Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

STRIVE
Report Series No.115

SIMBIOSYS: Sectoral Impacts on Biodiversity and Ecosystem Services

STRIVE

Environmental Protection Agency Programme

2007-2013

SSTI Strategy for Science, Technology and Innovation

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government

Environmental Protection Agency

The Environmental Protection Agency (EPA) is a statutory body responsible for protecting the environment in Ireland. We regulate and police activities that might otherwise cause pollution. We ensure there is solid information on environmental trends so that necessary actions are taken. Our priorities are protecting the Irish environment and ensuring that development is sustainable.

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EPA STRIVE Programme 2007-2013

SIMBIOSYS: Sectoral Impacts on Biodiversity and Ecosystem Services

(2007-B-CD-1-S1)

Synthesis Report

Prepared for the Environmental Protection Agency

by

Trinity College Dublin

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ACKNOWLEDGEMENTS

SIMBIOSYS (http://www.tcd.ie/research/simbiosys/) was funded as part of the Science, Technology, Research and Innovation for the Environment (STRIVE) Programme (2007-B-CD-1-S1), financed by the Irish Government under the National Development Plan 2007–2013, administered on behalf of the Department of the Environment, Heritage and Local Government by the Irish Environmental Protection Agency.

We are grateful to the SIMBIOSYS Steering Committee for their support and advice throughout the project: Brian Donlon and Niamh Connolly (Environmental Protection Agency), Andy Bleasdale (National Parks and Wildlife Service), Vincent O'Malley (National Roads Authority), Gráinne O'Brien (Bord Iascaigh Mhara), and Prof Michael Usher (University of Stirling).

The WP1 researchers are grateful to all the farmers for allowing us to sample in their fields. We are also grateful to the following for help, advice and collaboration: Mairi Knight, Jonathan Ellis and Lucy Turner (University of Plymouth), Trevor Hodkinson and Sarah Eftonga (Trinity College Dublin [TCD]), James Carolan (National University of Ireland Maynooth [NUIM]), Colm Roynane and Tom Gittings (Entomological consultants), Laura Kirwan (Waterford IT), Samantha Cook (Rothamsted Research), Darren Murray (VSN International). Thanks for practical help with field and lab work to Zeno Wong, Leanne Casey, Aoife O'Rourke, Susannah Cass, Kate Harte, Michael Crowley, Evie Flynn, Catherine Fontana, Soledad Colombe, James Desaegher, David Stanley, Florence Hecq, Katie Wennig, and Roseanne Hennessy. We are grateful to John Finnan (Teagasc), JJ Leahy (Irish Bioenergy Association) and Mel McDonagh (Department of Agriculture Fisheries and the Marine [DAFM]) for input to the sectoral review. PhD students Dara Stanley and Jesko Zimmermann received additional funding for travel and training from the University College Dublin (UCD) Graduate Research Education Programme in Sustainable Development which was itself funded by IRCSET and IRCHSS.

The WP2 researchers are grateful to Paul Green (Botanical Society of the British Isles), Mairead Kiely and Steven Darby (University College Cork [UCC]), Xie Quishi (Aquatic Services Unit – Environmental Research Institute, UCC), Lorraine Mounsey (TCD), Louise Russell, Jovanna Arndt, Dearbhail McKenna, Tad Kirakowski, Eugene Finnerty, Mary Hamilton, Aisling O'Shea, Eimear Egan, Sonia Monteiro, Emily Goldstein, Vincent Murphy, Nicola Foley, Stephanie Lombard, Sean Halligan, Ross Macklin, Noel Enright, Cian O'Connor and Siobhán Cremin (all UCC); and Simon Mills. We are also particularly grateful to the landowners and Kerry, Cork, Waterford and Wexford City and County Councils.

The WP2 researchers also gratefully thank the collaboration from Colin Kelleher from the National Botanic Gardens (Dublin), Tim Healy and Patrick O'Rafferty (Botany and Plant Science, National University of Ireland, Galway [NUIG]) for their collaboration with sample collection. We also wish to acknowledge the Botanical Museum (LD) O. Vallgatan Sweden, for the facilitation of access to the European materials.

The WP3 researchers are grateful to the following for help, advice and collaboration: Ciarán McGonigle (Loughs Agency), Gráinne O'Brien and regional officers (Bord Iascaigh Mhara), Catherine McManus & staff (Marine Harvest Ireland), Heike Büttger (BioConsult, Germany), Carlos Rocha (TCD), Nick Clipson, Evelyn Doyle and Bas Boots (UCD) and Claire Guy and Dai Roberts (Queen's University Belfast [QUB]). Thanks for practical help with field and lab work to Jennifer Coughlan, Javier Atalah, Julien Chopelet, Kelly Dunagan, Paul Brooks, Jayne Fitch, Erin Gleeson, Bas Boots, Angela Gallagher, Jesko Zimmermann, Rónan Mag Aoidh, Ciarán McGonigle & colleagues from the Loughs Agency, Claire Guy, Francis O'Beirn. Judith Kochmann's PhD research was funded by the UCD Graduate Research Education Programme in Sustainable Development which was itself funded by IRCSET and IRCHSS. We are grateful to the Department of Arts, Heritage and the Gaeltacht (DAHG) for permission to use a report submitted to them as the basis for the strategic review of sectoral impacts on coastal marine ecosystems and to the following for input to that report: Drs Eamonn Kelly and Liz Sides (DAHG), Prof. Michael Elliott (University of Hull), Prof. Stephen J. Hawkins (University of Southampton), Prof. David M. Paterson (St Andrews University), Prof. David G. Raffaelli (University of York), and Dr Pádraig Whelan (UCC).

The WP4 researchers are grateful to John McCann (Sustainable Energy Authority Ireland), Ainhoa Gonzáles and Soledad Colombe (TCD), staff of BirdWatch Ireland, Justin Gleeson and Gavin Daly (NUIM), and Richard Nairn (Natura Environmental Consultants) for their discussions and input into the Wind Sector Review.

DISCLAIMER

EPA STRIVE PROGRAMME 2007–2013

Published by the Environmental protection Agency, Ireland

PRINTED ON RECYCLED PAPER

ISBN: 978-1-84095-515-6 9/13/250

Price: Free

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Executive Summary

The SIMBIOSYS Project investigated the impacts that human activity have on biodiversity and ecological functioning, and the associated benefits of biodiversity to human society, that is, ecosystem services. Three expanding sectors of enterprise were addressed in the project: (i) the cultivation of bioenergy crops; (ii) the landscaping of road corridors; and (iii) the aquaculture of sea-food. Field-based studies quantified biodiversity at the genetic, species and habitat levels under current commercial regimes, compared with traditional practices, and investigated ecosystem service delivery in all three sectors. The SIMBIOSYS Project has been a four-and-a-half-year research effort, involving six leading academics in four institutions, six PhD students, eleven research assistants at graduate and postdoctoral level, more than twenty MSc and undergraduate students and many other academic collaborators, both in Ireland and overseas.

Overall, we found differential impacts of sectoral activity on the taxa studied. Whilst some species benefited, others were not affected significantly, or were affected negatively, by the activities examined. For example, several bee species benefited from the floral resources provided by oilseed rape, grown for biodiesel, whilst some other flower-visiting insects, including many species of hoverfly, did not. Road-landscaping treatments had few positive or negative impacts on plant, beetle or pollinating insect species. The project also demonstrated that Pacific oysters have now formed some well-established feral populations on the Irish coast, and documented a range of impacts on native ecosystems. These included negative impacts on species and habitat types that are of national and international importance (e.g. the protected habitat-forming species, the honeycomb worm *Sabellaria alveolata*), and changes to a number of ecosystem processes.

Additionally, we confirmed the positive relationship between species richness and ecosystem functioning and the delivery of ecosystem services. These relationships were apparent regardless of management type within a sector. Thus, management to promote species richness in particular taxa can have knock-on benefits in terms of the delivery of ecosystem services. For example, if the diversity of predatory ground beetles and pollinating insects in farmland increases, so does the potential for natural pest control and pollination services.

Finally, the project has identified some 'win-win' situations where both ecosystem health and socioeconomic outputs can be maximised. For example, road-landscaping treatments that result in the greatest flowering-plant species richness also require the lowest inputs and are, therefore, more sustainable in the long term; using sterile triploid oysters in aquaculture can reduce the risk of invasion and adverse impacts on coastal ecosystems, and triploid individuals grow more quickly; improving *Miscanthus* crop yields has both an economic benefit but also increases rates of carbon sequestration. These findings are crucial for a sustainable future.

Therefore, we recommend that specific policy actions to enhance biodiversity are required to increase the delivery of ecosystem services – not just in protected areas, but in also in highly managed/exploited sites. In addition, we recommend the prevention of the introduction of non-native species or non-native varieties that have the potential to spread in the wild. Furthermore, environmental and socioeconomic decision-making should be integrated with regards to biological resource management and biodiversity protection. Appropriate management can be specifically implemented to maximise the delivery of particular ecosystem services in any given context. Biodiversity and society can both benefit.

1 Introduction

Despite international commitment to halt global biodiversity loss by 2010, biodiversity continues to decline throughout the world (Butchart et al. 2010), including in Ireland (Department of Arts, Heritage and the Gaeltacht [DAHG] 2011). Although biodiversity can be measured at three fundamental levels of biological organisation (genetic, organismal and habitat), most focus in terms of research and policy has been at the species level, one aspect of organismal diversity. Determining species loss is complex, but it is widely accepted that current species extinction rates are higher than would be expected compared with background rates (Barnosky et al. 2011). Biodiversity loss has profound implications for ecological functioning as the rates of many ecosystem processes tend to be positively related to species richness (Hooper et al. 2005; 2012), and biodiversity also tends to increase the stability of ecosystem functions over time (Cardinale et al. 2012). However, this relationship is not always apparent in a given context, is often non-linear, and species contributions to functioning are not equal, with key species often exerting disproportionate influence (Schmid et al. 2009). Close links between biodiversity, ecosystem functioning and the provision of ecosystem services to society are often found (Millennium Ecosystem Assessment 2005). Thus, biodiversity loss can have knock-on impacts on both the use and non-use value of natural capital (The Economics of Ecosystems and Biodiversity 2010). However, the specific consequences of the loss of particular elements of biodiversity for particular ecosystem functions or services in a given context are as yet poorly understood.

The primary proximate drivers of biodiversity loss (habitat loss and fragmentation, climate change, invasive alien species, unsustainable exploitation and pollution [Millennium Ecosystem Assessment 2005]) arise as a result of human population growth and global enterprise in a range of sectors. The SIMBIOSYS Project was initiated to determine the effects of three growing sectors of Irish activity on biodiversity and the provision of ecosystem services. These sectors were: (i) bioenergy crop cultivation; (ii) landscaping along newly developed road corridors; and (iii) cultivation of fish and shellfish via aquaculture. Importantly, the project addressed biodiversity not only at the species level but also at the genetic and habitat level, and encompassed a range of ecosystem services, including provisioning, regulating and cultural services (Table 1.1). Several of these services were assessed in more than one sector (for example, pest control by natural enemies was examined in both the energy crops and the road landscapes; the provision of food in both the energy crops and aquaculture; and invasion resistance in both the road landscapes and aquaculture) (Fig. 1.1).

Table 1.1. Categorisation of ecosystem services according to the framework proposed by Haines-Young and Potschin (2010); examples of services within each category are also given.

Ecosystem service category	Examples
Provisioning	Food, water
	Raw materials, medicinal & ornamental resources
	Biofuels
Regulating & Maintenance	Bioremediation, wastewater treatment
	Wind breaks, water storage
	Global climate regulation, water purification, formation and maintenance of soil
	Lifecycle maintenance, biological control of pests and diseases
Cultural	Areas of natural beauty, sense of peace
	Nature watching, hunting/fishing, scientific research, education

1.1 Structure and Partners

The SIMBIOSYS Project addressed three sectors of increasing activity in Ireland: (i) the cultivation of bioenergy crops; (ii) the landscaping of road corridors; and (iii) the aquaculture of sea-food. Each sector formed a work-package (WP), led by a principal investigator (PI) (WP1: Energy crops – Prof Mark Emmerson; WP2: Road landscaping – Dr Pádraig Whelan; WP3: Aquaculture – Dr Tasman Crowe), with cross-cutting research questions (Fig. 1.1). In addition, in-depth reviews were made of each sector, incorporating not just academic literature but unpublished reports and 'grey literature'.

