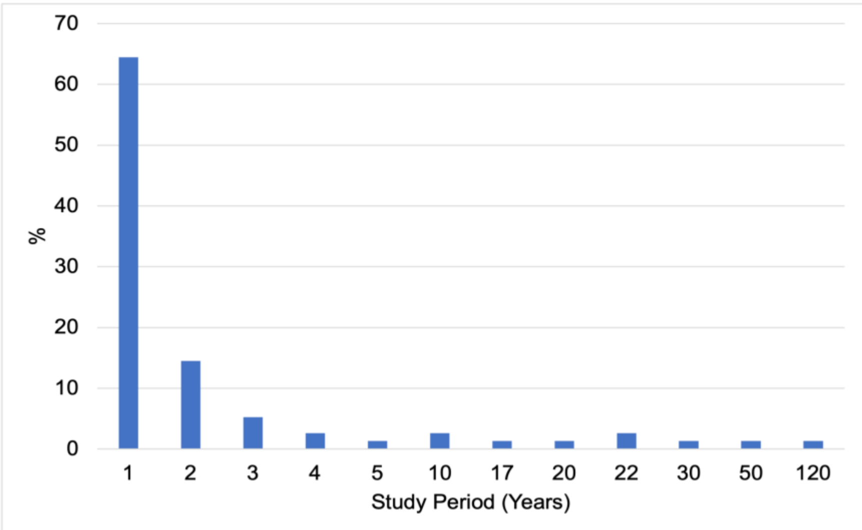


Figure 1: The percentage of papers found as a function of study period.

Sánchez-Bayo & Wyckhuys (2019) reviewed the literature on IPAD in Europe, including the European Red List of Butterflies finding that 19% of species are declining, particularly in the Mediterranean and Eastern countries. 8.5% of species were found to be threatened, and three critically endangered (Swaay et al., 2010). Melero et al. (2016) analysed data collected on butterflies in the Catalan region of Spain over a 20-year period. These studies were based on transect walks through seven different habitat types (meadows, forests, arable crops, woody crops, gardens, ruderal vegetation, and non-suitable habitat). They found evidence of declines in 70% of the 183 studied species of butterfly.

Somewhat in contrast, in the Sierras de Cazorla-Segura-Las Villas natural park of Southern Spain, Herrera (2019) drew on data from studies between 1997 and 2017, finding no evidence of IPAD decline in this particular area. The park was established in 1989, the area having been recognised as an area of exceptional ecological importance at risk from changes in land use. Herrera emphasised that this did not mean there was no decline in areas more severely impacted. Similarly, Ropars et al. (2020) reported on ten years of pollinator sampling in the French Mediterranean Calanques National Park, finding high levels of pollinator diversity (including a high abundance of honeybees). Ropars et al. (2020) did not present any trend in IPAD as they seemed to have no means of normalising different data sets for the effort that had been invested.

Herrera (2020) reviewed 336 estimates of wild bee and honeybee abundance in the region around the Mediterranean Sea, reported between 1963 and 2017. Though Herrera felt unable to report any trend in absolute numbers (because data had been collected using a wide range of methodologies), he raised a concern that honeybees are increasingly displacing wild species from their position in the ecosystem. This concern was also voiced by Lázaro et al. (2021).

These observations in Mediterranean areas do seem to reflect the perceived global trend of declining IPAD based on studies from non-Mediterranean regions. It should be noted much of the scientific evidence of insect pollinator decline comes from relatively restricted areas of the world, in particular North-Western Europe and the USA (Potts et al., 2010a and b; Cameron et al., 2011; Dupont et al., 2011; Burkle et al., 2013; Hallmann et al., 2017; Wagner, 2020). Some studies reporting a decline focus on collapses in populations of managed pollinators like the honeybee (Ellis et al., 2010). And there are suggestions that wild insect pollinators could compensate for such collapses. Of course, this compensating ecosystem service would remain available as long as any decline in wild IPAD is reversed (Kremen et al, 2002; Biesmeijer et al, 2006; Klein et al, 2007; Goulson et al, 2008; Ellis et al, 2010; Potts et al, 2010a and b; Goulson et al, 2015). This leads to further examination of articles where wild bees are the focus.

Biesmeijer et al. (2006) reviewed evidence from Britain and the Netherlands, finding a decline in local bee diversity in both countries. Carvalheiro et al. (2013) used statistical analyses across a number of studies to suggest the decline in pollinators and associated plants has slowed in Western Europe between 1990 and 2010, at least in areas where cropland expansion has decelerated. It may be important to note that pollinator declines were most frequently found in habitat and flower specialists. For example, Burkle et al. (2013) used historic data from an area of Illinois (USA), where woodland had been largely converted to agricultural land, leaving only a small number of degraded woodland patches. They found a reduction in bee diversity of approximately 50% in the last 120 years, with the most specialist, rare and ground nesting species suffering the greatest impact.

When pursuing reasons given for declines further, it becomes evident that many seem to come in response to land-use changes and can be related to specific species' traits. For example, Dupont et al. (2011) found long-tongued species of *Bombus* (bumblebee) to be declining, whilst the short-tongued species remained largely unaffected. This type of change is likely to be associated with a decline in the abundance of plants with long-tubed flowers. Bartomeus et al. (2013) also demonstrated that species in the genus *Bombus* were on the decline in their study area in the USA, whilst other genera like *Lasioglossum* were on the increase. This type of differential species response to human impact demonstrates the complexity of monitoring IPAD and characterising any changes taking place in insect pollinator communities with confidence. Indeed, this has led to some questioning the level of confidence some have in stating a decline in insect numbers is taking place; though even those with questions acknowledge there is sufficient evidence to justify a precautionary imperative to act (Ghazoul, 2005).

Despite the need to be conscious of the complexity involved, the evidence presented above and the extent of time and relative intensity with which Mediterranean climatic landscapes have been used for agriculture by humans, leads to a conclusion that it is highly likely IPAD is being adversely affected and in combination with the scale of the potential impact, that action should be taken to reverse this. The range of sources of variation in the ecosystem and measurement techniques, suggests a need for a standardised monitoring methodology applied in sufficient numbers of locations with different habitats, to better assess declining trends (Potts et al., 2020).

2.2.2. Causes of IPAD Decline and Mitigations in Mediterranean Agricultural Landscapes

Most articles (71 out of 76) reported particular threats to IPAD and pointed to the need of improving practice in conservation and restoration. So, it was possible to categorise these articles in terms of the main threat to IPAD they considered (Figure 2).

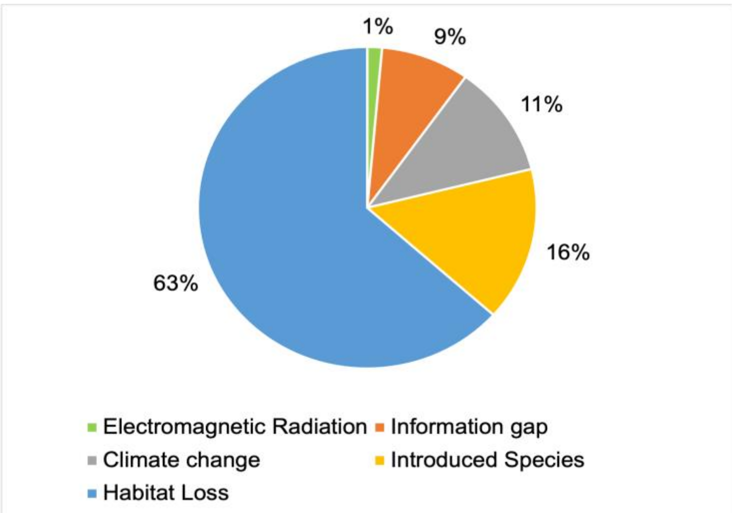


Figure 2: The percentage of papers according to the main threat the authors considered.

Habitat loss was the threat most often referred to, with 63% of articles pertaining to this. Agricultural intensification was the main 'sub-threat' referred to within habitat loss. Urbanisation and fire were referred as other drivers of habitat loss for pollinators, but much less often (about 4% and 1% of articles respectively). The other threats covered to a significant extent were introduced species (16%, of which flora represented 12% and fauna 4%), and climate change (11%). And 9% of articles expressed the opinion that more information is needed about IPAD, suggesting there is a real 'information gap' to be filled. This will be discussed further in Section 2.3.4.

It is interesting to note that pollution (in the form of pesticides and other man-made chemicals used on the land) was not addressed as a major threat in the articles retrieved, though it was mentioned as a cause for concern in a small number of cases (Kleijn et al., 2009; Cole et al., 2012 and 2015; Goulson et al., 2015; Sánchez-Bayo & Wyckhuys, 2019). Given a general background of concern about agricultural intensification and pollution, it may be important to investigate agrochemical usage in Mediterranean regions more into the future. Similarly, pathogens, parasites and predators were only mentioned to a very limited extent, and mainly regarding honeybees and the impact of the varroa mite (Goulson et al., 2007; Mandelik & Roll, 2009).

The three following subsections discuss the main threats to IPAD covered in the literature found in this review, identifying approaches to threat mitigation.

Habitat Loss

Changes in land use have resulted in habitat loss and risk reducing the quantity and quality of resources available to pollinators. Reversing this trend involves increasing the area of land available in every landscape for native species to forage and nest. The literature indicates that conservation and restoration efforts should be based on native floral species and take into consideration traits like inflorescence period and timing, and pollen, nectar and honeydew provision. Pollinators need to find the resources that support each stage of their life cycle (Goulson et al., 2007; Harrison et al, 2010). Increasing the diversity of plants in a landscape provides an opportunity for a greater range of floral traits, in support of a greater range of foraging strategies (Herrera, 1987, 1988 and 1989; Potts et al, 2006; Fijen et al, 2019). It also provides an opportunity to extend the timing of extensive flowering in the year, from early Spring to late Autumn. Larger size and greater connectivity of protected, natural and semi-natural zones are further recommended, as this would support smaller pollinators in particular, which tend to have shorter flight ranges (Kremen et al., 2007; Murray et al., 2012; Norris et al., 2018; Solé-Senan et al., 2018; Kline and Joshi, 2020; Griffin et al., 2021; Rodríguez et al., 2021).

Hedgerows and other types of field margin provide clear opportunities to support IPAD through the provision of foraging and nesting habitats (Dainese et al., 2017). And there are strong indications that all three vegetation layers: tree, shrub and herbaceous are important, if restoration activities are going to provide sustainable benefits in the long term, and hence represent value for the money and effort invested (Fernández & Gómez, 2012; Morrison et al., 2017; Bartual et al, 2018 and 2019; Mendoza-Garcia et al., 2018; Meiners et al., 2019; Sanchez et al., 2020).

By studying pollinator assemblages and pollinator-plant interactions, it is possible to determine which plants are most important for pollinator abundance and diversity in Mediterranean regions. For example, Morrison et al. (2021) showed that the specific wild plants *Daucus carota* (Linnaeus & Haartman, 1753), *Malva sylvestris* (L., 1753) and *Papaver rhoeas* (L., 1753) provided strong support for IPAD without a risk of invasive spread. Sanchez et al. (2020) found that plant species in the families Boraginaceae, Brassicaceae and Lamiaceae were most popular with the majority wild bees in their study region. Observations like this are indicative of good practice in designing flower mixes that could be advantageously sown in field margins and fallow, or semi-natural areas (Warzecha et al., 2018; Cole et al., 2022; Glenny et al., 2022; Lasway et al., 2022; Nichols et al., 2022). And in Mediterranean climatic zones it is particularly important to find plant species that provide forage through the Summer dry period, especially as climate change is likely to increase the frequency of drought in future (Benvenuti et al., 2016; Benelli et al., 2017; Cortés-Fernández et al., 2022).

Pisanty and Mandelik (2015) studied the wild bees in almond orchards and fields of sunflower and watermelon. They concluded that the diversity of nearby semi-natural areas and field margins had a beneficial impact on IPAD in the cultivated areas. Land cover management in orchards, vineyards and olive groves provides an important opportunity to support IPAD in Mediterranean regions, since these forms of agriculture are commonly practised (Petanidou & Lamborn, 2005; Mandelik & Roll, 2009; Petanidou et al., 2013a; Kehinde et al., 2018; Sáenz-Romo et al., 2019).

The literature also included references to agroforestry systems, which have been extensively common in parts of Southern Europe. These systems feature a sparse tree layer (typically cork oak or pine) interspersed with grassland for pasture or haying, and which may also be part of a crop rotation. Such systems are found to support relatively high levels of biodiversity (Staton et al., 2019, del Portillo et al., 2022). Faria and Morales (2022) indicated that these systems could be predictably managed to support insect abundance and diversity, though care needs to be taken not to over-graze (Minckley, 2014; Calleja et al., 2019).

Concern was sometimes voiced about the impact of land abandonment in Mediterranean regions (Colom et al., 2021). And Penado et al. (2022) used ‘succession stage’ as a surrogate for the temporal effects of land abandonment. They found that undisturbed early succession stages supported the greatest abundance and good diversity of bees, and that mature woodland supported a higher level of diversity, though with reduced abundance. This observation leads us to consider a ‘rewilding’ approach to restoration, in which natural succession is the main strategy leading to a return of higher levels of biodiversity. However, there is a ‘problem stage’ in natural vegetative recovery, which seems to be an intermediate one, where shrubs and bushes dominate, reducing the abundance of flowering herbs and holding back further development (Steffan-Dewenter & Tscharntke, 2001; Potts et al., 2003; Grundel et al., 2010; Taki et al., 2013). This suspension of succession is thought to be the result of human degradation of the soil and seed bank, and it may be necessary to find ways to enhance the quality of both to overcome it. Means by which suspended succession might be overcome include controlled grazing, controlled fires, shrub removal, seeding and tree planting, though landscape scale considerations should be given to ensure these measures are proportionate (Verdasca et al., 2012; Garrido et al., 2019).

Introduced Species

Introduced animal species are recognised as a global threat to biodiversity (Kleijn et al., 2009; Sánchez-Bayo & Wyckhuys, 2019). In the articles found in this review, only the competitive presence of the honeybee emerged as an animal-based threat to IPAD. However, the potential competitive and predatory impact of accidental introductions of the Asian hornet (*Vespa velutina,* Lepeletier, 1836) is of increasing concern, and is likely to feature more in the literature in future (Kenis et al., 2009; Monceau et al., 2014; Vanbergen et al., 2018; Liang et al., 2022; Verdasca et al, 2022). Penado et al. (2022) recorded relatively high numbers of honeybee at all successional stages in their study. This aligns with the observations of Herrera et al. (2020) and Lázaro et al. (2021) noted earlier, who expressed concern that honeybees may be out-competing native bees for resources. There may be a need to control the abundance of managed honey bees to ensure there is room for native species of pollinator, though this is likely to be highly controversial and need further study if it is to be justified.

Introduced species of plant may become invasive, squeezing important native plants out of the ecosystem. Herrera and Dudley (2003) focused on the impact of *Arundo donax* (L., 1753) on the community of insects alongside rivers and streams in California. They found the abundance of insects was significantly reduced and that aerial nesting species were particularly badly affected, almost certainly because the number of woody nesting site opportunities was reduced. The issue of invasion by *A. donax* and other rapidly growing introduced riparian species like *Acacia sp*. is common in most Mediterranean agricultural landscapes (Portela-Pereira et al., 2022). Some invasive plants provide forage and nesting for insect pollinators (Davis et al., 2018) but in general their removal is likely to be beneficial to IPAD in and around riparian zones (Nienhuis et al., 2009; Emery & Doran, 2013). Studies following the removal of invasive shrubs suggest the benefits for IPAD can be long lasting without major continued investment (Hanula & Horn, 2011; Hudson et al., 2013; Hanula et al., 2015; Ulyshen et al., 2020 & 2022).

Climate Change

Climate change is already seen as having a significant effect on the geographic distribution of many species. In Mediterranean climatic zones, the greatest threat is probably an increase in land surface temperatures and the frequency and intensity of summer droughts, which may mean some plants flower earlier in the year (Petanidou et al., 2013b) and cease to flower at all in the hottest periods. Such changes in the availability of forage represents an obvious threat to the pollinating insects that depend on these plants. Riparian zone vegetation has a cooling effect that extends the availability of floral resources through periods of drought (Benvenuti et al., 2016). So, the potential of riparian and irrigated zones to compensate for the effects of drought on flowering plants in Mediterranean climatic areas would be an important topic for further investigation.

2.2.3. Sampling Methods in Reviewed Articles

Scientists studying IPAD have used a wide range of methodologies in various combinations (Figure 3), and do not always indicate sampling effort, which makes it difficult to compare results. The most common sampling method involved a combination of transect walks with the observation of flower visitors and the netting of individual insects for detailed taxonomic examination (22%). Pan traps alone (typically sets of three coloured fluorescent blue, white and yellow) was a common methodology (17%). Flower visitor observation alone was quite common (13%). The combined use of pan traps, transect walks and netting individuals was applied in about 12% of studies and this combination is most consistent with the EU Pollinators Initiative (Potts et al., 2020), which was developed on the basis of a review of monitoring methodologies (Westphal et al., 2008; Kremen et al., 2011; Potts et al., 2011; Ullmann et al., 2011; Ward et al., 2014). The initiative includes a “Minimum Viable Scheme” (MVS) using pan traps and transect walks. The MVS is said to be a consistent, efficient and effective combination of methods that can give a representative measure of IPAD in a range of habitats. Power analysis suggests at least 2,000 sites are required across Europe to provide a likelihood of >80% to detect changes of 10% in abundance and species richness over 10 years for bees, butterflies and hoverflies. Member States each need at least 100 sites to have sufficient power (>80%) to detect a 30% decline over 10 years for common species, or pollinator groups. An impediment to this program is a lack of taxonomic skills and an initiative is underway to develop this capability (SPRING Project, 2022).

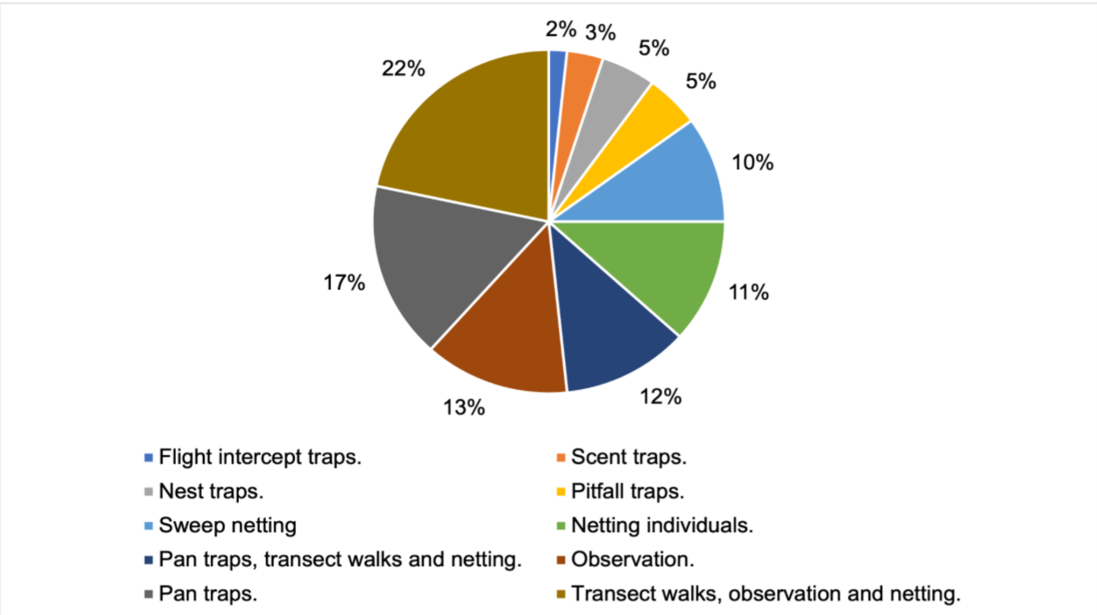


Figure 3: The range of sampling methods used by the authors of studies reviewed here.

The complexity involved in comparing studies of IPAD and combining data is increased by the range of techniques used to analyse the data gathered. Typically, abundance and diversity were the underlying metrics in the majority of studies, though the data was not always provided. General linear mixed models (GLMMs), analysis of variance (ANOVA), non-metric multidimensional scaling (NMDS) and principal component analysis (PCA) were the most frequently used data analysis techniques, and may represent good practice in comparing different levels of abundance and diversity over time, space and different treatments or habitats. However, it is important that these techniques are applied with a good knowledge of the underlying assumptions, and without over stating the power of the results.

2.2.4. Lack of Data and Information

One of the recurring themes across the literature is reviewed, was a lack of data and information about IPAD in countries with a Mediterranean climate. And without sufficient data, it is difficult to develop knowledge with confidence and establish rational arguments for investment in habitat conservation or restoration. As a consequence, several sets of authors were starting to collate lists of species in their geographic area of interest and to monitor IPAD over time: Petanidou et al. (2013b) and Stefanaki et al. (2015) in Greece, Lorite et al. (2020) in Spain, Nobile et al. (2021) in Italy and Vieli et al. (2021) in Chile.

The fact that pollinator communities involve species that respond differently to changes in their environment has already been noted as an element in the complexity when studying changes in IPAD. And this complexity is bound up with basic challenges like: the insects are often small; the number of taxa is high and species level identification is a skill that needs developing over a long period of time. Further, a wide range of environmental factors influence IPAD at any location and point in time, so natural variation can be significant and difficult to take into consideration, let alone control for. Technology may help address this problem in the future, perhaps through automated, multisensory monitoring stations, as proposed by Wägele et al. (2022). Where insects are concerned, Wägele et al built a prototype automated collection station based on a malaise trap, which operated on solar power collected samples at timed intervals and/or in response to weather conditions. Subsequently, samples were processed by mass DNA analysis. Whilst the pursuit of automation that makes sampling and analysis more consistent and efficient in future would be extremely valuable, a current way to mitigate the issues is to gather data from multiple studies. Unfortunately, as previously noted, data is often collected and analysed in different ways and this confounds most efforts to identify trends. These differences may well be justified as species specific, or innovative, but as stated in Section 2.2.3., the deployment of standardised procedures like those described in the EU Pollinators Initiative (Potts et al., 2020) is much needed. And if improvements to these procedures become available, their introduction to schemes like that of the EU would ideally take place with validation that the results can contribute to existing long term monitoring programs.

The deployment of standard monitoring methods and the consolidation of data from multiple studies would be of great value in connecting any changes in IPAD with the causes with confidence. For example, this literature search found no articles investigating the impact of agrochemicals. Cross-referencing revealed something of the potential impact of agrochemicals and suggests a study gap that would ideally be closed in Mediterranean regions. The purpose of closing this gap would be to understand the contribution of agrochemicals to a decline in IPAD in the region (individually and in combination), to clarify where the problem mainly lies in the lifecycle of the insects and to establish if some agrochemicals are safer to use than others (Goulson et al., 2015; Potts et al., 2016; Dharampal et al., 2019 and 2022; Sgolastra et al., 2020; Ali et al., 2021; Keller et al., 2021; Tamburini et al., 2021). Recognition of a gap in this area of study seems to be evident in recent action initiated by the European Food Safety Agency, which has issued new guidance on the testing of plant protection products for public consultation (Authority, 2013). The proposed guidance includes a 'higher effect tier' of study which includes field to landscape level studies, linked to population and ecological impact modelling (models for which still need developing). It seeks to define the previously non-specific limiting term 'unacceptable effects' more specifically, and to broaden the bee species under consideration beyond the honey bee to wild bees. The understanding of a topic like the impact of agrochemicals on IPAD would benefit greatly from multiple studies in different areas, undertaken with a consistent methodology.

2.2.5. Contribution of Riparian Zones in Support of IPAD

All 24 of the articles about riparian zones indicated that their conservation or restoration would be of benefit to IPAD. Habitat loss was again a main theme amongst the threats to riparian zones, and the invasive spread of introduced plant species featured strongly.

Because riparian zones provide ecological services of water filtration, flood protection (Hornigold, 2022; Kelley et al., 2022), shading and bank stabilisation, as well as pollination and biodiversity, they are typically protected by law. However, responsibility for their condition can fall between authorities. In Europe, for example, river managers are tasked under the Water Framework Directive (EU, 2000), to develop management plans for river basins that lead to surface waters of good ecological status, but the plans do not necessarily consider the ecological status of riparian zones as a part of the solution (Urbanič et al., 2022). Riparian zones may also be identified for protection under the Habitats Directive if they represent a habitat of recognised importance or places where threatened species survive (EU, 1992). Unfortunately, this selective mechanism is likely to mean many opportunities to conserve or improve the ecological status of riparian zones are missed.

As described by Petts and Amoros (1996), river basins can be thought of in terms of their longitudinal, transverse and temporal contributions to an ecosystem. Fully functioning riparian zones are diverse, dynamic features of the landscape, where vegetative succession takes place on a relatively frequent basis as the hydrological regime changes, often seasonally, enhancing the diversity of flowering plants through downstream dispersal (Neto, 2002; Nilsson et al., 2010; Clerici et al., 2013; Corenblit et al., 2015). For terrestrial forms of life, healthy riparian woody zones provide longitudinal connectivity between natural and semi-natural areas, providing a critical means of dispersal for terrestrial life forms, even when separated by challenging urbanised sections (Zhang et al., 2022). Across the transverse section of riparian zones, tree, shrub and herbaceous vegetation can provide for all the needs of insect pollinators to some extent (Clerici et al., 2013; Riis et al., 2020; Simon & Starzomski, 2022). Humid zones near the river enable a range of hygrophilous plants to flower, and woodland develops further from the water's edge providing shade for additional floral diversity (Saklaurs et al., 2022; Yuan et al., 2022). Ground and aerial nesting sites are relatively abundant compared to the agricultural matrix, due to the alluvial nature of the soil near the river and the transition to woody vegetation (Hanula et al., 2011, 2015 and 2016; Brito et al., 2017 and 2018; Clemente et al., 2017 and 2020; Araújo et al., 2018a and b; Affek et al., 2019; Cândido et al., 2021).

A number of authors have pointed out that the restoration for riparian zones and forests works for pollinators, which can spill over beneficially into adjacent farmland (Taki et al., 2007; Watson et al., 2011; Blitzer et al., 2012; Marini et al., 2012; Bailey et al., 2014; Monasterolo et al., 2015; Hanula et al., 2016; Proesmans et al, 2019). And it seems clear that to an extent, the widest riparian buffer strips provide the greatest support for IPAD, and that the presence of flowering perennials and shrubs within those strips is beneficial (Cole et al., 2012, 2015a and b, 2017, 2020a and b, and 2022, Hanula et al., 2015; Mitchel et al., 2015; Brito et al., 2017 and 2018; Araújo et al., 2018a and b; Clemente et al., 2020; Bak-Badowski et al., 2021).

The literature summarised above indicates how important healthy riparian zones could be for IPAD and that restoration works. This leads to the question of how to go about riparian ecological restoration should an opportunity present itself. In general, when considering ecological restoration, good practice involves identifying an appropriate reference habitat against which ecological status can be compared (McDonald et al., 2016; Perino et al., 2019). If we consider a particular example, EU Habitat 92A0 is commonly found in riparian zones to the North of the Mediterranean Sea. And there are habitats featuring plants with similar traits in other Mediterranean climatic regions (ALFA, 2004; Raposo et al., 2016 and 2020; Vallejo et al, 2022). Habitat 92A0 features *Salix spp*. (which are associated with high levels of pollen provision in Spring), and *Populus spp*. (providing woody nesting resources), which could form an important part of the tree layer community in a restoration project supporting IPAD in these regions.

Once a reference habitat is identified, it makes sense to establish a way of assessing restoration progress towards this habitat. Nelson and Andersen (1994), and González et al., (2017) reflected on the value of ecological indices in riparian zone restoration. Typically, the presence of invasive introduced plants is counter to establishing a high-quality habitat. And the positive effect of removing invasive plants from riparian zones on the diversity of pollinating insects has been revealed by a number of authors (Herrera & Dudley, 2003; Nienhuis et al., 2009; Bartomeus et al., 2010; Hanula et al., 2011 and 2015; Emery and Doran, 2013; Hudson et al., 2013; Davis et al., 2018; Ulyshen et al., 2020 and 2022; Portela-Pereira et al., 2022). This means that an enhancement in IPAD represents a goal in itself, and assessing IPAD provides a means of assessing success in ecological restoration. Indeed, an IPAD index or component to an index of ecological health would be quite a sensitive measure, given the relatively high rate with which insect pollinator generations turn over, compared to birds and mammals.

It seems important to note that the succession process of plant species following tree planting in riparian zones can take 10s of years to become sustainably established in connection with upstream plant communities, so long-term investment in restoration is required (Bourgeois et al., 2016a, b and c). And, that a mix of open and closed wooded areas leads to the greatest overall abundance and diversity of pollinating insects. Fortunately, the edges between riparian zones and agricultural matrices provide one synergistic way of establishing such a balance (Potts et al., 2006; Taki et al., 2007; Winfree et al., 2007; Brousil et al., 2015; Hanula et al., 2015; Abdullah et al., 2019; Bąk-Badowska et al., 2021).

2.3. Learning From the Literature Review

The number of long-term studies of IPAD in Mediterranean climatic zones is relatively low, and the experimental and analytical methodologies used across studies varies considerably. This means it is difficult to express trends with statistical confidence. However, there is sufficient published information on this specific topic, supported by evidence from other regions of the world, to suggest IPAD is likely to be declining in Mediterranean regions, with the main driver being habitat loss due to increases in agricultural land used and the intensity of use. Non-native species, in particular plants, emerge as the second major driver. Climate change does not appear, up to now, as a major concern. However, with global warming and drought intensification climate change may be an additional factor leading to IPAD decline, particularly in the Mediterranean regions. The effects may initially be manifest through changes in phenology and hence subtle changes in plant-pollinator interactions, reducing ecosystem stability, and eventually perhaps through the loss of certain species (Song et al., 2021; Freimuth et al., 2022). It is a source of hope that IPAD does not seem to have declined significantly in protected areas, as these could provide ‘reservoirs’ from which pollinators disperse across nearby areas if conditions became more favourable.

To confirm the decline, assess the rate, and understand where the impacts are greatest, it is important that long-term, consistent monitoring schemes are established, like the EU Pollinators Initiative. The areas monitored should cover a range of different habitats and provide an opportunity to demonstrate the benefits of conservation and restoration activities. Governments of countries with Mediterranean climates would ideally start to, or reinforce support in their scientific institutions for participation in schemes like this, as part of an effort to build capability and reverse a loss of biodiversity, and hence provide resilience to the ecosystem and a service to the crops that need insect pollinators. Ideally, the monitoring scheme would be extended to include an element investigating the specific impacts of the drivers mentioned above, along with an exploration of the impact of agrochemicals on IPAD at the landscape scale, as this seems to be a particular area of threat where scientific information is lacking.

In terms of ecological restoration practices that offer the most promise of conserving or reversing any decline in IPAD in Mediterranean agricultural landscapes, there are five principal themes that appear in the literature found here. These themes are summarised below.

Theme 1: Protected Area Management

Protecting, conserving and restoring natural and semi-natural areas adjacent to farmland, provides places where insect pollinators can naturally thrive and from which they can disperse to contribute to crop pollination.

Theme 2: Riparian Buffer Strips

Riparian zones are a special case of protected areas as they have a high potential for biodiversity and ecosystem service provision, and should be of a high ecological quality according to law. They can provide high levels of resource for pollinators from a relatively small spatial area. These resources include a long flowering season of diverse forage, and ground and aerial nesting opportunities. The conservation and restoration of riparian zones can create connecting corridors that enable pollinators to move between other natural and semi-natural areas, as well as enabling them to disperse into the crop fields and orchards between periods of disturbance. Riparian zones are prone to invasions of introduced plants and their removal should be a priority as part of restoration efforts, along with careful alteration of the riparian profile to aid natural, longitudinal and transverse connectivities, so that high quality habitats can re-establish themselves sustainably.

Theme 3: Field Margin Management

Allowing native plant species to re-establish themselves, and planting and sowing flowering trees, shrubs and herbs along field margins provides forage and nesting sites. The plants selected should be native and their genetic provenance considered, so that there is ecological alignment with local environmental conditions (Alimpić et al., 2022), as well as the life cycle needs of the native assemblage of pollinating insects. Planted vegetation should be typical of a reference habitat appropriate to the locality, provide a long flowering season (without presenting any great risk of invading cropland), and diverse ground and aerial nesting opportunities. In the case of orchards and vineyards, herbs can be sown (and/or allowed to grow from the existing seed bank), between the trees and vines. This offers an additional source of forage and further encourages pollinating insects to interact with the crops.

Theme 4: Grazing Management

Grazers can create clearings between trees in which flowering herbs and shrubs develop, supporting IPAD. However, overgrazing can quickly eradicate food sources for pollinating insects, particularly in regions where droughts are increasing in length and frequency, due to climate change. Grazing intensity should be kept low and grazed areas rotated to enable vegetation to recover, and grazers should be largely excluded from riparian zones.

Theme 5: Honeybee Population Management

Whilst the honeybee and other managed pollinators offer controlled pollination services, they do not meet the needs of all crops or other plants in the landscape, and they compete with wild pollinators. This dynamic should be better understood, along with the relative benefits of managed and wild pollinators, so that managed bee populations are not overused and so contribute to wild pollinator extinctions.

Finally, as stated in the summary of Theme 2 above, the literature indicates that riparian zones are a special case of protected areas, providing excellent opportunities to support IPAD. The higher the quality of the vegetation in the riparian zone, and the greater the extent to which the zone is functioning naturally, the greater the level of IPAD support it is likely to provide. In agricultural river valleys the consequence of fully functioning riparian zones would be enhanced ecosystem and agricultural system resilience into the future. Monitoring IPAD as part of a riparian zone restoration project would provide an indication of progress towards successful restoration, and contribute to long-term monitoring programs in countries with Mediterranean climates.

3. Pollinators of the Sorraia River Valley: A Case Study

With learning from the literature review of Section 2 in mind, and as stated in Section1, the aims of this case study were to:

e). Characterise the insect pollinator community of the Sorraia river valley, providing a 'baseline' set of data in line with good practice in ecological restoration (González et al., 2017; Optimus Prime project, Fonseca et al., 2021);
f). Test the hypothesis that IPAD was higher in riparian woody areas of the valley than herbaceous riparian areas or crop fields;
g). Infer ways in which IPAD could best be supported in this particular area;
h). Make suggestions for future work relevant to a real-world situation.

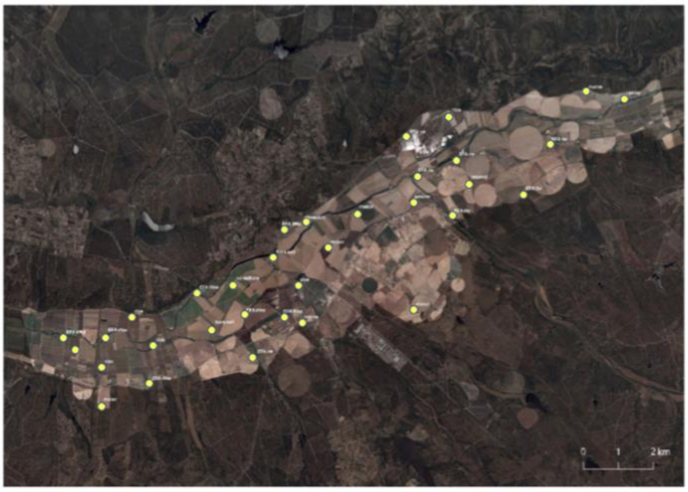
3.1. Materials and Methods

3.1.1. Study Area

Sampling for the study was carried out in 2019 in the irrigated agricultural valley of the Sorraia river in central Portugal (central point coordinates: Latitude 38.9581, Longitude. -8.52837, Figure 4 (a)). The landscape is mainly composed of intensively managed annual crops, with a predominance of rice paddies (*Oryza sativa,* L., 1753). The Sorraia valley is enclosed by an agroforestry system characterised by open canopy woodlands, mainly consisting of cork oak (*Quercus suber,* L., 1753) and holm oak (*Q. ilex spp*. *rotundifolia,* Lamarck, 1783), with an undercover of semi-natural grasslands, traditionally exploited through a range of land uses, including pastures and cereal crops (Pinto-Correia et al., 2011).

The regional climate can be described as Mediterranean, featuring mild winters and hot, dry summers with frequently irregular interannual fluctuations of precipitation. Flood peaks usually occur in early winter, and are followed by a slow decline in river flow and a consequent drying of the land during late Spring and through the Summer. The average annual level of precipitation is in the range 600 to 800 mm and annual average temperatures are between 15 and 17.5 ◦C (Atlas do Ambiente, 2021). Moisture levels in the land are affected by agricultural irrigation and this is particularly evident in the rice fields, which are typically flooded by farmers in June and July.

Two types of riparian ecological infrastructure (REIs) were defined as being part of the riparian buffer zone, according to their vegetation structure, based on the dominant strata, i.e., woody compared to herbaceous, riparian woody (RW) and riparian herbaceous (RH). The RW class included all the trees and tall shrub vegetation patches surrounding river systems, from the edge of the stream bank to the external limit of the canopy, where an abrupt change in vegetation composition, height, type, and amount typically occurs (Johansen & Phinn, 2006; Fernandes et al., 2011).



(a) (b)

Figure 4: The geographical location of the study area and sampling sites.

(a) A Google Earth map of Portugal with the Sorraia valley study area marked by a red ellipse. (b) The Sorraia valleys with yellow dots indicating the location of sampling sites. The average distance between nearest sites was 1.38 + 0.64 km with a range of 0.5 to 2.9 km.

The RH class included open areas at the riparian zone, mostly dominated by herbaceous vegetation and some low shrubs. In total 12 sites were sampled, six RW and six RH. The agricultural matrix was made up of 19 sites. 7 fields of maize, 6 fields of rice and 6 fields of 'mixed' crops. The mixed crops class was a pragmatic combination of sites with less common land uses. It included fields that had been recently ploughed or left fallow, and fields of potato and peanut. The sample sites are shown in Figure 4 (b).

3.1.2. Sampling Pollinating Insects

Three colours of pan trap were used in this study: blue, white and yellow. These colours were chosen, as this combination captures a wide range of bee species, outperforming other colours such as red, green, pink, orange and turquoise (Boyer et al., 2020). The pan traps were created by painting IKEA LURVIG pet food bowls (14cm in diameter and 6cm deep), with Pecol spray paints (Fluorescent Blue PECFIX, Acrylic P400 White and Fluorescent Yellow PECFIX). Each bowl in a set of three (one of each colour) was placed on the ground at the sampling sites, separated by approximately 5m, in an open setting. Each trap was filled with approximately 400ml of water and a small amount of fragrance-free dish detergent was added to break the surface tension (Popic et al. 2013; Shapiro et al. 2014). The traps were left in place for 24 hours on sunny days, with low wind velocities and no precipitation, during June 2019. When the traps were collected, larger specimens were removed and the remaining organisms filtered out of the liquid using a tea strainer. The samples were then transferred to flasks containing 70% alcohol, and taken to the laboratory to be identified as pollinators and quantified. In the field, the process of placing pan traps and collecting samples took a team of two approximately 45 person minutes per trap, most of which involved travel to the sites in vehicles and on foot. Identification of the pollinators to species or morphotype level took two people approximately 20 person minutes per individual insect, much of which was spent separating samples into orders and morphotypes and identifying representatives of particular species.

The study focused on pollinators in the orders Hymenoptera and Coleoptera. The taxa of insects considered in this study were, from Coleoptera: Cetoniidae, Dasytidae, Melyridae, Nitidulidae, Oedemeridae, Scarabaeidae; and from Hymenoptera: Andrenidae, Apidae, Chrysididae, Colletidae, Halictidae, Megachilidae, Mellitidae, Scoliidae. Identification to genus and species was achieved using taxonomic keys (Goulet & Huber, 1993; Falk, 2016; Valter, 2018; Vázquez, 2002). All specimens were separated to species or morphotype level.

Some Lepidoptera were captured and have been included in the statistical analyses, but pan traps are not a good way to sample Lepidoptera and numbers were very low (and probably far from representative of the order), so the captured species are not discussed. A significant number of Diptera were captured, but very few of these were considered pollinators (mostly Phoridae and Muscidae), so they were not included in this study.

3.1.3. Data Analysis

Microsoft Excel was used for basic data analysis, such as totals, means and standard errors. Statistical data analysis was performed using R (2020) in RStudio (2022). The “FSA” package was used for

Shapiro-Wilk and Kruskall-Wallis tests (Ogle et al., 2022). The “Vegan” package (Oksanen et al., 2013) was used for boxplots and biplots, species richness, Shannon-Wiener diversity indices, species accumulation, Chao species estimates, and non-metric multidimensional scaling (NMDS).

Boxplots were used to visualise the distributions of species abundance for each of the landcover types, and the Shapiro-Wilk test was used to statistically confirm the non-normal nature of the overall distribution of species.

Richness was measured as the simple number of species (S) for each land cover type and each pan trap colour. And the Chao species estimate was used to infer the number of species that might actually be present in the landscape. The Shannon-Wiener Diversity index (H) was used to calculate species diversity across all sites (γ-diversity), and for each land cover type (α-diversity), and for each pan trap colour. The Shannon Evenness Index (SEI= H/ln(S)) was further used to help interpret how species were distributed within each land cover. As SEI varies between 0 and 1, it also provides an easier interpretation of the species diversity.

Kruskall-Wallis tests and Wilcoxon rank sum tests with continuity correction were used to establish whether the abundance distributions of pollinators were statistically different between land cover types, and pan trap colours, recognising their non-normality and the consequent need to use non-parametric tests.

NMDS with Bray-Curtis distance criteria was used, in combination with biplots, first to reveal relative abundance differences in the communities of species between the different land cover types and pan trap colours. And then to visualise the apparent preferences of the most frequently captured genera of pollinator for particular land cover types and pan trap colours.

3.2. Results

This results section is divided into two main sub-sections. The first focuses on the primary results of pollinator identification and statistical analysis for all sites across 5 different land cover types: maize, mixed crops, rice, riparian herbaceous (RH) and riparian woody (RW). The second subsection reports on the data in terms of the influence of pan trap colour.

3.2.1. Land Cover Statistics

A total of 1129 insect specimens were collected across the 31 of the 33 sites originally targeted, as some traps were lost due to human or animal interference (Appendix 2). Overall, 113 species or morphotypes of the target groups were sampled. The Chao estimate of species richness was 164 ± 20. The Shannon-Wiener Diversity across the landscape was 3.06 (γ-diversity). The 1129 species were found to be in 55 genera, of which 6 genera represented almost 80% of the individual pollinators captured.

The average number per species per trap on each type of habitat varied between 2.7 and 4.1. The low average numbers, relatively large standard deviations and a significant number of outliers indicates the non-normal nature of the species number distributions in all land cover types (Fig. 9). And this was confirmed by a Shapiro-Wilk normality test of the overall distribution of species numbers (p-value < 0.01).

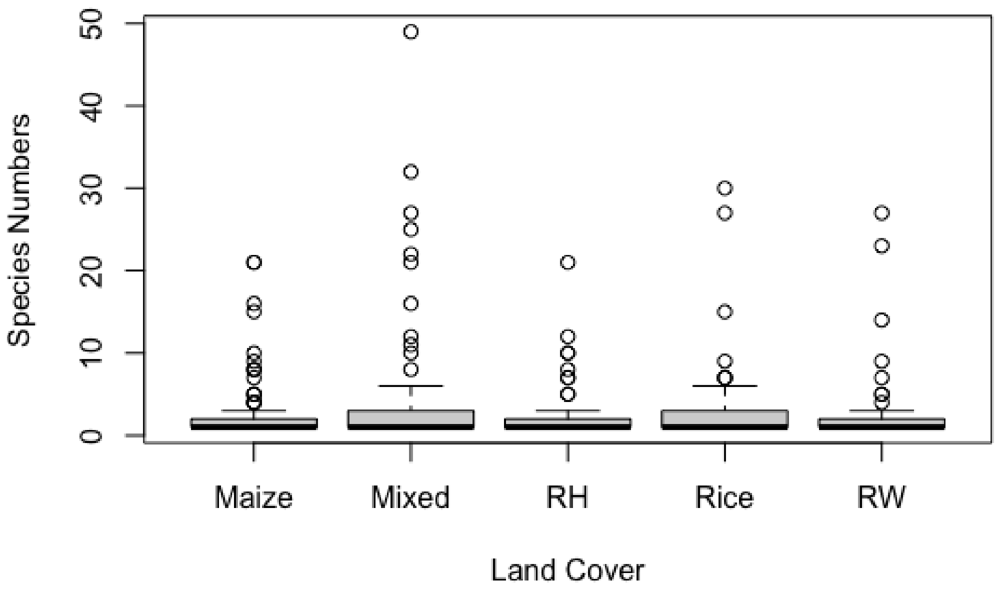


Figure 5: Boxplots of species numbers for each of the 5 different land cover types.

No statistically significant difference between the abundance distributions of species was found among habitats using the Kruskal-Wallis rank sum test, $chi^2 = 2.20$, p-value = 0.70. And this was corroborated by pairwise comparisons using a Wilcoxon rank sum test with continuity correction, with p values ranging from 0.69 to 0.94.

The number of pollinators captured was highest in areas representing the agricultural matrix (maize, mixed crops and rice). The ratio of Hymenoptera to Coleoptera was also higher in the matrix. Mean species richness per trap was lower for riparian woody areas than the other land cover types, which had similar values, but values did not differ significantly. However, woody riparian areas, fields of maize and herbaceous riparian areas had slightly higher levels of pollinator diversity (Shannon-Wiener index) as well as higher evenness distribution than fields of rice or mixed crops (Table 2). Woody riparian areas, in particular, are distinguished by the higher evenness distribution of species (0.81).

A comparison of the abundance of species in pollinator communities among habitat types was undertaken using NMDS with Bray-Curtis distance criteria across all sites. Convergence was achieved with a stress of 0.136 after 20 cycles. Note that stress values > 0.2 are considered poor.

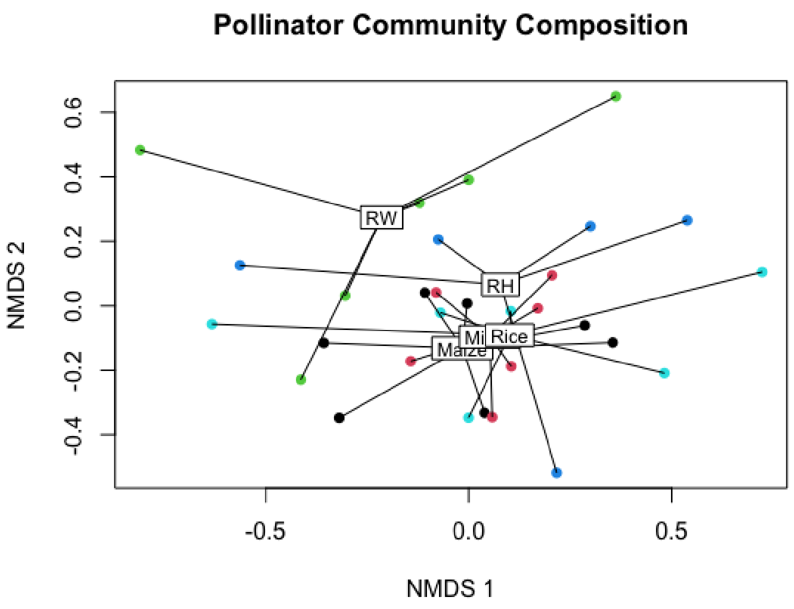
Table 2: Summary statistics of the pollinators captured.

Providing the number of pollinators captured, ratio of Hymenoptera to Coleoptera (H/C), species richness and mean species richness per trap, and Shannon-Wiener diversity index for the five land cover types. The number of pan traps is given as the total N and the number of each colour (b=blue, w=white, y=yellow). N/A=not applicable.

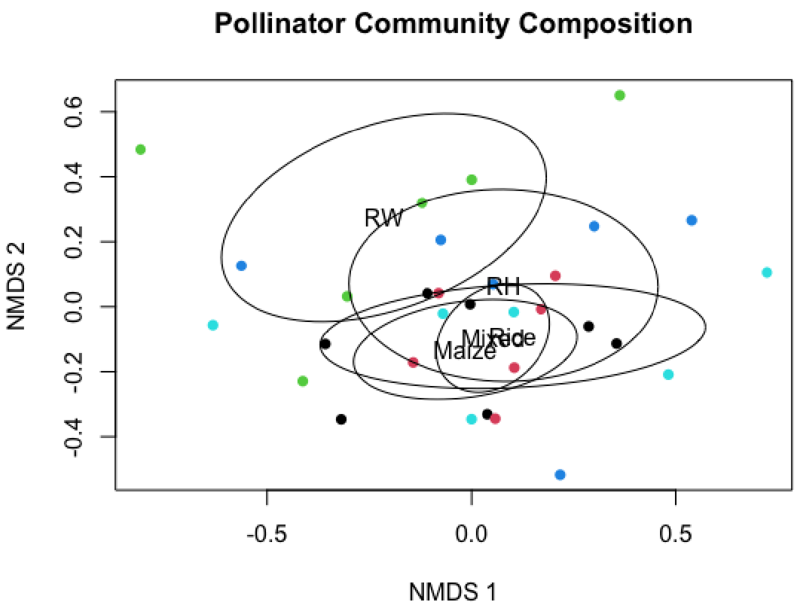
Land Cover	No. of Sites	Pan Trap No. by Colour (b,w,y)	No. of Individuals	Mean Species Abundance per Trap ± S.E.	Ratio H/C	Species Richness	Mean Species Richness per trap ± S.E.	Shannon-Wiener Diversity Index α	Shannon Evenness Index
Maize	7	17(6,5,6)	263	15.2 ± 3.5	2.2	49	5.7 ± 0.8	3.02	0.77
Mixed	6	15(5,5,5)	356	22.3 ± 5.0	4.8	42	5.3 ± 0.7	2.01	0.53
RH	6	13(5,4,4)	158	12.2 ± 4.5	1.8	42	5.1 ± 1.1	2.92	0.78
Rice	6	13(4,6,3)	191	17.4 ± 5.0	3.1	33	5.2 ± 0.9	2.21	0.63
RW	6	14(5,4,5)	161	13.6 ± 5.3	1.6	43	4.1 ± 1.1	3.06	0.81
Totals	31	72(25,24,23)	1129	16.2 ± 2.1	2.7	113	5.1 ± 0.4	3.06	0.65

Figure 6 (a) contains a plot of the NMDS of sites against the principal components of the NMDS solution in ‘species space’. Labels for the central positions of the land cover types are connected with points representing their corresponding sites. It can be seen that the crop field sites (maize, mixed and rice) are closely associated in species space. The riparian herbaceous sites and riparian woody sites are centred apart from the crop field sites, indicating different communities of pollinators, though with significant overlap. The extent of overlap can also be visualised using ellipses of one standard deviation for each land cover type in species space, as shown in Figure 6 (b).

As shown in Figure 7 (a), the majority of the difference in pollinator community between the riparian and matrix areas can be attributed to the woody sites (RW), whilst riparian herbaceous (RH) sites overlap strongly with matrix sites and partially with riparian woody sites. The extent of overlap between the combination of riparian herbaceous and riparian woody sites as ‘riparian ecological infrastructures’ (REIs) can be seen in Figure 7 (b). The REI assemblage covers a greater expanse of species space than that of the agricultural matrix.



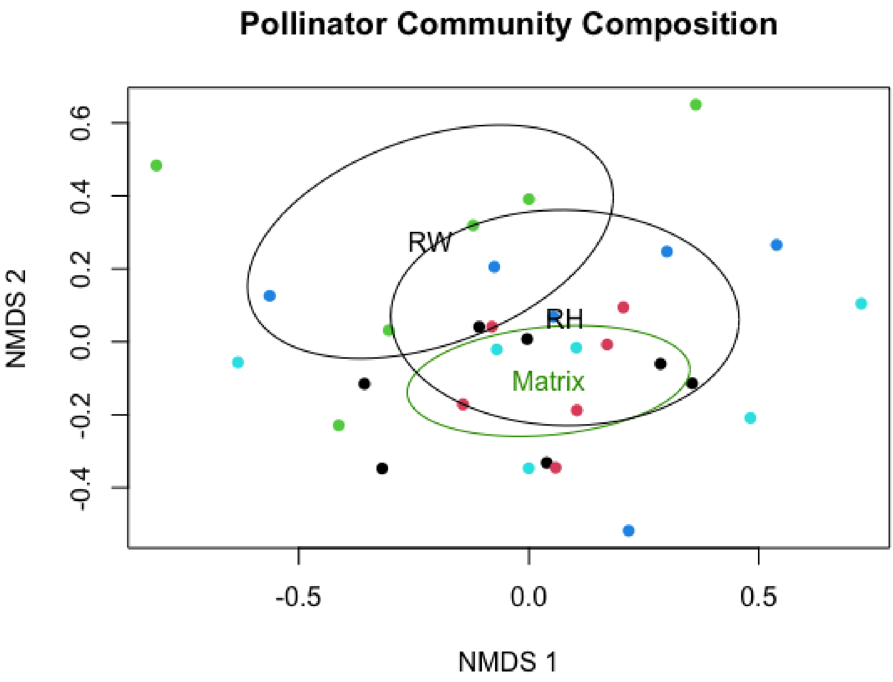
(a)



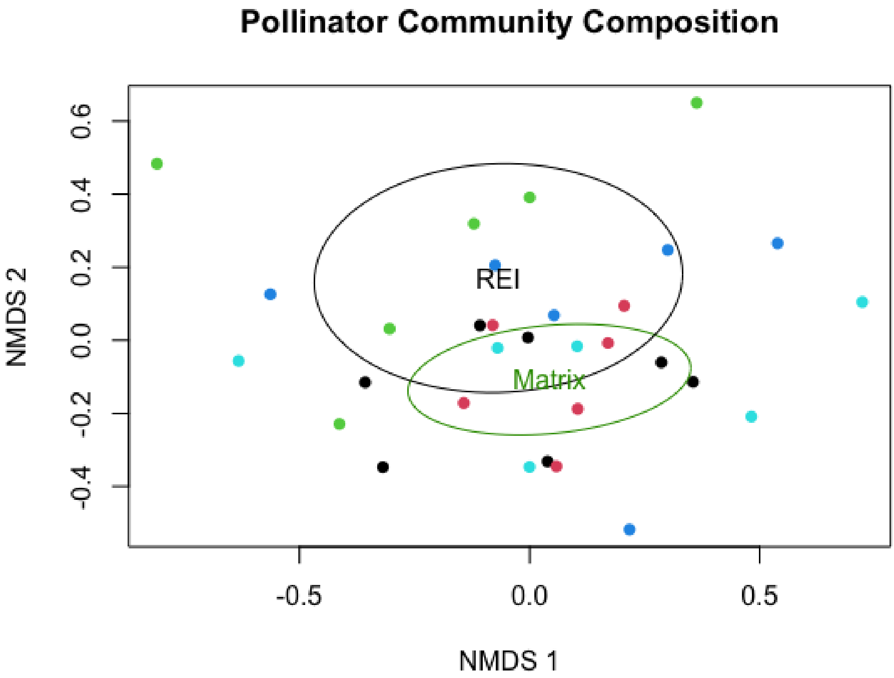
(b)

Figure 6: (a) A plot of the NMDS of sites according to species captured. (b) The same data with ellipses representing the standard deviation of the pollinator community distribution in species space for each land cover type.

Colour code for sites: maize = black; other mixed crops = red; riparian herbaceous = dark blue; rice = pale blue; riparian woody = green. Land cover type labels are connected by lines to the points representing their corresponding sites. Ellipses represent one standard deviation from the central coordinates, where land cover type labels are positioned.



(a)



(b)

Figure 7: (a) Ellipses representing the core species space of riparian ecological infrastructure areas (REI) and the agricultural matrix (Matrix). (b) Ellipses representing the core species space of the agricultural matrix (Matrix), riparian herbaceous (RH) and riparian woody (RW) areas.

Individual pollinators were concentrated in six most commonly captured genera. Three Hymenoptera (*Dasypoda, Lasioglossum* and *Panurgus*) and three Coleoptera (*Anthaxia*, *Oedemera* and *Psilothrix*). These genera were selected for closer attention as they represented 874 of the 1129 individual pollinators captured (almost 80%). Table 3 shows the abundance, and its percent of each of these genera for each land cover type

Table 3: The numbers and percentages of the 6 most frequently captured genera for each land cover type. Greatest abundances are picked out in bold text.

Order	Coleoptera						Hymenoptera					
Genera/Land Cover	*Anthaxia*		*Oedemera*		*Psilothrix*		*Dasypoda*		*Lasioglossum*		*Panurgus*	
Maize	29	53%	8	18%	7	9%	8	14%	81	18%	63	33%
Mixed	13	24%	8	18%	17	23%	5	8%	200	45%	69	36%
RH	9	16%	6	13%	23	31%	19	32%	46	10%	5	3%
Rice	2	4%	5	11%	26	35%	1	2%	98	22%	21	11%
RW	2	4%	18	40%	2	3%	26	44%	24	5%	33	17%
Totals	55	100%	45	100%	75	100%	59	100%	449	100%	191	100%

NMDS based on abundance across all sites for these genera was undertaken to see which genera were most abundant for each land cover type. This enabled specific discussion later, of the drivers of abundance according to their lifecycle needs for forage and nesting (Section 3.4.2.). The calculation was performed using the Bray-Curtis distance criterion and converged on a solution after 20 iterations with a stress of 0.110 (a reasonably good solution having a stress of less than 0.2).

Figure 8 shows the positions of land cover types with the locations of the six main genera. *Anthaxia* favoured maize fields, whilst *Dasypoda* favoured riparian woody and herbaceous areas. Individuals of the most abundant genus, *Lasioglossum*, were captured in greatest numbers in fields represented as mixed crops, and well represented, though less abundant in riparian areas. *Oedemera* seemed to favour riparian woody areas. *Panurgus* were captured most often in mixed crop and maize fields. *Psilothrix* seemed to favour rice fields and riparian herbaceous areas. In this visualisation of the data, the area representing rice fields can be seen to overlap strongly with the two riparian types of land cover, whilst the regions representing maize and mixed crops do not overlap with them.

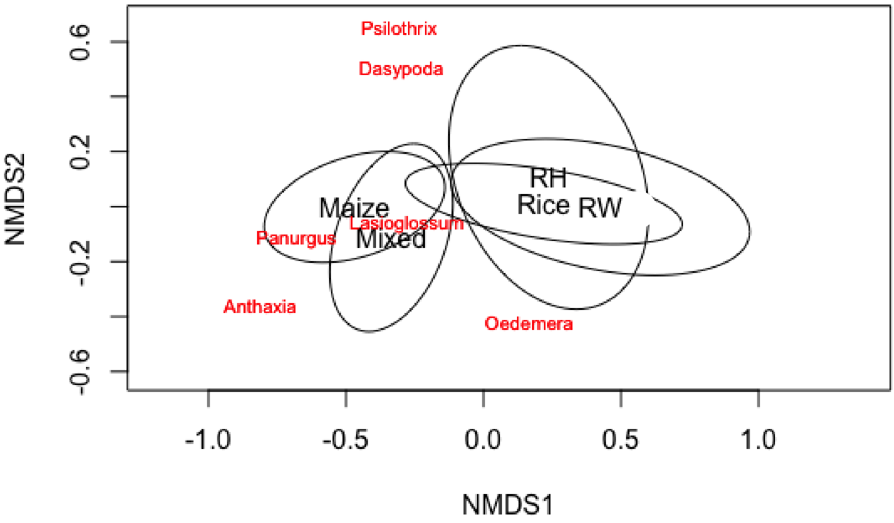
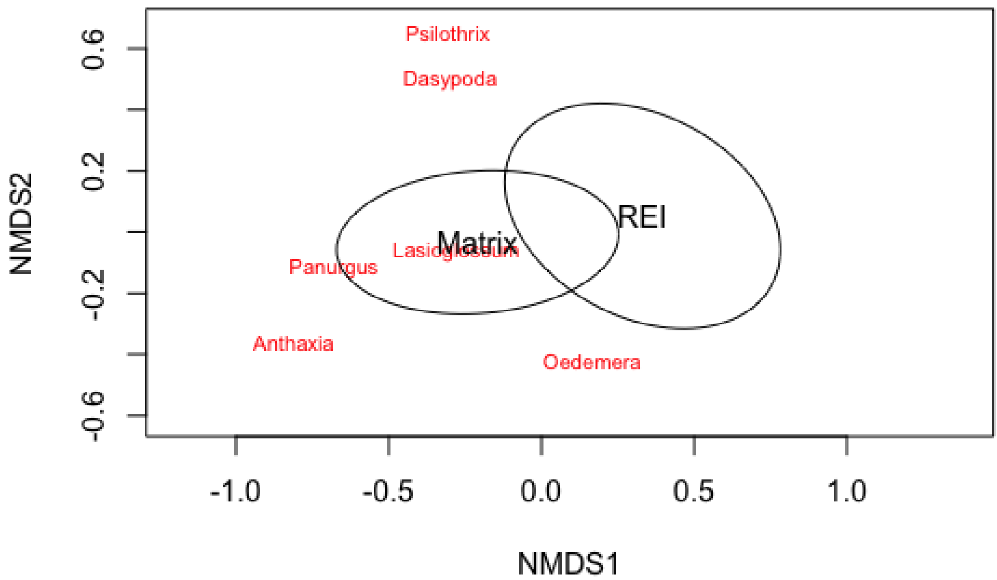
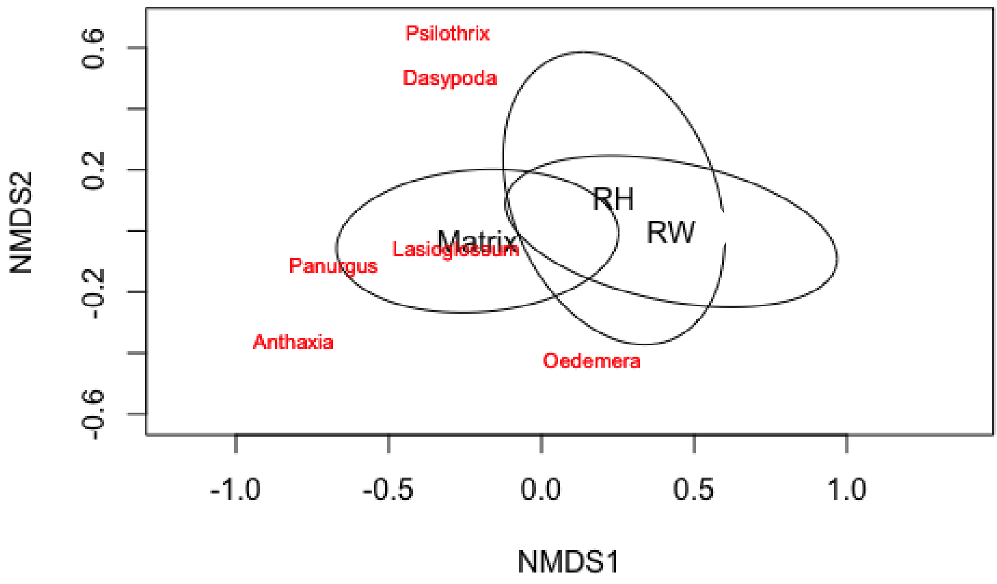


Figure 8: The distribution of the six most frequently captured genera in genus space, with ellipses representing the core of genus community space for each of the land cover types.