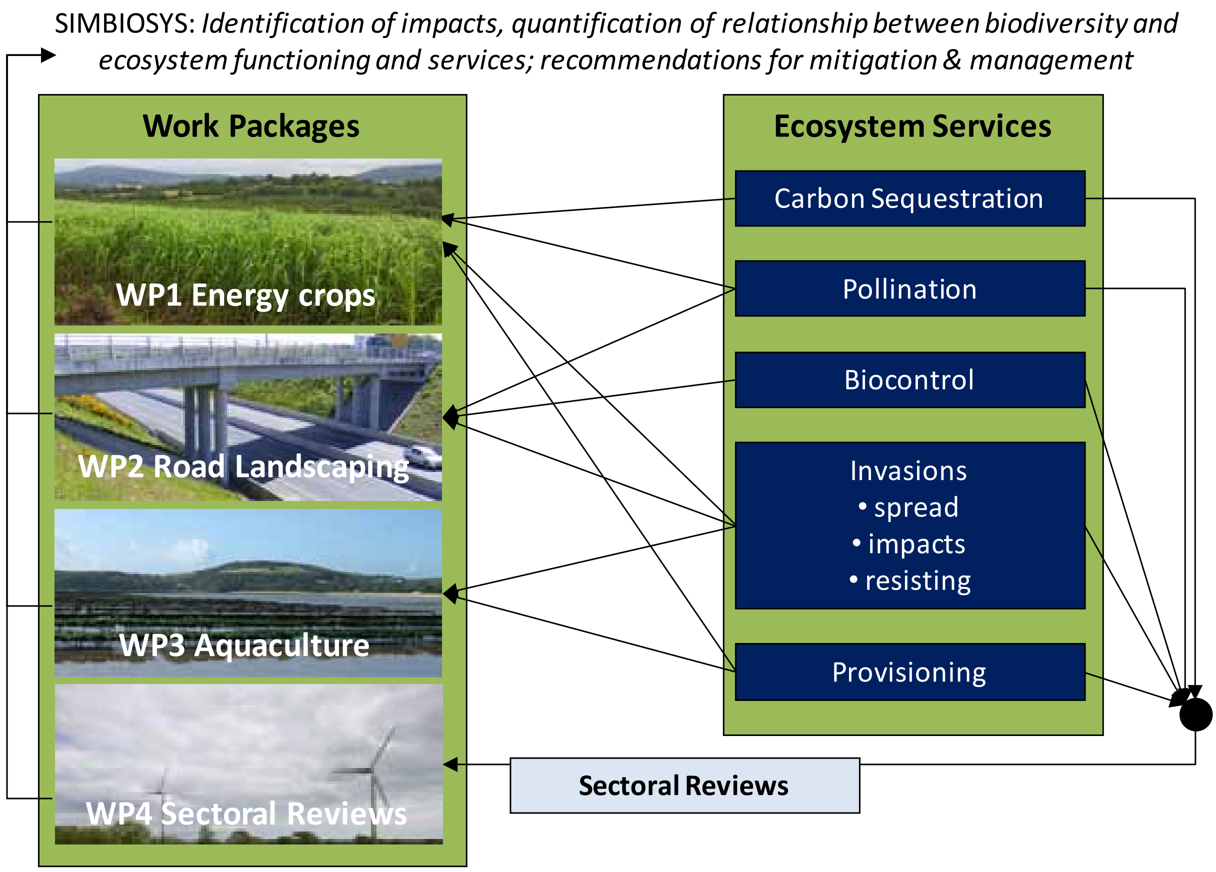


Figure 1.1. Structure of the SIMBIOSYS Project: work-packages (WPs) are given in the box on the left and the Ecosystem Services addressed in the box on the right. Arrows indicate ecosystem services addressed in the project in each sector.

The SIMBIOSYS project also executed two additional sectoral reviews on: (i) the impacts of wind farms on biodiversity and (ii) sectoral impacts on marine coastal habitats (WP4: Sectoral reviews – Dr Jane Stout). The project was coordinated and managed by Dr Jane Stout and Drs Jens Dauber and David Bourke respectively.

Four partner institutions were involved in the project: Trinity College Dublin (TCD) (lead), University College Dublin (UCD), University College Cork (UCC) and the National University of Ireland Galway (NUIG). Several other institutions and individuals were also involved with the project, as collaborators, advisors and stakeholders (please see Acknowledgements for details). Six PhD students and three postdoctoral researchers were the primary data gatherers, supervised by PIs. These PhD students and their research topics were:

1 Jesko Zimmermann: Energy crops & carbon sequestration (PI Mike Jones);

2 Dara Stanley: Energy crops & pollination (PI Jane Stout);

3 Erin O'Rourke: Natural enemies in energy crops and roadsides (PI Mark Emmerson);

4 Rosalyn Thompson: Vegetation in energy crops and roadsides (PI Pádraig Whelan);

5 Dannielle Green: Aquaculture impacts on ecosystem functioning (PI Tasman Crowe);

6 Judith Kochmann: Aquaculture impacts of invasion (PI Tasman Crowe).

The postdoctoral researchers were:

1 Dr Myriam Callier: Impacts of salmon farming (PI Tasman Crowe);

2 Dr Jens Dauber: Impacts of energy crops (PI Jane Stout);

3 Dr David Bourke: Impacts of energy crops, road landscaping and wind-energy (PI Jane Stout).

1.2 Main Objectives

The project's overall objectives were to:

1 Quantify the impact of several sectors on biodiversity at the genetic, species and landscape scales;

2 Determine the consequences of biodiversity change for ecosystem functioning and services;

3 Recommend management practices to mitigate for sectoral impacts;

4 Provide a sound evidence base to inform policy decisions;

5 Train a number of highly qualified personnel at the interface between research, policy and management.

Within this framework of broad objectives, each WP had a specific objective. Work-packages were linked and integrated through the ecosystem services they addressed, and the research team met regularly to ensure cohesion and integration in the project. This report is structured around the WPs, giving rationale, a summary of findings and key recommendations and conclusions for decision-makers.

2 Impacts of Energy Crops on Biodiversity and Ecosystem Functioning

2.1 Context

To mitigate global climate change and substitute fossil fuels, bioenergy will become an important component of global and national energy portfolios. As a result, several countries, including Ireland, have introduced policies and targets to increase the contribution of bioenergy (biomass in particular) to the national energy supply, and to promote the increasing application of bioenergy generation (Donnelly et al. 2011). At the same time, there are major concerns about the introduction of a large land-use sector that could further accelerate land-use change and associated biodiversity loss (Beringer et al. 2011; Eggers et al. 2009), and disruption to the delivery of ecosystem services (Werling et al. 2011). Furthermore, the large-scale cultivation of energy crops may actually increase greenhouse gas (GHG) emissions and environmental degradation, or introduce risks for food security if not managed correctly (Robertson et al. 2008; Wissenschaftliche Beirat der Bundesregierung Globale Umweltveränderungen 2009).

The expansion of biomass production will induce complex interactions among a large number of important ecosystem processes that are poorly understood (Dale et al. 2010). The conversion of existing crops or other land to biomass will be accompanied by changes in land management, including altered fertilisation, irrigation, cultivation, and harvesting regimes (Dale et al. 2010). These changes will affect biodiversity and ecosystem functioning at field scale and thus the ecological services those ecosystems provide, but the direction and magnitude of these effects are largely unknown (Dauber et al. 2010). In addition, increases in energy cropping may contribute to the structural simplification of agricultural landscapes, resulting in the loss of semi-natural habitats and hedgerows, increased use of more intensive and specialised cropping systems, and the creation of larger fields (Firbank et al. 2008). We investigated the impacts of energy-crop cultivation on species biodiversity at three trophic levels: (i) primary producers (plants); (ii) primary consumers (flower-visiting insects); and (iii) secondary consumers (carabid beetles). In addition, we examined effects on genetic-level biodiversity (of bumblebees) and landscape-level habitat diversity, in terms of the compositional heterogeneity (number of land-use/habitat components in the landscape and their relative proportions) and configurational heterogeneity (spatial pattern of the landscape) (Fahrig et al. 2011; Flick et al. 2012). Furthermore, we quantified effects of energy crops on ecosystem services, including soil carbon sequestration, pollination by flower-visiting insects and biocontrol by natural enemies (carabid beetles). We used two model bioenergy crops with contrasting management requirements: the perennial rhizomatous grass *Miscanthus* x *giganteus* and the annual oil seed crop *Brassica napus* L.

2.1.1 Carbon Sequestration

The use of biomass for energy production was traditionally considered largely carbon neutral. However, recent research has shown that this is not necessarily the case and that bioenergy production can act as either a carbon sink – leading to carbon sequestration – or can be a net source of carbon under certain circumstances. Loss of vegetation and soil disturbance due to ploughing when converting natural and managed ecosystems into bioenergy crops can lead to CO_2 emissions that can take centuries of bioenergy use to compensate for (Searchinger et al. 2008; Fargione et al. 2008). On the other hand, perennial rhizomatous energy crops such as *Miscanthus* have the potential to incorporate and store plant organic material into the soil, therefore acting as active GHG sinks. Also, in the case of *Miscanthus*, soil disturbance caused by ploughing only takes place during initial planting, leading to a stabilisation of soil organic matter. Finally, *Miscanthus* is usually harvested during spring time, allowing senescence and therefore the accumulation of plant litter, supporting further carbon sequestration. Studies using modelling as well as research on experimental *Miscanthus* plantations in counties Carlow and Tipperary have shown a high soil-carbon sequestration potential under Irish conditions (Dondini et al. 2009; Clifton-Brown et al. 2007). However, sequestration rates may differ on commercial plantations due to differences in soil properties and farming practices, and the impacts of planting *Miscanthus* on existing soil organic carbon stocks are also unclear. Moreover, although only rarely mentioned in the scientific literature (see Sage et al. 2010; Semere & Slater 2007), commercial farms in Ireland have large open patches within *Miscanthus* crops which may have impacts on crop yield and soil carbon sequestration.

2.1.2 Pollination

Pollination is an essential supporting ecosystem service, benefiting the majority of flowering-plants species (Ollerton et al. 2011), including many major food and seed oil crops. The value of pollination to the world economy has been estimated at €153 billion per year (Gallai et al. 2009), with a figure of €85 million in Ireland primarily for clover, soft fruit, peas and beans, apples and oilseed rape (Bullock et al. 2008). However, pollinator biodiversity is threatened by land-use change and agricultural intensification (Kearns et al. 1998; Kremen et al. 2002). Pollinating insects require a variety of flowers to forage on, but also require habitat for nesting, over-wintering and mating. Since these insects tend to be highly mobile organisms with large foraging distances (Gathmann & Tscharntke 2002; Knight et al. 2005), they can also be affected not only by changes in crop types but also by the composition of the surrounding landscape (Steffan-Dewenter et al. 2002). The effects of energy crops on pollinators and pollination services have not been previously studied, but both grass and entomophilous energy crops have the potential to affect pollinator diversity and community composition, as well as the availability of floral and nesting resources for pollinator populations. This may have knock-on impacts on the delivery of pollination services to both wild and crop plants through the modification of plant–pollinator interaction networks, which may themselves be affected by the composition of the surrounding landscape. Finally, oilseed rape is a mass flowering crop and may have particular impacts on populations of the primary group of insects that visit its flowers, the bumblebees, and on the pollination of native plant species via the transfer of pollen.

2.1.3 Natural Enemies of Crop Pests

Ground beetles (Coleoptera, Carabidae) live on the soil surface and feed on other ground-dwelling invertebrates. Abundant and diverse, their biology is well known and they can be studied with a standardised methodology (pitfall trapping), which makes them suitable for investigating how changes in land-use affect ground-dwelling invertebrates. They have been studied intensively in agricultural ecosystems (Sanderson 1994; Alderweireldt & Desender 1994), and the influence of various agricultural factors (e.g. crop type, management practices, use of pesticides) on carabid biology (phenology, density, activity, spatial distribution, survival, dispersal) investigated, with particular attention on the impact of their predation on agricultural pests (Thiele 1977; Sunderland & Vickerman 1980; Carcamo & Spence 1994). The diversity, abundance and community composition of ground beetles in bioenergy crops as well as their role in the provision of natural biological control services had not previously been examined prior to the start of the SIMBIOSYS Project.

2.2 Work-package Objectives

This WP investigated how land-use through the production of bioenergy crops contributes to biodiversity change and loss or enhancement of ecosystem services in agro-ecosystems. The WP specifically addressed the following objectives:

- Documentation of how bioenergy crop production affects biodiversity at a hierarchy of scales, including genetic, species and landscape diversity;
- Investigation of how field margins in energy crops contribute to biodiversity of associated flora and fauna;
- Understanding of how bioenergy crops contribute to the biodiversity of pollinators, natural enemies, and agricultural weeds at the landscape scale in agro-ecosystems;
- Quantification of the relationship between biodiversity and soil carbon sequestration in bioenergy crops;
- Documentation of correlations between biodiversity and associated ecosystem functions and services;
- Definition of the mechanisms underpinning biodiversity effects on ecosystem services.

2.3 Study Sites

Field surveys were carried out during 2009–2011 on commercial farms in south-east Ireland. Fifty farms were initially selected (Fig. 2.1), ten for each of five crop types: (i) grass silage (representing current/traditional perennial land-use); (ii) *Miscanthus* planted on former arable land; (iii) *Miscanthus* planted on former grassland; (iv) winter oilseed rape; and (v) winter wheat (representing current/traditional annual land-use). Since large-scale commercial plantation of *Miscanthus* in Ireland only started in 2006, all field sites were two to three years from planting at the time of sampling. These farms were surveyed for plants, flower-visiting insects and carabid beetles; and soil samples were analysed for organic carbon content. Sampling used current best-practice techniques appropriate for each taxonomic group (for details see Stanley, O'Rourke, Zimmermann, Thompson PhD theses). In addition, further smaller-scale experiments were carried out to investigate biodiversity and ecosystem services in energy crops (including bee genetic diversity, pollination services, biocontrol and soil carbon sequestration), and a survey of spiders in a subset of the sites (10 *Miscanthus* on former arable land and 10 winter wheat fields) was made using a range of sampling techniques (for details see Hennessy 2009 unpublished thesis). Furthermore, landscape composition (land cover types and habitats according to Fossitt [2000]) and configuration surrounding each of the 50 fields were characterised in a 1km x 1km square with the sampling field at the centre (see Bourke et al. 2013 for further details).