Figure 9 shows the same data with (a) ellipses representing REIs and the agricultural matrix and then (b) the REIs broken down as RH and RW sites.



(a)



(b)

Figure 9: (a) The distribution of the 6 most frequently captured genera in genus space, with ellipses representing the core of genus community space for combined REI sites and the agricultural matrix. (b) The same data with REI sites broken down into RH and RW.

3.2.2. Pan Trap Colour Statistics

This sub-section of the study explores the influence of pan trap colour through the analysis of data corresponding to 18 sites where all three colours of pan trap were available for analysis.

838 individual insects were collected across these sites, representing 88 species or morphotypes. The landscape scale Shannon-Wiener diversity index was 3.12. The Chao estimate of potential species richness is 124.19, Standard Error = 16.76.

Yellow traps captured more pollinators at a higher average rate per species, though the distribution was wide and clearly non-normal as shown in the boxplots (Fig. 10).

A Kruskal-Wallis rank sum test indicated that the abundance distributions of species data were similar across pan trap colours (chi-squared = 94.161, df = 87, p-value = 0.2813). And this was confirmed in pairwise comparisons using the Wilcoxon rank sum test with continuity correction (p=0.37 for blue vs. yellow and white vs. Yellow, p=0.70 for blue vs. white).

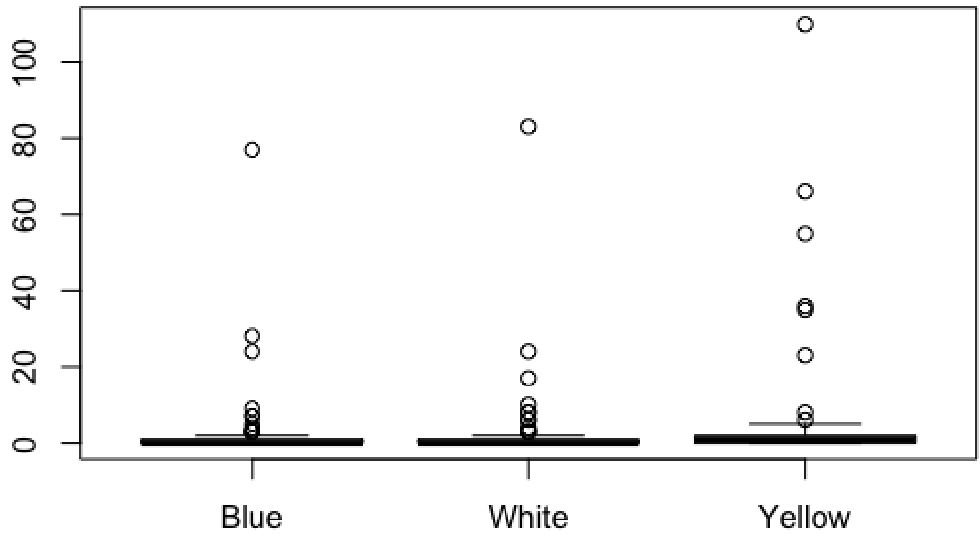


Figure 10: Boxplots of the species distributions captured in pan traps of different colours.

Table 4 contains the summary statistics of pollinators captured in pan traps of different colours across the 18 sites.

Table 4: Summary statistics for the species of pollinator captured in pan traps of different colours across the 18 sites where all colours were available.

Pan Trap Colour	No. of Sites	Pan Trap No. by Colour	No. of individual pollinators	Mean Species Abundance per Trap ± S.E.	Ration H/C	Species Richness	Mean Species Richness per trap ± S.E.	Shannon-Wiener Diversity Index	Shannon Evenness Index
Blue	18	18	211	10.9 ± 2.2	2.5	41	4.9 ± 0.6	2.60	0.70
White	18	18	209	12.4 ± 3.9	1.8	39	4.7 ± 1.1	2.56	0.70
Yellow	18	18	418	26.1 ± 5.5	2.2	49	8.4 ± 1.3	2.60	0.67
Totals	18	54	838	16.5 ± 2.6	2.2	113	6.0 ± 0.6	3.16	0.67

NMDS of these data using the Bray-Curtis distance criterion converged after 23 iterations with a stress of 0.163. A biplot of this NMDS shows a high degree of overlap for the core areas of species space occupied by the three pan trap colours (Fig. 11).

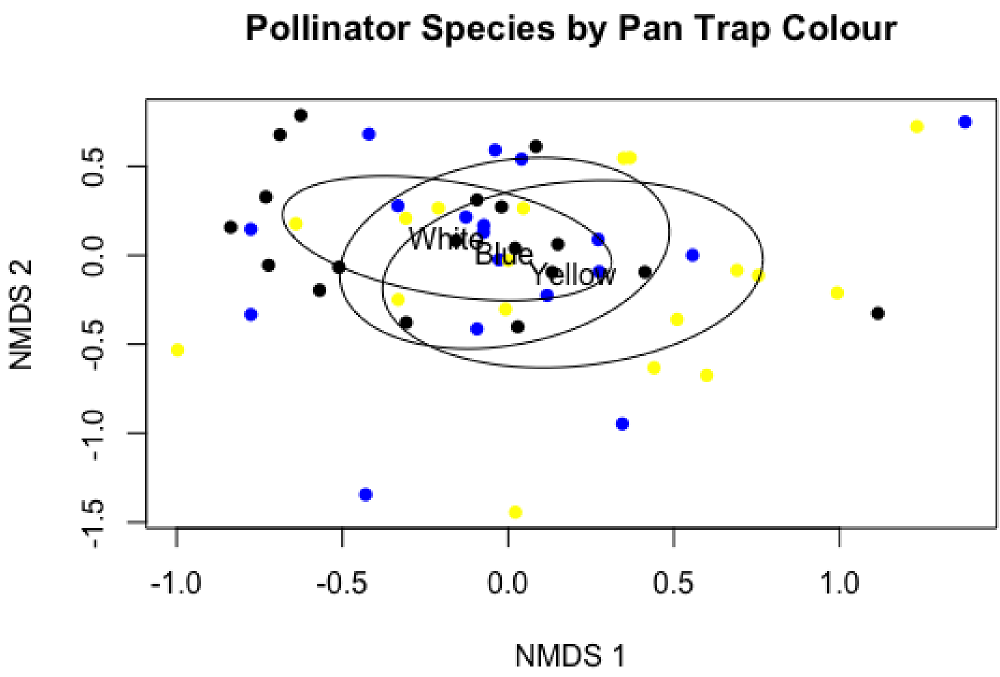


Figure 11: A plot of points related to each trap from the 18 sites where all three trap colours were available, in species space, represented by the two main principal components of the NMDS calculation. Blue points = blue traps, black points = white traps, yellow points = yellow traps.

For the six genera that make up around 80% of the captured species, Table 5 shows the numbers across pan traps. Figure 12 contains a visualisation of Table 5 resulting from a genus specific NMDS for sites where all three pan trap colours were available. The purpose of this analysis was to explore any genus specificity for colour, which might relate to preferred colours of flower and hence forage species of plant. All genera were captured in greatest numbers by yellow pan traps except for Dasypoda. Lasioglossum were also captured in relatively high numbers in white and blue traps. Oedemera were also captured in quite high numbers in white traps and Psilothrix were found quite frequently in blue ones.

Table 5: The numbers of the 6 most frequently captured genera for each pan trap colour. The highest number for each genus is shown in bold.

Order	Coleoptera						Hymenoptera					
Genera/Trap Colour	*Anthaxia*		*Oedemera*		*Psilothrix*		*Dasypoda*		*Lasioglossum*		*Panurgus*	
Blue	0	0%	8	8%	28	34%	38	81%	84	27%	11	7%
White	1	3%	44	43%	17	20%	4	9%	102	33%	1	1%
Yellow	34	97%	51	50%	38	46%	5	11%	123	40%	128	86%
Totals	35	100%	103	100%	83	100%	47	100%	309	100%	149	100%

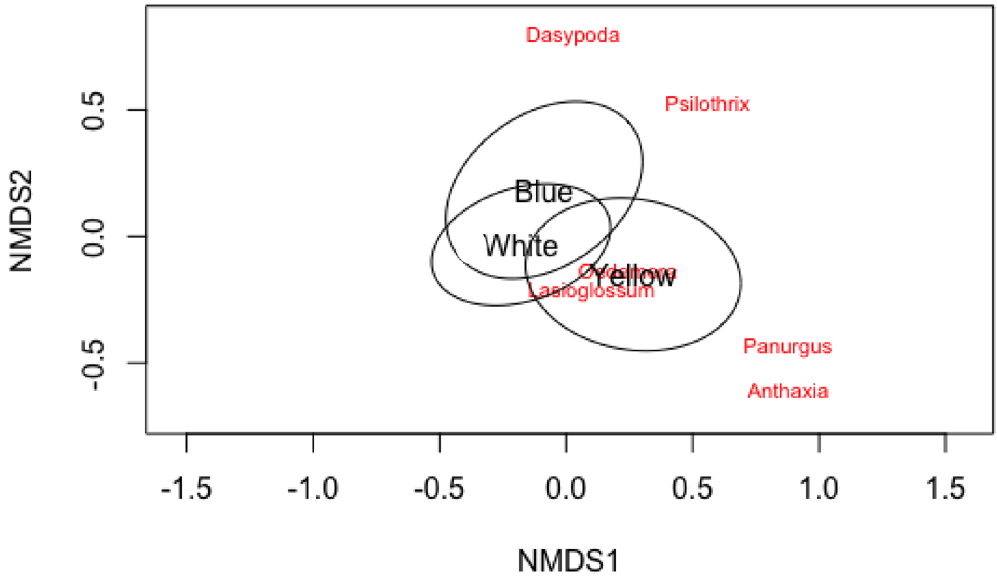


Figure 12: A plot of the 6 most frequently captured genera in genus space, using the two principal components of NMDS analysis. Ellipses represent the core location of the distributions of species for pan traps of different colours.

3.3. Discussion

3.3.1. Influence of Land Cover Type on Pollinator Assemblage

The diversity of pollinators found in this study was similar to (if a little higher than) diversities reported in other recent studies from the Iberian Peninsula (Gómez et al., 2010; Moreno et al., 2016; Pardo et al., 2022). Whilst the methodologies used and the landscapes featured in the other studies were different to those used and studied here, the similarity in diversity indicators provides some confidence in the scale of the results obtained. Further, in line with this study, Pardo et al. (2022) reported similar high relative numbers of *Lasioglossum spp*. and *Panurgus (sp. P. calcaratus*, Scopoli, 1763) in their work. Chao diversity estimates suggest the true diversity of pollinators in the study area is likely to be significantly higher than that represented by the species and morphotypes captured. And the true level of diversity is likely to be even higher than that suggested by the Chao estimates as pan traps are limited in their effectiveness at capturing larger Hymenoptera (e.g., *Bombus spp*.).

The number of pollinators captured was greatest in the land cover category called ‘mixed crops’, and the ratio of *Hymenoptera* to *Coleoptera* was relatively high there. This may have been the result of a number of factors, for example, some of these areas were left fallow and a cover of native flowering herbs had developed, and the crops of potato and peanut produce relatively large quantities of pollen, though they do not necessarily need insects to aid pollination. The reasons for the high levels of capture in this class deserves further investigation, since it could point to rotation as good practice in agricultural land management for the area.

Fields of maize provided the next greatest number of individual pollinators, and this may have been because maize produces significant amounts of pollen and was coming into flower at the time of year samples were collected. Yet, differences among habitat types were not found to be significant when using non-parametric tests. It has been suggested that certain pollinators, bees in particular, do well in fields of maize and other cultures, with species in the genera *Lasioglossum* doing particularly well in such environments (Wheelock et al., 2016). The relative abundance of Hymenoptera (mainly *Lasioglossum* spp.) was also high in rice fields and this is hard to explain by foraging levels alone, since rice produces small flowers with no nectar and pollen highly suited to wind pollination. However, in the margins of the rice field, herbaceous flowering plants may provide food resources, also favoured by the availability of water. It is interesting to speculate whether the practice of flooding rice fields with water pumped or diverted from the Sorraia river and its tributaries in this area leads to alluvial soils, and that these provide good Hymenopteran nest sites as they dry.

One of the most important observations arising from the data gathered in this study is that the Shannon-Wiener diversity index and Shannon Evenness Index were highest for riparian woody areas, though maize fields and riparian herbaceous areas provided similar values. This was consistent with the observations of Penado et al. (2022). The most likely reasons for this are that riparian woody areas provide a diverse range of flowering vegetation (especially when considered in connection with riparian herbaceous areas at their edges), and that they are probably the most diverse and least disturbed habitats in terms of nesting resources. The lowest diversity indices were found for rice and mixed crops. This is perhaps unsurprising for rice fields, which essentially are a very uniform element of the landscape. Studies could valuably collect accurate data on the abundance and diversity of pollen and nectar producing plants in particular study sites at the time of sample collection. The strength of the assertion that riparian woody areas provide for the highest levels of pollinator diversity needs to be moderated with the caution that non-parametric tests for richness did not reveal any statistically significant difference between riparian areas and fields in the matrix. Still the results presented in this study are consistent with others showing the differing impact of various land cover types on pollinator assemblages (Tangtorwongsakul et al., 2018).

NMDS revealed that the pollinator assemblages for maize, mixed crops and rice (the elements of agricultural matrix) are closely centred in species space and that the range of space they occupied was small compared to riparian herbaceous and riparian woody areas. The riparian woody assemblage is quite different to that of the matrix, and it is particularly interesting that the riparian herbaceous areas part of species space overlaps with both the matrix and riparian woody areas. This suggests that riparian woody areas, in combination with riparian herbaceous areas, can provide a reservoir of species which can repopulate the matrix after anthropogenic disturbances like ploughing and inundation. The species that do best in the matrix are probably able to exploit a range of foraging resources, disperse quickly after one disturbance and perhaps multiply rapidly in that environment before any subsequent disturbance takes place (Martin et al., 2019; Tooker et al., 2020). This would explain the high numbers of the genera *Lasioglossum*, *Panurgus* and *Anthaxia* that were found in maize and mixed crop fields.

Interestingly, high numbers of *Psilothrix* were found in rice fields, and *Dasypoda* and *Oedemara* were relatively abundant in riparian woody areas, providing a real-world demonstration of the importance of diversity in the landscape if IPAD is to be supported.

Curiously, the area representing rice fields in space, defined by the numbers of the most common genera, overlaps strongly with riparian woody and herbaceous areas. This may be the result of soil type as much as available forage, as suggested earlier in this discussion section. It would also be interesting to monitor nesting habits in each land cover type, without depending on a study methodology that depends on pan traps (which mimic flower colour) or flower visitation. This would be quite inefficient if undertaken in a random fashion, and searches for nest sites could be most efficiently undertaken by returning to search those sites where the abundance of common species was highest.

The flowering plants of a landscape are not the only thing that can affect the assemblage of pollinating insects, as they need to find biomes that support their entire lifecycle. Nesting sites and nesting resources are likely to be important, however their effect on pollinator assemblages is relatively under-studied (Cane, 1991; Potts & Willmer, 1997; Wuellner, 1999; Potts et al., 2003a and b). This is at least in part because of the difficulty in locating nests in many settings such as scrubland. Bee guilds are often described as miners, masons, carpenters and social nesters, because of their preferences for certain nesting resources, and the nesting related factors that have been found to relate to the abundance of certain bee guilds include soil texture and hardness, moisture content, slope and orientation, existing cavities, and the presence of pithy or woody vegetation. Unfortunately, it has proven difficult to deconvolute the importance of nesting resources from the availability of floral resources. And sampling for studies of either type of resource are typically based on the abundance of pollinators visiting floral resources, or captured in traps based on floral traits like colour. Potts et al. (2005) succeeded in this deconvolution to some extent, concluding that the flowers available as forage may explain some 60% of assemblage variation between habitats, whilst nesting resources may explain around 40%. This observation emphasises the need for conservation and restoration projects to consider the provision of nesting as well as foraging resources.

3.3.2. Most Captured Genera

Consideration of the foraging and nesting needs of the most captured genera provides clues as to specific ways in which restoration might support IPAD in the study area.

Lasioglossum was the genus of Hymenopteran pollinators captured most frequently in this study. An image of a pinned specimen is contained in Figure 13 (a) and of a live specimen in Figure 13 (b). Perhaps this high capture rate is not surprising as this genus is known to be abundant in Portugal, where there are reported to be some 70 species. It’s one of the most diverse genera of bees in the country (Baldock et al., 2018).

(a) (b)

Figure 13: (a) A pinned specimen of *Lasioglossum* (cf. *leucozonium*). (b) An image of a live specimen.

This genus has a characteristic median furrow (rima) in the fifth tergite, impuntate and shiny first tergite, hair bands only at the base of the tergites and, in this case, three sub-marginal cells with weak veins. *Lasioglossum* species are relatively small, with body sizes in the range 6 to 10 mm and intertegular distances of 1 to 2 mm. Their flight range is estimated to be 100 to 400 m (Wright et al., 2015).

Lasioglossum were most frequently captured in fields of mixed crops, rice and maize compared to other land cover types. The species of *Lasioglossum* most frequently captured was *L. malachurum* (Kirby, 1806). This is the most frequently reported species in Portugal, with 121 reports and suggestions it is widely polylectic (Lopatin & Tregub, 2004). Of the 14 most common species of *Lasioglossum* (those with more than 20 reports), 13 are thought to be widespread and polylectic, with one thought to be oligolectic for Asteraceae (*L. villosulum,* Kirby, 1802, 52 reports). Workers from different European areas have been observed to visit many different flowers, mainly yellow composites. This wide polylectic foraging behaviour is likely to be one of the reasons for its abundance in this landscape.

Polidori et al. (2010) studied the floral and nesting needs of *L. malachurum* in a Mediterranean semi-agricultural landscape. They called it a typical, primitively eusocial 'sweat bee', finding that *Asteraceae* was the family of flowering plants it exploited most, although inter-population differences appeared in pollen types and the pollen spectrum varied through the annual nesting cycle. There was some evidence of pollen from Brassicaceae (also known as Cruciferae) in the samples taken from cropped areas, suggesting the species is an effective pollinator of this family of plants (Abrol, 1989). This widely polylectic foraging behaviour may explain the fact that it was captured quite frequently across all land cover types in this study.

The families of flowers upon which *Lasioglossum* have been reported to forage in the references above are Asteraceae and Brassicaceae. Asteraceae is the second most diverse family of flowering plants, with more than 32,000 species. For Portugal, some 327 species are mapped on the open reporting website "Flora-on" (de Botânica, 2018), with a combined flowering time period from February to October, making them a very important resource to pollinators. In the Sorraia river valley, Asteraceae spp. are dominant in herbaceous riparian areas, in the borders between fields, and on any fallow land. Brassicaceae is a smaller family of plants, but it is also dominant in some areas of the Sorraia valley. And importantly, it contains some commercially important plants like cabbage, kale, cauliflower and broccoli. As a result, *Lasioglossum* is thought to be one of the most important genera of wild pollinators for commercial crops.

Though *Lasioglossum* species are said to favour yellow flowers, they were captured in relatively high numbers in all three colours of pan trap, probably as a result of their wide polylectic foraging habit. The fact that *Lasioglossum* were captured more frequently in rice and maize fields than in riparian areas is consistent with the observations of Gollan et al. (2011) and Acharya et al. (2021) and suggests there were relatively high levels of foraging and nesting resources in or on the margins of crop fields like these. Neither of these crops require insect pollination, though maize produces significant quantities of pollen, and herbaceous cover at the margins of the riparian sites might be similar to that at the margins of the fields, so there is a possibility that the availability of suitable nest sites was a significant factor in this observation.

Lopatin and Tregub (2004) found that *L. malachurum* nest in horizontal ground with hard soils (with a high % of sand and silt), of low acidity, and with rare superficial stones. Typically, there was moderately variable content of organic matter and high variability in vegetation cover. They continued to a conclusion that the creation of ground patches with these characteristics in cultivated and semi-natural areas could promote colonisation of new areas by this bee. *L. malachurum* are said to establish their colonies in subterranean nests in Spring and then produce one (in Northern Europe) to three (in Southern Europe) worker phases and a last phase composed of males and gynes; these phases are separated by several days during which no foraging activity takes place. Mated gynes (queens) overwinter and found new colonies in the following Spring. The fact that *Lasioglossum* produces multiple worker phases in Southern Europe may well be contributing to its success in the agricultural matrix, as its numbers may rapidly reach high levels between disturbance events like ploughing and flooding, though they may need 'reservoir habitats' from which to recover their agricultural populations after disturbance. It may also be worth considering that a lack of activity between worker production phases could lead to some variation in the numbers captured depending on the exact timing of a site being sampled.

The relatively high abundance of *Lasioglossum* found in this study is firstly indicative of their abundance across Portugal, and secondly the result of the agricultural practices that dominate the river valley. The landscape provides a relative abundance of foraging resources and places where their nesting needs for horizontal, hard, sandy soils are met (Cane, 1991; Westrich, 1996).

Panurgus was the second-most captured genus of Hymenoptera in this study. By far, the greatest number of individuals were captured in yellow pan traps in fields of mixed crops and maize. Figure 20 contains images of *Panurgus*. In Portugal, there are reported to be 6 species in this genus (Baldock et al., 2018). *P. calcaratus* is the most frequently reported species with 61 reports. Of the 5 most common species (more than 20 reports), 3 are thought to be widespread and oligolectic on Asteraceae, with one thought to be oligolectic for *Brassica* in the Brassicaceae family (*P. albopilosus*, 30 reports). Of the Asteraceae favouring species, *Andryala integrifolia* (L., 1753) has been most commonly found amongst pollen loads for *P. perezi* (Saunders, 1882), (42 reports).

(a) (b)

Figure 14: (a) a specimen of Panurgus (cf. banksianus). (b) A live example of Panurgus (cf. calcaratus).

Panurgus have a characteristic hairy body, broad head and well-developed pollen brushes on the hind legs. The marginal cell of the forewing has a truncated tip. They are typically between 10 and 12mm long, with an intertegulary distance of about 2 mm and a flight range of at least 250 m (Zurbuchen et al., 2010) and perhaps up to 1 km using the model of Greenleaf et al. (2007).

In the Sorraia valley, as already mentioned, Asteraceae and Brassicaceae are dominant in herbaceous areas. *Andryala integrifolia* is one of the most widespread members of the *Asteraceae* family in Portugal, favouring the types of sandy soils found in the edges of fields in this particular study area. Some species of *Panurgus* have been shown to favour yellow flowers and pan traps (Tengö et al., 1988), which aligns with the relatively high abundance of *Panurgus* in yellow pan traps found here. In Scandinavia at least, species of this genera are oligolectic on the *Asteraceae* species *Hypochaeris radicata* (L., 1753), which is also abundant across Portugal, including the study area.

Like *Lasioglossum*, *Panurgus* is a genera of ground nesting bee species (Westrich, 1996), though it is said to be solitary in its nesting habits (Münster-Swendsen, 1968). Panurgus seem to prefer open landscapes with sparse vegetation and sandy-silty soils. Whilst maize fields provide no nectar, they provide ample pollen and little disturbance through the Spring and Summer, when herbaceous field margins develop. And they have ample nesting opportunities for ground nesting bees.

There is no mention of *Panurgus* producing more than one phase in the year, as *Lasioglossum* do. This, along with their oligolectic tendencies, and a suggestion that they reach higher numbers later in the year, may account for their abundance being lower than that of *Lasioglossum*. Still, they tend to be slightly larger than most *Lasioglossum* and this may provide them with an advantage in foraging range (Gathmann & Tscharntke, 2002; Steffan-Dewenter et al., 2002).

Dasypoda was the third most frequently captured genus of Hymenoptera, with the greatest number being captured in blue pan traps in riparian woody locations. These observations differentiate it distinctly from those for *Lasioglossum* and *Panurgus*. Images of *Dasypoda* are contained in Figure 15.

(a) (b)

Figure 15: (a) A pinned specimen of a female of the genera Dasypoda (cf. dusmeti). (b) A live example.

Dasypoda have characteristically large scopa on the hind tibia, hairy body and two sub-marginal cells in the wings. They tend to be relatively large species with a body size between 9 and 16mm, an intertegular distance (thorax size) of 3.2 to 3.6mm and a consequently large potential foraging range of 1.7km. This is according to El Abdouni et al. (2021) who estimate the foraging range based on the intertegular distance model of Greenleaf et al. (2007).

In Portugal, there are reported to be 9 species of *Dasypoda* (Baldock et al., 2018). *D. dusmeti* (Quilis, 1928) is the most frequently reported species with 41 reports. It is said to be oligolectic for Asteraceae, though this assertion will be discussed further below. The only other *Dasypoda* species with more than 20 reports is *D. cingulata* (Erichson, 1835), (24 reports), which is thought to be polylectic. *D. hirtipes* (Fabricius, 1793) had only 14 reports, but was identified in this case study and featured in the discussion of El Abdouni et al. (2021) who wrote: '*Dasypoda* species tend to forage oligolectically on Asteraceae, with some subspecies preferring Dipsacaceae, Cistaceae and Malvaceae.' A preference for the last three plant families mentioned by El Abdouni et al. may in part explain the difference in observations for this genus compared to the other frequently captured Hymenoptera.

Westrich (1996) suggested *Dasypoda* is a genus with oligolectic foraging habits, seeking out the oils in particular, of certain families or even species of plant. Focusing on *D. argentata* (Panzer 1809), Westrich wrote that this species favours the Dipsacaceae family of plants, which is also known as the 'teasel family'. Interestingly, Leverman et al. (2000) reported species of *Panurgus* (*P. calcaratus*) and *Dasypoda* (*D. hirtipes)* are "sympatric and synchronous". And in their study both species were said to be oligolectic for yellow, liguliflorous Asteraceae as a pollen-source and sandy soil for nesting. *D. hirtipes* being a larger bee provided some differentiation in their ecological niches through longer diurnal foraging times and greater flight distances, and the pollen collecting strategies differed, with *P. calcaratus* wriggling through flower heads and *D. hirtipes* hovering. Given their foraging range advantage, perhaps *Dasypoda* can exploit the deep nesting site opportunities in the riparian areas whilst accessing the herbaceous and crop foraging opportunities across the agricultural landscape.

The observation that these particular species of *Panurgus* and *Dasypoda* foraged on the same yellow-flowering plants is somewhat at odds with the finding in this case study where *Dasypoda* were captured more often in blue pan traps and in riparian herbaceous areas than *Panurgus* (which favoured yellow traps, mixed crops and maize). However, Heneberg and Bogusch (2014) offered a possible explanation for the differences between the *Dasypoda* and *Panurgus* observations made here, when reporting sex-specific differences in the colour preferences in 11 of the 96 species captured in their study. Such differences in other species of Hymenoptera have also been reported by Leong and Thorp (1999), Edwards and Telfer (2001) and Michener (2007), and there is a suggestion that in some cases these sex-specific differences may reach extremes. Heneberg and Bogusch (2014) reported 14 of the 16 *D. hirtipes* males they trapped were in the yellow traps, but 34 of the 38 females were captured in turquoise (blue green) traps. The species to which the females were most attracted were *Cichorium intybus* (L., 1753) and *Knautia arvensis* (L., 1753). This observation led to a review of the sexes of the Dasypoda individuals captured in the riparian woody areas of this study and all 26 were female.

There are several families of plants mentioned above as preferred forage for *Dasypoda*: Asteraceae, Dipsacoceae, Cistaceae and Malvaceae. Asteraceae tend to be yellow and/or white, and as such this family would not differentiate *Dasypoda* from *Lasioglossum* or *Panurgus*. However, *Chicorum intybus*, a species of plant in the Asteraceae family mentioned by Heneberg and Bogusch (2014), is blue in colour and has been reported quite frequently during the month of June in the Sorraia valley (de Botânica, 2018). *Knautia arvensis* is a purple flowering perennial in the plant family Dipsacaceae, which favours light soils in moist areas, and is known to produce high levels of nectar. There are no entries for this species on Flora-On (de Botânica, 2018), but a similar plant in the same family, *Scabiosa atropurpurea* (L., 1753) is reported with moderate frequency in June in the Sorraia valley. Malvaceae and Cistaceae are families of plants that are commonly found in Portugal. Malvaceae are abundant in the Sorraia valley, with *Malvaceae sylvestris* (L., 1753) inflorescence peaking in June. This species of plant produces mauve flowers, which have a high blue component in their colour spectrum. There are no reports of the presence of Cistaceae in June in the Sorraia valley (de Botânica, 2018; Fonseca et al., 2021).