2.4 Summary of Findings

2.4.1 Impacts on Species Diversity

Significant differences in species richness and abundance of individuals were found between crop types in all three trophic groups of species studied

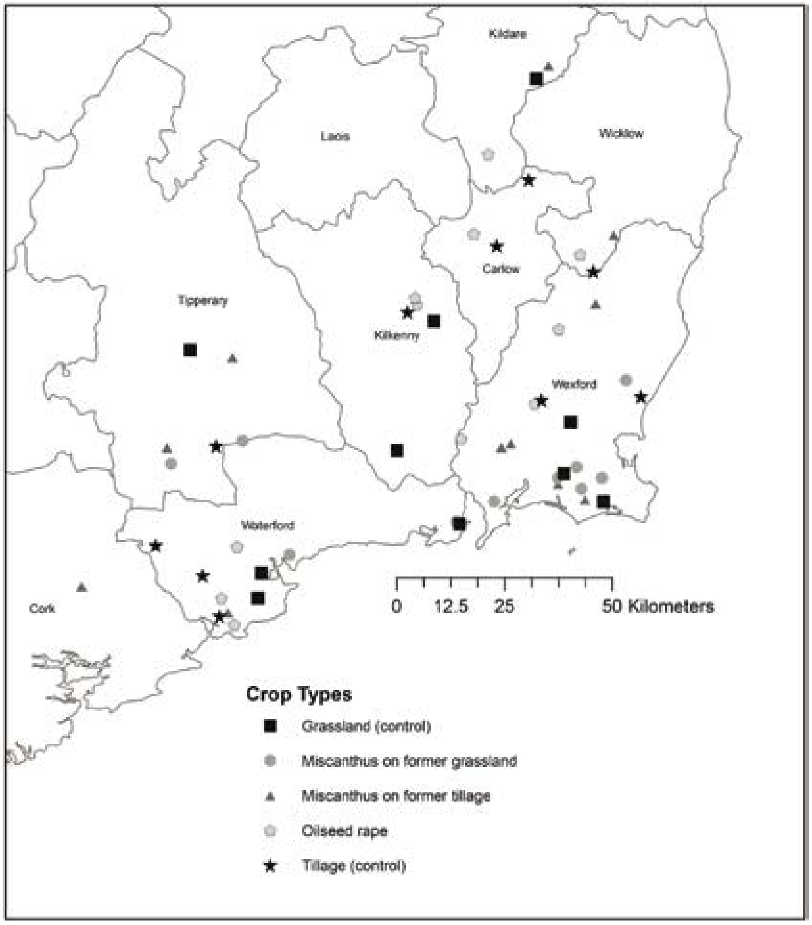


Figure 2.1. The 50 SIMBIOSYS study sites: commercial farms with either grass silage, *Miscanthus* planted on former arable land, *Miscanthus* planted on former grassland, winter oilseed rape or winter wheat.

(Fig. 2.2). There were significantly fewer plant species in winter wheat compared to all other crop types, and significantly more pollinating insect species in oilseed rape. Differences were less clear for the carabid beetles, with more species in oilseed rape compared with the perennial crops (both *Miscanthus* types as well as the grass silage), but no difference between oilseed rape and winter wheat, or between winter wheat and the perennial crops. Similar patterns were found in terms of the abundance of individuals (insects) and cover (plants) (data not shown). Spider species richness, which was measured in *Miscanthus* on former arable land and winter wheat, increased with prey composition and, to a lesser extent, vegetation composition. However, only immature spiders were found to differ in relation to crop type: other invertebrates (including mature spiders) and vegetation composition were similar in the two crop types.

Within the pollinating insect group, we found few differences between crop types for hoverflies, but more bumblebees in oilseed rape than in *Miscanthus* or conventional wheat. We also found more butterflies in *Miscanthus* fields than conventional grass silage. Higher species richness and abundance of solitary bees were found in both energy crops (oilseed rape and *Miscanthus*) than in conventional wheat, and significantly more trap-nesting bees and wasps emerged from nests left in *Miscanthus* than in any other crop type. This suggests that both energy crops provide habitats for solitary bees, with perennial *Miscanthus* possibly being most important. However, although there were differences in the composition of communities of bumblebees and hoverflies among the different crop types, these differences were driven by different proportions of the same common species, not by the presence of novel communities. However, differences in solitary bee communities were found between oilseed rape and *Miscanthus* with different species found among crop types, suggesting that a diversity of crop types in the landscape could be beneficial for this group. With regards to nesting and floral resources, significantly more non-crop flowers were available for pollinators in the energy crops than in conventional ones. However, similar numbers of bumblebees were found searching for nests in all crop types, although they searched almost exclusively in the field margins and hedges. Significantly more flowers, and species richness of all pollinator groups, were found in the field margins and hedges compared to the field centres (see Stanley and Stout 2013 for further details).

Within-field heterogeneity in the establishment of *Miscanthus* plants in commercial fields can result in open patches within the crop vegetation and patchiness in light penetration to the ground level. We investigated whether this patchiness had an effect on the biodiversity associated with, and yield of, the *Miscanthus* crop. Open patches were quantified on 14 farms, and ranged from $0.07m^2$ to $43.50m^2$ in

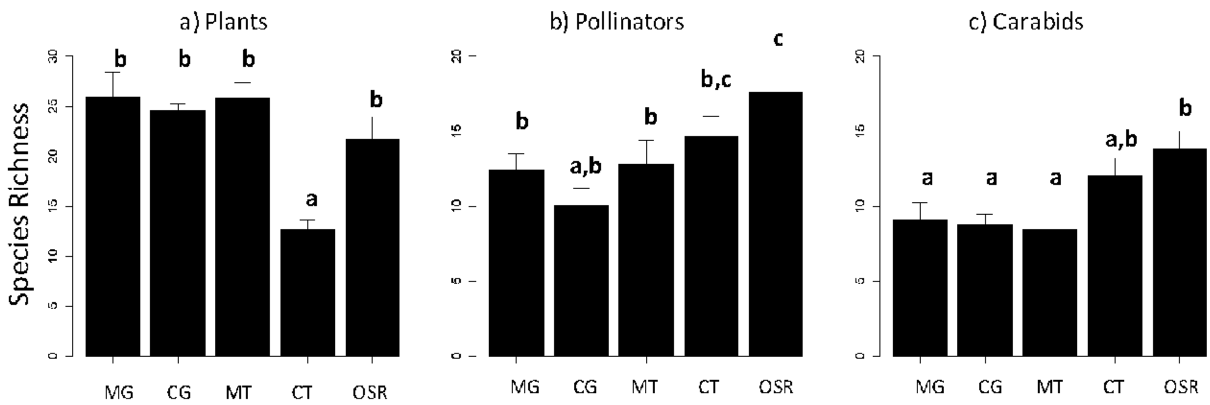


Figure 2.2. Mean (+SE) number of species of a) plants, b) flower-visiting insects and c) carabid beetles in the five crop types (MG: *Miscanthus* planted on former grassland; CG: grass silage; MT: *Miscanthus* planted on former arable land; CT: winter wheat; OSR: oilseed rape). Letters above bars indicate significant differences for each trophic group (*p*<0.05).

Miscanthus on former arable land and from 1.55m^2 to 212.88m^2 in *Miscanthus* on former grassland. The light penetration to the lower canopy ranged massively, from 1.20% to 94.58% in *Miscanthus* on arable land and from 2.85% to 96.16% in *Miscanthus* on grass; and the estimated yield was on average 9.5 t d.m. ha^{-1} yr^{-1} (and only in three fields were yields below 8 t d.m. ha^{-1} yr^{-1}, which is the minimum expected yield level for *Miscanthus* in Ireland). We found that light intensity was positively correlated with the number of plant species and vegetation cover of non-crop plants in the stands, and an increase in vegetation cover had a positive impact on species richness of ground beetles and on the activity density of spiders (for more details see Dauber et al. in revision). As patchiness decreases with the maturation of a stand (5–20 years), a mosaic of establishing and mature stands at the farm or landscape scale would be necessary to maximise biodiversity in the long term.

2.4.2 Impacts on Populations and Genetic Diversity

The *Bombus sensu strictu* group is a complex of cryptic bumblebee species in Ireland (Murray et al. 2008), and the most common flower visitors to oilseed rape. It is extremely difficult to tell these species apart morphologically (Carolan et al. 2012) as a result little is known about the individual requirements of these species, their colony densities, or how they are distributed. This information is important to manage this pollinator group as its members play an important role in oilseed rape pollination. By sampling 14 spring oilseed rape fields and using molecular methods (Restriction Fragment Length Polymorphism [RFLP] fingerprinting and microsatellite genotyping), we examined the proportions of these species in relation to each other, and the number of colonies of each species in comparison to the second most common visitor to oilseed rape, *B. lapidarius*. We also quantified the landscape around each of the oilseed rape fields to see if this influenced the proportions or number of colonies within the fields. We found unequal proportions of three cryptic species (with *B. terrestris* and *B. lucorum* most abundant, and *B. cryptarum* rarer) and estimated an extremely high number of colonies of these species in oilseed rape fields (Fig. 2.3) (Stanley et al. 2013).

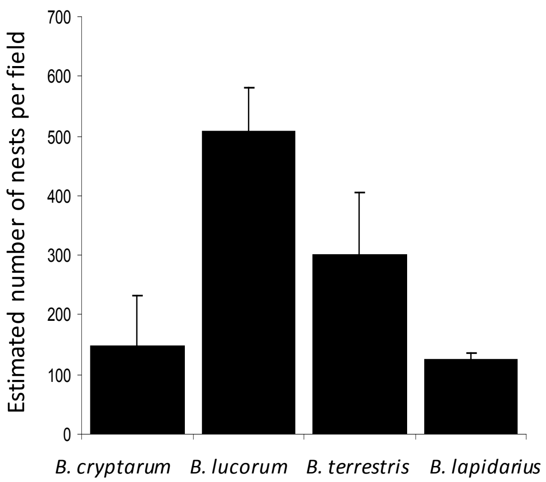


Figure 2.3. Mean number of colonies (+SE) of the *Bombus sensu strictu* group and of *B. lapidarius* found per oilseed rape field.

2.4.3 Influence of Surrounding Landscape

While crop type effects on biodiversity are shown in Section 2.3.1, we also found that field-scale species biodiversity was dependent on surrounding landscape compositional and configurational heterogeneity (Figs 2.4 & 2.5; see Bourke et al. 2013 for more details). The 50 landscapes were dominated by agricultural improved grassland and tillage cropping systems, with mean proportions of 45% and 41%, respectively. Semi-natural habitats accounted for just under 3% (range 0–16%) of the landscapes, and included semi-natural wet grassland (1.4%), freshwater marsh (0.46%), scrub (0.89%), oak-ash-hazel woodland (0.10%), riparian woodland (0.01%), and wet willow-alder-ash woodland (0.08%).

Figure 2.4. (Opposite) Selected relationships between species response variables and landscape composition metrics: (a) carabid beetle abundance and % grassland, (b) carabid beetle abundance and percentage of semi-natural habitat, (c) hoverfly abundance and hedgerow length, (d) hoverfly diversity and Shannon's habitat diversity index, (e) bumblebee abundance and % grassland, and (f) solitary bee abundance and Shannon's habitat diversity index. Data are aggregated across all crop types as no significant crop type-landscape context interactions were found. All explanatory variables are standardised. Shaded bands represent 95% confidence intervals. Two landscapes illustrating examples of landscape compositional structures: (g) high Shannon Habitat Diversity (1.370), and (h) low Shannon Habitat Diversity (0.252). Habitats were classified according to Fossitt (2000) (from Bourke et al. 2013).

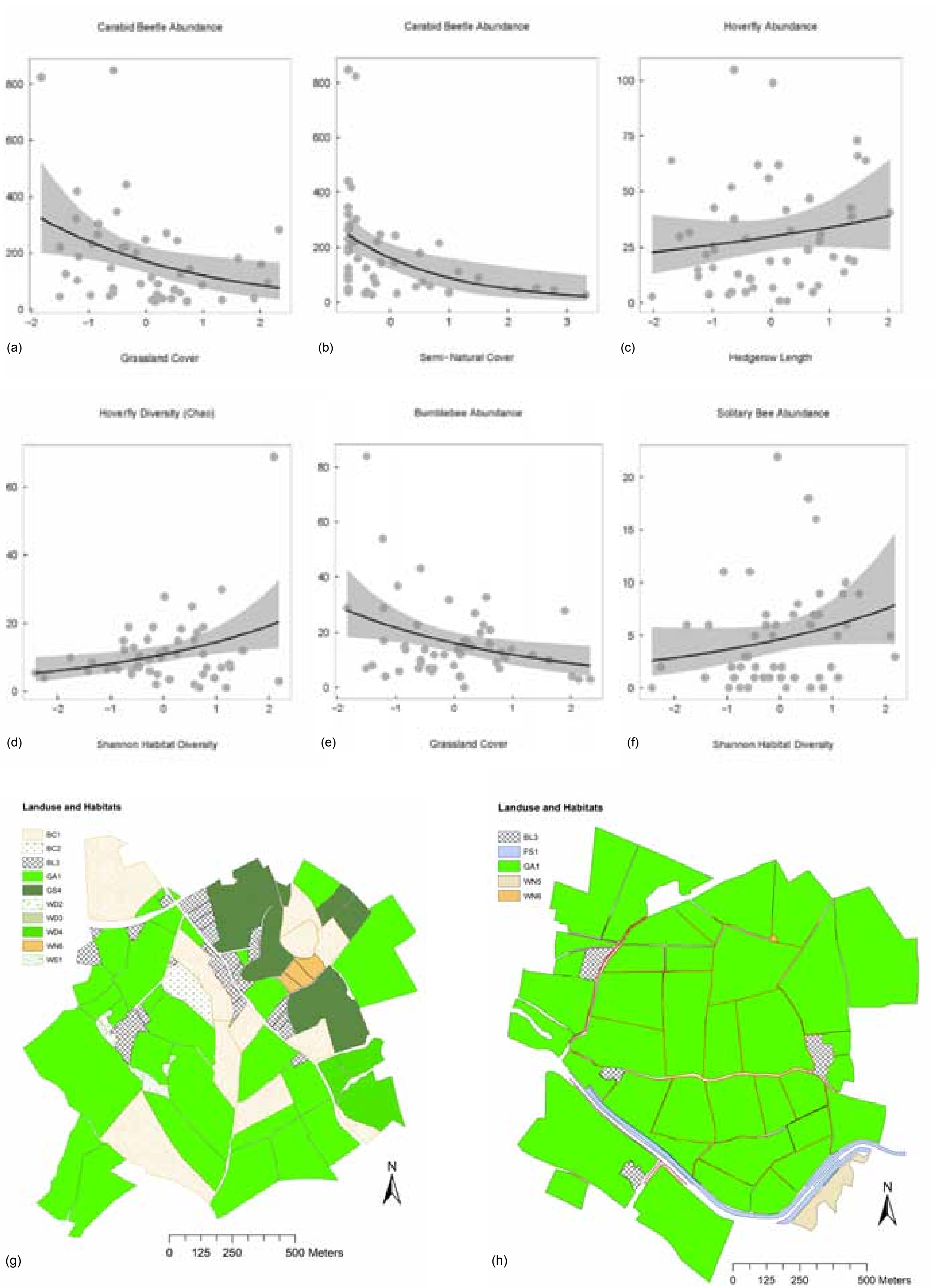
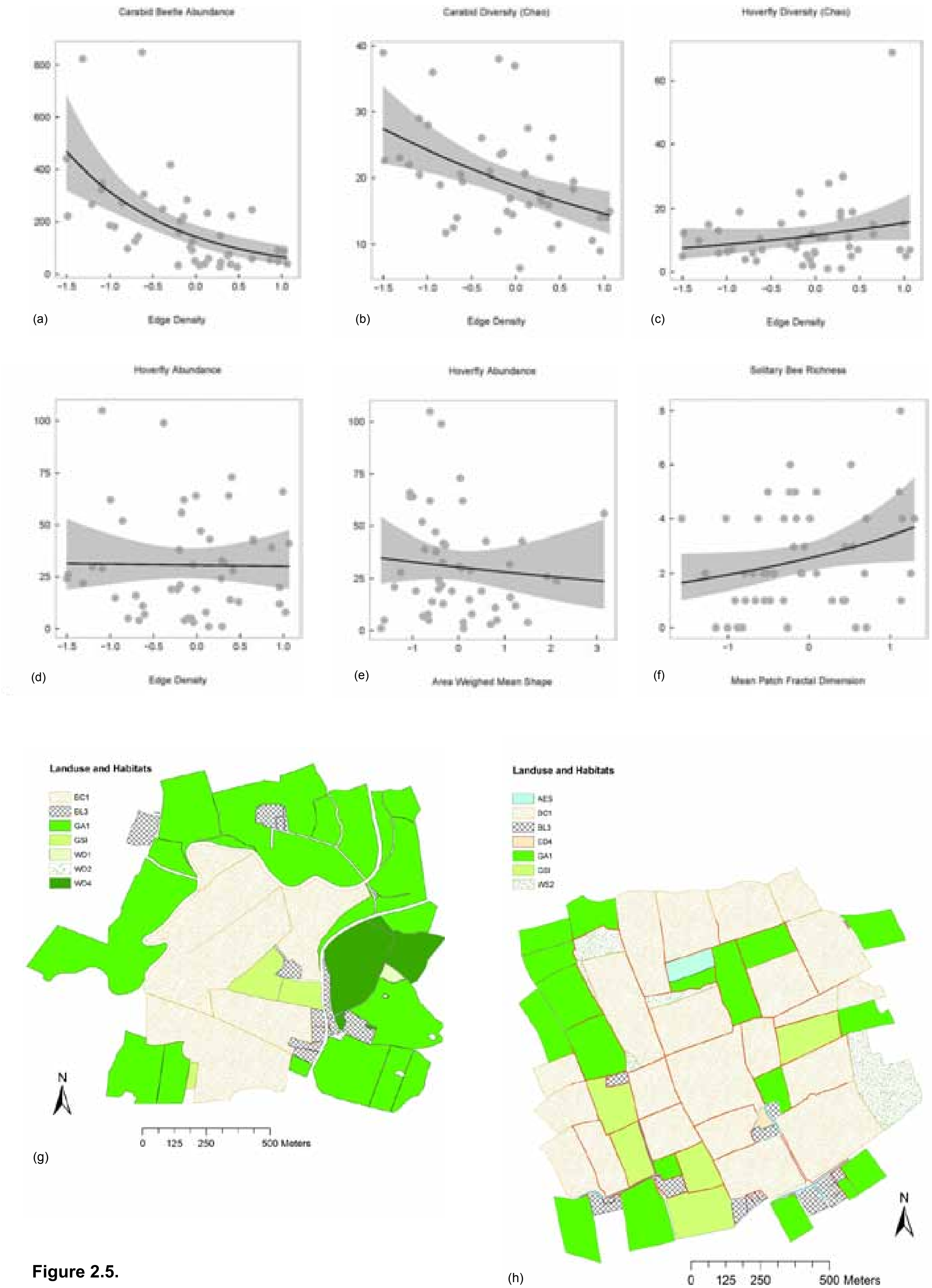

Carabid Beetle Abundance
Grassland Cover
(a)
Carabid Beetle Abundance
Semi-Natural Cover
(b)
Hoverfly Abundance
Hedgerow Length
(c)
Hoverfly Diversity (Chao)
Shannon Habitat Diversity
(d)
Bumblebee Abundance
Grassland Cover
(e)
Solitary Bee Abundance
Shannon Habitat Diversity
(f)
Landuse and Habitats
BC1
BC2
BL3
GA1
GS4
WD2
WD3
WD4
WN6
WS1
N
0 125 250 500 Meters
(g)
Landuse and Habitats
BL3
FS1
GA1
WN5
WN6
N
0 125 250 500 Meters
(h)

Figure 2.4.



Carabid Beetle Abundance
(a)
Edge Density
Carabid Diversity (Chao)
(b)
Edge Density
Hoverfly Diversity (Chao)
(c)
Edge Density
Hoverfly Abundance
(d)
Edge Density
Hoverfly Abundance
(e)
Area Weighed Mean Shape
Solitary Bee Richness
(f)
Mean Patch Fractal Dimension
Landuse and Habitats
BC1
BL3
GA1
GS1
WD1
WD2
WD4
N
0 125 250 500 Meters
(g)
Landuse and Habitats
AES
BC1
BL3
CD4
GA1
GS1
WS2
N
0 125 250 500 Meters
(h)

Figure 2.5.

Figure 2.5. (Opposite) Selected relationships between species response variables and landscape configuration metrics: (a) carabid beetle abundance and edge density, (b) carabid beetle diversity and edge density, (c) hoverfly diversity and edge density, (d) hoverfly abundance and edge density, (e) hoverfly abundance and Area Weighted Mean Shape Index (AWMSI), and (f) solitary bee richness and Mean Patch Fractal Dimension Index (MPFDI). Data are aggregated across all crop types as no significant crop type-landscape context interactions were found. Shaded bands represent 95% confidence intervals. Two landscapes illustrating examples of landscape configurational structures: (g) high AWMSI (1.533), and (h) low AWMSI (1.209). Habitats were classified according to Fossitt (2000) (from Bourke et al. 2013).

While the differences between the bioenergy crops compared with the conventional crops on farmland biodiversity were mostly positive (e.g. higher vascular plant richness in *Miscanthus* planted on former conventional tillage, higher solitary bee abundance and richness in *Miscanthus* and oilseed rape compared to conventional crops) or neutral (e.g. no differences between crop types for hoverflies), we showed that these crop type effects were independent of (i.e. no interactions with) the surrounding landscape composition and configuration. However, surrounding landscape context did independently relate to biodiversity in these farms. Carabid beetles and hoverflies were the most responsive taxonomic groups to landscape composition and configuration. Carabid beetle abundance in particular was negatively associated with hedgerow length, the proportion of semi-natural habitats, percentage of grassland, field shape (Area Weighted Mean Shape Index [AWMSI]) and edge density (Figs 2.4 & 2.5). Carabid beetle diversity was similarly negatively associated with hedgerow length, percentage of semi-natural habitats, habitat diversity (Shannon), and edge density, while carabid beetle richness was negatively associated with percentage of semi-natural habitats and edge density (Figs 2.4 & 2.5). Conversely, hoverflies were positively associated with all the landscape composition variables, and edge density (Figs 2.4 & 2.5). Bumblebees as a group did not display a response to the landscape composition and configuration variables, except for one very strong negative association between abundance and the proportion of grassland in the landscapes (Fig. 2.4).

However, more species-specific responses to landscape were found within the cryptic *Bombus sensu strictu* complex of bumblebees. The proportion of the rarest cryptic bumblebee species *B. cryptarum* in oilseed rape fields was higher when there was less arable land and artificial land in surrounding landscapes. We estimated more *B. lucorum* colonies when there was less arable land in the surrounding landscape, but other colony estimations were not affected by surrounding landscape (Stanley et al., 2013). Solitary bee richness and abundance were found to have positive associations with field shape (Mean Patch Fractal Dimension) and solitary bee abundance was also positively associated with habitat diversity. In addition, solitary bee diversity was negatively associated with semi-natural habitat cover (Figs 2.4 & 2.5). No significant relationships were found between plant richness and any of the landscape composition and configuration variables at this scale (for details see Bourke et al. 2013).

2.4.4 Impacts on Ecosystem Services

2.4.4.1 Carbon sequestration

A regional-scale estimate of the soil carbon sequestration, and an estimate of the loss of soil organic carbon during establishment, was made in 16 *Miscanthus* fields and adjacent control sites which represented the former land-use. Using the ^{13}C natural abundance method, which tracked carbon from *Miscanthus*, the quantity of plant-derived carbon could be determined; and soil pH, particle distribution and bulk density were also measured. After two years from planting, carbon-sequestration rates were significantly higher for *Miscanthus* planted on former grassland (mean ± SE: 0.90 ± 0.53 Mg ha^{-1} yr^{-1}) compared with that on former tillage (0.62 ± 0.59 Mg ha^{-1} yr^{-1}) (Fig. 2.6). Higher initial soil organic carbon content and a higher pH were shown to promote soil-carbon sequestration. The comparison with the adjacent former land-use also showed no significant differences between total soil organic stocks between the *Miscanthus* sites and the control sites.

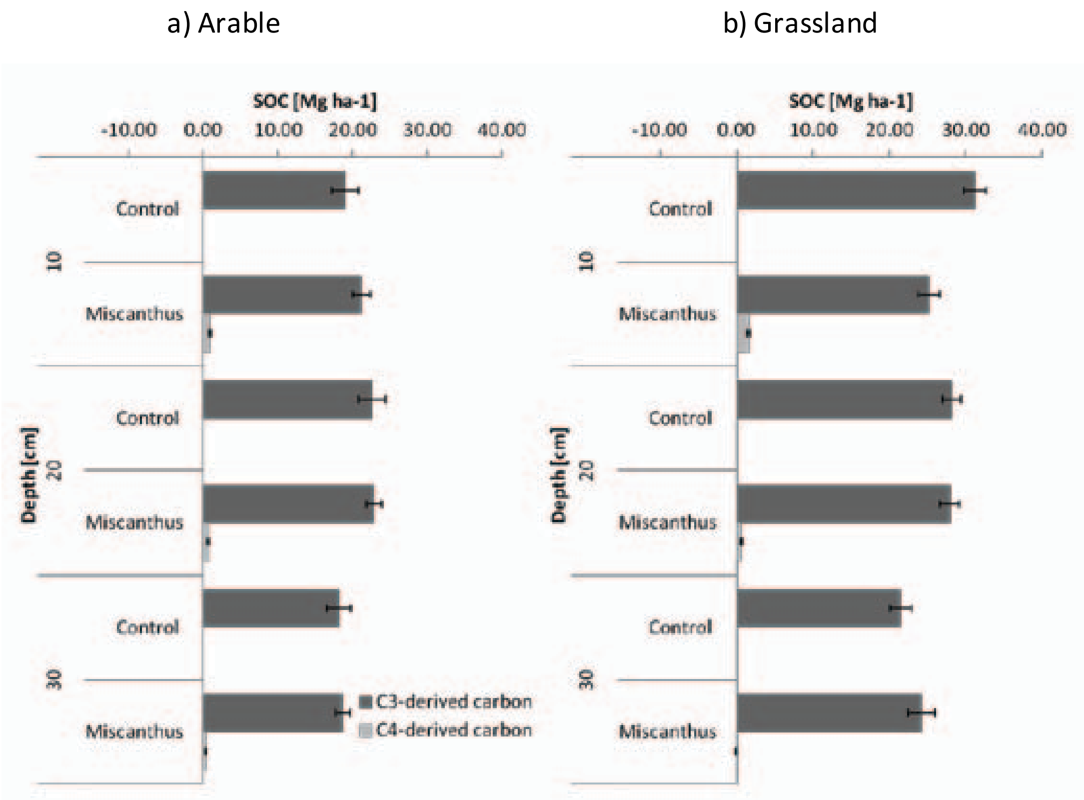


Figure 2.6. Mean soil organic carbon stocks (±SE) in (a) arable and (b) grassland fields either planted with *Miscanthus*, or representing the original land-use (Control). C3-derived carbon represents old carbon, C4-derived carbon represents *Miscanthus*-derived carbon (after Zimmermann et al., 2012).

The results show that even two years after plantation a significant amount of carbon was already sequestered into the soils. The results are within the range of previously reported modelled and measured soil carbon sequestration values (e.g. Grogan & Matthews 2002; Freibauer et al. 2004; Smith 2004), confirming the high potential to sequester carbon under perennial rhizomatous grasses. Furthermore, it was shown that soil organic carbon losses associated with the planting of *Miscanthus* are not significant. Since *Miscanthus* is a perennial crop, any soil disturbance is limited to the planting process, minimising soil organic carbon losses. There is also the indication that the initial ploughing of grassland in preparation for *Miscanthus* planting leads to a redistribution of carbon rather than to emission. Both results show that planting of *Miscanthus* does not necessarily add to the carbon debt. However, neither losses from vegetation nor the effects of indirect land-use change have been taken into account. In addition, we found large differences in soil carbon sequestration rates between farms on a regional scale. Furthermore, we found that soil properties, as well as the former land-use, have a significant impact on soil carbon sequestration.