Dasypoda is another ground nesting bee genus according to Westrich (1996), with supporting evidence from subsequent studies of four particular species: *D. argentata* and *D. thoracica* (Baer, 1853; Celary, 2002), *D. braccata* (Eversmann, 1852; Radchenko, 1988), and *D. hirtipes* (Müller 1884; Vereecken et al. 2006; Loonstra 2010). Based on the information gathered from these species, it is thought that after mating, *Dasypoda* females initiate nest construction in sandy soil and then start to collect pollen. They place pollen balls in brood cells and lay an egg on the top. The larvae feed on the pollen ball and do not spin a cocoon. The nests are generally deep and can exceed 90 cm in depth (Celary 2002; Yang et al., 2010). Some species like *D. hirtipes* build their cells near the main gallery and make tripod-like structures below the pollen balls to reduce contact between the provisions and the cell wall (Müller 1884; Vereecken et al. 2006). Nesting sites that would support this type of nest building are abundant in the Sorraia valley and perhaps most present in riparian zones where levees have been created and disturbance is relatively low.

Oedemera was the most captured genus of pollinating Coleoptera in this study. It was most frequently captured in yellow and white pan traps in riparian woody areas. The species captured most often was *O. simplex* (L., 1767) (39 individuals identified), O. lurida (Marsham, 1802) was also identified (7 individuals). *Oedemera* have been relatively well studied in connection with their production of cantharidin, a toxic, blister producing compound. Still, little seems to have been published about their life cycle (Lencina et al., 2008; Ghoneim & Ghoneim, 2013).

Species in the genus *Oedemera* include slender, soft-bodied beetles of medium size, between 5 and 20 mm of length, like the example shown in Figure 16. Their colours may be bright and metallic (green, golden, copper), black and yellow and brown and black. The jaws are bifid at the apex, the last segment of maxillary palps is narrow and elongated, the antennae are long and threadlike. The elytra of most species are narrowed behind exposing part of the hind wings. The pronotum lacks lateral edges and is much narrower than the elytra. The tibiae have two apical spines, in most species the hind femora of males are strongly dilated. Figure 22 contains an image of a specimen of the genus *Oedemera*.

Figure 16: An image of *Oedemera simplex* (L., 1767). *O. simplex*, observed in Portugal by Daniela Costa (licensed under http://creativecommons.org/licenses/by-sa/4.0/).

Larvae of the species *O. lurida* develop in rotten wood or humus and feed on stems of herbaceous plants and on rotten wood, while adult beetles feed on pollen and nectar of a wide variety of flowers, especially of umbels, *Taraxacum* and *Ranunculus* flowers and hawthorns. They can mostly be encountered from April through July. The adult's body is covered with abundant pubescence on which pollen grains remain attached, thus they are likely to contribute to pollination of the plants they frequent (Zito et al., 2018). Species of the subgenus *Oncomera* fly at dusk and at night, visiting the flowers and inflorescences of aromatic shrubs and various plants (*Clematis*, *Crataegus*, *Tilia*, *Quercus*, etc.). By contrast, the species of the subgenus *Stenaxis* and true *Oedemera* (s. str.) are diurnal, flying in full sun in the middle of the day and visiting flowers of different families such as Apiaceae, Asteraceae and Cistaceae (Vázquez, 2002). As indicated earlier, Asteraceae are a dominant flowering herbaceous family in the area of the Sorraia valley. Apiaceae are abundant, but there are no records of Cistaceae.

Zito et al., (2018) studied *Oedemera* foraging on wild grapevines (*Vitis vinifera*, (L., 1753)) finding that they visited male vines more often than female vines, and that they dwelt longer on single flowers than bees, but that they still may perform a pollination role. Atanassova and Sivilov (2014), showed that *Oedemera* species feed on a wide range of pollens and honeydew, from trees like *Salix spp*. and shrubs like *Rubus spp*., to a number of herbaceous plant families including Asteraceae and Brassicaceae. *Salix spp.* are dominant in the remaining tree layer of the riparian zones of the river Sorraia, and in the underlying shrub layer *Rubus spp*. is dominant and *Vitis vinifera* is abundant in places (Fonseca et al., 2021).

Somewhat contradictorily, El Harche et al. (2021), sampled *coleoptera* in three stations with different habitats in Morocco, finding *O. simplex* to be present in bean (*Vicia faba,* L., 1753) and wheat fields (*Triticum aestivum,* L., 1753), but not in an undisturbed area (even though the diversity of beetle species was greatest there). They hypothesised this relative abundance could be due to the nature of the soil in the cultivated fields, but it could also have been influenced by the land cover.

On balance, it seems likely the relative abundance of *Oedemera* in riparian areas of the Sorraia valley is the result of the availability of woody vegetation like *Salix spp*. and shrubs like *Rubus spp*., in combination with adjacent herbaceous vegetation. As species of this genus are thought to lay their eggs in old wood and stems, woody riparian areas with adjacent herbaceous areas are likely to offer good support for their entire life cycle.

Anthaxia was the second most frequently captured genus of Coleoptera in this study. It was most often captured in yellow traps and from maize fields. Figure 17 is an image of *Anthaxia parallela* (Gory & Laporte, 1839) the species of *Anthaxia* most often identified to that level.

Figure 17: Anthaxia parallela, and example of the Anthaxia genus most often identified in this study. Anthaxia parallela Gory & Laporte, 1839, observed in Portugal by mariel98 (licensed under http://creativecommons.org/licenses/by-nc/4.0/).

Anthaxia is a genus of beetles in the family Buprestidae. It is a large genus with many species, few of which have detailed ecological descriptions. There is evidence that they are present and potentially quite abundant in Portugal (Arnáiz & Bercedo Páramo, 2010; GBIF, 2022). And a search for recent publications on *Anthaxia* provided the following information.

Karaman and Tezcan (1998) reported broadly on *Anthaxia* of Turkey, indicating that they are commonly found on flowering trees and herbs, with particular mention of trees in the genera *Salix*, *Fraxinus*, *Cornus*, *Malus* and *Prunus*; shrubs in the genera *Rosa* and *Rubus*, and herbs in the family Apiaceae. From the work of Karaman and Tezcan, it seems the adults lay their eggs on the bark of trees, with the larvae boring beneath the bark and into the wood. On reaching adulthood, *Anthaxia* forage on the immediately available flowering trees and shrubs, extending their foraging resources by dispersing across herbaceous areas, consuming and incidentally moving pollen from one flower to the next (Ghobari & Kalashian, 2016).

Bolu Özgen (2011) studied Buprestidae species in almond orchards in Turkey. Whilst the main focus of their study was the wood boring species of *Capnodis* (Eschscholtz, 1829) (because they damage the roots of cultivated stone fruits), *Anthaxia* were relatively abundant in their samples, confirming the importance of flowering trees to this species of insect. Whilst adult *Anthaxia* provide a pollination service, the larvae are considered a threat to fruit and nut trees in some cases (Gentry, 1965; EPPO, 2007). It is interesting to consider whether species like those in the genus Anthaxia are on balance beneficial to different agricultural systems because of their pollination service, or detrimental on the basis of their wood or stem boring larval stages.

Anthaxia seem to follow a similar life cycle to *Oedemera*, and as a result they are likely to have a dependency on woody areas for their larval stage. Their abundance in maize fields may be the result of a difference in the timing of their transformation to adulthood (it may precede that of the *Oedemera*) or that they have a greater preference for maize pollen. In either case, this difference in observed abundance may be worthy of further investigation.

The third most captured *Coleopteran* genera in this study was *Psilothrix* (Melyridae, Dasytinae) and the species identified most was *P. viridicoerulea* (Geoffroy, 1785), (36 individuals), along with a small number of *P. ilustris* (Wollaston, 1854), (3 individuals). An image of *P. viridicoerulea* is contained in Figure 18. In this study, Psilothrix were found most often in rice fields and in yellow traps.

Figure 18: Psilothrix viridicoerulea. Psilothrix viridicoerulea (Geoffroy, 1785), observed in Portugal by Thijs Valkenburg (licensed under http://creativecommons.org/licenses/by-nc/4.0/).

Barbir et al. (2015) studied the attractiveness of flowers to pollinators in central Spain, finding *Calendula arvensis* (L., 1753) to be highly attractive for *P. viridicoerulea*. *C. arvensis* is a member of the Asteraceae family of plants and produces yellow composite flowers between November and April in the region of the Sorraia valley (de Botânica, 2018).

Liberti (2009) reported on the Dasytidae (Coleoptera) of Sardinia, describing *P. viridicoerulea* as a relatively well-known species; still, there seem to be few articles published on the ecology of this insect. Fiori (1971) studied the larval stage and their report on the results has been cited by a number of others with little development on the original observations. The larvae initially feed on dead insects they find on the ground and, later, they become phytophagous and bore galleries in the stems of tall annual 'weeds' (*Ferula, Magydaris, Carlina, Cirsium* etc.), with a marrow of sufficient size to hold the fully grown larva. Metamorphosis takes place late in the Winter and the adults leave the pupal cell in early Spring by boring an oval hole in the stem walls (Liberti & Plonski, 2019).

It is possible that *Psilothrix* are viewed as pests given their potential for damage to rice stems, though they are not listed as such in literature encountered during this study. As with *Anthaxia*, this poses the question about the balance of pollination benefit adult *Psilothrix* provide versus any damage their larval stage may do. They are likely to be susceptible to pesticides used to control stink bugs (Insect Pests of Rice, 2016; Heinrichs, 2022), which may be increasingly used in areas like the Sorraia, now that stink bugs are recognised as an invasive threat in Portugal (Portugal News, 2019). This study did not include information about the use of pesticides or other agrochemicals in the Sorraia valley, and it would certainly be interesting to build such information into a future study.

3.3.3. Least Captured Genera

Whilst the most captured species indicate the features of the environment that have led to their success, it may also be important to consider the needs of pollinators that are captured infrequently, with the aim of increasing pollinator diversity as well as abundance.

Amongst the *Hymenoptera*, 1 individual was captured in each of the genera *Hylaeus*, *Osmia* and *Stelis*, 3 *Halictus* and *Eucera*, 5 *Colletes*, 9 *Ceratina* and 11 *Anthophora*. A high-level search of the literature regarding these genera suggests nesting resources may be at least as important for their success as foraging resources. In particular, species of *Hylaeus*, *Osmia* and *Ceratina* benefit from the availability of hollow stems in native reeds and holes in dead wood (Daly, 1983; Sedivy et al., 2013; Benton, 2017; Mikát et al., 2021), whilst *Eucera*, *Halictus*, *Colletes* and *Anthophora* tend to be ground nesting species for which mud or clay may be preferred. Indeed, some species in these genera are capable of sealing their nests with polymeric or waxy material that resists annual inundations (Hefetz et al., 1979, Carman and Packer, 1996; Shebl, 2016; Else, 2013). *Stelis* are cleptoparasitic and so depend on the successful nest building and provisioning of the other Hymenoptera species (Ascher & Pickering, 2017). These observations are worthy of more investigation, but even at this initial level of secondary research, they suggest an increased presence of native reeds like *Phragmatis australis* (Cavanilles, 1790) in place of the stands of invasive *Arundo donax* currently found (Bogusch et al., 2015) and less steep banks where alluvial deposits can build as a result of periods of high-water level would be important contributions to the landscape. In addition, there is an observation that *Eucera* tend to be an early flying pollinator and this start to the season is aided by the presence of species of Primulaceae (Benton, 2017).

Regarding the least captured coleoptera, no detailed investigation was attempted, as initial searches of the literature revealed little additional, useful information over and above that found for the most frequently captured species. For example, the genera *Anthocomus*, *Attalus* and *Lobonys* fall into the grouping of ‘soft-winged flower beetles’, like the genus *Oedemera*, and are likely to follow similar lifecycles and so have similar needs and offer similar contributions to the ecosystem.

3.3.4. Influence of Pan Trap Colour on Pollinator Assemblage

Pan traps were used to collect samples, as their efficiency and effectiveness has been widely recognised (Westphal et al., 2008; Boyer et al., 2020). They are easy to use, lack collector bias and can capture a good, standard measure of IPAD. However, pan traps may also be subject to biases; for example, they fail to attract all pollinating species and larger insects can escape them. For example, Boyer et al. (2020) reviewed the literature on netting and pan trap methodologies and performed their own study, finding netting to be more effective at capturing known pollinators of alfalfa belonging to the *Bombus* and *Apis* genera. Still, standard protocols using pan traps are easier to implement than those based on sweep netting.

In this study, yellow pan traps captured approximately twice as many pollinators as white or blue ones, and had a somewhat higher species richness. However, blue traps captured a slightly higher ratio of Hymenoptera to Coleoptera. And the Shannon-Wiener diversity index was similar for all three colours. This may be because the abundance of polylectic pollinators was very much higher than the number of oligolectic pollinators, overwhelming any significant difference between the results for each colour, and perhaps because the landscape is relatively homogeneous with the agricultural matrix dominating the landscape compared to the areal extent of riparian ecological infrastructure.

In NMDS, areas of species space representing each pan trap colour overlapped strongly, and though the use of all three colours did enlarge the area of species space covered, there might be an argument for focusing on yellow pan traps in a future study if effort in the field is limited and the highest possible number of pollinators per pan trap would be statistically beneficial.

Still, *Anthaxia*, *Lasioglossum*, *Panurgus* and *Psilothrix* were captured most frequently in yellow traps, whilst *Dasypoda* were captured most often in blue traps and *Oedemera* slightly more often in white traps than in yellow ones. These observations are consistent with the majority of publications related to the influence of pan trap colour on captured pollinators. For example, Buffington et al. (2021) used blue, white and yellow traps in their study, finding a significant difference between the pollinator species captured by yellow and white pan traps and those captured by blue traps. Yellow pan traps had the highest pollinator capture rate and exhibited the highest Shannon diversity index. This is thought to be because pollinators are attracted to objects reflecting light in the same frequency range as the flowers upon which they tend to forage, many of which are yellow. Yellow traps are likely to be at least equally effective as traps of other colours for polylectic species (those which forage on a wide range of flowering plants) whilst also attracting a significant number of oligolectic species (those that prefer a much-restricted range of flowering plants). Similarly, Gollan et al. (2011) found yellow pan traps captured a greater abundance and diversity of bees than white ones. The Halictidae family was by far the most highly represented in their samples and *Lasioglossum* was the most common genera, and also as found here, it was typically captured most often in yellow traps. Gollan et al. (2011) pointed out that some species captured by white traps were not present in yellow ones, and this is consistent with the differences in species captured between pan traps of different colours in this case study.

The species captured in different coloured pan traps is related to the environment in which they are placed since the floral assemblages differ, influencing the relative abundance and diversity of pollinators present. Interestingly, Gollan et al. confirmed pan traps can be used to look for differences between land cover types in a particular landscape and this observation has been supported by a number of other authors. For example, Saunders and Luck (2013) reported that yellow pan traps captured more Hymenoptera in monocultural fields and grasslands, whilst blue traps captured more in almond orchards. In the (savanna-like) areas in Chapada Diamantina, Bahia, Brazil, Moreira et al. (2016) found the species richness for blue and yellow traps to be similar and greater than that for white traps; and blue traps were most successful for bees. Pan traps of different colour showed low species composition overlap with 61 % of species collected exclusively in one of the three pan trap colours, and the species composition in the blue traps differed consistently from that in the traps of the other colours. Similar pan trap performance was reported by Campbell and Hanula (2007) for forested ecosystems. Pan traps captured a higher bee diversity relative to netting and each trap colour was more efficient at capturing certain bee genera. Acharya et al. (2021) studied bees in a livestock-pasture ecosystem and regarding pan trap colours concluding that blue traps exhibited the highest rates of bee capture, species accumulation and hence richness. Purple- and yellow-coloured traps were moderately effective in capturing bees, while the green colour pan traps were least effective. Again, greatest abundance was found for the genus *Lasioglossum*. Yellow traps were found to be more efficient in attracting a higher number and diversity of bees in open fields, riverside habitats, forests and roadside verges in Australia (Gollan et al., 2011). Overall pollinator abundance and diversity was also higher in yellow traps compared to white and blue traps in the Yellow River region of China (Wang et al., 2017). Blue pan traps have been reported to be highly effective at trapping bees in a variety of ecosystems, including fruit orchards (Joshi et al., 2015), savannas (Moreira et al., 2016), and forested ecosystems (Campbell & Hanula, 2007). This is consistent with the observation made here that certain species are found to be more abundant in woody riparian areas and that some of these may favour blue pan traps. Whether pan traps are fluorescent or non-fluorescent may also affect insect capture rates (Shrestha et al., 2019), and this points to the specificity the use of a pan trap colour in a particular range of the spectrum may have.

In addition to diversity measures, the sex ratios of bees in samples collected in pan traps may vary based on the colour of pan trap, and differences in colour preferences between males and females can vary among species (Leong & Thorp, 1999; Heneberg & Bogusch, 2014).

Unfortunately, clear flower species preferences are not reported for many and certainly not for every species of pollinator that may be of interest, and the topic of plant-pollinator associates is complex and recognised as a topic for which more studies are needed (Potts et al., 2020).

3.4. Learning From the Case Study

This case study provided baseline pollinator abundance and diversity data for any subsequent ecological restoration work in the Sorraia river valley, with 1129 pollinators in 113 species or morphotypes captured in 55 genera (Appendix 2), across 31 sites.

The use of pan traps in sampling was efficient for a study of this nature, covering a relatively large area with a range of land cover types. And though pan traps are not effective for the full pollinator assemblage their use here provided data that is consistent with that of other studies using this methodology. However, learning gained here suggests future studies could be designed with more statistical power.

This could involve more replicates, balanced numbers of traps across land cover types, more consideration to the risks to pan traps in the field, and complementary sampling techniques; if resources allow. If resources are very limited, it may be more beneficial to focus on priority sites (e.g., restored areas) and reduced sampling methodology e.g., to use yellow pan traps alone, as these sample the greatest abundance and diversity per trap. Scientifically, it would be extremely interesting to collect more precise data on the vegetation covering the land, and the abundance and quality of nest sites and nesting resources in restored and unrestored areas. The aim would be to understand exactly which restoration measures have most effect on IPAD in this type of river valley. A study of pollinator use of nest sites and resources would be highly complementary to any study methodology based on foraging behaviours, as this would help in understanding the relative contributions of forage and nesting to IPAD, and the impact of nesting on the evenness with which pollinators are found across the landscape.

The original hypothesis, that woody riparian areas would have a higher diversity than herbaceous riparian areas and croplands was not supported statistically, though there was evidence that certain genera of insect pollinators were more abundant in woody riparian areas. This difference in pollinator assemblage suggests ecological restoration of riparian woody zones would benefit diversity at a landscape level. Indeed, it seems likely some riparian areas are valuable reservoirs of diversity, from which insect pollinators disperse to repopulate crop fields after human disturbance in this type of agricultural landscape. An investigation of this theme could be important in justifying riparian restoration measures and could focus on the lifecycle behaviours of species most frequently found in the agricultural matrix in this study: *Anthaxia*, *Lasioglossum*, *Panurgus* and *Psilothrix*.

Identifying the genera most frequently captured, enabled focused searches of the literature giving quite specific information about the foraging and nesting needs of pollinators in the study area. For Hymenoptera, this may be associated with soil conditions for the digging of nests and their ability to rapidly colonise areas after disturbance, as much as the type of forage available within and at the margins of the fields. *Lasioglossum* seem particularly well suited to crop field conditions in agricultural areas like the Sorraia valley, on account of their polylectic nature and their production of multiple phases of workers during long hot Summers. It would be interesting to return to the agricultural matrix to assess the nesting habits and generation phases of *Lasioglossum* and *Panurgus* in these settings. Regarding the Coleoptera that were abundant in the fields, there is a question about the pollination benefit they provide compared to any damage their larvae may be causing, and this would be worthy of further investigation. And there is the question of the impact of agrochemicals on the pollinator community, which may be reducing IPAD in riparian areas as well as in the fields upon which they are targeted. Ideally, more organic, integrated pest management practices would be applied, with monitoring of the changes in the level of IPAD compared to current farming practices. A study designed to evaluate the relative benefits versus the costs of supporting species in the genera Anthaxia, Oedemera and Psilothrix through changes in the agricultural system could be highly informative.

Further, genera specific needs provide a basis for detailed plans for riparian zone and field margin interventions that would support IPAD. *Dasypoda* and *Oedemera*, were captured in greater numbers in riparian areas than in the agricultural matrix. For *Dasypoda*, the preference for riparian areas is probably the result of a combination of factors: their need for undisturbed, deep alluvial soils in which to dig their nests, and the presence of greater diversity of flowering plants, and particularly those with flowers in the blue part of the spectrum. It would be very interesting to return to sites where high numbers of *Dasypoda* were captured, in search of nest sites, to explore the idea that nesting needs are a significant factor related to their presence in riparian areas. And it is probably the presence of significant quantities of woody debris that supports the high numbers of *Oedemera*, as their larvae depend on this for food and shelter. In general, it is to be expected that riparian woody areas provide a cooling effect and help retain moisture levels, extending the period when plants are able to flower through the long, hot Summers that are typical of Mediterranean climatic regions, and this topic could also be worthy of further investigation.

Reflecting on the learning from the literature review of Section 2, and given that riparian areas in the Sorraia valley are significantly degraded by anthropogenic activities, (as indicated by the restricted width of the riparian zone, the invasion of *Arundo donax*, and the presence of *Acacia spp*.), there is real potential to improve on the abundance and diversity of pollinators in these areas and therefore across the landscape. Native species of perennial riparian vegetation are still present and restoration activities to increase their number at tree, shrub and herb levels would be beneficial. In particular, in line with a reference habitat of (ALFA, 2004), and the needs of the pollinator assemblage found in this study, trees in the genera *Salix* and *Populus*, along with *Fraxinus* and *Alnus* could be allowed to establish themselves further, building upon their existing presence (Fonseca et al., 2021). Shrubs in the genera *Prunus* and *Rosa* would be beneficial, alongside the *Rubus*, which is already relatively abundant. And the most valuable enhancement in the herbaceous layer would involve native species with a range of floral traits in the families: Asteraceae (e.g., *Andryala integrifolia*, *Cichorium intybus* and *Hypochaeris radicata*), Brassicaceae, Dipsacaceae (e.g., *Knautia arvensis* and *Scabiosa atropurpurea*), Cistaceae, Malvaceae and Primulaceae. Perhaps the most critical part of such a restoration project would be the removal and control of the invasive species of vegetation, specifically *Arundo donax*. And whilst chemical treatments like glyphosate could be used, this is likely to harm the river ecosystem and effort would need to be invested in mechanically removing *A. donax* stands below the rhizome level. This process could be doubly advantageous, as it would also provide a means of reducing the slope of river banks (which is often near vertical in the Sorraia valley), providing more slopes upon which native plant species could be established, and increasing the range of sites available for a more diverse set of pollinating insect species. Such moderation of bank slope would also increase the potential for periods of higher water flow to bring native plant species from less degraded areas upstream to establish themselves on the banks of the middle reaches, as part of natural dispersal or rewilding process. It is likely to be beneficial if *A. donax* were replaced by stands of *Phragmites australis*, which is native to the region, better suited to native pollinators that nest in reed stems, and has a greater range of synergistic ecosystem connections, as well as human uses.

4. Summary Conclusions and Suggested Future Work

On the whole, the goals listed in Section 1 seem to have been achieved and the summary conclusions and suggested future work are given below.

It is highly likely IPAD has been reduced and is still declining in Mediterranean climatic, agricultural river valleys like that of the Sorraia. This thesis provides evidence that considerable diversity remains in the pollinator assemblage of the Sorraia, though a relatively small number of genera dominate in terms of abundance. The types of conservation measure that would support IPAD in such regions can be clearly identified as, the ecological restoration of riparian zones (including the removal of invasive vegetation), more and better connected natural and semi-natural protected areas, better field margin management, reduced grazing intensity, and consideration of the impact of managed bees on wild pollinator populations.

The case study reported in this thesis supports the first three conservation measures listed above where the Sorraia and similar agricultural river valleys are concerned. And case studies like it can be used to identify specific, locally appropriate vegetation and landscape features that would support IPAD. However, it is imperative that consistent sampling methodologies are used if differences in, or changes in IPAD over time and space are to be confirmed with statistical confidence, and the EU Pollinators Initiative provides an excellent basis for this.

A number of intriguing observations have been made during the development of this thesis and these are listed below in the form of suggestions for potential future work:

a. Apply restoration measures in the Sorraia valley and monitor their impact of IPAD over time.
b. Test the hypothesis that pollinators disperse from riparian areas across crop fields after periods of disturbance.
c. Establish the potential for riparian areas to extend the flowering period and level of inflorescence during periods of drought.
d. Investigate the relative benefit of pollination by Coleoptera versus any adverse impact of their larvae on crop productivity.
e. Assess the effect of managed bee populations on the wild bee populations.
f. Explore the impact of agrochemical use on pollinators in agricultural river valleys.
g. Evaluate the relative importance of foraging and nesting resources in determining the pollinator assemblages in riparian areas and the agricultural matrix.

References – Main Text and Appendix 1

Abdullah, N. A., Radzi, S. N. F., Asri, L. N., Idris, N. S., Husin, S., Sulaiman, A., Khamis, S., Sulaiman, N., & Hazmi, I. R. (2019). Insect community in riparian zones of Sungai Sepetang, Sungai Rembau and Sungai Chukai of Peninsular Malaysia. *Biodiversity data journal*, *7*, e35679. https://doi.org/10.3897/BDJ.7.e35679

Abrol, D. P. (1989). Studies on abundance diversity, behaviour and importance of native pollinators for crop production. *Korean Journal of Apiculture*, *4*, 25-40.

Acharya, R.S., Leslie, T., Fitting, E., Burke, J., Loftin, K., Joshi, N.K. (2021). Colour of Pan Trap Influences Sampling of Bees in Livestock Pasture Ecosystem. *Biology*, *10*, 445. https://doi.org/10.3390/biology10050445

Affek, A. N., Regulska, E., Kolaczkowska, E., Kowalska, A., & Affek, K. (2021). Pollination Potential of Riparian Hardwood Forests-A Multifaceted Field-Based Assessment in the Vistula Valley, Poland. *Forests, 12(7)*, 907. https://doi.org/10.3390/f12070907

ALFA (2004). Tipos de Habitat Naturais e Semi-Naturais *do Anexo I da Directiva 92/43/CEE (Portugal continental): Fichas de Caracterização Ecológica e de Gestão para o Plano Sectorial da Rede Natura 2000*. Lisbon, PT: Associação Lusitana de Fitossociologia. Retrieved from http://www.icnf.pt/portal/naturaclas/rn2000/plan-set/hab-1a9. Accessed 10 March 2022.

Ali, S., Ullah, M. I., Sajjad, A., Shakeel, Q., & Hussain, A. (2021). Environmental and Health Effects of Pesticide Residues BT - Sustainable Agriculture Reviews 48: Pesticide Occurrence, Analysis and Remediation Vol. 2 Analysis (Eds. Inamuddin, M. I. Ahamed, & E. Lichtfouse); pp. 311–336). Springer International Publishing. https://doi.org/10.1007/978-3-030-54719-6_8

Alimpić, F., Milovanović, J., Pielech, R., Hinkov, G., Jansson, R., Dufour, S., Beza, M., Bilir, N., del Blanco, L. S., Božič, G., Bruno, D., Chiarabaglio, P. M., Doncheva, N., Gültekin, Y. S., Ivanković, M., Kelly-Quinn, M., La Porta, N., Nonić, M., Notivol, E. … Rodríguez-González, P. M. (2022). The status and role of genetic diversity of trees for the conservation and management of riparian ecosystems: A European experts' perspective. *Journal of Applied Ecology*, *59*, 2476– 2485. https://doi.org/10.1111/1365-2664.14247

Aparício, B. A., Nunes, J. P., Bernard-Jannin, L., Dias, L. F., Fonseca, A., & Ferreira, T. (2022). Modelling the role of ground-true riparian vegetation for providing regulating services in a Mediterranean watershed. *International Soil and Water Conservation Research*. Corrected proof, available online https://doi.org/10.1016/J.ISWCR.2022.07.005

Araújo, G. J., Fagundes, R., & Antonini, Y. (2018a). Trap-Nesting Hymenoptera and Their Network with Parasites in Recovered Riparian Forests Brazil. *Neotropical Entomology, 47(1)*, 26–36. https://doi.org/10.1007/s13744-017-0504-4

Araújo, G. J., Monteiro, G. F., Messias, M., & Antonini, Y. (2018b). Restore it, and they will come: trap-nesting bee and wasp communities (Hymenoptera: Aculeata) are recovered by restoration of riparian forests. *Journal of Insect Conservation, 22(2)*, 245–256. https://doi.org/10.1007/s10841-018-0058-8

Arnáiz Ruiz, L., & Bercedo Páramo, P. (2010). New data on Iberian Buprestidae III (Coleoptera). *Boletin de La SEA*, *46*, 561–563.

Ascher, J. S., & Pickering, J. (2017). *Discover life: bee species guide and world checklist (Hymenoptera: Apoidea: Anthophila*). Accessed 15th September 2022 from: http://www. discoverlife. org/mp/20q? guide= Apoidea_species&flags= HAS.

Ascher, J. S., Zestin, W. W., Shao, X. C., Eunice, J. Y., Benjamin, M. H., John, X. Q., ... & Xin, R. O. (2022). The bees of Singapore (Hymenoptera: Apoidea: Anthophila): first comprehensive country checklist and conservation assessment for a Southeast Asian bee fauna. *Raffles Bulletin of Zoolology*, *70*, 39-64. DOI: 10.26107/RBZ-2022-0004

Atanassova, J., & Sivilov, O. (2014). Pollen analysis of the crop contents of adult Oedemeridae (Coleoptera) in Bulgaria. *European Journal of Entomology*, *111*(4), 588–593. DOI: 10.14411/eje.2014.068

Atlas do Ambiente. Available online: http://www.iambiente.pt/atlas/ (accessed on 2 August 2021).

Bailey, S., Requier, F., Nusillard, B., Roberts, S. P. M., Potts, S. G., & Bouget, C. (2014). Distance from forest edge affects bee pollinators in oilseed rape fields. *Ecology and Evolution, 4(4)*, 370–380. https://doi.org/https://doi.org/10.1002/ece3.924

Bąk-Badowska, J., Wojciechowska, A., & Czerwik-Marcinkowska, J. (2021). Effects of open and forest habitats on distribution and diversity of Bumblebees (Bombus) in the Małopolska upland (Southern Poland): Case study. *Biology*, *10*(12), 1266.