To investigate the effect of large open patches within *Miscanthus* crops on yield and carbon sequestration, remote sensing was used to determine the patchiness of two fields for which data were available (see Table 2.1). The overall patchiness of the other SIMBIOSYS sites was modelled using GIS and the estimated loss of area due to patchiness is summarised in Fig. 2.7. To assess the impact of the patchiness on crop yield, the yield per hectare (assuming complete coverage) was estimated using the MISCANFOR model and then reduced by total patch area. To assess the impact of patchiness on soil carbon sequestration, the *Miscanthus*-derived carbon contents in open patches and adjacent high crop density plots was estimated. Significantly lower carbon-sequestration rates in the open patches compared to adjacent high-density *Miscanthus* patches were found (1.51 ± 0.31 Mg ha^{-1} and 2.78 ± 0.25 Mg ha^{-1}, respectively). The yield and sequestration results

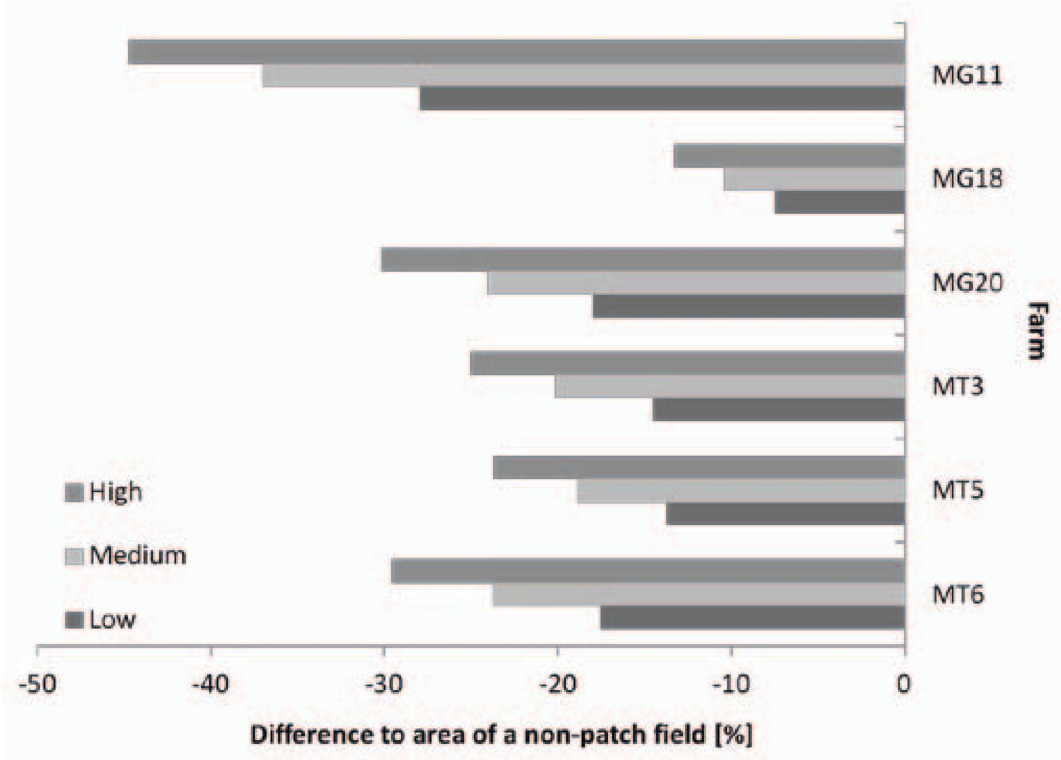


Figure 2.7. Loss of area due to patches in percentage of the respective field without patches.

were layered together using spatial models to produce a raster file representing the carbon sequestration in a patchy *Miscanthus* field. Using spatial statistic tools, we estimated that the average loss of carbon sequestration in the top 30cm of the soil column, in a patchy field compared to a field without patches, was estimated to be 11.93 ± 9.55%.

Table 2.1. Summary of the patchiness estimated using remote sensing.

Farm	MG14	TCD_2_1
Average patch area (m^2)	4.357	3.710
Standard deviation	8.702	25.245
No. Patches	901	1243
Sum of patch area (ha)	0.393	0.461
Overall field size (ha)	4.390	3.982
Share of field (%)	8.95	11.58

2.4.4.2 Pollination

Pollinating insects tend not to visit just a single species of flower, but most pollinators visit a variety of plant species and most plants are visited by a variety of pollinators (i.e. plant–pollinator interactions are generalised; Waser et al. 1996), although there may be species-specific preferences and differences in pollination efficiency among pollinating insect species. Therefore, if we only quantify the diversity of pollinators in different crop types, variation in the types and frequencies of plant–pollinator interactions may be overlooked (Tylianakis et al. 2007). Interactions between insects and flowers have been studied by visualising and quantifying the structure of plant–pollinator interaction networks.

We constructed plant–pollinator interaction networks in 25 sites to examine the impacts of these crops on interaction network structure, and to investigate differences in network structure when oilseed rape is in flower and after flowering. We also wanted to see how these networks are influenced by what is in the surrounding landscape and so examined the local effects of crop type and landscape scale effects measured in a 1km x 1km square surrounding the fields. As a mass flowering crop, oilseed rape becomes well integrated into native plant-pollinator networks (Fig. 2.8) and is visited by 11 of the 17 pollinating insect taxa observed. However, the temporal pulse of mass-flowering resource provided by oilseed rape does not affect network structure, possibly due to re-wiring (the switching of flower visitors to different plant species) or because the fauna of agricultural areas is already more sparse than semi-natural areas and may contain more

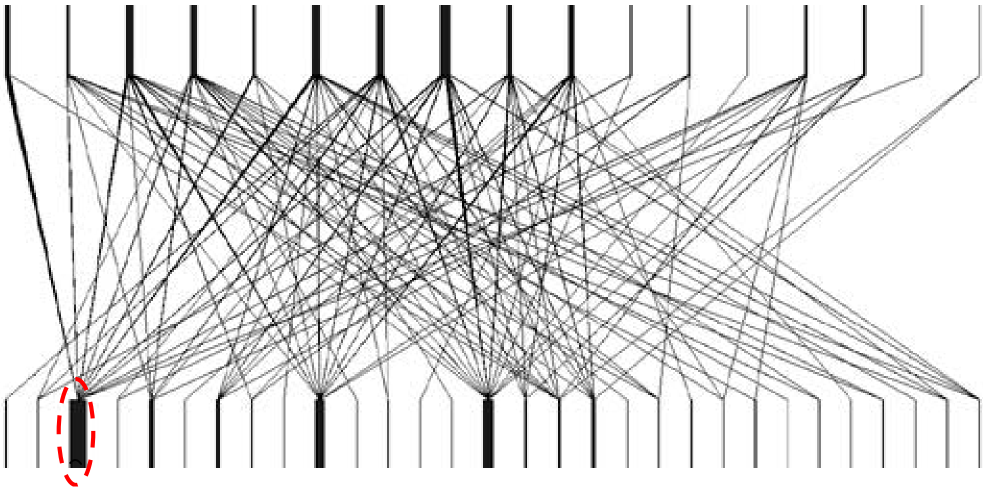


Figure 2.8. Oilseed rape interaction network (all 5 fields combined together). Insect species are represented by bars at top, plant species by bars at bottom, and lines in between represent observed interactions. Oilseed rape (*Brassica napus)* is highlighted with dashed red ellipse, and is well integrated into network (Stanley et al. In prep).

generalised species. Bioenergy production at the field scale caused some differences in networks structure, especially when conventional wheat is replaced with *Miscanthus*, resulting in differences in interaction evenness and connectance among the arable crop types, but few differences when grass is replaced with *Miscanthus*. Some landscape elements can also be determinants of network structure: interaction evenness, number of interactions and generality were explained best by statistical models which included the diversity of habitats in the surrounding landscape; and interaction evenness and number of interactions were best explained by models which included hedgerow length.

Although these networks can be very useful for understanding how land-use can influence interactions between plants and pollinating insects, they only represent visitation to flowers by insects, and not the transfer of pollen and the service of pollination. As a mass-flowering crop, oilseed rape can affect the pollination of native plant species growing beside the crop (Cussans et al. 2010; Diekotter et al. 2010) as well as other flowering crop species. We wanted to investigate the mechanisms by which oilseed rape influences native plant pollination, and so we examined the dynamics of pollen transfer between the crop and native species growing in the adjacent hedgerow. We examined pollen found on the bodies of insects visiting both the crop and the native species, and also investigated whether oilseed rape pollen gets deposited on the stigmas of native plants growing beside the crop. We found that insects foraging in field margins beside oilseed rape carried large quantities of oilseed rape pollen, but that very little oilseed rape pollen was deposited on the stigmas of co-flowering native flowers. Therefore, interference with pollination services to native plants via stigma clogging is unlikely, but could be due to changes in the frequency of visitation (either as a result of increased competition between the crop and wild plants for visitors, or as a result of facilitation). This is an area which deserves further research.

2.4.4.3 Biocontrol

Carabid generalist predators provide an ecosystem service of importance by biologically controlling pest populations in agricultural crop systems (Bilde & Toft 1997; Lang 2003; Snyder & Ives 2003). Greater predator biodiversity appears to correlate with a reduced frequency of pest outbreak (Letourneau & Goldstein 2001), and it has become apparent that increasing the diversity of predator communities leads to greater total resource consumption (Loreau et al. 2001). Therefore, managing for greater predator diversity may improve pest suppression (Snyder et al. 2006). We hypothesised that the functioning of a community of predators will depend on the identity of predators (identity effects), interactions among the predators (diversity effects) and the abundance of predators (biomass effect). We used Simplex designs (Cornell 2002; Ramseier et al.

2005; Sheehan et al. 2006; Kirwan et al. 2007; 2009) to investigate role of identity, diversity and biomass of three carabid beetle species (*Poecilus cupreus*, *Harpalus affinis* and *Pterostichus melanarius*) on the consumption of the pollen beetle (*Meligethes aeneus*), a common pest of oilseed rape.

When monospecific groups of carabids were introduced into test arenas containing the pollen beetles, a decline in pest survival rates was measured. This effect was greatest for *Poecilus cupreus*. We detected predatory facilitation between some species (pollen beetle survival declined when *P. melanarius* and *H. affinis* were introduced in combination, and when *P. cupreus* and *H. affinis* were combined) and behavioural interference between others (pollen beetle survival rate increased when *P. melanarius* and *P. cupreus* were combined together) (Fig. 2.9). This suggests that both antagonistic and synergistic interactions exist in these predator assemblages. Pollen beetle survival rate was further reduced at higher carabid biomass, which shows that there was a single overall biomass effect that was not determined by species identity or species interactions.

To provide some context for the relative importance of predator diversity and biomass effects in existing agricultural systems, a field study was undertaken to quantify the impacts of management (in this case, pesticide applications) on the diversity and biomass of carabid beetle predators at winter oilseed rape sites. We found no significant difference between the oilseed rape yield or carabid species richness according to whether there was high or low intensity of pesticide management. There was, however, a significant difference between the carabid species abundance in crops under high and low pesticide management, with a 59% reduction in carabid abundance with high pesticide management.

2.5 Conclusions

Overall, similar to many other studies to date, we can conclude that the cultivation of bioenergy crops in Ireland in general had mixed effects on the species richness of a wide range of taxa when compared with conventional crops (Dauber et al. 2010; Bourke et al. 2013), and that while landscape heterogeneity overall is very important for biodiversity, field-scale effects were independent of surrounding landscape context. This indicates that maximising the abundance and diversity of species, associated ecosystem functions, and the delivery of ecosystem services will be best achieved by maintaining landscape compositional (including diverse mosaics of both food and bioenergy crops) and configurational heterogeneity.

It must be remembered that the results in the current study reflect low-density planting of bioenergy crops in Ireland to date and thus large-scale replacement of conventional crops with novel bioenergy crops and changes to the current land-use mosaics in Ireland's

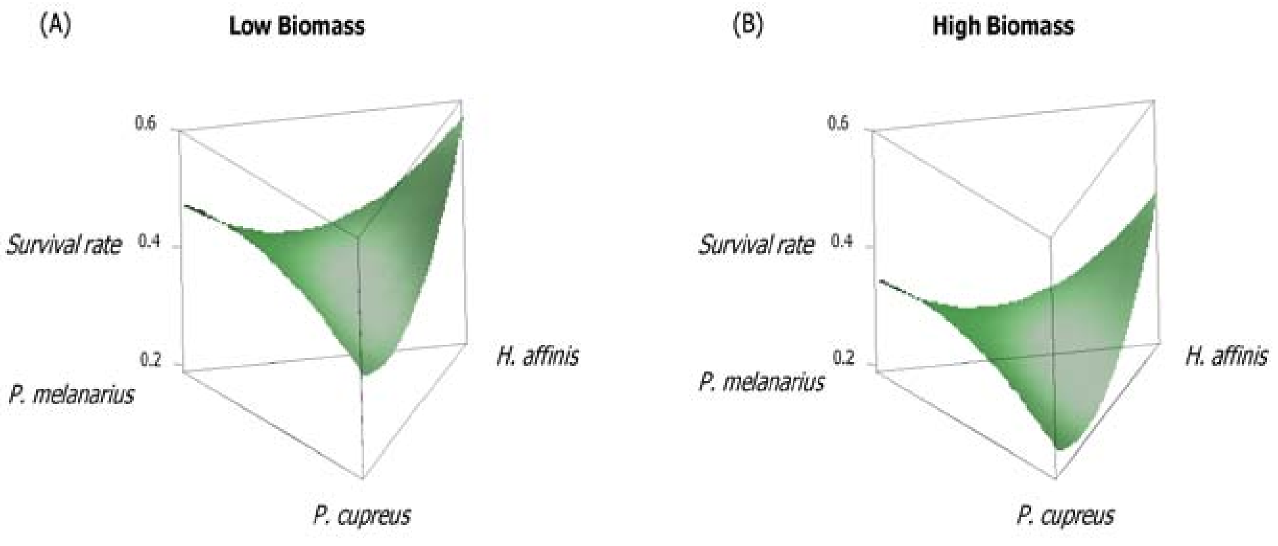


Figure 2.9. Carabid predator–pest interactions and the survival of pollen beetle larval under low and high predator biomass.

landscapes are increasingly likely as schemes in Ireland and Europe target significantly more planting in the coming years. So, while we can say that the introduction of *Miscanthus* and oilseed rape into agricultural landscapes did not result in an obvious negative impact on biodiversity measured at the field scale, EU renewable energy policies are driving an increase in the planting of bioenergy crops, and it is likely that the effects of large-scale planting in these landscapes could result in very different impacts on the biodiversity with consequences for ecosystem functioning.

It is clear that greater knowledge of spatial processes across ecosystems, and not just what we measure at the field-scale, is critical to better understand the effects of landscape changes on biodiversity and ecosystem functioning and services (Christian et al. 1998; Tscharntke et al. 2005). This means that for an impact assessment the mainly positive or neutral effects on biodiversity that we report at the field scale here would require landscape-scale assessments to take landscape scale ecological processes into account (Dauber et al. 2010; Bourke et al. 2013).

A greater understanding of aggregated impacts (ecological, socioeconomic) at the landscape scale can contribute to improved impact assessment and planning, helping achieve win–win solutions for biodiversity conservation and bioenergy production and the sustainable development of climate change mitigation measures (Fargione et al. 2009; Dauber et al. 2012).

Miscanthus has a high potential to sequester soil organic carbon, and carbon losses during establishment are not significant. However, high regional variation and the impact of crop patchiness on both yield and soil carbon sequestration illustrate the importance of an efficient planting strategy. *Miscanthus* yields in Ireland are on the margin of economic feasibility: therefore, such losses in yield can have a significant economic impact. While the impacts of patchiness on soil carbon sequestration are much lower, there is still an incentive to avoid patchiness in *Miscanthus* fields to enhance its GHG mitigation potential.

We find no negative effects of energy crops on any pollinator group studied, with some positive impacts in some cases for bumblebees, butterflies and solitary bees. Whether *Miscanthus* is planted on former grassland or former tillage can alter the effects on pollinators. The plant–pollinator interaction network structure seemed reasonably robust to the introduction of isolated fields of energy crops. Oilseed rape provides important forage for a large number of bumblebee colonies and other pollinator groups. However, it is important to remember that we compared energy crops to conventional ones in agricultural regions of the south east that would already be relatively species poor, and as a result oilseed rape may become an important forage resource. If energy crops began to replace semi-natural habitats or high-nature value farmland, the impacts on pollinators could be different. However, the small-scale planting of energy crops in conventional agricultural areas has little impact on pollinators, and could potentially create a wider variety of habitats that could have a positive effect.

We found that increased predator diversity and biomass had a positive effect on biocontrol, expressed as a reduction of pest survival. In addition, the biomass effect was shown to play a greater role than the diversity effect in the consumption of pollen beetles.

2.6 Recommendations for Decision-makers

1. We examined the growth of energy crops in Ireland at the small scale, when they replace conventional farmland. The impacts on biodiversity and ecosystem services may be very different if they are planted on marginal or semi-natural land, and if they are planted more frequently and/or at a higher density. These issues require further research attention.
2. The transition of land-used for arable crops or grassland to *Miscanthus* resulted in surprisingly low losses in soil organic carbon stocks two to three years after the plantation. Also, while there was significant carbon sequestration on land formerly used for either arable crops or grassland production, sequestration rates were significantly higher under former grassland. Converting both former land-uses to *Miscanthus* production can be recommended in terms of soil organic carbon dynamics.
3. Our research showed large differences on a regional scale in the amount of soil carbon sequestration. While part of the variation can be explained by former land-use, initial soil organic carbon stocks, soil pH, as well as patchiness, further drivers of

the variation are still unknown. Furthermore, the processes by which these factors influence soil carbon sequestration are not yet fully understood. It is therefore important to conduct further research on the processes driving soil carbon sequestration.

4 Crop patchiness is caused by uneven planting and poor soil conditions, particularly water logging. Patchiness reduces crop yield significantly but it was shown that more than three-quarters of the overall yield loss can be attributed to large patches (>4m^2). It is therefore recommended to immediately replant areas that were not planted due to problems with machinery, and to avoid areas that have a tendency for water-logging.

5 Small patches contribute to only a small portion of the overall yield loss due to patchiness and there is an indication that they can have a positive impact on biodiversity. It is therefore not recommended to replant small patches of <4m^2.

6 Agriculture is the dominant form of land-use in Ireland, and pollinator services are required by both crop and wild plants. Thus, it is essential that efforts to conserve pollinators are implemented in agricultural settings. Since more individuals and species of all pollinator groups were found in field margins and hedgerows than in the centres of fields, possibly as there were more flowers to forage on in these areas, and bumblebees search for nests almost exclusively along margins and hedgerows, these features are essential in providing habitats for pollinators. Therefore, we can recommend the appropriate management and promotion of flower-rich field margins and hedges within agricultural areas to provide forage and nesting resources to sustain pollinator populations. We recommend that specific agri-environmental schemes are implemented (and monitored appropriately) to promote all pollinator groups (bees, hoverflies and butterflies).

7 Solitary bees are less abundant than social ones, tend to fly shorter distances to forage, and complete their lifecycles more rapidly. Thus, although less is known about their ecology, they are considered to be more vulnerable to environmental change. We found distinct communities of solitary bee species in different crop types. Therefore, we can recommend that a diversity of crop types within the landscape in agricultural areas could be beneficial for solitary bee biodiversity, rather than large mono-cultures of the same crop types.

8 Recent work has shown that some neo-nicotinoid pesticides such as imidacloprid, which are commonly used on Irish farms (especially as seed treatments for oilseed rape and other crops: DAF 2004), can have sub-lethal effects on bumblebees, affecting reproduction and colony growth (Laycock et al. 2012; Whitehorn et al. 2012). As bumblebees forage on pollen and nectar from treated plants, they ingest the pesticide. Using genetic methods we found that hundreds of colonies of bumblebees are found foraging in a single spring oilseed rape field. This means the effects of these pesticides could permeate widely into bumblebee populations. Therefore, we can suggest a reduced use of these pesticides as seed treatments, and reduced and more appropriate use of sprayed pesticides. In addition, intensive pesticide management practices in winter oilseed rape are having a detrimental effect on carabid beetle predator biomass, while in parallel increasing agri-economic cost, and failing to achieve a higher crop yield. Here we show that carabid beetle predator biomass drives the ecosystem service of natural biocontrol. Less intensive pesticide management practices in winter oilseed rape will enhance carabid beetle biomass and diversity. As it is predator biomass that drives the service this change in management practice would be expected to improve the delivery of carabid beetle biocontrol while not causing the producer to suffer low crop yields.

9 Although we have advanced the field of knowledge of the impacts of energy crops on pollinators, there are still knowledge gaps which should be addressed, including: (i) long-term, multi-season impacts and effects of introducing oilseed rape into new areas versus expanding planting in existing landscapes; (ii) impacts of growing energy crops at higher density and on a larger spatial scale; (iii) the distribution, pollination efficiency and other ecological requirements of the cryptic bumblebee complex; (iv) impacts of other mass-flowering and/or bioenergy crops; and (v) the pollination requirements of and impacts of novel crops (including genetically modified crops).

3 Impacts of Road Landscape Treatments on Biodiversity within Road Corridors and Adjacent Ecosystems

3.1 Context

The development of transport infrastructure is central to economic development and growth. However, these developments are known to negatively affect biodiversity and the delivery of ecosystem services, modifying the surrounding landscape, fragmenting habitats, and affecting the biology of plants and animals. Nevertheless, when roads are managed appropriately, they offer opportunities for biodiversity – providing vegetated cover along road sides, and acting as a corridor for flora and fauna to move through the landscape. While major advances have been made to the environmental performance of the road-development process in recent years, key areas for improvement remain. The overall aim of this research therefore was to evaluate the national road-development process and the National Roads Authority (NRA) Environmental Assessment and Construction Guidelines (NRA EACG) to identify potential improvements in biodiversity conservation for future road development, and provide ways of mitigating the effects of road planning, design, construction, maintenance and decommissioning.

The 'Celtic Tiger' years in Ireland featured a large investment in the country's road infrastructure. Improved roads are seen as both a result of prosperity and also as an essential part of maintaining prosperity. Under the National Development Plan 2002–2007, the national roads programme sought to extend the motorway and dual carriageway network by 400% by 2007. Further road development continued post-Celtic Tiger, since roads are considered vital improvements to infrastructure, which, in turn, facilitates economic development in the longer term.

The construction of roads invariably involves modifying the landscape from mainly agricultural land-uses, incorporating a transport corridor into the landscape. Road margins/verges in rural areas provide a vegetated cover (normally maintained) along the length of the road. Such 'Road Ecosystems' provide corridors for flora and fauna to move between areas that are not otherwise linked. In Ireland, before 2005, most road margins/verges were designed and managed to horticultural specifications, often using alien plant species. The vegetation often required high management inputs for their maintenance (frequent mowing and applications of herbicides/fertilisers). In 2004, the NRA embarked on a review of road landscaping treatments and, in 2006, *Guide to Landscape Treatments for National Road Schemes in Ireland* (NRA 2006) set out newly defined protocols for the development of road margins. These new protocols, based on the principles of ecological landscape design (Makhzoumi 2000), were designed to:

1. 'Fit' the road at the planning stage, including its verge composition and management, to the surrounding ecosystems and landscape;
2. Address habitat loss through restoration and compensation;
3. Restore connectivity between elements of existing native vegetation that had been severed by the road; and
4. Use only native species from indigenous seed sources.

While such landscape treatments provided evidence of the Government's promotion of biodiversity conservation as well as sustainability, their ecological functioning required validation. The changes in road-landscaping protocols mirror changes internationally. While the focus of many of the earlier studies on roads was on their deleterious effects (Lugo & Gucinski 2000), today international best practice in relation to roadside landscape design utilises native plant species to mitigate the negative effect and to enhance biological diversity and landscape connectivity (Southerland 1995; Meunier et al. 1999; Lugo & Gucinski 2000; Pauwels & Gulinck 2000; Spellerberg 2001). Landscape treatments also provide the opportunity to establish new habitats (e.g. ponds, linear woodlands and semi-natural grasslands). With the publication of the *Guide to Landscape Treatments for National Road Schemes in Ireland* (NRA 2006) this watershed in landscape treatment protocols represented a unique opportunity to compare both former and new practices, since there are parallel instances of both practices being operated in the 2004–2007 time window.

Linked to the changes in road-corridor landscaping, other complementary aspects of management of biodiversity along roads also merited investigation. In contrast to other parts of Europe, no studies had been undertaken in Ireland to specifically examine the flora and fauna of roadsides on a large scale, nor had the relationship between roadside flora and fauna and that of the surrounding landscape been well documented (Forman 2000). Such comparisons permit an understanding of the ecological role of such roadside landscapes (Safford & Harrison 2001).

Increasing attention is also being focused on alien plants on roads. Movement of materials for road construction can disperse alien plants and, once established, these plants may disperse along road corridors and the wider landscape through maintenance activities on the road verge or through the dispersal of wind-blown seeds in slipstreams of vehicles. Recent legislation (S.I. No. 447 of 2011 European Communities Bird and Natural Habitats Regulations 2011) in Ireland has sought to control the movement of what are considered to be the most invasive alien plants on the island. Internationally, a considerable body of work has been developed to investigate the effects of biodiversity in conferring resistance to invasion by alien species (Naeem et al. 2000; Turnbull et al. 2005; Thomsen & D'Antonio 2007) but not within the context of roadside vegetation. The facility to promote resistance to invasion by invasive alien plant species, through specific management regimes, has the potential to be an important tool which would enhance native biodiversity by establishing native vegetation cover along road corridors and reduce costs of controlling alien invasive weeds.

Additionally, the national road-planting scheme in Ireland is considered to be an important agent for the dispersion of hawthorn (*Crataegus monogyna*). Road landscaping has encouraged the widespread planting of hedgerows, which can function as corridors to maintain gene flow between populations of native species which would otherwise be fragmented (Foulkes & Murray 2005; Fuller 2006). The use of hedging around farm and field boundaries has also been encouraged as a conservation strategy geared towards the maintenance of genetic biodiversity within species (Wehling & Diekmann 2009). Despite being planted for biodiversity conservation purposes, the extensive use of *C. monogyna* has the paradoxical potential to have a negative impact on its own conservation status. Approximately 80% of the hawthorn material planted along Irish roads is considered to be of continental European provenance (Jones & Evans 1994; Hall 1998; Jones et al. 2001, Foulkes & Murray 2005; Fuller 2006). The use of hawthorn planting material of non-Irish provenance may have an effect on the genetic and phenotypic diversity of native or older naturalised stands of hawthorn in Ireland. However, genetic diversity and population structure relationships between non-native and native/naturalised stands of hawthorn in Ireland had not been elucidated to determine possible impacts on hawthorn genetic diversity. Therefore, hawthorn was used as a model species to investigate the effect of road landscaping practices on gene-flow and genetic variation in populations of native plants.

The objective of this study was therefore to investigate the impacts of pre- and post-NRA road landscaping guidelines of 2006 on species biodiversity at three trophic levels: (i) primary producers (plants), (ii) primary consumers (flower-visiting insects) and (iii) secondary consumers (carabid beetles). In addition, we compared the biodiversity associated with the landscaping treatments and the land-uses in the surrounding landscapes. Furthermore, we quantified the effects of landscaping treatments on associated ecosystem services (invasion resistance and biocontrol). Linked to these we evaluated the road-development process and the NRA EACG. Finally, we investigated the possible effects of road landscaping on the gene-flow and genetic variation in Ireland's populations of hawthorn. Comparisons were made between hawthorn trees used for recent landscaping along the N22/N25 road with trees from older sources of likely Irish provenance to establish if there are any differences in genetic structure among the recently introduced trees in hedgerows versus the trees considered to be of native or older naturalised provenance.