Balasubramanian, M. (2019). Economic value of regulating ecosystem services: a comprehensive at the global level review. *Environmental Monitoring and Assessment*, *191*(10), 616. https://doi.org/10.1007/s10661-019-7758-8

Baldock, D., Wood, T.J., Cross, I., Smit, J. (2018). *The Bees of Portugal*. (Ed. Prof. Maximilian Schwarz.). Ansfelden, Austria: Prof. Maximilian Schwarz.

Barbir, J., Badenes-Pérez, F. R., Fernández-Quintanilla, C., & Dorado, J. (2015). The attractiveness of flowering herbaceous plants to bees (Hymenoptera: Apoidea) and hoverflies (Diptera: Syrphidae) in agro-ecosystems of Central Spain. *Agricultural and Forest Entomology*, *17*(1), 20–28. https://doi.org/https://doi.org/10.1111/afe.12076

Bartomeus, I., Vila, M., & Steffan-Dewenter, I. (2010). Combined effects of Impatiens glandulifera invasion and landscape structure on native plant pollination. *Journey of Ecology, 98(2)*, 440–450. https://doi.org/10.1111/j.1365-2745.2009.01629.x

Bartomeus, I., Ascher, J. S., Gibbs, J., Danforth, B. N., Wagner, D. L., Hedtke, S. M., & Winfree, R. (2013). Historical changes in northeastern US bee pollinators related to shared ecological traits. *Proceedings of the National Academy of Sciences*, *110*(12), 4656-4660. https://doi.org/10.1073/pnas.1218503110

Bartual, A.M., Bocci, G., Marini, S., & Moonen, A. C. (2018). Local and landscape factors affect sunflower pollination in a Mediterranean agroecosystem. *PloS One*, *13*(9), e0203990.

Bartual, A. M., Sutter, L., Bocci, G., Moonen, A.-C., Cresswell, J., Entling, M., Giffard, B., Jacot, K., Jeanneret, P., Holland, J., Pfister, S., Pintér, O., Veromann, E., Winkler, K., & Albrecht, M. (2019). The potential of different semi-natural habitats to sustain pollinators and natural enemies in European agricultural landscapes. *Agriculture, Ecosystems & Environment, 279*, 43–52. https://doi.org/https://doi.org/10.1016/j.agee.2019.04.009

Benelli, G., Benvenuti, S., Scaramozzino, P. L., & Canale, A. (2017). Food for honeybees? Pollinators and seed set of Anthyllis barba-jovis L. (Fabaceae) in arid coastal areas of the Mediterranean basin. *Saudi Journal of Biological Sciences, 24(5)*, 1056–1060. https://doi.org/https://doi.org/10.1016/j.sjbs.2017.01.018

Benton, T. (2017). *Solitary bees*. Exeter, UK: Pelagic Publishing Ltd.

Benvenuti, S., Benelli, G., Desneux, N., & Canale, A. (2016). Long lasting summer flowerings of Lythrum salicaria as honeybee-friendly flower spots in Mediterranean basin agricultural wetlands. *Aquatic Botany, 131*, 1–6. https://doi.org/https://doi.org/10.1016/j.aquabot.2016.02.002

Biesmeijer, C.J., Roberts, S.P.M., Reemer, M., Ohlemüller, R., Edwards, T., Peeters, P., Schaffers, A.P., Potts, S.G., Kleukers, R., D., Thomas, C.D., Settele, J., & E., Kunin, W. E. (2006). Parallel Declines in Pollinators and Insect-Pollinated Plants in Britain and the Netherlands. *Science, 313(5785)*, 351–354. https://doi.org/10.1126/science.1127863

Blitzer, E. J., Dormann, C. F., Holzschuh, A., Klein, A.-M., Rand, T. A., & Tscharntke, T. (2012). Spillover of functionally important organisms between managed and natural habitats. *Agriculture, Ecosystems & Environment, 146(1)*, 34–43. https://doi.org/https://doi.org/10.1016/j.agee.2011.09.005

Bogusch, P., Astapenková, A., & Heneberg, P. (2015). Larvae and nests of six aculeate Hymenoptera (Hymenoptera: Aculeata) nesting in reed galls induced by Lipara spp.(Diptera: Chloropidae) with a review of species recorded. *PloS one*, *10*(6), e0130802.

Bolu, H., & Özgen, İ. (2011). On the Buprestidae (Coleoptera) species of almond orchards in the Southeastern and Eastern Anatolia in Turkey. *Munis Entomology & Zoology*, *6*(2), 970–976.

Bourgeois, B., Vanasse, A., González, E., Andersen, R., & Poulin, M. (2016a). Threshold dynamics in plant succession after tree planting in agricultural riparian zones. *Journal of Applied Ecology, 53(6*), 1704–1713. https://doi.org/https://doi.org/10.1111/1365-2664.12675

Bourgeois, B., González, E., Vanasse, A., Aubin, I., & Poulin, M. (2016b). Spatial processes structuring riparian plant communities in agroecosystems: implications for restoration. *Ecological Applications, 26(7)*, 2103–2115. https://doi.org/https://doi.org/10.1890/15-1368.1

Bourgeois, B., Vanasse, A., Rivest, D., & Poulin, M. (2016c). Establishment success of trees planted in riparian buffer zones along an agricultural intensification gradient. *Agriculture, Ecosystems & Environment, 222*, 60–66. https://doi.org/https://doi.org/10.1016/j.agee.2016.01.013

Boustani, M., Rasmont, P., Dathe, H. H., Ghisbain, G., Kasparek, M., Michez, D., Müller, A., Pauly, A., Risch, S., Straka, J., Terzo, M., VAN Achter, X., Wood, T. J., & Nemer, N. (2021). The bees of Lebanon (Hymenoptera: Apoidea: Anthophila). *Zootaxa, 4976(1)*, 1146. https://doi.org/10.11646/zootaxa.4976.1.1

Boyer, K. J., Fragoso, F. P., Dieterich Mabin, M. E., & Brunet, J. (2020). Netting and pan traps fail to identify the pollinator guild of an agricultural crop. *Scientific reports*, *10*(1), 1-11. https://doi.org/10.1038/s41598-020-70518-9

Brito, T. F., Phifer, C. C., Knowlton, J. L., Fiser, C. M., Becker, N. M., C Barros, F., ... & Silva, D. P. (2017). Forest reserves and riparian corridors help maintain orchid bee (Hymenoptera: Euglossini) communities in oil palm plantations in Brazil. *Apidologie*, *48*(5), 575-587. https://doi.org/10.1007/s13592-017-0500-z

Brito, T. F., Contrera, F. A., Phifer, C. C., Knowlton, J. L., Brasil, L. S., Maués, M. M., & Silva, D. P. (2018). Effects of habitat type change on taxonomic and functional composition of orchid bees (Apidae: Euglossini) in the Brazilian Amazon. *Journal of insect conservation*, *22*(3), 451-463. https://doi.org/10.1007/s10841-018-0073-9

Brousil, M., Humann, C., & Fischer, D. (2015). Plant-pollinator interactions in a Northwest arum related to plant traits but not riparian forest management. *Northwest Science*, *89*(3), 297-307.

Buffington, M. L., Garretson, A., Kula, R. R., Gates, M. W., Carpenter, R., Smith, D. R., & Kula, A. A. R. (2021). Pan trap color preference across Hymenoptera in a forest clearing. *Entomologia Experimentalis et Applicata*, *169*(3), 298–311.

Burkle, L. A., Marlin, J. C., & Knight, T. M. (2013). Plant-pollinator interactions over 120 years: loss of species, co-occurrence, and function. *Science*, *339*(6127), 1611-1615. https://doi.org/10.1126/science.1232728

Calleja, J. A., Escolà, M., Carvalho, J., Forcadell, J. M., Serrano, E., & Bartolomé, J. (2019). Cattle Grazing Fails to Control Shrub Encroachment in Mediterranean Landscapes. *Rangeland Ecology & Management, 72*(5), 803–811. https://doi.org/https://doi.org/10.1016/j.rama.2019.04.005

Cameron, S.A., Lozier J.D., Strange, J.P., Koch, J.B., Cordes, N., Solter, L.F., Griswold, T. L. (2011). Patterns of widespread decline in North American bumble bees. *Proceedings of the National Academy of Sciences, 108*(2), 662–667. https://doi.org/10.1073/pnas.1014743108

Campbell, J.W., Hanula, J.L. Efficiency of Malaise traps and colored pan traps for collecting flower visiting insects from three forested ecosystems. *Journal of Insect Conservation 11*, 399–408 (2007). https://doi.org/10.1007/s10841-006-9055-4

Canale, A., Benvenuti, S., Raspi, A., & Benelli, G. (2016). Insect pollinators of the late winter flowering Rhamnus alaternus L., a candidate for honeybee-friendly scrubland spots in intensively managed agricultural areas. *Plant Biosystems - An International Journal Dealing with All Aspects of Plant Biology, 150*(4), 611–615. https://doi.org/10.1080/11263504.2014.993742

Cândido, M. E. M. B., Miranda, P. N., & Morato, E. F. (2021). Orchid bees in riparian and terra-firme forest fragments in an urban matrix in southwestern Brazilian Amazonia. *Acta Amazonica*, *51*, 214-223. https://doi.org/10.1590/1809-4392202003781

Cane, J. H. (1991). Soils of Ground-Nesting Bees (Hymenoptera: Apoidea): Texture, Moisture, Cell Depth and Climate. *Journal of the Kansas Entomological Society*, *64*(4), 406–413. http://www.jstor.org/stable/25085307

Carman, G. M., & Packer, L. (1996). A Cryptic Species Allied to Halictus ligatus Say (Hymenoptera: Halictidae) Detected by Allozyme Electrophoresis. *Journal of the Kansas Entomological Society*, *69*(4), 168–176. http://www.jstor.org/stable/25085714

Carvalheiro, L. G., Kunin, W. E., Keil, P., Aguirre-Gutiérrez, J., Ellis, W. N., Fox, R., & Biesmeijer, J. C. (2013). Species richness declines and biotic homogenisation have slowed down for NW-European pollinators and plants. *Ecology Letters, 16*, 870–878. https://doi.org/https://doi.org/10.1111/ele.12121

Celary, W. (2002). The ground-nesting solitary bee, Dasypoda thoracica Baer, 1853 (Hymenoptera: Apoidea: Melittidae) and its life history. *Folia Biologica-Krakow*, *50*, 191–198.

Chao, A., & Shen, T.-J. (2004). Nonparametric prediction in species sampling. *Journal of Agricultural, Biological, and Environmental Statistics*, *9*(3), 253–269. https://doi.org/10.1198/108571104X3262

Clemente, M. A., Campos, N. R., Vieira, K. M., Del-Claro, K., & Prezoto, F. (2017). Social wasp guild (Hymenoptera: Vespidae) visiting flowers in two of the phytophysiognomic formations: Riparian Forest and campos rupestres. *Sociobiology, 64*(2), 217–224. https://doi.org/10.13102/sociobiology.v64i2.1364

Clemente, M. A., Guevara, R., Moleiro, H. R., Silveira, O. T., & Giannotti, E. (2020). Community Structure and Composition of Social Wasps (Hymenoptera: Vespidae) in Different Vegetation Types in Sao Paulo, Brazil. *Sociobiology, 67*(3), 449–461. https://doi.org/10.13102/sociobiology.v67i3.5444

Clerici, N., Weissteiner, C. J., Paracchini, M. L., Boschetti, L., Baraldi, A., & Strobl, P. (2013). Pan-European distribution modelling of stream riparian zones based on multi-source Earth Observation data. *Ecological Indicators, 24*, 211–223. https://doi.org/https://doi.org/10.1016/j.ecolind.2012.06.002

Cole, L. J., Brocklehurst, S., Elston, D. A., & McCracken, D. I. (2012). Riparian field margins: can they enhance the functional structure of ground beetle (Coleoptera: Carabidae) assemblages in intensively managed grassland landscapes? *Journal of Applied Ecology, 49*(6), 1384–1395. https://doi.org/10.1111/j.1365-2664.2012.02200.x

Cole, L. J., Brocklehurst, S., Robertson, D., Harrison, W., McCracken, D. I., Fonseca, A., Zina, V., Duarte, G., Aguiar, F. C., Rodríguez-González, P. M., Ferreira, M. T., Fernandes, M. R., Cole, L. J., Stockan, J., Helliwell, R., … Fischer, D. (2015a). Managing riparian buffer strips to optimise ecosystem services: A review. *Agriculture, Ecosystems & Environment, 89*(19), 656–666. https://doi.org/10.3390/su131910508

Cole, L. J., Brocklehurst, S., Robertson, D., Harrison, W., & McCracken, D. I. (2015b). Riparian buffer strips: Their role in the conservation of insect pollinators in intensive grassland systems. *Agriculture, Ecosystems & Environment, 211*, 207–220. https://doi.org/https://doi.org/10.1016/j.agee.2015.06.012

Cole, L. J., Brocklehurst, S., Robertson, D., Harrison, W., & McCracken, D. I. (2017). Exploring the interactions between resource availability and the utilisation of semi-natural habitats by insect pollinators in an intensive agricultural landscape. *Agriculture, Ecosystems & Environment*, *246*, 157–167. https://doi.org/https://doi.org/10.1016/j.agee.2017.05.007

Cole, J. S., Siegel, R. B., Loffland, H. L., Elsey, E. A., Tingley, M. B., & Johnson, M. (2020a). Plant Selection by Bumble Bees (Hymenoptera: Apidae) in Montane Riparian Habitat of California. *Environmental Ecology, 49*(1), 220–229. https://doi.org/10.1093/ee/nvz159

Cole, L. J., Kleijn, D., Dicks, L. V, Stout, J. C., Potts, S. G., Albrecht, M., Balzan, M. V, Bartomeus, I., Bebeli, P. J., Bevk, D., Biesmeijer, J. C., Chlebo, R., Dautartė, A., Emmanouil, N., Hartfield, C., Holland, J. M., Holzschuh, A., Knoben, N. T. J., Kovács-Hostyánszki, A., & Mandelik, Y. (2020b). A critical analysis of the potential for EU Common Agricultural Policy measures to support wild pollinators on farmland. *Journal of Applied Ecology, 57*(4), 681–694. https://doi.org/10.1111/1365-2664.13572

Cole, L. J., Baddeley, J. A., Robertson, D., Topp, C. F. E., Walker, R. L., & Watson, C. A. (2022). Supporting wild pollinators in agricultural landscapes through targeted legume mixtures. *Agriculture, Ecosystems & Environment, 323*, 107648. https://doi.org/https://doi.org/10.1016/j.agee.2021.107648

Colom, P., Traveset, A., & Stefanescu, C. (2021). Long-term effects of abandonment and restoration of Mediterranean meadows on butterfly-plant interactions. *Journal of Insect Conservation*, *25*(3), 383-393. https://doi.org/10.1007/s10841-021-00307-w

Corenblit, D., Baas, A., Balke, T., Bouma, T., Fromard, F., Garófano-Gómez, V., González, E., Gurnell, A. M., Hortobágyi, B., & Julien, F. (2015). Engineer pioneer plants respond to and affect geomorphic constraints similarly along water–terrestrial interfaces world-wide. *Global Ecology and Biogeography, 24*(12), 1363–1376.

Cortés-Fernández, I., Cerrato, M. D., Ribas-Serra, A., & Gil Vives, L. (2022). Floral traits and reproductive success variation among inflorescence orders in Eryngium maritimum. *Plant Biology, 24*(2), 249–258. https://doi.org/https://doi.org/10.1111/plb.13354

Cowling, R. M., Rundel, P. W., Lamont, B. B., Kalin Arroyo, M., & Arianoutsou, M. (1996). Plant diversity in mediterranean-climate regions. *Trends in Ecology & Evolution*, *11*(9), 362–366. https://doi.org/https://doi.org/10.1016/0169-5347(96)10044-6

Dainese, M., Montecchiari, S., Sitzia, T., Sigura, M., & Marini, L. (2017). High cover of hedgerows in the landscape supports multiple ecosystem services in Mediterranean cereal fields. *Journal of Applied Ecology, 54*(2), 380–388. https://doi.org/10.1111/1365-2664.12747

Daly, H. V. (1983). Taxonomy and ecology of ceratinini of North Africa and the Iberian Peninsula (Hymenoptera: Apoidea). *Systematic Entomology*, *8*(1), 29–62.

Danforth, B. N., Minckley, R. L., Neff, J. L., & Fawcett, F. (2019). *The solitary bees: biology, evolution, conservation*. Princeton & Oxford: Princeton University Press.

Davis, E. S., Kelly, R., Maggs, C. A., & Stout, J. C. (2018). Contrasting impacts of highly invasive plant species on flower-visiting insect communities. *Biodiversity and Conservation, 27*(8), 2069–2085. https://doi.org/10.1007/s10531-018-1525-y

de Botânica, S. P. (2018). Flora-On: Flora de Portugal Interactiva. Sociedade Portuguesa de Botânica. Retrieved 18th July 2022 from: www.flora-on.pt.

del Portillo, D. G., Arroyo, B., & Morales, M. B. (2022). The adequacy of alfalfa crops as an Agri-Environmental Scheme: a review of agronomic benefits and effects on biodiversity. *Journal for Nature Conservation 69*, 126253. https://doi.org/10.1016/j.jnc.2022.126253

Dharampal, P. S., Danforth, B. N., & Steffan, S. A. (2022). Exosymbiotic microbes within fermented pollen provisions are as important for the development of solitary bees as the pollen itself. *Ecology and Evolution, 12*(4), e8788. https://doi.org/https://doi.org/10.1002/ece3.8788

Dharampal, P., Carlson, C., Currie, C., & Steffan, S. (2019). Pollen-borne microbes shape bee fitness. *Proceedings of the Royal Society B: Biological Sciences, 286*, 20182894. https://doi.org/10.1098/rspb.2018.2894

Dikmen, F. (2007). The role and the importance of the family Halictidae (Apiformes: Apoidea) in pollination of natural and agricultural vegetation. *Mellifera*, *7*(13-14), 16-19. Retrieved 1st September 2022 from: https://search.ebscohost.com/login.aspx?direct=true&db=asn&AN=36935191&lang=pt-pt&site=ehost-live&scope=site

Dunn, O. J. (1964). Multiple Comparisons Using Rank Sums. *Technometrics*, *6*(3), 241–252. https://doi.org/10.1080/00401706.1964.10490181

Dupont, Y. L., Damgaard, C., & Simonsen, V. (2011). Quantitative historical change in bumblebee (Bombus spp.) assemblages of red clover fields. *PloS one*, *6*(9), e25172. https://doi.org/10.1371/journal.pone.0025172

Edwards, R., & Telfer, M.G. (eds.) (2001). *Provisional atlas of the aculeate Hymenoptera of Britain and Ireland. Part 3*. Huntingdon, UK: Biological Records Centre.

El Abdouni I, Lhomme P, Hamroud L, Wood T, Christmann S, Rasmont P, Michez D (2021) Comparative ecology of two specialist bees: Dasypoda visnaga Rossi, 1790 and Dasypoda maura Pérez, 1895 (Hymenoptera, Melittidae). *Journal of Hymenoptera Research 81*: 109–126. https://doi.org/10.3897/jhr.81.60528

El Harche, H., Fegrouch, R., Chavanon, G., Ghailoul, D., Benhoussa, A., Arahou, M., & Fadli, M. (2021). Comparison of Terrestrial Beetles in Cultivated and Natural Biotopes of Semi-Arid Region of Morocco. *Indian Journal of Ecology*, *48*(4), 1184–1190.

Ellis, J. D., Evans, J. D., & Pettis, J. (2010). Colony losses, managed colony population decline, and Colony Collapse Disorder in the United States. *Journal of Apicultural Research, 49*(1), 134–136. https://doi.org/10.3896/IBRA.1.49.1.30

Else, G.R. (2013). Bees, Wasps & Ants Recording Society, 2013. Anthophora plumipes. Retrieved 1st January 2013 from: http://www.bwars.com/index.php?q=bee/apidae/anthophora-plumipes.

Emery, S. M., & Doran, P. J. (2013). Presence and management of the invasive plant Gypsophila paniculata (baby's breath) on sand dunes alters arthropod abundance and community structure. *Biological Conservation, 161*, 174–181. https://doi.org/10.1016/j.biocon.2013.03.015

EPPO, 2007. Forest pests on the territories of the former USSR. Retrieved 1st March 2022 from: https://www.eppo.int/media/uploaded_images/RESOURCES/special_projects/forestry_pests/EPPOforestry_project.pdf

EU. (2013). Guidance on the risk assessment of plant protection products on bees (Apis mellifera, Bombus spp. and solitary bees). *EFSA Journal*, *11*(7), 3295. https://doi.org/https://doi.org/10.2903/j.efsa.2013.3295

EU. (1992). Council Directive 92/43/EEC of 21 May 1992. The conservation of natural habitats and of wild fauna and flora. *Official Journal of the European Union*, *206*, 7-50. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31992L0043

EU. (2000). Council Directive 2000/60/EC of 23 October 2000. Establishing a Framework for Community Action in the Field of Water Policy. *Official Journal of the European Union*, *327,* 1-73. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0060

EU. (2022). Integrated Pest Management. Retrieved 1st September 2022 from: https://food.ec.europa.eu/plants/pesticides/sustainable-use-pesticides/integrated-pest-management-ipm_en

Eversmann, E. V. (1852). Fauna hymenopterologica volgo-uralensis. *Bulletin Moscou*, *25*(2), 3. Retrieved 20th September from: https://digitalcommons.usu.edu/bee_lab_er/177

Falk, S. (2016). *Field Guide to the Bees of Great Britain and Ireland*. London, England: Bloomsbury Publishing.

Faria, N., & Morales, M. B. (2022). Linking entomofauna and farmland management to enhance ecosystem services in Mediterranean drylands. *Annals of Applied Biology, 180*(3), 407– 418. https://doi.org/10.1111/aab.12741

Fernandes, M. R., Aguiar, F. C., & Ferreira, M. T. (2011). Assessing riparian vegetation structure and the influence of land use using landscape metrics and geostatistical tools. *Landscape and Urban Planning*, *99*(2), 166-177. https://doi.org/10.1016/j.landurbplan.2010.11.001

Fernández, J. D., & Gómez, J. M. (2012). Advantages and drawbacks of living in protected areas: The case of the threatened Erysimum popovii (Brassicaceae) in SE Iberian Peninsula. *Biodiversity and Conservation*, *21*(10), 2539-2554. https://doi.org/10.1007/s10531-012-0316-0

Fijen, T. P., Scheper, J. A., Boekelo, B., Raemakers, I., & Kleijn, D. (2019). Effects of landscape complexity on pollinators are moderated by pollinators' association with mass-flowering crops. *Proceedings of the Royal Society B*, *286*(1900), 20190387. https://doi.org/http://doi.org/10.1098/rspb.2019.0387

Fiori, G. (1971). Contributi alla conoscenza morfologica ed etologica dei Coleotteri. IX. *Psilothrix viridicaeruleus* (Geoffr.) (Melyridae, Dasytinae). *"Studi Sassaresi" Sez. III. Annali Della Facolta di Agraria Dell'Universiti di Sassari*, *19*, 2– 70.

Fonseca, A., Zina, V., Duarte, G., Aguiar, F. C., Rodríguez-González, P. M., Ferreira, M. T., & Fernandes, M. R. (2021). Riparian Ecological Infrastructures: Potential for Biodiversity-Related Ecosystem Services in Mediterranean Human-Dominated Landscapes. *Sustainability*, *13*(19), 10508. https://doi.org/10.3390/su131910508

Freimuth, J., Bossdorf, O., Scheepens, J. F., & Willems, F. M. (2022). Climate warming changes synchrony of plants and pollinators. *Proceedings of the Royal Society B, 289*(1971), 20212142.

Gallai, N., Salles, J.-M., Settele, J., Vaissière, B. E. (2009). Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological Economics*, *68*(3), 810–821. https://doi.org/https://doi.org/10.1016/j.ecolecon.2008.06.014

Garibaldi, L. A., Steffan-Dewenter, I., Winfree, R., Aizen, M. A., Bommarco, R., Cunningham, S. A., Kremen, C., Carvalheiro, L. G., Harder, L. D., Afik, O., Bartomeus, I., Benjamin, F., Boreux, V., Cariveau, D., Chacoff, N. P., Dudenhöffer, J. H., Freitas, B. M., Ghazoul, J., Greenleaf, S., … Klein, A. M. (2013). Wild Pollinators Enhance Fruit Set of Crops Regardless of Honey Bee Abundance. *Science, 339*(6127), 1608–1611. https://doi.org/10.1126/science.1230200

Garibaldi, L. A., Carvalheiro, L. G., Leonhardt, S. D., Aizen, M. A., Blaauw, B. R., Isaacs, R., Kuhlmann, M., Kleijn, D., Klein, A. M., Kremen, C., Morandin, L., Scheper, J., & Winfree, R. (2014). From research to action: enhancing crop yield through wild pollinators. *Frontiers in Ecology and the Environment, 12*(8), 439–447. https://doi.org/10.1890/130330

Garibaldi, L. A., Requier, F., Rollin, O., & Andersson, G. K. S. (2017). Towards an integrated species and habitat management of crop pollination. *Current Opinion in Insect Science*, *21*, 105–114. https://doi.org/https://doi.org/10.1016/j.cois.2017.05.016

Garrido, P., Marell, A., Ockinger, E., Skarin, A., Jansson, A., & Thulin, C. G. (2019). Experimental rewilding enhances grassland functional composition and pollinator habitat use. *Journal of Applied Ecology, 56*(4), 946–955. https://doi.org/10.1111/1365-2664.13338

Gathmann, A., & Tscharntke, T. (2002). Foraging ranges of solitary bees. *Journal of Animal Ecology*, *71*(5), 757–764. https://doi.org/https://doi.org/10.1046/j.1365-2656.2002.00641.x

GBIF. (2022). Anthaxia Eschscholtz, 1829 in *GBIF Secretariat. GBIF Backbone Taxonomy*. Checklist dataset https://doi.org/10.15468/39omei accessed via GBIF.org on 2023-01-02.

Geiger, F., Bengtsson, J., Berendse, F., Weisser, W. W., Emmerson, M., Morales, M. B., Ceryngier, P., Liira, J., Tscharntke, T., Winqvist, C., Eggers, S., Bommarco, R., Pärt, T., Bretagnolle, V., Plantegenest, M., Clement, L. W., Dennis, C., Palmer, C., Oñate, J. J., … Inchausti, P. (2010). Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. *Basic and Applied Ecology, 11*(2), 97–105. https://doi.org/https://doi.org/10.1016/j.baae.2009.12.001

Gentry, J.W., (1965). *Crop insects of northeast Africa-southwest Asia* (No. 273). Agricultural Research Service, US Department of Agriculture. Washington, D.C.: U.S. Government Printing Office.

Ghazoul, J. (2005). Buzziness as usual? Questioning the global pollination crisis. *Trends in Ecology & Evolution, 20*(7), 367–373. https://doi.org/https://doi.org/10.1016/j.tree.2005.04.026

Ghobari, H., & Kalashian, M. (2016). Contribution to the knowledge of the jewel beetles (Coleoptera: Buprestidae) fauna of Kurdistan Province (Iran), Subfamilies Buprestinae and Agrilinae. *Iranian Journal of Animal Biosystematics*, *12*(2), 157-166. DOI: 10.22067/ijab.v12i2.54867

Ghoneim, K. S., & Ghoneim, K. S. (2013). Human dermatosis caused by vesicating beetle products (Insecta), cantharidin and paederin: An overview. *World J Med Med Sci*, *1*(1), 1–26.

Glenny, W., Runyon, J., Burkle, L. (2022). *Assessing pollinator friendliness of plants and designing mixes to restore habitat for bees*. Gen. Tech. Rep. RMRSGTR-429. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Retrieved 10th September 2022 from: https://doi.org/https://doi.org/10.2737/RMRS-GTR-429

Gollan, J.R., Ashcroft, M.B. & Batley, M. (2011), Comparison of yellow and white pan traps in surveys of bee fauna in New South Wales, Australia (Hymenoptera: Apoidea: Anthophila). *Australian Journal of Entomology, 50*: 174-178. https://doi.org/10.1111/j.1440-6055.2010.00797.x

Gómez, J. M., Abdelaziz, M., Lorite, J., Jesús Muñoz-Pajares, A., & Perfectti, F. (2010). Changes in pollinator fauna cause spatial variation in pollen limitation. *Journal of Ecology*, *98*(5), 1243–1252. https://doi.org/https://doi.org/10.1111/j.1365-2745.2010.01691.x

González, E., Felipe-Lucia, M. R., Bourgeois, B., Boz, B., Nilsson, C., Palmer, G., & Sher, A. A. (2017). Integrative conservation of riparian zones. *Biological Conservation, 211*, 20–29. https://doi.org/https://doi.org/10.1016/j.biocon.2016.10.035

Goulet, H., & Huber, J. (Eds.) (1993). *Hymenoptera of the World: An Identification Guide to Families.* Ottawa, Ontario (Canada), Agriculture Canada.

Goulson, D., Lye, G. C., & Darvill, B. (2008). Decline and Conservation of Bumble Bees. *Annual Review of Entomology, 53*(1), 191–208. https://doi.org/10.1146/annurev.ento.53.103106.093454

Goulson, D., Nicholls, E., & Botías, C.L., Ellen, R. (2015). Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science, 347*(6229), 1255957. https://doi.org/10.1126/science.1255957

Greenleaf, S. S., Williams, N. M., Winfree, R., & Kremen, C. (2007). Bee foraging ranges and their relationship to body size. *Oecologia, 153*(3), 589–596. https://doi.org/10.1007/s00442-007-0752-9

Griffin, S. R., Bruninga-Socolar, B., & Gibbs, J. (2021). Bee communities in restored prairies are structured by landscape and management, not local floral resources. *Basic and Applied Ecology, 50*, 144–154. https://doi.org/https://doi.org/10.1016/j.baae.2020.12.004

Grundel, R., Jean, R. P., Frohnapple, K. J., Glowacki, G. A., Scott, P. E., & Pavlovic, N. B. (2010). Floral and nesting resources, habitat structure, and fire influence bee distribution across an open-forest gradient. *Ecological Applications, 20*(6), 1678–1692. https://doi.org/https://doi.org/10.1890/08-1792.1

Hallmann, C. A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., ... & de Kroon, H. (2017). More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PloS one*, *12*(10), e0185809.

Hanula, J. L., & Horn, S. (2011). Removing an invasive shrub (Chinese privet) increases native bee diversity and abundance in riparian forests of the southeastern United States. *Insect Conservation and Diversity, 4*(4), 275–283. https://doi.org/10.1111/j.1752-4598.2011.00131.x

Hanula, J. L., Horn, S., & O'Brien, J. J. (2015). Have changing forests conditions contributed to pollinator decline in the southeastern United States? *Forest Ecology and Management, 348*, 142–152. https://doi.org/10.1016/j.foreco.2015.03.

Hanula, J. L., Ulyshen, M. D., & Horn, S. (2016). Conserving Pollinators in North American Forests: A Review. *Natural Areas Journal, 36*(4), 427–439. https://doi.org/10.3375/043.036.0409

Harrison, P. A., Vandewalle, M., Sykes, M. T., Berry, P. M., Bugter, R., de Bello, F., Feld, C. K., Grandin, U., Harrington, R., Haslett, J. R., Jongman, R. H. G., Luck, G. W., da Silva, P. M., Moora, M., Settele, J., Sousa, J. P., & Zobel, M. (2010). Identifying and prioritising services in European terrestrial and freshwater ecosystems. *Biodiversity and Conservation*, *19*(10), 2791–2821. https://doi.org/10.1007/s10531-010-9789-x

Hefetz, A., Fales, H. M., & Batra, S. W. T. (1979). Natural Polyesters: Dufour's Gland Macrocyclic Lactones Form Brood Cell Laminesters in Colletes Bees. *Science*, *204*(4391), 415–417. https://doi.org/10.1126/science.204.4391.415

Heinrichs, E.A., (2022). Maize Insect Pests in North America. In *Radcliffe's IPM World Textbook.* E.B. Radcliffe, W.D. Hutchison & R.E. Cancelado [eds.]. St. Paul, Minnesota: University of Minnesota. URL: https://ipmworld.umn.edu,

Heneberg, P., & Bogusch, P. (2014). To enrich or not to enrich? Are there any benefits of using multiple colors of pan traps when sampling aculeate Hymenoptera? *Journal of Insect Conservation. 18*, 1123–1136. https://doi.org/10.1007/s10841-014-9723-8

Herrera, A. M., & Dudley, T. L. (2003). Reduction of riparian arthropod abundance and diversity as a consequence of giant reed (Arundo donax) invasion. *Biological Invasions*, *5*(3), 167–177. https://doi.org/10.1023/A:1026190115521

Herrera, C. M. (1987). Components of Pollinator "Quality": Comparative Analysis of a Diverse Insect Assemblage. *Oikos, 50*(1), 79–90. https://doi.org/10.2307/3565403

Herrera, C. M. (1988). Variation in mutualisms: the spatiotemporal mosaic of a pollinator assemblage. *Biological Journal of the Linnean Society, 35*(2), 95–125. https://doi.org/10.1111/j.1095-8312.1988.tb00461.x

Herrera, C. M. (1989). Pollinator abundance, morphology, and flower visitation rate: analysis of the "quantity" component in a plant-pollinator system. *Oecologia, 80*(2), 241–248. https://doi.org/10.1007/BF00380158

Herrera, C. M. (2019). Complex long-term dynamics of pollinator abundance in undisturbed Mediterranean montane habitats over two decades. *Ecological Monographs, 89*(1), e01338. https://doi.org/10.1002/ecm.1338

Herrera, C. M. (2020). Gradual replacement of wild bees by honeybees in flowers of the Mediterranean Basin over the last 50 years. *Proceedings of the Royal Society B: Biological Sciences, 287*(1921), 20192657. https://doi.org/10.1098/rspb.2019.2657

Hines, H.M. & Hendrix, S.D. (2005) Bumble bee (Hymenoptera: Apidae) diversity and abundance in tallgrass prairie patches: Effects of local and landscape floral resources. *Environmental Entomology 34*, 1477–1484.

Hornigold, K. (Ed.) (2022). *Wood Wise: Trees for water*. Grantham, UK: The Woodland Trust.

Hudson, J. R., Hanula, J. L., & Horn, S. (2013). Removing Chinese privet from riparian forests still benefits pollinators five years later. *Biological Conservation, 167*, 355–362. https://doi.org/https://doi.org/10.1016/j.biocon.2013.09.001

Insect Pests of Rice. (2016). Texas A&M AgriLIFE Research Centre at Beaumont. Retrieved 10th Sep. 2022 from: https://beaumont.tamu.edu/eLibrary/StudyRiceContest/2017/5.pdf

Johansen, K., & Phinn, S. (2006). Linking riparian vegetation spatial structure in Australian tropical savannas to ecosystem health indicators: Semi-variogram analysis of high spatial resolution satellite imagery. *Cananadian Journal of Remote Sensing, 32*(3), 228–243.

Joshi, N. K., Leslie, T., Rajotte, E. G., Kammerer, M. A., Otieno, M., & Biddinger, D. J. (2015). Comparative Trapping Efficiency to Characterize Bee Abundance, Diversity, and Community Composition in Apple Orchards. *Annals of the Entomological Society of America*, *108*(5), 785–799. https://doi.org/10.1093/aesa/sav057

Kaloveloni, A., Tscheulin, T., Vujic, A., Radenkovic, S., & Petanidou, T. (2015). Winners and losers of climate change for the genus Merodon (Diptera: Syrphidae) across the Balkan Peninsula. *Ecological Modelling, 313*, 201–211. https://doi.org/10.1016/j.ecolmodel.2015.06.032

Karaman, S., & Tezcan, S. (1998). Contribution to the study of the genus Anthaxia (subgenus Anthaxia s. str.) Eschscholtz, 1829 (Coleoptera, Buprestidae) of Turkey. *Türkiye Entomoloji Dergisi*, *22*(1), 19–35.

Keesing, F., Belden, L. K., Daszak, P., Dobson, A., Harvell, C. D., Holt, R. D., Hudson, P., Jolles, A., Jones, K. E., Mitchell, C. E., Myers, S. S., Bogich, T., & Ostfeld, R. S. (2010). Impacts of biodiversity on the emergence and transmission of infectious diseases. *Nature, 468*(7324), 647–652. https://doi.org/10.1038/nature09575

Kehinde, T., Wehrden, H., Samways, M., Klein, A. M., & Brittain, C. (2018). Organic farming promotes bee abundance in vineyards in Italy but not in South Africa. *Journal of Insect Conservation, 22*(1), 61–67. https://doi.org/10.1007/s10841-017-0038-4

Keller, A., McFrederick, Q. S., Dharampal, P., Steffan, S., Danforth, B. N., & Leonhardt, S. D. (2021). (More than) Hitchhikers through the network: the shared microbiome of bees and flowers. *Current Opinion in Insect Science, 44*, 8–15. https://doi.org/https://doi.org/10.1016/j.cois.2020.09.007

Kelley, L. C., Shattuck, A., & Thomas, K. A. (2022). Cumulative Socionatural Displacements: Reconceptualizing Climate Displacements in a World Already on the Move. *Annals of the American Association of Geographers*, *112*(3), 664-673.

Langhans, K. E., Schmitt, R. J., Chaplin-Kramer, R., Anderson, C. B., Bolaños, C. V., Cabezas, F. V., ... & Daily, G. C. (2022). Modelling multiple ecosystem services and beneficiaries of riparian reforestation in Costa Rica. *Ecosystem Services*, *57*, 101470.

Kenis, M., Auger-Rozenberg, M.-A., Roques, A., Timms, L., Péré, C., Cock, M. J. W., Settele, J., Augustin, S., & Lopez-Vaamonde, C. (2009). Ecological effects of invasive alien insects. *Biological Invasions*, *11*(1), 21–45.

Kirby, W. (1802). *Monographia Apum Angliae. 2*. 387. Ipswich: J. Raw.

Kirby, W., 1806, Familien der Bienenartigen Insekten mit Zusätzen, Nachweisungen and Bemerkungen. *Magazin für Insektenkunde 5*: 28-175.

Kleijn D, Kohler F, Báldi A, Batáry P, Concepción E.D, Clough Y, Díaz M, Gabriel D, Holzschuh A, Knop E, Kovács A, Marshall E.J.P, T. T. & V. J. (2009). On the relationship between farmland biodiversity and land-use intensity. *European Proceedings of the Royal Society B, 276*, 903–909. https://doi.org/doi:10.1098/rspb.2008.1509

Klein, A. M., Vaissière, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the royal society B: biological sciences*, *274*(1608), 303-313. https://doi.org/http://doi.org/10.1098/rspb.2006.3721

Kline, O., & Joshi, N. K. (2020). Mitigating the effects of habitat loss on solitary bees in agricultural ecosystems. *Agriculture*, *10*(4), 115. https://doi.org/10.3390/agriculture10040115

Kowalska, A., Affek, A., Wolski, J., Regulska, E., Kruczkowska, B., Zawiska, I., Kołaczkowska, E., & Baranowski, J. (2021). Assessment of regulating ES potential of lowland riparian hardwood forests in Poland. *Ecological Indicators*, *120*, 106834. https://doi.org/https://doi.org/10.1016/j.ecolind.2020.106834

Kremen, C., Williams, N.W., Thorp, R. (2002). Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences, 99*(26), 16812–16816. https://doi.org/10.1073/pnas.262413599

Kremen, C., Williams, N. M., Aizen, M. A., Gemmill-Herren, B., LeBuhn, G., Minckley, R., Packer, L., Potts, S. G., Roulston, T., Steffan-Dewenter, I., Vázquez, D. P., Winfree, R., Adams, L., Crone, E. E., Greenleaf, S. S., Keitt, T. H., Klein, A.-M., Regetz, J., & Ricketts, T. H. (2007). Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. *Ecology Letters, 10*(4), 299–314. https://doi.org/https://doi.org/10.1111/j.1461-0248.2007.01018.x

Kremen, C., Ullman, K. S., & Thorp, R. W. (2011). Evaluating the Quality of Citizen-Scientist Data on Pollinator Communities. *Conservation Biology, 25*(3), 607–617. https://doi.org/https://doi.org/10.1111/j.1523-1739.2011.01657.x

Kruskal, W. H., & Wallis, W. A. (1952). Use of Ranks in One-Criterion Variance Analysis. *Journal of the American Statistical Association*, *47*(260), 583–621. https://doi.org/10.1080/01621459.1952.10483441

Kumar, A., Tripti, Prasad, M. N. V, Maiti, S. K., Favas, P. J. C., Villemey, A., Jeusset, A., Vargac, M., Bertheau, Y., Coulon, A., Touroult, J., Vanpeene, S., Castagneyrol, B., Jactel, H., Witte, I., Deniaud, N., De Lachapelle, F. F., Jaslier, E., Roy, V., … McCracken, D. I. (2018). Phenology of farmland floral resources reveals seasonal gaps in nectar availability for bumblebees. *Journal of Applied Ecology*, *56*(7), 1585–1596. https://doi.org/https://doi.org/10.1111/1365-2664.13403

Lambert, A. M., Dudley, T. L., & Saltonstall, K. (2010). Ecology and Impacts of the Large-Statured Invasive Grasses Arundo donax and Phragmites australis in North America. *Invasive Plant Science and Management*, *3*(4), 489–494. https://doi.org/DOI: 10.1614/IPSM-D-10-00031.1

Lasway, J. V., Peters, M. K., Njovu, H. K., Eardley, C., Pauly, A., & Steffan-Dewenter, I. (2022). Agricultural intensification with seasonal fallow land promotes high bee diversity in Afrotropical drylands. *Journal of Applied Ecology*, 59, 3014– 3026. https://doi.org/10.1111/1365-2664.14296

Lazaro, A., Chroni, A., Tscheulin, T., Devalez, J., Matsoukas, C., & Petanidou, T. (2016). Electromagnetic radiation of mobile telecommunication antennas affects the abundance and composition of wild pollinators. *Journal of Insect Conservation, 20*(2), 315–324. https://doi.org/10.1007/s10841-016-9868-8

Lázaro, A., Müller, A., Ebmer, A. W., Dathe, H. H., Scheuchl, E., Schwarz, M., Risch, S., Pauly, A., Devalez, J., Tscheulin, T., Gómez-Martínez, C., Papas, E., Pickering, J., Waser, N. M., & Petanidou, T. (2021). Impacts of beekeeping on wild bee diversity and pollination networks in the Aegean Archipelago. *Ecography, 44*(9), 1353–1365. https://doi.org/https://doi.org/10.1111/ecog.05553

Lamarck, J.-B. (1783). *Encyclopédie méthodique botanique*. Paris: l'Académie Royale des Sciences, Tome Premier.

Lencina, J. L., Gallego, D., & Andújar, C. (2008). Nuevos datos de Oedemeridae latreille, 1810 de la Peninsula Ibérica (Coleoptera). *Heteropterus Revista de Entomología*, *8*(1), 95–117.

Leong, J. M., & Thorp, R. W. (1999). Colour-coded sampling: the pan trap colour preferences of oligolectic and nonoligolectic bees associated with a vernal pool plant. *Ecological Entomology*, *24*(3), 329–335. https://doi.org/https://doi.org/10.1046/j.1365-2311.1999.00196.x

Leonhardt, S. D., Gallai, N., Garibaldi, L. A., Kuhlmann, M., & Klein, A.-M. (2013). Economic gain, stability of pollination and bee diversity decrease from southern to northern Europe. *Basic and Applied Ecology*, *14*(6), 461–471. https://doi.org/https://doi.org/10.1016/j.baae.2013.06.003

Levermann, E. M., Bischoff, I., & Wagner, T. (2000). Species-specific foraging strategies of the syntopical and synchronous bees Panurgus calcaratus (Scopoli, 1763) and Dasypoda hirtipes (Fabricius, 1793) (Hymenoptera: Apidae). *Beiträge zur Entomologie= Contributions to Entomology*, *50*(1), 179-191.

Liang, C. T., Shiels, A. B., Haines, W. P., Sandor, M. E., & Aslan, C. E. (2022). Invasive predators affect community-wide pollinator visitation. *Ecological Applications*, *32*(2), e2522. https://doi.org/https://doi.org/10.1002/eap.2522

Liberti, G. (2009). The Dasytidae (Coleoptera) of Sardinia. *Zootaxa*, *2318*(1), 339–385.

Liberti, G., & Plonski, I. S. (2019). The Psilothrix Küster, 1850 of the group viridicoerulea Geoffroy, 1785 (Coleoptera: Melyridae: Dasytinae). *Zeitschrift Der Arbeitsgemeinschaft Österreichischer Entomologen*, *71*, 153–170.

Linnaeus, C. & Haartman J. (1753). *Systema naturae*. Stockholm, Sweden: Lars Salvius.

Lopatin, A.V., & Tregub, T.F. Studying Trophic Relationships of the Bee *Seladonia subaurata* (Rossi) (Hymenoptera, Halictidae) by Analyzing Pollen from Nest Cells. *Russian Journal of Ecology 35*, 259–262 (2004). https://doi.org/10.1023/B:RUSE.0000033796.74232.25

Lorite, J., Ros-Candeira, A., Alcaraz-Segura, D., & Salazar-Mendías, C. (2020). FloraSNevada: a trait database of the vascular flora of Sierra Nevada, southeast Spain. *Ecology, 101*(9), e03091. https://doi.org/10.1002/ecy.3091

Loy, X., & Brosi, B. J. (2022). The effects of pollinator diversity on pollination function. *Ecology*, *103*(4), e3631. https://doi.org/https://doi.org/10.1002/ecy.3631

Maceda-Veiga, A., Basas, H., Lanzaco, G., Sala, M., de Sostoa, A., & Serra, A. (2016). Impacts of the invader giant reed (Arundo donax) on riparian habitats and ground arthropod communities. *Biological Invasions*, *18*(3), 731–749. https://doi.org/10.1007/s10530-015-1044-7

Mandelik, Y., & Roll, U. (2009). Diversity patterns of wild bees in almond orchards and their surrounding landscape. *Israel Journal of Plant Sciences, 57*(3), 185–191. https://doi.org/10.1560/IJPS.57.3.185

Marini, L., Quaranta, M., Fontana, P., Biesmeijer, J. C., & Bommarco, R. (2012). Landscape context and elevation affect pollinator communities in intensive apple orchards. *Basic and Applied Ecology, 13*(8), 681–689. https://doi.org/10.1016/j.baae.2012.09.003

Martin, E. A., Dainese, M., Clough, Y., Báldi, A., Bommarco, R., Gagic, V., Garratt, M. P. D., Holzschuh, A., Kleijn, D., & Kovács-Hostyánszki, A. (2019). The interplay of landscape composition and configuration: new pathways to manage functional biodiversity and agroecosystem services across Europe. *Ecology Letters*, *22*(7), 1083–1094.

McDonald T, Gann GD, Jonson J, & D. K. (2016). *International standards for the practice of ecological restoration – including principles and key concepts*. Retrieved 20th February 2022, from: https://cdn.ymaws.com/sites/www.ser.org/resource/resmgr/docs/SER_International_Standards.pdf

McGill, R., Tukey, J. W., & Larsen, W. A. (1978). Variations of Box Plots. *The American Statistician*, *32*(1), 12–16. https://doi.org/10.2307/2683468

McKergow, L. A., Matheson, F. E., & Quinn, J. M. (2016). Riparian management: a restoration tool for New Zealand streams. *Ecological Management & Restoration*, *17*(3), 218-227.

Meehan, T. D., Gratton, C., Diehl, E., Hunt, N. D., Mooney, D. F., Ventura, S. J., ... & Jackson, R. D. (2013). Ecosystem-service tradeoffs associated with switching from annual to perennial energy crops in riparian zones of the US Midwest. *PloS one*, *8*(11), e80093. https://doi.org/10.1371/journal.pone.0080093

Meiners, J. M., Griswold, T. L., & Carril, O. M. (2019). Decades of native bee biodiversity surveys at Pinnacles National Park highlight the importance of monitoring natural areas over time. *PloS one, 14*(1), e0207566. https://doi.org/10.1371/journal.pone.0207566

Melero, Y., Stefanescu, C., & Pino, J. (2016). General declines in Mediterranean butterflies over the last two decades are modulated by species traits. *Biological Conservation, 201*, 336–342. https://doi.org/https://doi.org/10.1016/j.biocon.2016.07.029

Mendoza-García, M., Blanco-Moreno, J. M., Chamorro, L., José-María, L., & Sans, F. X. (2018). Patterns of flower visitor abundance and fruit set in a highly intensified cereal cropping system in a Mediterranean landscape. *Agriculture, Ecosystems & Environment, 254*, 255–263. https://doi.org/https://doi.org/10.1016/j.agee.2017.12.001

Michener, C.D. (2007). *The bees of the world* (2nd ed.). Baltimore: Johns Hopkins University Press.

Mikát, M., & Straka, J. (2021). Overwintering strategy and longevity of European small carpenter bees (Ceratina). *Journal of Ethology*, *39*(2), 155–164. https://doi.org/10.1007/s10164-020-00688-6

Minachilis, K., Kantsa, A., Devalez, J., Trigas, P., Tscheulin, T., & Petanidou, T. (2020). Bumblebee diversity and pollination networks along the elevation gradient of Mount Olympus, Greece. *Diversity and Distributions, 26*(11), 1566–1581. https://doi.org/https://doi.org/10.1111/ddi.13138

Minckley, R. L. (2014). Maintenance of richness despite reduced abundance of desert bees (Hymenoptera: Apiformes) to persistent grazing. *Insect Conservation and Diversity, 7*(3), 263–273. https://doi.org/10.1111/icad.

Mitchell, M. G. E., Suarez-Castro, A. F., Martinez-Harms, M., Maron, M., McAlpine, C., Gaston, K. J., Johansen, K., & Rhodes, J. R. (2015). Reframing landscape fragmentation's effects on ecosystem services. *Trends in Ecology & Evolution, 30*(4), 190–198. https://doi.org/https://doi.org/10.1016/j.tree.2015.01.011

Monasterolo, M., Musicante, M. L., Valladares, G. R., & Salvo, A. (2015). Soybean crops may benefit from forest pollinators. *Agriculture, Ecosystems & Environment, 202*, 217–222. https://doi.org/https://doi.org/10.1016/j.agee.2015.01.012

Monceau, K., Bonnard, O., & Thiéry, D. (2014). Vespa velutina: a new invasive predator of honeybees in Europe. *Journal of Pest Science*, *87*(1), 1–16. https://doi.org/10.1007/s10340-013-0537-3

Monteiro, A., Teixeira, G., & Moreira, J. F. (2015). Relationships between leaf anatomical features of Arundo donax and glyphosate efficacy. *Revista de Ciencias Agrarias*. Lisbon, Portugal: SCAP. http://hdl.handle.net/10400.5/9467

Moreira, E. F., Santos, R. L. D. S., Penna, U. L., Angel-Coca, C., de Oliveira, F. F., & Viana, B. F. (2016). Are pan traps colors complementary to sample community of potential pollinator insects? *Journal of Insect Conservation*, *20*(4), 583-596. https://doi.org/10.1007/s10841-016-9890-x

Moreno, G., Gonzalez-Bornay, G., Pulido, F., Lopez-Diaz, M. L., Bertomeu, M., Juárez, E., & Diaz, M. (2016). Exploring the causes of high biodiversity of Iberian dehesas: the importance of wood pastures and marginal habitats. *Agroforestry Systems*, *90*(1), 87–105. https://doi.org/10.1007/s10457-015-9817-7

Morrison, J., Izquierdo, J., Plaza, E. H., & González-Andújar, J. L. (2017). The role of field margins in supporting wild bees in Mediterranean cereal agroecosystems: Which biotic and abiotic factors are important? *Agriculture, Ecosystems & Environment, 247*, 216–224. https://doi.org/https://doi.org/10.1016/j.agee.2017.06.047

Morrison, J., Izquierdo, J., Plaza, E. H., Gonzalez-Andujar, J. L., Bartual, A. M., Bocci, G., Marini, S., Moonen, A. C., Pisanty, G., Mandelik, Y., Murray, T. E., Fitzpatrick, U., Byrne, A., Fealy, R., Brown, M. J. F., Paxton, R. J., & Herrera, C. M. (2021). From pastures to forests: Changes in Mediterranean wild bee communities after rural land abandonment. *PloS One, 89*(1), 742–752. https://doi.org/10.1002/ecm.1338

Münster-Swendsen, M. (1968). On the biology of the solitary bee Panurgus banksianus Kirby (Hymenoptera, Apidae), including some ecological aspects. *Arsskrift Kongelige Veterinaer Og Landbohojskole*, *51*, 215-241.

Murray, T. E., Fitzpatrick, U., Byrne, A., Fealy, R., Brown, M. J. F., & Paxton, R. J. (2012). Local-scale factors structure wild bee communities in protected areas. *Journal of Applied Ecology, 49*(5), 998–1008. https://doi.org/10.1111/j.1365-2664.2012.02175.x

Nelson, S. M., & Andersen, D. C. (1994). An Assessment of Riparian Environmental Quality by Using Butterflies and Disturbance Susceptibility Scores. *The Southwestern Naturalist, 39*(2), 137–142. https://doi.org/10.2307/3672237

Neto, C. S. (2002). The flora and the vegetation of Superdistrito Sadense (Portugal). *Guineana 8*, 1-269. http://hdl.handle.net/10810/38452

Nichols, R. N., Holland, J. M., & Goulson, D. (2022). Can novel seed mixes provide a more diverse, abundant, earlier, and longer-lasting floral resource for bees than current mixes? *Basic and Applied Ecology*, *60*, 34-47. https://doi.org/https://doi.org/10.1016/j.baae.2022.02.002

Nienhuis, C. M., Dietzsch, A. C., & Stout, J. C. (2009). The impacts of an invasive alien plant and its removal on native bees. *Apidologie, 40*(4), 450–463. https://doi.org/10.1051/apido/2009005

Nilsson, C., Brown, R. L., Jansson, R., & Merritt, D. M. (2010). The role of hydrochory in structuring riparian and wetland vegetation. *Biological Reviews, 85*(4), 837–858.

Nobile, V., Catania, R., Niolu, P., Pusceddu, M., Satta, A., Floris, I., Flaminio, S., Bella, S., & Quaranta, M. (2021). Twenty New Records of Bees (Hymenoptera, Apoidea) for Sardinia (Italy). *Insects, 12*(7), 627. https://doi.org/10.3390/insects12070627

Ogle DH, Doll JC, Wheeler P, Dinno A (2022). *FSA: Fisheries Stock Analysis*. R package version 0.9.3, https://github.com/fishR-Core-Team/FSA.

Oksanen, J., Blanchet, F. G., Kindt, R., Legendre, P., Minchin, P. R., O'hara, R. B., ... & Oksanen, M. J. (2013). Package 'vegan'. *Community ecology package, version*, *2*(9), 1-295. https://CRAN.R-project.org/package=vegan

Ollerton, J., Tarrant, S. & Winfree, R. (2011) How many flowering plants are pollinated by animals? *Oikos 120*: 321–326. doi: 10.1111/j.1600-0706.2010.18644.x

Ollerton, J., Erenler, H.,Edwards, M., Crockett R.(2014) Extinctions of aculeate pollinators in Britain and the role of large-scale agricultural changes. *Science, 346* (6215), 1360-1363.

Ollerton, J. (2017). Pollinator Diversity: Distribution, Ecological Function, and Conservation. *Annual Review of Ecology, Evolution, and Systematics*, *48*(1), 353–376. https://doi.org/10.1146/annurev-ecolsys-110316-022919

Papa, G., Maier, R., Durazzo, A., Lucarini, M., Karabagias, I. K., Plutino, M., ... & Negri, I. (2022). The honey bee Apis mellifera: An insect at the interface between human and ecosystem health. *Biology*, *11*(2), 233. https://doi.org/https://doi.org/10.3390/ biology11020233

Pardo, A., & Borges, P. A. V. (2020). Worldwide importance of insect pollination in apple orchards: A review. *Agriculture, Ecosystems & Environment*, *293*, 106839. https://doi.org/https://doi.org/10.1016/j.agee.2020.106839

Pardo, A., Rolo, V., Carrascosa, A., Gonzalez-Bornay, G., & Moreno, G. (2022). Management linked to ecological intensification supports pollinator abundance in Iberian wood-pastures, 13 July 2022, PREPRINT (Version 1) available at Research Square [https://doi.org/10.21203/rs.3.rs-1824207/v1]

Penado, A., Rebelo, H., Goulson, D., Wood, T.J., Porto, M., Rotheray, e.L., Beja, P. (2022). From pastures to forests: Changes in Mediterranean wild bee communities after rural land abandonment. *Insect Conservation and Diversity, 15*(3), 325-326. https://doi.org/https://doi.org/10.1111/icad.12562

Perino, A.M., Pereira H.M., Navarro, L., Néstor, F.M., Bullock, J., Ceaușu, S., Cortés-Avizanda, A., van Klink, R., Kuemmerle, T., Lomba, A., Pe'er, G., Plieninger, Rey Benayas, J.M. Sandom, C., Svenning, J.-C., & Wheeler, H. (2019). *Rewilding complex ecosystems. Science, 364*(6438), eaav5570. https://doi.org/10.1126/science.aav5570

Petanidou, T., & Lamborn, E. (2005). A land for flowers and bees: studying pollination ecology in Mediterranean communities. *Plant Biosystems - An International Journal Dealing with All Aspects of Plant Biology, 139*(3), 279–294. https://doi.org/10.1080/11263500500333941

Petanidou, T., Duffy, K. J., Karatza, A., & Kantsa, A. (2013a). Reduced fecundity in large populations of a Mediterranean orchid - Evidence for pollinator limitation. *Basic and Applied Ecology, 14*(1), 36–43. https://doi.org/10.1016/j.baae.2012.11.007

Petanidou, T., Stahls, G., Vujic, A., Olesen, J. M., Rojo, S., Thrasyvoulou, A., Sgardelis, S., Kallimanis, A. S., Kokkini, S., & Tscheulin, T. (2013b). Investigating plant-pollinator relationships in the Aegean: the approaches of the project POL-AEGIS (The pollinators of the Aegean archipelago: diversity and threats). *Journal of Apicultural Research, 52*(2), 106-117. https://doi.org/10.3896/IBRA.1.52.2.20

Petts, G. E., & Amoros, C. (1996). The fluvial hydrosystem. In *The Fluvial Hydrosystems* (pp. 1-12). Dordrecht, Springer.

Pinto-Correia, T.; Ribeiro, N.; Sá-Sousa, P. (2011). Introducing the montado, the cork and holm oak agroforestry system of Southern Portugal. *Agroforest. Syst., 82*, 99.

Pisanty, G., & Mandelik, Y. (2015). Profiling crop pollinators: life history traits predict habitat use and crop visitation by Mediterranean wild bees. *Ecological Applications, 25*(3), 742–752. https://doi.org/10.1890/14-0910.1

Polidori, C., Rubichi, A., Barbieri, V., Trombino, L., & Donegana, M. (2010). Floral resources and nesting requirements of the ground-nesting social bee, Lasioglossum malachurum (hymenoptera: Halictidae), in a Mediterranean semiagricultural landscape. *Psyche (London)*, *2010*, 1–11. https://doi.org/10.1155/2010/851947

Popic, T.J., Davila, Y.C., Wardle, G.M. (2013) Evaluation of common methods for sampling invertebrate pollinator assemblages: net sampling out-perform pan traps. *PloS one 8*(6): e66665.

Porqueddu, C., Ates, S., Louhaichi, M., Kyriazopoulos, A. P., Moreno, G., Del Pozo, A., Ovalle, C., Ewing, M. A., & Nichols, P. G. H. (2016). Grasslands in ‘Old World’and ‘New World’ Mediterranean-climate zones: past trends, current status and future research priorities. *Grass and Forage Science*, *71*(1), 1–35.

Portela-Pereira, E., Gutierres, F., Neto, C., & Costa, J. C. (2009). Riparian Forests of Alenquer/Ota Sub-basin (Tagus Basin, Portugal): The Invasion of Arundo donax L. *Book of Abstracts of BIOLIEF, Word Conference on Biological Invasions and Ecosystems Functioning. Porto, Portugal*, 27–30.

Portela-Pereira, E., Monteiro, P., & Rodríguez-González, P. M. (2022). Control of Invasive Plant Species in Wetland Forests (91E0*). In *Biology and Life Sciences Forum 13*(1), 84. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/blsf2022013084

Portugal News, (2019). Retrieved 10th September 2022 from: https://www.theportugalnews.com/news/brown-marmorated-stink-bug-warning/51642

Potts, S., & Willmer, P. A. T. (1997). Abiotic and biotic factors influencing nest-site selection by Halictus rubicundus, a ground-nesting halictine bee. *Ecological Entomology*, *22*(3), 319–328.