3.2 Study Sites

The study was conducted in 2009 along the E30 (N25 and N22) Irish national road corridor from Rosslare, Co. Wexford to Tralee, Co. Kerry, an east-to-west road transect extending ~310 kilometres (Fig. 3.1). Study sites were selected on the basis that they featured one of the following roadside habitat engineering types: (i) soil slope, (ii) rock/scree slope or (iii) soil on a flat wider verge. These categories were sub-divided on the basis of being established before and after the 2006 NRA's *A Guide to Landscape Treatments for National Road Schemes in Ireland*, which were implemented along the road corridor between 2004 and 2007 (Fig. 3.2). In addition, 22 sites were sampled to study gene flow in *Crataegeous monogyna*, both along the E30 road corridor and from more remote sites (Fig. 3.1). The latter were remote from road-planting schemes to increase their likelihood of being native Irish origin.

The soil slope landscaping treatment consisted of (i) planting; (ii) standard grass seed mix (SGSM) and (iii) open habitat mosaic (OHM) (Fig. 3.2). The rock/scree slope landscaping treatments consisted of (iv) planting and (v) natural recolonisation (NR) (Fig. 3.2). There was only one wider verge landscaping treatment of (vi) standard grass seed mix (Fig. 3.2) as no sites landscaped according to the post-NRA guidelines were found along the E30 road corridor. In addition to the pre- and post-NRA road landscaping treatments, improved agricultural grassland was selected as a non-roaded control treatment, representative of the dominant land-use lost because of road

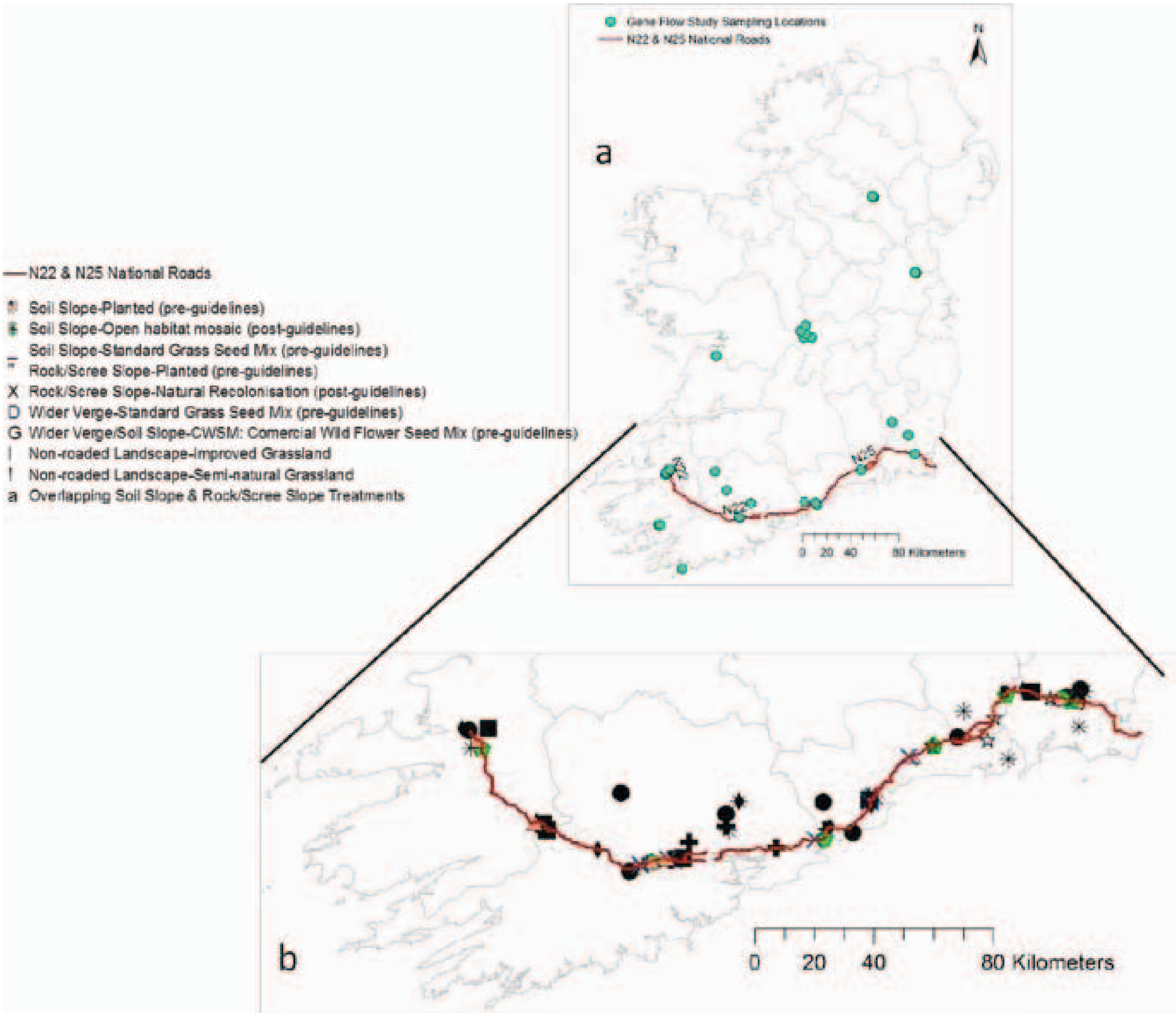


Figure 3.1. Distribution of sampling sites for the (a) gene flow study and (b) road landscape treatment study.

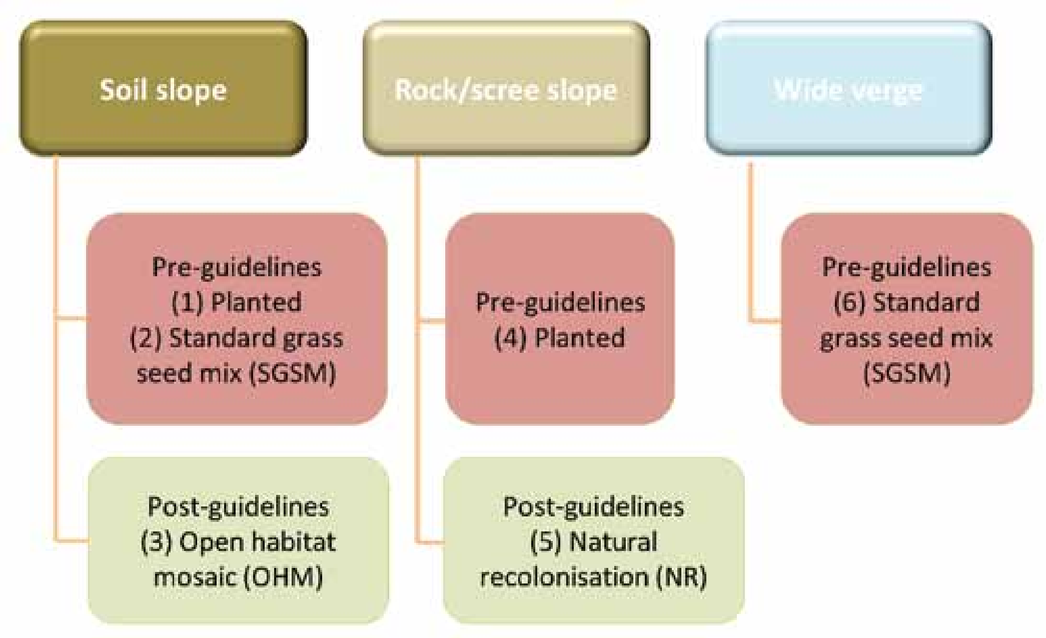


Figure 3.2. Overview of landscaping treatments (1 to 6) investigated in this study, comparing National Roads Authority (NRA) pre- and post-guidelines from three different roadside habitat engineering types (soil slopes, rock/scree slopes and wide verges). Improved agricultural grassland was selected as a non-roaded control treatment. Approximately 10 replicates of each treatment were used.

construction in Ireland's landscapes. These improved agricultural grassland control sites were selected along the length of the study transect, but never closer than 3km to the road corridor. All study sites had a southerly aspect. Each rock/scree slope site was either old red sandstone or limestone, the rock types typical of southern Ireland. Spatial aggregation of individual soil slope, rock/scree slope and wider verge landscaping treatment sites and the improved agricultural grassland control sites in one area was avoided, with sites non-contiguous, allowing each to be an independent sampling location; however, sites were in geographically similar locations, allowing comparisons. At each treatment (i.e. soil slope, rock/scree slope and wider verge) three habitat types were sampled: (i) the road verge; (ii) the road margin; and (iii) the road field (directly adjacent to the road margin). Similarly, at each improved agricultural grassland (IAG) control site three habitat types were sampled: (i) the verge (the edge of the field as control to the road verge); (ii) the margin (the field hedgerow as a control to the road margin); and (iii) the field (the centre of the field as control to the road field).

At each site in the landscape treatment study, vascular plant diversity and abundance were surveyed by recording percentage cover of each species in two 1m x 1m quadrats, in each habitat (defined above) for each road-landscaping treatment (six quadrats per site). Plant species nomenclature followed Stace (2010). Carabid beetles were sampled using three pitfall traps, where one trap was placed in each of the three defined habitat types per sampling site. Traps were operational for a period of 14 days on two occasions, May and August 2009 (Baars 1979; Spence & Niemelä 1994; Luff 1996; Rainio & Niemelä 2003). The experimental design of the soil slope, rock/scree slope and wider verge studies, therefore, followed a hierarchical structure where pitfall traps were nested within habitat types, nested within road landscaping treatments. (Full details of the sampling procedures can be found in Thompson, O'Rourke PhD theses.) Soil samples were collected and analysed for soil nutrients (Morgan's extract Available P, total nitrogen, pH organic matter, and hydraulic conductivity). Pollinating insects were captured using pan-traps during two separate 48-hour trapping periods in 2010 on pre-guideline SGSM and post-guideline SGSM-OHM sites (see Mounsey 2010, Unpublished Thesis for details).

In the gene-flow study, an assessment of the genetic diversity of hawthorn in Ireland was undertaken by developing nuclear microsatellites and cpDNA markers and applying them to Irish populations to test for possible impacts of road landscaping on gene flow in plants. Samples were collected and analysed from a series of populations along the E30 road corridor and plants from older/more remote areas (greater likelihood of being of Irish provenance) (Fig. 3.2a) to establish possible impacts of plantation on hedgerows, in particular road-landscaping effects on the genetic diversity of Irish hawthorn populations. Six sets of novel Simple Sequence Repeats (SSR) primers were developed and used to characterise a total of 125 alleles with a mean number of 20.6 alleles per locus in the Irish populations and the European controls. Full details of the sampling and molecular methods used can be found in Mina-Vargas et al. (in review).

3.3 Summary of Findings

3.3.1 Impacts of Road-landscaping Treatments on Species Diversity (Plants, Natural Enemies, Pollinators)

3.3.1.1 Plants

Overall, few differences were detected between horticultural (pre-NRA Guidelines, 2006) and ecological based (post-NRA Guidelines, 2006) landscaping treatments on plant biodiversity. No significant differences in plant-species richness were found between the various road-landscape treatments (Fig. 3.3b), but species richness was found to be lower in the centre of the adjacent fields than the road verge or margin of the adjacent field (p<0.001) (Fig. 3.3a). Soil-available P concentration was found to be a key determinant of plant-species richness; for every mg/kg increase in Morgan's P, 0.32 fewer species were found. Soil-available phosphorus (Morgan's extractant) (Fig. 3.4a) was shown to be lower in road verge treatments than the margins and the centres of the adjacent fields (p=0.0059) (Fig. 3.4b). Soil total nitrogen concentrations were shown to be lower in road verge treatments than the margins (p=0.005) and the centres of the adjacent fields (p<0.001) (Fig. 3.5b). However, there were no significant differences in soil properties (pH, Morgan's P, total N, conductivity) found between the NRA pre- and post-guidelines treatments, and no significant differences in soil properties were found between the various road treatments (soil slopes, rock/scree slopes, wider verge).

3.3.1.2 Carabid beetles

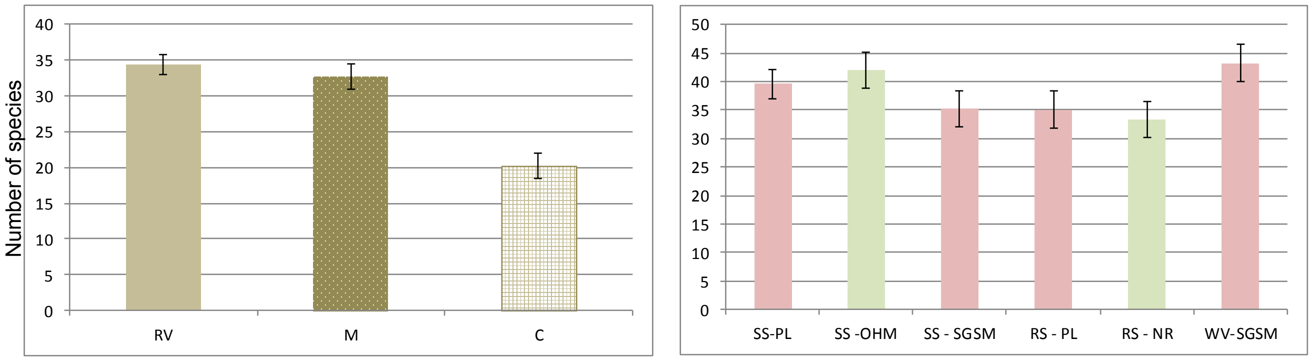
Similar to the plants, few differences were detected between the horticultural (pre-NRA Guidelines, 2006) and ecological based (post-NRA Guidelines, 2006) landscaping treatments on carabid beetle biodiversity. For the most part, no differences were found between roadside landscapes and the previously existing land-use.