Potts, S. G., Vulliamy, B., Dafni, A., Ne’eman, G., O’Toole, C., Roberts, S., & Willmer, P. (2003a). Response of plant-pollinator communities to fire: changes in diversity, abundance and floral reward structure. *Oikos*, *101*(1), 103–112. https://doi.org/https://doi.org/10.1034/j.1600-0706.2003.12186.x

Potts, S. G., Vulliamy, B., Dafni, A., Ne’eman, G., & Willmer, P. (2003b). Linking bees and flowers: How do floral communities structure pollinator communities? *Ecology*, *84*(10), 2628–2642. https://doi.org/10.1890/02-0136

Potts, S.G., Vulliamy, B., Roberts, S., O'Toole, C., Dafni, A., Ne'eman, G. and Willmer, P. (2005), Role of nesting resources in organising diverse bee communities in a Mediterranean landscape. *Ecological Entomology, 30*: 78-85. https://doi.org/10.1111/j.0307-6946.2005.00662.x

Potts, S. G., Petanidou, T., Roberts, S., O'Toole, C., Hulbert, A., & Willmer, P. (2006). Plant-pollinator biodiversity and pollination services in a complex Mediterranean landscape. *Biological Conservation, 129*(4), 519–529. https://doi.org/https://doi.org/10.1016/j.biocon.2005.11.019

Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010a). Global pollinator declines: trends, impacts and drivers. *Trends in Ecology & Evolution, 25*(6), 345–353. https://doi.org/https://doi.org/10.1016/j.tree.2010.01.007

Potts, S. G., Roberts, S. P. M., Dean, R., Marris, G., Brown, M. A., Jones, R., Neumann, P., & Settele, J. (2010b). Declines of managed honey bees and beekeepers in Europe. *Journal of Apicultural Research, 49*(1), 15–22. https://doi.org/10.3896/IBRA.1.49.1.02

Potts, S. G., Biesmeijer, J. C., Bommarco, R., Felicioli, A., Fischer, M., Jokinen, P., Kleijn, D., Klein, A.-M., Kunin, W. E., Neumann, P., Penev, L. D., Petanidou, T., Rasmont, P., Roberts, S. P. M., Smith, H. G., Sørensen, P. B., Steffan-Dewenter, I., Vaissière, B. E., Vilà, M., … Schweiger, O. (2011). Developing European conservation and mitigation tools for pollination services: approaches of the STEP (Status and Trends of European Pollinators) project. *Journal of Apicultural Research, 50*(2), 152–164. https://doi.org/10.3896/IBRA.1.50.2.07

Potts, S. G., Imperatriz-Fonseca, V., Ngo, H. T., Aizen, M. A., Biesmeijer, J. C., Breeze, T. D., Dicks, L. V, Garibaldi, L. A., Hill, R., Settele, J., & Vanbergen, A. J. (2016). Safeguarding pollinators and their values to human well-being. *Nature, 540*(7632), 220–229. https://doi.org/10.1038/nature20588

Potts, S., Dauber, J., Hochkirch, A., Oteman, B., Roy, D., Ahnre, K., Biesmeijer, K., Breeze, T., Carvell, C., Ferreira, C., Fitzpatrick, Ú., Isaac, N., Kuussaari, M., Ljubomirov, T., Maes, J., Ngo, H., Pardo, A., Polce, C., Quaranta, M., Settele, J., Sorg, M., Stefanescu, C. & Vujic, A., (2020). *Proposal for an EU Pollinator Monitoring Scheme, EUR 30416 EN*. Luxembourg: Publications Office of the European Union. ISBN 978-92-76-23859-1, doi:10.2760/881843, JRC122225.

Proesmans, W., Bonte, D., Smagghe, G., Meeus, I., Decocq, G., Spicher, F., Kolb, A., Lemke, I., Diekmann, M., Bruun, H. H., Wulf, M., Van Den Berge, S., & Verheyen, K. (2019). Small forest patches as pollinator habitat: oases in an agricultural desert? *Landscape Ecology*, *34*(3), 487–501. https://doi.org/10.1007/s10980-019-00782-2

Quilis Pérez, M. (1928). Los ápidos de España. Estudio monográfico de las Dasypoda Latr. *Eos-Revista Española de Entomología, 4*(2), 173–241.

R (2020). R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Raji, S. A., Odunuga, S., & Fasona, M. (2021). Quantifying ecosystem service interactions to support environmental restoration in a tropical semi-arid basin. *Acta Geophysica*, *69*(5), 1813-1841. https://doi.org/10.1007/s11600-021-00644-z

Raposo, M., Mendes, P., Cano-Ortiz, A., Pinto Gomes, C. (2016). Series de vegetacao prioritarias para a conservacao no entro e dul de Portugal continental. *Botanique, 1*, 113–148.

Raposo, M., Quinto-Canas, R., Cano-Ortiz, A., Spampinato, G., & Pinto Gomes, C. (2020). Originalities of willow of salix atrocinerea brot. In mediterranean europe. *Sustainability*, *12*(19), 8019. https://doi.org/10.3390/su12198019

Riis, T., Kelly-Quinn, M., Aguiar, F. C., Manolaki, P., Bruno, D., Bejarano, M. D., Clerici, N., Fernandes, M. R., Franco, J. C., Pettit, N., Portela, A. P., Tammeorg, O., Tammeorg, P., Rodríguez-González, P. M., & Dufour, S. (2020). Global Overview of Ecosystem Services Provided by Riparian Vegetation. *BioScience*, *70*(6), 501–514. https://doi.org/10.1093/biosci/biaa041

Rodríguez S, S., Pérez-Giraldo, L. C., Vergara, P. M., Carvajal, M. A., & Alaniz, A. J. (2021). Native bees in Mediterranean semi-arid agroecosystems: Unravelling the effects of biophysical habitat, floral resource, and honeybees. *Agriculture, Ecosystems & Environment, 307*, 107188. https://doi.org/https://doi.org/10.1016/j.agee.2020.107188

Rodríguez-González, P. M., Abraham, E., Aguiar, F., Andreoli, A., Baležentienė, L., Berisha, N., ... & Dufour, S. (2022). Bringing the margin to the focus: 10 challenges for riparian vegetation science and management. *Wiley Interdisciplinary Reviews: Water*, *9*(5), e1604. https://doi.org/10.1002/wat2.1604

Ropars, L., Affre, L., Aubert, M., Fernandez, C., Flacher, F., Genoud, D., Guiter, F., Jaworski, C., Lair, X., Mutillod, C., Nève, G., Schurr, L., & Geslin, B. (2020). Pollinator Specific Richness and Their Interactions with Local Plant Species: 10 Years of Sampling in Mediterranean Habitats. *Environmental Entomology, 49*(4), 947–955. https://doi.org/10.1093/ee/nvaa061

RStudio Team (2022). RStudio: Integrated Development for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/. Now 2023, POSIT Software, URL http://www.posit.co

Sáenz-Romo, M. G., Veas-Bernal, A., Martínez-García, H., Campos-Herrera, R., Ibáñez-Pascual, S., Martínez-Villar, E., Pérez-Moreno, I., & Marco-Mancebón, V. S. (2019). Ground cover management in a Mediterranean vineyard: Impact on insect abundance and diversity. *Agriculture, Ecosystems & Environment, 283*, 106571. https://doi.org/https://doi.org/10.1016/j.agee.2019.106571

Saklaurs, M., Lībiete, Z., Donis, J., Kitenberga, M., Elferts, D., Jūrmalis, E., & Jansons, Ā. (2022). Provision of Ecosystem Services in Riparian Hemiboreal Forest Fixed-Width Buffers. *Forests*, *13*(6), 928. https://doi.org/10.3390/f13060928

Sánchez-Bayo, F. & Wyckhuys, K. A. G. (2019). Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation*, *232*, 8–27. https://doi.org/https://doi.org/10.1016/j.biocon.2019.01.020

Sanchez, J. A., Carrasco, A., La Spina, M., Pérez-Marcos, M., & Ortiz-Sánchez, F. J. (2019). How bees respond differently to field margins of shrubby and herbaceous plants in intensive agricultural crops of the Mediterranean area. *Insects*, *11*(1), 26. https://doi.org/10.3390/insects11010026

Santos, A., Fernandes, M.R., Aguiar, F.C., Branco, M.R. (2018) Effects of riverine landscape changes on pollination services: A case study on the River Minho, Portugal. *Ecological Indicators 89*, 656-666.

Saunders, M.E. & Luck, G.W. (2013), Pan trap catches vary with habitat. *Australian Journal of Entomology, 52*, 106-113. https://doi.org/10.1111/aen.12008

Scopoli (1763), Higgins, L. G. (1963). Entomologia Carniolica: JA Scopoli, 1763. *Journal of the Society for the Bibliography of Natural History, 4*(3), 167–169.

Sedivy, C., Dorn, S., & Müller, A. (2013). Evolution of nesting behaviour and kleptoparasitism in a selected group of osmiine bees (Hymenoptera: Megachilidae). *Biological Journal of the Linnean Society*, *108*(2), 349–360. https://doi.org/10.1111/j.1095-8312.2012.02024.x

Senapathi, D., Biesmeijer, J. C., Breeze, T. D., Kleijn, D., Potts, S. G., & Carvalheiro, L. G. (2015). Pollinator conservation—the difference between managing for pollination services and preserving pollinator diversity. *Current Opinion in Insect Science*, *12*, 93–101. https://doi.org/https://doi.org/10.1016/j.cois.2015.11.002

Senapathi, D., Fründ, J., Albrecht, M., Garratt, M. P., Kleijn, D., Pickles, B. J., ... & Klein, A. M. (2021). Wild insect diversity increases inter-annual stability in global crop pollinator communities. *Proceedings of the Royal Society B*, *288*(1947), 20210212. https://doi.org/https://doi.org/10.1098/rspb.2021.0212

Sgolastra, F., Medrzycki, P., Bortolotti, L., Maini, S., Porrini, C., Simon-Delso, N., & Bosch, J. (2020). Bees and pesticide regulation: Lessons from the neonicotinoid experience. *Biological Conservation, 241*, 108356. https://doi.org/https://doi.org/10.1016/j.biocon.2019.108356

Shapiro, S. S. & Wilk, M. B. (1965). An analysis of variance test for normality: Complete samples. *Biometrika, 52,* 591–611.

Shapiro, L.H., Tepedino, V.J., Mincley, R.L. (2014) Bowling for bees: optimal sample number for “bee bowl” sampling transects. *Journal of Insect Conservation 18*(6), 1105-1113.

Shebl, M. (2016). Nesting Biology and Seasonality of Long-Horned Bee Eucera nigrilabris Lepeletier (Hymenoptera, Apidae). *Sociobiology*, *63*(4), 1031–1037.

Shrestha, M., Garcia, J. E., Chua, J. H., Howard, S. R., Tscheulin, T., Dorin, A., ... & Dyer, A. G. (2019). Fluorescent pan traps affect the capture rate of insect orders in different ways. *Insects*, *10*(2), 40. https://doi.org/10.3390/insects10020040

Simon, A. & Starzomski, B. M. (2022). Landscape Integrity Eclipses Local Effects of Floral Resource Availability on Bumble Bee (Bombus Spp.) Abundance in a Water-Limited Island Ecosystem. Research Square - Preprint. https://doi.org/https://doi.org/10.21203/rs.3.rs-1128511/v1

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research, 104*, 333–339. https://doi.org/https://doi.org/10.1016/j.jbusres.2019.07.039

Solé-Senan, X. O., Juárez-Escario, A., Conesa, J. A., & Recasens, J. (2018). Plant species, functional assemblages and partitioning of diversity in a Mediterranean agricultural mosaic landscape. *Agriculture, Ecosystems & Environment, 256*, 163–172. https://doi.org/https://doi.org/10.1016/j.agee.2018.01.014

Song, Y., Zajic, C. J., Hwang, T., Hakkenberg, C. R., & Zhu, K. (2021). Widespread Mismatch Between Phenology and Climate in Human-Dominated Landscapes. *AGU Advances*, *2*(4), e2021AV000431.

SPRING Project (2022, 1st September). Retrieved from: https://www.ufz.de/spring-pollination/

Staton, T., Walters, R. J., Smith, J., & Girling, R. D. (2019). Evaluating the effects of integrating trees into temperate arable systems on pest control and pollination. *Agricultural Systems, 176*, 102676. https://doi.org/https://doi.org/10.1016/j.agsy.2019.102676

Stefanaki, A., Kantsa, A., Tscheulin, T., Charitonidou, M., & Petanidou, T. (2015). Lessons from red data books: plant vulnerability increases with floral complexity. *PloS one*, *10*(9), e0138414. https://doi.org/10.1371/journal.pone.0138414

Steffan-Dewenter, I., & Tscharntke, T. (2001). Succession of bee communities on fallows. *Ecography, 24*(1), 83–93. https://doi.org/https://doi.org/10.1034/j.1600-0587.2001.240110.x

Steffan-Dewenter, I., Münzenberg, U., Bürger, C., Thies, C., & Tscharntke, T. (2002). Scale-dependent effects of landscape context on three pollinator guilds. *Ecology*, *83*(5), 1421–1432.

Stella, J.C., Rodríguez-González, P.M., Dufour, S. & Bendix, J. (2013). Riparian vegetation research in Mediterranean-climate regions: common patterns, ecological processes, and considerations for management. *Hydrobiologia, 719*(1), 291-315. doi: 10.1007/s10750-012-1304-9

Norris, S. L., Blackshaw, R. P., Critchley, C. N. R., Dunn, R. M., Smith, K. E., Williams, J., ... & Murray, P. J. (2018). Intercropping flowering plants in maize systems increases pollinator diversity. *Agricultural and Forest Entomology*, *20*(2), 246-254. https://doi.org/https://doi.org/10.1111/afe.12251

Swaay, C. van, Cuttelod, A., Collins, S., Maes, D., Munguira, M. L., Šašic, M., Settele, J., Verovnik, R., Verstrael, T., Warren, M., Wiemers, M., & Wynhoff, I. (2010). *European Red List of butterflies*. International Union for Conservation of Nature PP - IUCN Species Survival Commission (SSC), IUCN, Regional Office for Europe, European Commission, Butterfly Conservation Europe. https://policycommons.net/artifacts/1375275/european-red-list-of-butterflies/

Taki, H., Kevan, P. G., & Ascher, J. S. (2007). Landscape effects of forest loss in a pollination system. *Landscape Ecology, 22*(10), 1575–1587. https://doi.org/10.1007/s10980-007-9153-z

Taki, H., Okochi, I., Okabe, K., Inoue, T., Goto, H., Matsumura, T., & Makino, S. (2013). Succession Influences Wild Bees in a Temperate Forest Landscape: The Value of Early Successional Stages in Naturally Regenerated and Planted Forests. *PloS one, 8*(2), e56678. https://doi.org/10.1371/journal.pone.0056678

Tamburini, G., Pereira-Peixoto, M.-H., Borth, J., Lotz, S., Wintermantel, D., Allan, M. J., Dean, R., Schwarz, J. M., Knauer, A., Albrecht, M., & Klein, A. (2021). Fungicide and insecticide exposure adversely impacts bumblebees and pollination services under semi-field conditions. *Environment International, 157*, 106813. https://doi.org/https://doi.org/10.1016/j.envint.2021.106813

Tangtorwongsakul, P., Warrit, N., & Gale, G. A. (2018). Effects of landscape cover and local habitat characteristics on visiting bees in tropical orchards. *Agricultural and Forest Entomology*, *20*(1), 28-40. https://doi.org/10.1111/afe.12226

Tengö, J., Eriksson, J., Borg-Karlson, A.-K., Smith, B. H., & Dobson, H. (1988). Mate-Locating Strategies and Multimodal Communication in Male Mating Behavior of Panurgus banksianus and P. calcaratus (Apoidea, Andrenidae). *Journal of the Kansas Entomological Society, 61*(4), 388–395. http://www.jstor.org/stable/25085029

Tooker, J. F., O'Neal, M. E., & Rodriguez-Saona, C. (2020). Balancing Disturbance and Conservation in Agroecosystems to Improve Biological Control. *Annual Review of Entomology*, *65*(1), 81–100. https://doi.org/10.1146/annurev-ento-011019-025143

Tscharntke, T., Klein, A. M., Kruess, A., Steffan-Dewenter, I., & Thies, C. (2005). Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. *Ecology Letters, 8*(8), 857–874. https://doi.org/https://doi.org/10.1111/j.1461-0248.2005.00782.x

Ullmann, K., Vaughan, M., Kremen, C., Shih, T., Shepherd, M. (2011) Published by the Xerces Society for Invertebrate Conservation University of California at Berkeley. https://xerces.org/sites/default/files/2018-05/11-010_01_XercesSoc_Citizen-Science-Monitoring-Guide_California_web.pdf

Ulyshen, M. D., Horn, S., & Hanula, J. L. (2020). Effects of Chinese Privet on Bees and Their Vertical Distribution in Riparian Forests. *Forest Science, 66*(4), 416–423. https://doi.org/10.1093/forsci/fxz088

Ulyshen, M. D., Horn, S., & Hanula, J. L. (2022). Decadal patterns of forest and pollinator recovery following the eradication of an invasive shrub. *Frontiers in Ecology and Evolution*, 138. https://www.frontiersin.org/article/10.3389/fevo.2022.832268

Urbanič, G., Politti, E., Rodríguez-González, P. M., Payne, R., Schook, D., Alves, M. H., ... & Dufour, S. (2022). Riparian Zones—From Policy Neglected to Policy Integrated. *Frontiers in Environmental Science*, *10*, 868527. https://www.frontiersin.org/article/10.3389/fenvs.2022.868527

Vallejo, M., López-Sánchez, J. G., Hernández-Ordoñez, O., Torres-García, I., & Ramírez, M. I. (2022). Biodiversity of riparian vegetation under a management gradient in the Monarch Butterfly Biosphere Reserve, Mexico. *Botanical Sciences, 100*(4), 837-856. https://doi.org/10.17129/botsci.3015

Valter, J. (2018). Retrieved 1st August 2022 from: iNaturalist, *Beetles of Portugal*. https://www.inaturalist.org/

Vanbergen, A. J. (2013). Threats to an ecosystem service: pressures on pollinators. *Frontiers in Ecology and the Environment Frontiers in Ecology and the Environment*, *11*(5), 251–259. https://doi.org/https://doi.org/10.1890/120126

Vanbergen, A. J., Espíndola, A., & Aizen, M. A. (2018). Risks to pollinators and pollination from invasive alien species. *Nature Ecology & Evolution*, *2*(1), 16–25.

Vázquez, X. A. (2002). *European Fauna of Oedemeridae: Coleoptera*. Barcelona, Spain: Argania editio.

Verdasca, M. J., Leitão, A. S., Santana, J., Porto, M., Dias, S., & Beja, P. (2012). Forest fuel management as a conservation tool for early successional species under agricultural abandonment: The case of Mediterranean butterflies. *Biological Conservation, 146*(1), 14–23. https://doi.org/https://doi.org/10.1016/j.biocon.2011.10.031

Verdasca MJ, Carvalheiro L, Aguirre Gutierrez J, Granadeiro JP, Rome Q, Puechmaille SJ, Rebelo R, Rebelo H. (2022). Contrasting patterns from two invasion fronts suggest a niche shift of an invasive predator of native bees. *PeerJ 10,* e13269 https://doi.org/10.7717/peerj.13269

Vereecken, N., Toffin, E., Gosselin, M., & Michez, D. (2006). Observations relatives à la biologie et à la nidification de quelques abeilles sauvages psammophiles d'intérêt en Wallonie. 1. *Observations printanières. Parc et Réserves*, *61*, 8-13.

Vieli, L., Murúa, M. M., Flores-Prado, L., Carvallo, G. O., Valdivia, C. E., Muschett, G., ... & Fontúrbel, F. E. (2021). Local actions to tackle a global problem: A multidimensional assessment of the pollination crisis in Chile. *Diversity*, *13*(11), 571. https://doi.org/10.3390/d13110571

Wägele, J. W., Bodesheim, P., Bourlat, S. J., Denzler, J., Diepenbroek, M., Fonseca, V., ... & Wildermann, S. (2022). Towards a multisensor station for automated biodiversity monitoring. *Basic and Applied Ecology*, *59*, 105-138. https://doi.org/https://doi.org/10.1016/j.baae.2022.01.003

Wagner, D. L. (2020). Insect Declines in the Anthropocene. *Annual Review of Entomology, 65*(1), 457–480. https://doi.org/10.1146/annurev-ento-011019-025151

Wang, M., Lu, X., Ding, S., Ren, J., Bian, Z., & Xu, Z. (2017). Pollinator diversity in different habitats of the agricultural landscape in the middle and lower reaches of the Yellow River based on the three-color pan trap method. *Acta Ecologica Sinica*, *37*(3), 148–155. https://doi.org/https://doi.org/10.1016/j

Ward, K., Cariveau, D., May, E., Roswell, M., Vaughan, M., Williams, N., Winfree, R., Isaacs, R. & Gill, K. (2014). *Streamlined bee monitoring protocol for assessing pollinator habitat.* Portland, Oregon: Xerces Society for Invertebrate Conservation.

Warzecha, D., Diekötter, T., Wolters, V., & Jauker, F. (2018). Attractiveness of wildflower mixtures for wild bees and hoverflies depends on some key plant species. *Insect Conservation and Diversity*, *11*(1), 32-41.

Watson, J. C., Wolf, A. T., & Ascher, J. S. (2011). Forested Landscapes Promote Richness and Abundance of Native Bees (Hymenoptera: Apoidea: Anthophila) in Wisconsin Apple Orchards. *Environmental Entomology, 40*(3), 621–632. https://doi.org/10.1603/EN10231

Westphal, C., Bommarco, R., Carré, G., Lamborn, E., Morison, N., Petanidou, T., Potts, S., Roberts, S., Rgyi, H., Tscheulin, T., Vaissi, B., Woyciechowski, M., Biesmeijer, J., Kunin, W., Settele, J., & Ingolf, A. (2008). Measuring bee diversity in different European habitats and biogeographical regions. *Ecological Monographs, 78*, 653–671. https://doi.org/10.1890/07-1292.1

Westrich, P. (1996). Habitat requirements of central European bees and the problems of partial habitats. *Linnean Society Symposium Series*, *18*, 1-16. London, UK: Academic Press Limited.

Wheelock, M. J., Rey, K. P., & O'Neal, M. E. (2016). Defining the Insect Pollinator Community Found in Iowa Corn and Soybean Fields: Implications for Pollinator Conservation. *Environmental Entomology*, *45*(5), 1099–1106. https://doi.org/10.1093/ee/nvw087

Whitehorn, P. R., Seo, B., Comont, R. F., Rounsevell, M. & Brown, C. (2022). The effects of climate and land use on British bumblebees: Findings from a decade of citizen-science observations. *Journal of Applied Ecology, 59*, 1837– 1851. https://doi.org/10.1111/1365-2664.14191

Winfree, R., Griswold, T., & Kremen, C. (2007). Effect of Human Disturbance on Bee Communities in a Forested Ecosystem. *Conservation Biology, 21*(1), 213–223.

Wright, I. R., Roberts, S. P. M., & Collins, B. E. (2015). Evidence of forage distance limitations for small bees (Hymenoptera: Apidae). *European Journal of Entomology, 112*(2), 303-310. doi: 10.14411/eje.2015.028

Wuellner, C. T. (1999). Nest site preference and success in a gregarious, ground-nesting bee Dieunomia triangulifera. *Ecological Entomology*, *24*(4), 471–479.

Yang, J., Xu, H., & Hu, H. (2010). Nesting biology of Dasypoda hirtipes (Fabricius)(Hymenoptera: Melittidae). *Acta Entomologica Sinica*, *53*(4), 442–448.

Yuan, X., Jia, E., Liu, Y., & Chen, S. (2022). The return of river life: Urban river ecosystem restoration based on biodiversity enhancement. *Eco Cities*, *3*(1), 10.

Zhang, X., Zhang, L., Wang, Y., Shao, Y., Daniels, B., Roß-Nickoll, M., & Chen, Z. (2022). Pollinators and urban riparian vegetation: important contributors to urban diversity conservation. *Environmental Sciences Europe*, *34*(1), 78. https://doi.org/10.1186/s12302-022-00661-9

Zito, P., Serraino, F., Carimi, F., Tavella, F., & Sajeva, M. (2018). Inflorescence-visiting insects of a functionally dioecious wild grapevine (Vitis vinifera subsp. sylvestris). *Genetic Resources and Crop Evolution*, *65*(5), 1329-1335. https://doi.org/10.1007/s10722-018-0616-7

Zurbuchen, A., Landert, L., Klaiber, J., Müller, A., Hein, S., & Dorn, S. (2010). Maximum foraging ranges in solitary bees: only few individuals have the capability to cover long foraging distances. *Biological Conservation, 143*(3), 669–676. https://doi.org/https://doi.org/10.1016/j.biocon.2009.12.003

References - Appendix 1 Only

de la Peña, E., Pérez Méndez, V., Alcaraz, L., Lora, J., Larranaga, N., & Hormaza, J. (2018). Pollinators and pollination in subtropical fruit crops: management and implications for conservation and food-security. *Ecosistemas, 27*, 91–101. https://doi.org/10.7818/ECOS.1480

Dorchin, A., Dafni, A., Izhaki, I., Sapir, Y., & Vereecken, N. J. (2018). Patterns and drivers of wild bee community assembly in a Mediterranean IUCN important plant area. *Biodiversity and Conservation, 27*(3), 695–717. https://doi.org/10.1007/s10531-017-1459-9

García, Y., Clara Castellanos, M., & Pausas, J. G. (2018). Differential pollinator response underlies plant reproductive resilience after fires. *Annals of Botany, 122*(6), 961–971. https://doi.org/10.1093/aob/mcy122

Hoover, S., Ladley, J., Shchepetkina, A., Tisch, M., Gieseg, S., & Tylianakis, J. (2012). Warming, CO2, and nitrogen deposition interactively affect a plant-pollinator mutualism. *Ecology Letters, 15*, 227–234. https://doi.org/10.1111/j.1461-0248.2011.01729.x

Kantsa, A., Raguso, R. A., Dyer, A. G., Olesen, J. M., Tscheulin, T., & Petanidou, T. (2018). Disentangling the role of floral sensory stimuli in pollination networks. *Nature communications*, *9*(1), 1-13. https://doi.org/10.1038/s41467-018-03448-w

Lázaro, A., Fuster, F., Alomar, D., & Totland, Ø. (2020). Disentangling direct and indirect effects of habitat fragmentation on wild plants' pollinator visits and seed production. *Ecological Applications, 30*(5). e02099. https://doi.org/10.1002/eap.2099

Lhotte, A., Affre, L., & Saatkamp, A. (2014). Are there contrasted impacts of urbanization and land uses on population persistence? The case of Teucrium pseudochamaepitys, an endangered species in Southern France. *Flora, 209*(9), 484–490. https://doi.org/10.1016/j.flora.2014.05.002

López-Aliste, M., Flores-Prado, L., Ruz, L., Sepúlveda, Y., Rodríguez, S., Saraiva, A. M., & Fontúrbel, F. E. (2021). Wild bees of Chile: a database on taxonomy, sociality, and ecology. *Ecology, 102*(8), e03377. https://doi.org/https://doi.org/10.1002/ecy.3377

Ornai, A., Ne'eman, G., & Keasar, T. (2020). Management of forest fire buffer zones: Implications for flowering plants and bees. *Forest Ecology and Management*, *473*, 118310. https://doi.org/10.1016/j.foreco.2020.118310

Park, B., & Nieh, J. C. (2017). Seasonal trends in honey bee pollen foraging revealed through DNA barcoding of bee-collected pollen. *Insectes Sociaux, 64*(3), 425–437. https://doi.org/10.1007/s00040-017-0565-8

Pinke, G., & Pál, R. (2009). Floristic composition and conservation value of the stubble-field weed community, dominated by Stachys annua in western Hungary. *Biologia, 64*, 279–291. https://doi.org/10.2478/s11756-009-0035-5

Ropars, L., Affre, L., Schurr, L., Flacher, F., Genoud, D., Mutillod, C., & Geslin, B. (2020). Land cover composition, local plant community composition and honeybee colony density affect wild bee species assemblages in a Mediterranean biodiversity hot-spot. *Acta Oecologica*, *104*, 103546. https://doi.org/10.1016/j.actao.2020.103546

Schurr, L., Affre, L., Flacher, F., Tatoni, T., Le Mire Pecheux, L., & Geslin, B. (2019). Pollination insights for the conservation of a rare, threatened plant species, Astragalus tragacantha (Fabaceae). *Biodiversity and Conservation, 28*(6), 1389–1409. https://doi.org/10.1007/s10531-019-01729-4

Traveset, A., Castro-Urgal, R., Rotllàn-Puig, X., & Lázaro, A. (2018). Effects of habitat loss on the plant–flower visitor network structure of a dune community. *Oikos*, *127*(1), 45-55. https://doi.org/10.1111/oik.04154

Appendix 1: Table summarising the analysis of articles.

Column headers and cell content are kept brief whilst seeking to provide key pieces of information. Ref. is short for Reference. The Question column contains a number and one word indicating the search question that led to the discovery of this reference (see Table 1). The Yrs column indicates the length of the study period in years. Threat and Mitigation relate to the categories of Figure 3. Factor analysed and IPAD Effect are provided to give a sense of the main factor in the article and its effect on IPAD (+ve = Positive, -ve = Negative).

Ref.	Country / Climate	Habitat	Taxa	Yrs	Method	Main Observation	Threat	Mitigation	Factor analysed	IPAD Effect
Abdullah et al, 2019	Malaysia / Tropical	Riparian zones in mangrove and non-mangrove habitats.	All pollinators	1	Sweep netting	Insect Family diversity corresponds with plant species diversity.	Habitat Loss - Agricultural intensification	Riparian buffer strips	Plant diversity enhancement	+ve
Affek et al, 2021	Poland / Temperate	Riparian hard-wood forests.	Apidae	1	Trap-nests	Patches of riparian hardwood forests seem to have a higher pollination potential than reported earlier for riparian and other broadleaved temperate forests, in an agricultural matrix.	Habitat Loss - Agricultural intensification	Riparian buffer strips	Riparian forest conservation	+ve

Araújo et al, 2018a	Brazil / Tropical	Restored riparian sites of various ages compared to an undisturbed reference.	Bees and wasps	1	Trap-nests	Bees were most abundant in continuous forest with natural gaps, whilst wasps were favoured by forest fragments and cleared areas.	Habitat Loss - Agricultural intensification	Riparian buffer strips	Riparian forest conservation	+ve
Araújo et al, 2018b	Brazil / Tropical	Restored riparian sites of various ages compared to an undisturbed reference.	Bees and wasps	1	Trap-nests	Even relatively small and fragmented restored habitats, enhanced re-colonization by bees and wasps communities towards that of an undisturbed reference.	Habitat Loss - Agricultural intensification	Riparian buffer strips	Riparian forest conservation	+ve
Bąk-Badowska et al, 2021	Poland / Temperate	Two natural forests and two semi-natural habitats.	Bumble bees	17	Transect walks and netting	The meadows were characterized by more complex bumblebee communities. Landscape complexity enhance diversity.	Habitat Loss - Agricultural intensification	Protected area management	Landscape diversity enhancement	+ve

Bartomeus et al, 2010	Germany / Temperate	Intensive agricultural areas invaded by I. glandulifera	All pollinators	1	Transect walks and netting	Invasive I. glandulifera altered the diversity profile of the pollinator community.	Introduced Species - Flora	Invasive plant management	Plant diversity reduction	-ve
Bartual et al, 2018	Italy / Mediterranean	Sunflower fields with various surrounding habitats.	Bees, hoverflies and butterflies.	1	Transect walks and netting	Sunflower seed set was higher in fields surrounded by landscapes containing a greater abundance of beehives, and diverse landscape.	Habitat Loss - Agricultural intensification	Field margin management	Landscape diversity enhancement	+ve
Benelli et al, 2017	Italy / Mediterranean	Coastal zone.	Apidae and Scarabaeidae	1	Sweep netting	A. barba-jovis was of particular importance to bumblebees during the summer period.	Climate change	Dry season forage provision	Plant diversity enhancement	+ve
Benvenuti et al, 2016	Italy / Mediterranean	Mediterranean wetlands. Field drainage channels.	Bees	1	Transect walks and netting	Lythrum salicaria favours long-tongued Apoidae. Including B. sylvarum, a threatened species of bumblebee.	Climate change	Dry season forage provision	Plant diversity enhancement	+ve
Boustani et al, 2021	Lebanon / Mediterranean	Mediterranean	Wild Bees	1	Literature review	Knowledge on the current state of wild	Information gap	Monitoring scheme		

						bees is scarce in the Mediterranean basin.				
Brito et al, 2018	Brazil / Tropical	Palm plantation, legal reserves and riparian corridors.	Orchid bees	1	Scent traps	Forest patches and semi-natural habitats connected with the riparian zones serve as corridors for bees.	Habitat Loss - Agricultural intensification	Riparian buffer strips	Riparian forest conservation	+ve
Brito et al, 2017	Brazil / Tropical	Amazon oil palm plantations and riparian zones	Orchid bees	1	Scent traps	Riparian corridors had the highest abundance, followed by reserves, and oil palm plantations.	Habitat Loss - Agricultural intensification	Riparian buffer strips	Riparian forest conservation	+ve
Brousil et al, 2015	USA / Temperate	Forest management strategies in riparian zones.	Rove beetles	1	Transect walks	Pollinator interactions may be more dependent on traits of host plants than direct effects of forest management.	Habitat Loss - Agricultural intensification	Riparian buffer strips	Plant diversity enhancement	+ve
Burkle et al, 2013	Illinois, USA / Temperate	Natural woodland and degraded woodland patches.	Bees	120	Literature review	Rare and specialized species were most vulnerable to land-use and climate change. The pollinator service has declined over time.	Habitat Loss - Agricultural intensification	Monitoring scheme	Landscape diversity reduction	-ve

Canale et al, 2016	Italy / Mediterranean	Mediterranean chapperal in a protected area	All pollinators	1	Sweep netting	R. alaternus scrubland spots should be encouraged in agrigultural Mediterranean river basins, to support pollinators with forage into the Winter.	Climate change	Dry season forage provision	Landscape diversity enhancement	+ve
Candido et al, 2021	Brazil / Tropical	Urban habitats	Orchid bees	1	Scent traps	In an urban landscape, the remaining riparian and forest fragments maintain 62.7% of orchid bee species.	Habitat Loss - Urbanisation	Riparian buffer strips	Riparian forest conservation	+ve
Clemente et al, 2017	Brazil / Tropical	Riparian forest compared with campus rupestres.	Eusocial wasps	1	Observation and netting	The diversity of eusocial wasps was higher in the riparian forest than in the campus rupestres.	Habitat Loss - Agricultural intensification	Protected area management	Riparian forest conservation	+ve
Clemente et al, 2020	Brazil / Tropical	Riparian forest and regenerating Cerrado.	Eusocial wasps	1	Observation and netting for identification	The highest richness of social wasps was found in the riparian forest and regenerating Cerrado, compared	Habitat Loss - Agricultural intensification	Protected area management	Riparian forest conservation	+ve

						with the agricultural matrix.				
Cole et al, 2012	Scotland / Temperate	Farmland riparian zones	Ground beetles, carabids	1	Pitfall traps	Assemblages were greatest in undisturbed riparian zones larger than 4.5m in width.	Habitat Loss - Agricultural intensification	Riparian buffer strips	Riparian forest conservation	+ve
Cole et al, 2015c	Scotland / Temperate	Farmland riparian zones	Bumblebees	1	Transect walks	Fenced riparian buffer strips, over 5 m wide, have the potential to provide resources for insect pollinators in intensively grazed systems.	Habitat Loss - Agricultural intensification	Riparian buffer strips	Plant diversity enhancement	+ve
Cole et al, 2017	Scotland / Temperate	Various, including riparian buffer zones	Butterflies, bumblebees and hoverflies	2	Transect walks	Floral resources in road verges, riparian buffer strips and open scrub. These were key habitats for pollinators in relation to the agricutlural matrix.	Habitat Loss - Agricultural intensification	Riparian buffer strips	Plant diversity enhancement	+ve
Colom et al, 2021	Spain / Mediterranean	Abandoned versus restored farm land	Butterflies	22	Transect walks	Communities of flowers and butterflies became	Habitat Loss - Agricultural intensification	Riparian buffer strips	Landscape diversity enhancement	+ve

						more abundant in abandoned areas where riparian woodland recovered.				
Cortes-Fernandez et al, 2022	Balearic islands / Mediterranean	Dunes	Flower visitors	1	Observation of flower visitors	The reproductive success of endangered Eryngium maritimum L., depends on the conservation status of pollinating insects. E. Maritimum flowers through dry periods.	Climate change	Dry season forage provision	Plant diversity enhancement	+ve
Davis et al, 2018	Ireland / Temperate	Areas affected by invasive species.	Bees and hoverflies	1	Pan traps (b,w,y)	Control of invasive species is complex and potential losses and gains for biodiversity must be carefully evaluated on a case-by-case basis.	Introduced Species - Flora	Invasive plant management	Plant diversity reduction	-ve
de la Pena et al, 2018	Mediterranean	Fruit crops	Pollinators	N/A	Literature review	Wild insect pollinators are important and provision of forage out of the flowering period of the fruit	Habitat Loss - Agricultural intensification	Field margin management	Plant diversity enhancement	+ve

						crop leads to pollinator readiness.				
Dorchin et al, 2018	Israel / Mediterranean	Natural fragments	Bees	1	Pan traps (b,w,y), transect walks, netting	Natural habitat sites had higher species richness than disturbed sites. Even the smallest fragments (~1Ha) harbored unique bee assemblages.	Habitat Loss - Agricultural intensification	Protected area management	Landscape diversity enhancement	+ve
Emery & Doran, 2013	USA/ Temperate	Sand dunes with invasive G. paniculata plant species	Arthopods	3	Sweep netting	Invaded plots had almost double the total numbers of arthropods and 20% more families than the reference and managed plots.	Introduced Species - Flora	Invasive plant management	Landscape diversity reduction	+ve
Faria et al, 2021	Portugal / Mediterranean	Extensive grasslands following changed agricultural practices.	Pollinators	2	Sweep netting	Higher animal stocking rates reduced ecosystem services (pollination, biological control) and increased disservices (crop pest-infestation).	Habitat Loss - Agricultural intensification	Field margin management	Landscape diversity reduction	-ve

Fernandez et al, 2012	Spain / Mediterranean	Mediterranean scrub.	Flower visitors.	1	Observation of flower visitors	Protected areas led to greater numbers of beeflies but not necessarily greater numbers of other pollinators.	Habitat Loss - Agricultural intensification	Protected area management	Landscape diversity enhancement	+ve
Fijen et al, 2019	Italy / Mediterranean	Semi-natural areas in a Mediterranean agricultural area.	Pollinators	1	Transect walks and netting	Complex landscapes are local hotspots for both biodiversity conservation and potential ecosystem service provision.	Habitat Loss - Agricultural intensification	Protected area management	Landscape diversity enhancement	+ve
Garcia et al, 2018	Spain / Mediterranean	Burnt and unburnt areas.	Beetles	1	Pollinator exclusion and pollen load sampling	Resilience in the face of major disturbances depends on pollinator diversity, as this provides a degree of redundancy and provides time for recolonisation by specialist species.	Habitat disturbance	Protected area management	Landscape diversity enhancement	+ve
Hanula & Horn, 2011	USA / Temperate	Riparian forests, invaded, non-invaded and cleared.	Apoidea	2	Pan traps (b,w,y)	Removing Chinese Privet resulted in a great increase in the abundance (3x) and diversity of bees in	Introduced Species - Flora	Invasive plant management	Landscape diversity enhancement	+ve

						the first year after treatment.				
Hanula et al, 2015	USA / Temperate	Forest including mature riparian hardwood areas.	Bees	1	Pan traps (b,w,y)	Numbers of bees and richness were highest in mature riparian hardwood forests, compared to cleared areas or young pine or hardwood plantations. Thinning and shrub control improved bee habitat.	Habitat Loss - Agricultural intensification	Protected area management	Landscape diversity enhancement	+ve
Herrera et al, 2003	California, USA / Mediterranean	Riparian willow zones, invaded by A. donax.	Aerial and ground-dwelling insects	2	Pitfall and sticky traps	Invasive *Arundo donax* reduced the diversity of insects compared to areas dominated by native willow, particularly for the aerial insects.	Introduced Species - Flora	Invasive plant management	Landscape diversity reduction	-ve
Herrera, 2019	Spain / Mediterranean	Herbaceous montane landscapes.	All pollinators	20	Observation of flower visitors	Pollinator declines are not universal beyond anthropogenic ecosystems. Flower	Climate change	Protected area management	Altitude	+ve

						visitation increased, perhaps due to climate change.				
Herrera, 2020	Spain / Mediterranean	Various	Bees	50	Literature review	The rise of honeybees dominance as pollinators could in the long run undermine the diversity of plants and wild bees in the Mediterranean.	Introduced Species - Fauna	Honeybee population management	Competition	-ve
Hoover et al, 2012	Laboratory	Pumpkin plantation	Bumblebees	1	Observation of flower visitors	Climate change combined with agricultural intensification may alter plant chemistry, and bees may be attracted to nectar that shortens their lifetime.	Habitat Loss - Agricultural intensification	Protected area management	Temperature	-ve
Hudson et al, 2013	USA / Temperate	Riparian forests, invaded, non-invaded and cleared.	Bees and butterflies	5	Pan traps (b,w,y)	The abundance and diversity of bees and butterflies remained higher in cleared plots than in invaded	Introduced Species - Flora	Invasive plant management	Plant diversity enhancement	+ve

						plots, five years after clearing.				
Kaloveloni et al, 2015	Mediterranean	Various	Hoverflies	1	Modelling	Species abundance and richness is likely to decline and range move to higher altitudes.	Climate change	Protected area management	Altitude	+ve
Kantsa et al, 2018	Greece / Mediterranean	Lesvos scrubland.	Pollinators	2	Observation and netting	Coevolution in plant–pollinator networks shows how restoration activities might be optimised.	Habitat Loss - Agricultural intensification	Field margin management	Plant diversity enhancement	+ve
Kehinde et al, 2018	Italy and South Africa / Mediterranean	Organic and conventional Mediterranean climate vineyards.	Wild bees.	1	Pan traps (b,w,y)	Bee abundance was greater in organic vineyards in Italy and with more uncultivated land in the surrounding area. Between and within row flowers support pollinators.	Habitat Loss - Agricultural intensification	Orchard cover crop management	Plant diversity enhancement	+ve
Lazaro et al, 2016	Greece / Mediterranean	Greek islands. With and without electromagnetic fields.	Pollinators	1	Pan-traps (b,w,y)	Electromagnetism -vely affected several insect guilds, and changed the composition of wild	Electromagnetic Radiation	Protected area management	EMR	-ve

						pollinators in natural habitats.				
Lazaro et al, 2020	Sweden / Temperate	Agricultural landscape with natural and semi-natural patches.	Pollinators	1	Transect walks and observation	Overall flower abundance and richness increasing both total number of pollinator visits and richness.	Habitat Loss - Agricultural intensification	Protected area management	Plant diversity enhancement	+ve
Lazaro et al, 2021	Greece / Mediterranean	Greek islands	Bees	3	Pan traps (b,w,y) transect walks, netting	Increasing honey bee visitation rate had a -ve effect on wild bee species richness and abundance.	Introduced Species - Fauna	Honeybee population management	Competition	-ve
Lhotte et al, 2014	France / Mediterranean	Urban	Pollinators	1	Observation of flower visitors	Pollinator abundance and diversity is lower in urban areas and this threatens the survival of Teucrium pseudochamaepitys.	Habitat Loss - Urbanisation	Protected area management	Landscape diversity reduction	-ve
Lopez-Aliste et al, 2021	Chile / Mediterranean	Various	Bees	1	Literature review	There are 464 listed species of bee in Chile and related data are now included in GBIF.	Information gap	Monitoring scheme		

Lorite et al, 2020	Spain / Mediterranean	Sierra Navada mountains	Pollinators	1	Literature review	Biodiversity is high in the reserve including the pollinators of the plant species recorded.	Information gap	Monitoring scheme		
Mandelik & Roll, 2009	Israel	Habitats around almond orchards.	Wild bees.	1	Pan traps (b,w,y), transect walks, netting	Honeybees were the main bee visitor to almond flowers. The wild bee community warrants investigation as pollinators.	Habitat Loss - Agricultural intensification	Orchard cover crop management	Plant diversity enhancement	+ve
Meiners et al, 2019	California, USA / Mediterranean	Pinnacles National Park	Bees	30	Pan traps (b,w,y), transect walks, netting	The Park has a high diversity of bees, and is likely to be contributing pollination services to surrounding agricultural areas.	Habitat Loss - Agricultural intensification	Protected area management	Landscape diversity enhancement	+ve
Mendoza-Garcia et al, 2018	Spain / Mediterranean	Agricultural landscape with oilseed rape. Semi-natural oak woodland in mozaic.	Hymenoptera and Dyptera.	1	Transect netting and examination of pollen on insects	Oilseed rape and wildflower resources in agri-environmental schemes improved pollination services in agricultural landscapes.	Habitat Loss - Agricultural intensification	Field margin management	Plant diversity enhancement	+ve

Minachilis et al, 2020	Greece / Mediterranean	Mount Olympus	Bumblebees	3	Pan traps and transect walks with netting	Bumblebee-plant visitation networks were larger, more diverse and more generalized at intermediate altitudes.	Climate change	Protected area management	Altitude	+ve
Minckley et al, 2014	Mexico, USA / Mediterranean	Riparian, mesquite forest, abandoned field, grassland, and desert scrub.	Bees	22	Pan-traps (b,w,y)	Long term grazing reduces the abundance of bees, though species richness and diversity may remain the same or similar to ungrazed areas	Habitat Loss - Agricultural intensification	Grazing management	Plant diversity reduction	-ve
Morrison et al, 2017	Spain / Mediterranean	Cereal field margins.	Bees	1	Pan traps (b,w,y) and visiting insect observations.	Wider margins with trees and shrubs and a high flowering plant richness best correlated with a dense and diverse bee community.	Habitat Loss - Agricultural intensification	Field margin management	Landscape diversity enhancement	+ve
Morrison et al, 2021	Spain / Mediterranean	Agricultural plain with monoculture and mixed plots of wildflowers.	Bees	2	Oberservation of flower visitors	D. carota, P. rhoeas, and M. sylvestris were the most likely to contribute +vely to the conservation of	Habitat Loss - Agricultural intensification	Field margin management	Plant diversity enhancement	+ve

						pollinators in agroecosystems.				
Murray et al, 2012	Ireland / Temperate	Five distinct European Natura 2000 habitats	Bees.	1	Pan traps (y) and transect walks with netting	Wild bee richness and abundance were highly dependent on habitat type. Bee communities were primarily structured by local-scale factors associated with nesting resources and grazing.	Habitat Loss - Agricultural intensification	Field margin management	Landscape diversity enhancement	+ve
Nienhuis et al, 2008	Ireland / Temperate	Riparian zone.	Bees in functional groups	1	Oberservation of flower visitors	Although I. glandulifera removal does not seem to affect insect abundance, there is a need for further, regional experimental work.	Introduced Species - Flora	Invasive plant management	Plant diversity reduction	None
Nobile et al, 2021	Italy / Mediterranean	The island of Sardinia	Bees	1	Transect netting	20 bee species identified in Sardinia for the first time, based on observations made	Information gap	Monitoring scheme		

						in different coastal and mountain ecosystems of the island.				
Ornai et al, 2020	Israel	Mount Carmel Nature Reserve.	Bees	1	Transect walks and netting	The abundance and diversity of flowers and bees, and the bees' community composition, did not differ with grazing.	Habitat Loss - Agricultural intensification	Grazing management	Plant diversity reduction	None
Park & Nieh, 2017	California, USA / Mediterranean	Mediterranean scrub.	Honeybees	1	DNA barcoding of pollen on bees	Honey bee dance and pollen analysis indicated focused foraging on a restricted number of the native plants flowering at various times of the year.	Introduced Species - Fauna	Honeybee population management	Competition	Unclear
Penado et al, 2022	Portugal (Baixo Sabor Centre) / Mediterranean	Successional stages, from grasslands to oak woodlands.	Wild bees	1	Pan traps (b,w,y), with transect walks and netting	The abundance was greatest for grassland, whilst diversity was greatest in mature oak woodland.	Habitat Loss - Agricultural intensification	Woodland conservation	Landscape diversity enhancement	+ve

Petanidou et al, 2013b	Greece and Turkey / Mediterranean	Aegean islands.	Bees and hoverflies	3	Literature review	Limited research was found to exist on pollinators of the Aegean islands, so it is not possible to know the scale of decline or the primary causes.	Information gap	Monitoring scheme		
Petanidou et al, 2013a	Greece / Mediterranean	Lesvos, Olive groves.	Bees	1	Observation of flower visitors	Orchids in olive groves are suffering pollen limitation as management practices intensify.	Habitat Loss - Agricultural intensification	Orchard cover crop management	Plant diversity reduction	-ve
Petanidou et al, 2014	Greece / Mediterranean	Phrygana scrub in gardens at the University of Athens.	Pollinators	4	Observation and netting for identification	Shifts toward earlier phenology driven by climate change may reduce pollination services due to phenological mismatch.	Climate change	Protected area management	Temperature	-ve
Pinke & Pal, 2009	Hungary / Temperate	Stubble-fields	Bees	10	Observation of flower visitors	The proportion of insect-pollinated plant species is approximately 70%.	Habitat Loss - Agricultural intensification	Field margin management	Plant diversity enhancement	+ve

Pisanty et al, 2015	Israel / Mediterranean	Almond, sunflower and watermelon fields with semi-natural habitats around them.	Bees	1	Pan traps (b, w, y and pink).	Bee abundance and species richness drops across an ecotone. Ground-nesting bees dominated within fields. % semi-natural habitat has a +ve effect bee diversity.	Habitat Loss - Agricultural intensification	Protected area management	Landscape diversity enhancement	+ve
Potts et al, 2003	Israel / Mediterranean	Mount Carmel Nature Reserve	Bees	2	Transect walks and netting.	The structure of the bee community was dependent upon nectar resource diversity. Bee diversity was closely linked to floral diversity.	Habitat Loss - Fire	Protected area management	Plant diversity enhancement	+ve
Ropars et al, 2020	France / Mediterranean	Calanques National Park, phrygana and scrubland.	Bee, hoverflies and beeflies	10	Pan traps (b,w,y), transect walks, netting	Analysis of the pollination network showed that generalist and specialist pollinators do not share the same floral resources. The Cistaceae plant family acted as a	Habitat Loss - Agricultural intensification	Protected area management	Plant diversity enhancement	+ve

						central network node.				
Ropars et al, 2020	France / Mediterranean	Calanques National Park, scrubland	Bees	2	Transect walks and netting.	The presence of a diversified land cover maximized wild bee species richness, which was -vely affected by honeybee colony density.	Habitat Loss - Agricultural intensification	Protected area management	Competition	-ve
Saenz-Romo et al, 2019	Spain / Mediterranean	Mediterranean vineyards with tillage, spontaneous cover, and flower-driven cover.	Insect predators, parasitoids, phytophagous insects, and pollinators	2	Pitfall traps, field aspirator sampling above ground level	The greatest insect abundance and diversity was found for natural cover. Vegetation cover could be used to promote beneficial entomofauna in vineyards.	Habitat Loss - Agricultural intensification	Orchard cover crop management	Plant diversity enhancement	+ve
Sanchez et al, 2020	Spain / Mediterranean	Crop margins in agricultural landscapes.	Andrenidae, Halictidae, Colletidae and Melittidae.	2	Pan traps (y) and transect walks with observation	The abundance and diversity of wild bees was greater in restored margins. Significant differences in the	Habitat Loss - Agricultural intensification	Field margin management	Plant diversity enhancement	+ve

						structure of bee communities were found between shrubby and herbaceous margins.				
Schurr et al, 2019	France / Mediterranean	Calanques National Park, phrygana and scrubland.	Pollinators	1	Observation and netting for identification.	Pollination of endangered Astragalus tragacantha depended largely on solitary bees. Habitat fragementation distances adversely affected the pollination process.	Habitat Loss - Agricultural intensification	Protected area management		
Sole-Senan et al, 2018	Spain / Mediterranean	Abandoned fields, boundaries, roadverges, edges and cropped lands.	Not applicable	1	Oberservation of flower visitors	Non-cropped habitats and low levels of agricultural intensification provided greater foraging resources for pollinators and correlated with trait diversity.	Habitat Loss - Agricultural intensification	Field margin management	Plant diversity enhancement	+ve

Stefanaki et al, 2015	Greece / Mediterranean	Coastal zone plants	Pollinators	1	Literature review	Flowers that were more complex were pollinated by specialists, increasing their vulnerability to a collapse in their populations.	Information gap	Monitoring scheme	Plant diversity reduction	-ve
Traveset et al, 2018	Spain	Mallorca, in and around building sites.	Pollinators	4	Observation and netting for identification.	There was a considerable decrease in species richness and abundance, after the disturbance.	Habitat Loss - Urbanisation	Minimise ecological disturbance	Plant diversity reduction	-ve
Ulyshen et al, 2020	USA / Temperate	Riparian forests of hardwood and softwood.	Bees	1	Flight intercept traps	Eliminating Chinese privet from invaded forests increased native bee diversity near the forest floor.	Introduced Species - Flora	Invasive plant management	Plant diversity enhancement	+ve
Vieli et al, 2021	Chile / Mediterranean	Various	Pollinators	1	Literature review	There is a severe gap in knowledge about wild pollinators in Chile. Crop management needs to involve a reduced use of pesticides, inter-cropping and	Information gap	Monitoring scheme		

						retention of landscape diversity.				
Warzecha et al, 2018	Germany / Temperate	Experimental farm.	Flower visiting bees and flies.	2	Sweep netting	Plant species diversity is required to support a diverse pollinator community. Flower mixtures may not need to be highly diverse to support pollinators in agricultural landscapes.	Habitat Loss - Agricultural intensification	Sown flowering fields	Plant diversity enhancement	+ve

Appendix 2: Table of the number of each species / morphotypes captured, in each genus and order.

Order	Genus	Species / Morphotype	Number of Individuals
Coleoptera			306
	Adalia		2
		Adalia decempunctata	2
	Amara		2
		Amara sp.	2
	Anthaxia		55
		Anthaxia dimidiata	8
		Anthaxia impunctata	2
		Anthaxia parallela	20
		Anthaxia sp.	1
		Anthaxia sp1	1
		Anthaxia sp2	19
		Anthaxia sp4	1
		Anthaxia sp5	1
		Anthaxia sp6	1
		Anthaxia sp7	1
	Anthocomus		1
		Anthocomus fenestratus	1
	Aphthona		2
		Aphthona lutescens	2
	Attalus		2
		Attalus sp.	1
		Attalus sp1	1
	Cerocoma		8
		Cerocoma schreberi	8
	Chasmatopterus		20

		Chasmatopterus sp.	8
		Chasmatopterus villosulus	12
	Chryptocephalus		13
		Chryptocephalus sp.	13
	Chrysanthia		1
		Chrysanthia sp.	1
	Coccinella		3
		Coccinella septempunctata	3
	Colotes		3
		Colotes maculatus	3
	Dasytides		2
		Dasytinae sp.	2
	Heliotaurus		8
		Heliotaurus ruficollis	8
	Lobonyx		1
		Lobonyx aenus	1
	Mordellista		1
		Mordelista sp.	1
	Mylabris		3
		Mylabris quadripunctata	1
		Mylabris sp.	1
		Mylabris varians	1
	Nitidula		25
		Nitidulidae sp.	1
		Nitidulidae sp1	1
		Nitidulidae sp2	5
		Nitidulidae sp3	2
		Nitidulidae sp4	2
		Nitidulidae sp5	2
		Nitidulidae sp7	9

		Nitidulidae sp8	2
		Nitidulidae sp9	1
	Oedemera		45
		Oedemera simplex	27
		Oedemera sp.	2
		Oedemera sp1	11
		Oedemera sp2	1
		Oedemera sp3	2
		Oedemera sp4	2
	Oxythyrea		1
		Oxythyrea funesta	1
	Psilothrix		75
		Dasytinae sp.	3
		Psilothrix illustris	2
		Psilothrix viridicoerulea	70
	Rhagonycha		1
		Rhagonycha sp.	1
	Scraptia		14
		Scraptiidae sp.	14
	Scymnus		8
		Scymnus sp.	2
		Scymnus sp1	6
	Stenolopus		5
		Stenolopus teutonus	5
	Trichodes		2
		Trichodes leucopsideus	1
		Trichodes octopunctatus	1
	Tropinota		3
		Tropinota squalida	3
Hymenoptera			811

	Andrena		24
		Andrena sp.	13
		Andrena sp1	9
		Andrena sp2	2
	Anthophora		11
		Anthophila sp1	10
		Anthophora sp1	1
	Apis		27
		Apis mellifera	27
	Bombus		1
		Bombus terrestris	1
	Ceramius		1
		Ceramius lusitanicus	1
	Ceratina		9
		Ceratina sp.	8
		Ceratina sp1	1
	Colletes		2
		Colletes sp.	1
		Colletes sp1	1
	Dasypoda		59
		Dasypoda dusmeti	41
		Dasypoda hirtipes	8
		Dasypoda sp.	9
		Dasypoda sp1	1
	Eucera		3
		Eucera sp.	1
		Eucera sp1	2
	Halictus		3
		Halictus sp.	2
		Halictus sp1	1

	Hylaeus		1
		Hylaeus sp.	1
	Lasioglossum		449
		Lasioglossum (Dialictus) sp.	4
		Lasioglossum (Leuchalictus) leucozonium	8
		Lasioglossum (Leuchalictus) sp.	3
		Lasioglossum interruptus	1
		Lasioglossum malachurum	2
		Lasioglossum sp.	386
		Lasioglossum sp1	28
		Lasioglossum sp2	6
		Lasioglossum sp3	5
		Lasioglossum sp4	3
		Lasioglossum sp5	2
		Lasioglossum sp6	1
	Megachilae		13
		Megachilidae sp.	13
	Megascolia		6
		Megascolia maculata	6
	Nomada		6
		Nomada sp.	4
		Nomada sp1	2
	Osmia		1
		Osmia sp.	1
	Panurgus		191
		Panurgus sp	2
		Panurgus sp.	108
		Panurgus sp1	76
		Panurgus sp2	5

	Sphecodes		3
		Sphecodes sp.	3
	Stelis		1
		Stelis sp.	1
Lepidoptera			12
	Colias		1
		Colias croceus	1
	Euchloe		1
		Euchloe belemia	1
	Lycaena		2
		Lycaena phlaeas	2
	Meganola		1
		Meganola togatulalis	1
	Pararge		1
		Pararge aegeria	1
	Pieris		1
		Pieris rapae	1
	Polyommatus		2
		Polyommatus icarus	2
	Pyraloidea		2
		Pyraloidea sp.	1
		Pyraloidea sp1	1
	Zygaena		1
		Zygaena sarpedon	1
Grand Total			1129

Appendix 3: Table of genera and numbers captured.

The top six pollinator genera are emboldened. They made up close to 80% of all individuals captured. The genus Apis, whose sole species is Apis mellifera (the honey bee), completed the 80% level.

Genus	Number of individuals	%	Cumulative %
Lasioglossum	449	39.8	40
Panurgus	191	16.9	57
Psilothrix	75	6.6	63
Dasypoda	59	5.2	69
Anthaxia	55	4.9	73
Oedemera	45	4.0	77
Apis	27	2.4	80
Nitidula	25	2.2	82
Andrena	24	2.1	84
Chasmatopterus	20	1.8	86
Scraptia	14	1.2	87
Chryptocephalus	13	1.2	88
Megachilae	13	1.2	89
Anthophora	11	1.0	90
Ceratina	9	0.8	91
Cerocoma	8	0.7	92
Heliotaurus	8	0.7	93
Scymnus	8	0.7	93
Megascolia	6	0.5	94
Nomada	6	0.5	94
Stenolopus	5	0.4	95
Coccinella	3	0.3	95
Colotes	3	0.3	95
Eucera	3	0.3	96
Halictus	3	0.3	96
Mylabris	3	0.3	96
Sphecodes	3	0.3	96

Tropinota	3	0.3	97
Adalia	2	0.2	97
Amara	2	0.2	97
Aphthona	2	0.2	97
Attalus	2	0.2	97
Colletes	2	0.2	98
Dasytides	2	0.2	98
Lycaena	2	0.2	98
Polyommatus	2	0.2	98
Pyraloidea	2	0.2	98
Trichodes	2	0.2	98
Anthocomus	1	0.1	99
Bombus	1	0.1	99
Ceramius	1	0.1	99
Chrysanthia	1	0.1	99
Colias	1	0.1	99
Euchloe	1	0.1	99
Hylaeus	1	0.1	99
Lobonyx	1	0.1	99
Meganola	1	0.1	99
Mordellista	1	0.1	99
Osmia	1	0.1	99
Oxythyrea	1	0.1	100
Pararge	1	0.1	100
Pieris	1	0.1	100
Rhagonycha	1	0.1	100
Stelis	1	0.1	100
Zygaena	1	0.1	100
Total	1129		