Specifically, there were no significant effects of soil slope treatments on ground beetle abundance, species richness, alpha diversity, evenness, or beta diversity. However, there was a significant effect of soil slope habitats on carabid beetle abundance (p<0.001), species richness (p<0.001), alpha diversity (p<0.001), and beta diversity (p<0.001) (Fig. 3.6a). Mean carabid beetle abundance and alpha diversity were highest in the margin, followed by the verge and the field (Fig. 3.6a). Mean species richness was significantly higher in the margin compared to the verge and field (Fig. 3.6a).

There were also no significant effects of the rock/scree slope treatments on carabid beetle abundance, species richness, evenness, or beta diversity (Fig. 3.6b). However, there was a significant effect of the rock/scree slope treatment on carabid beetle alpha diversity (p=0.023) (Fig. 3.6b), where mean alpha diversity was significantly higher in the planting treatment (pre-NRA guidelines) compared to the natural recolonisation treatment (post-NRA guidelines) and the improved agricultural grassland control.

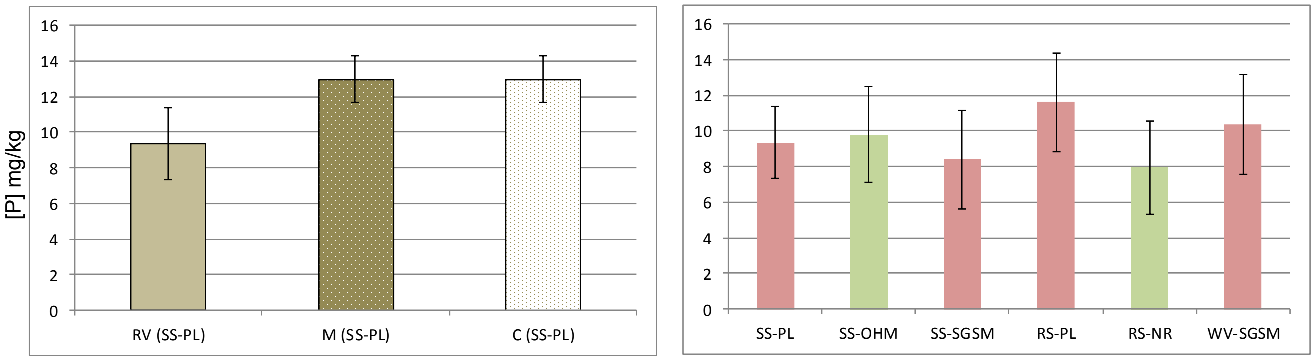
There was a significant effect of rock/scree slope habitats on carabid beetle abundance (p<0.001), species richness (p<0.001), alpha diversity (p=0.047), and beta diversity (p=0.013) (Fig. 3.6b). Mean carabid abundance and species richness were significantly higher in the margin compared to the verge and field (Fig. 3.6b).

Again, there were no significant effects of wider verge treatments on abundance (p=0.106), species richness (p=0.500), alpha diversity (p=0.857), evenness (p=0.266), or beta diversity (p=0.285) (Fig. 3.6c). However, there was a significant effect of wider verge habitats on carabid beetle abundance (p=0.014) and species richness (p=0.045) (Fig. 3.6c). Mean carabid beetle abundance was significantly higher in the margin compared to the verge and field (Fig. 3.6c). Mean carabid beetle species richness was significantly higher in the margin compared to the field (Fig. 3.6c).



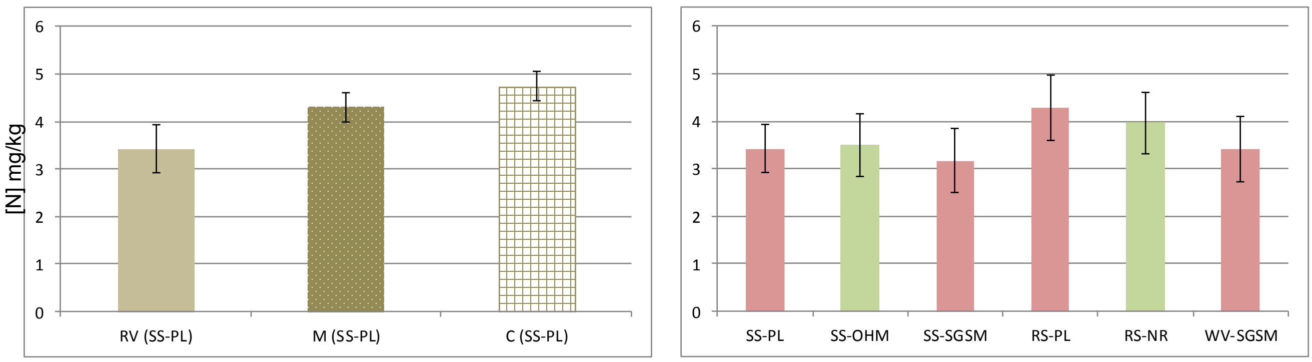
(a) Position (b) Treatment

Figure 3.3. Effect of position (a) and road landscaping treatment (b) on plant species richness. RV = road verge; M = margin; C = centre of field; SS-PL = soil slope-planted; SS-OHM = soil slope-open habitat mosaic; SS-SGSM = soil slope-standard grassland seed mix; RS-PL = rock/scree slope-planted; RS-NR = rock/scree slope-natural recolonisation; WV-SGSM = wider verge-standard grassland seed mix.



(a) Position (b) Treatment

Figure 3.4. Effect of position (a) and road landscaping treatment (b) on soil available phosphorus (Morgan's extractant) content. RV = road verge; M = margin; C = centre of field; SS-PL = soil slope-planted; SS-OHM = soil slope-open habitat mosaic; SS-SGSM = soil slope-standard grassland seed mix; RS-PL = rock/scree slope-planted; RS-NR = rock/scree slope-natural recolonisation; WV-SGSM = wider verge-standard grassland seed mix.



(a) Position (b) Treatment

Figure 3.5. Effect of position (a) and road landscaping treatment (b) on soil total nitrogen content. RV = road verge; M = margin; C = centre of field; SS-PL = soil slope-planted; SS-OHM = soil slope-open habitat mosaic; SS-SGSM = soil slope-standard grassland seed mix; RS-PL = rock/scree slope-planted; RS-NR = rock/scree slope-natural recolonisation; WV-SGSM = wider verge-standard grassland seed mix.

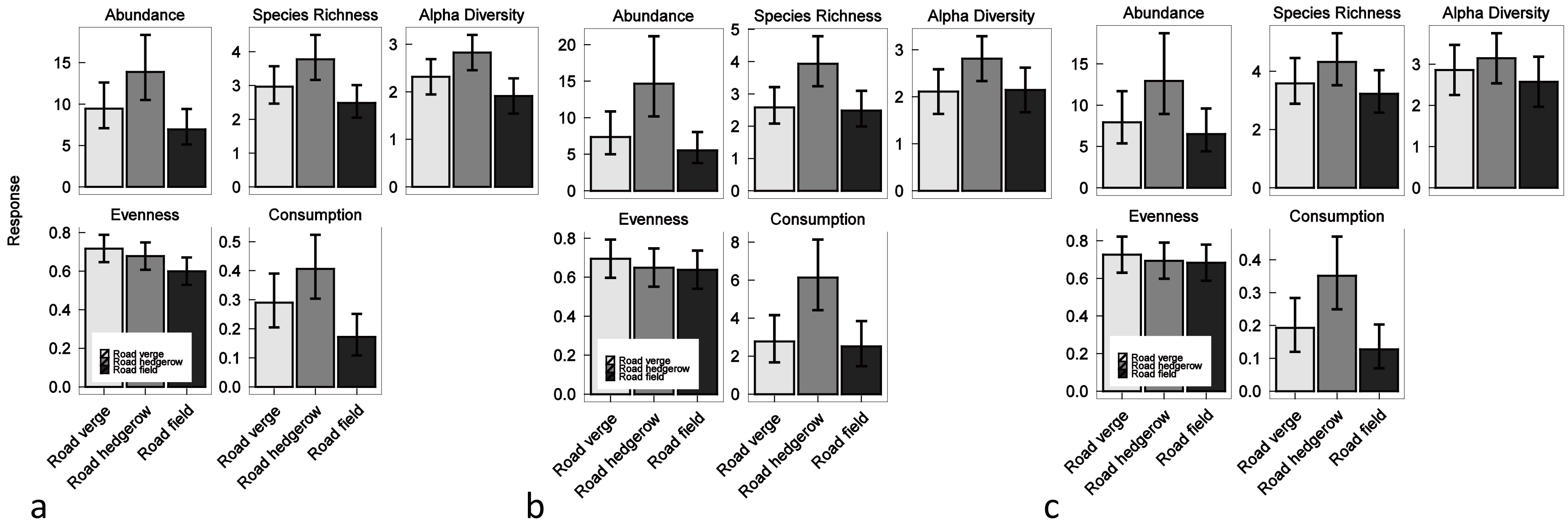


Figure 3.6. Effect of (a) soil slope road habitats (verge, hedgerow/margin and field), (b) rock slope road habitats (verge, hedgerow/margin and field), and (c) wider verge road habitats (verge, hedgerow/margin and field), on measures of carabid beetle biodiversity (abundance, species richness, alpha diversity, beta diversity, evenness) and potential consumption (a proxy for the ecosystem service biocontrol).

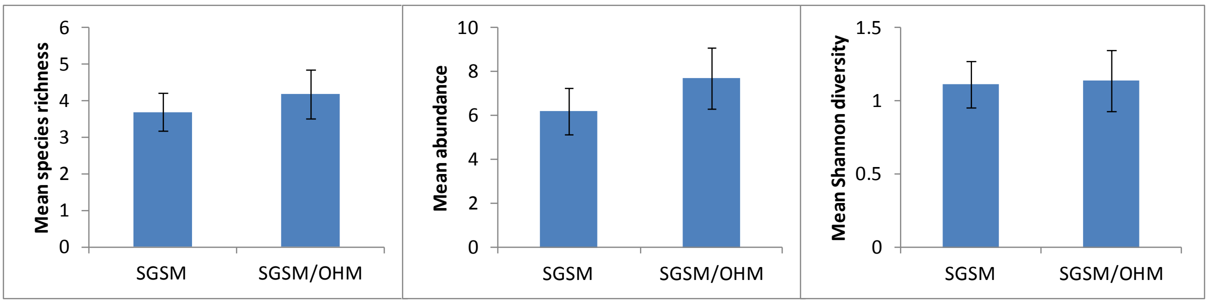


Figure 3.7. Mean (±SE) of pollinating insect species richness, abundance and diversity on SGSM and SGSM/OHM treatments.

3.3.1.3 Pollinating insects

Few pollinating insects were captured on roadsides: during two rounds of pan-trapping, only 52 hoverflies of nine species and 87 bees of eleven species were captured in total from 10 sites of each of two roadside treatments (SGSM and SGSM-OHM). Similar to the plants and natural enemies, there were no significant differences in the species richness, abundance or diversity of pollinating insects in the pre- versus post-guideline landscaping treatments examined (t-test: t_{18} = 0.1–0.9, p>0.05, Fig. 3.7). Furthermore, there were no differences in community composition in the two treatments (PERMANOVA: Pseudo $F_{1,18}$= 1.03, p=0.404).

3.3.2 Impacts of Road Landscaping on Gene Flow in Plants (Hawthorn)

Eight of the nine populations investigated displayed a significant excess of homozygotes and positive fixation coefficient values (*Fis*), indicating a deficiency of heterozygotes and suggesting that the populations are inbred and displaying low genetic variability. The overall observed heterozygosity (0.475) was significantly lower than the expected value (0.751), which is also suggestive of inbreeding and a narrow genetic base of these populations (Table 3.1). The results indicate high levels of inbreeding in hawthorn populations in Ireland, which could be a result of founder effects (planted from common stocks and/or clonally propagated), including possible effects of reproductive isolation by distance (e.g. seed-dispersal systems) of populations from each other.

Table 3.1. Location and labels of populations of hawthorn sampled: total number of alleles (Na); effective number of alleles (Ne); number of alleles with frequency greater than 0.05 (Na Freq. ≥ 5%); number of private alleles (No. P.A); observed heterozygosity (Ho); expected heterozygosity (He); co-efficient of inbreeding (F) and allelic sample size (N) for the nine groups of *C. monogyna* tested.

Population	Na	Ne	Na Freq. ≥ 5%	No. P.A.	Ho	He	F	N
Cork RS	7.17	5.27	5.33	1	0.45	0.68	0.32	9.00
East RS	7.67	5.8	5.33	1	0.52	0.77	0.32	9.00
West RS	8.17	5.28	5.33	1	0.41	0.80	0.49	10.50
Cork IS	6.00	4.62	6.00	0	0.50	0.77	0.34	7.17
West IS	8.50	4.93	5.00	1	0.43	0.78	0.45	12.67
U-F	5.33	3.91	5.33	0	0.41	0.63	0.35	7.33
OI	10.00	6.00	6.17	2	0.45	0.82	0.45	23.00
INT	5.00	4.20	5.00	1	0.71	0.73	-0.04	4.33
Sweden	6.17	5.11	6.17	1	0.40	0.78	0.48	5.83

No genetic structure was detected in comparisons between roadside planted samples and samples interior to the roads that are more likely to be of older provenance. This indicates that all of the studied populations are likely to belong to a single genepool. To determine the sources of variation within and between population groups, Analysis of Molecular Variance (AMOVA) was performed. This indicated that 96% of the detected variation could be attributed to differences between the individual trees within groups ($p<0.001$). The AMOVA Fst statistic attributes 3% of the variation to differences between groups (Fig. 3.8b). This result indicates that the molecular variation found amongst hawthorn samples can be largely attributed to variation between individuals within each group, rather than between groups (Fig. 3.8a & b).

Overall, the results indicate that there is little genetic variation observed both between and within Irish populations of hawthorn, and that recent versus older populations cannot be distinguished using the genetic markers employed. The study suggests that a choice of hawthorn planting materials sourced from Ireland versus continental Europe cannot be justified on the basis of genetic diversity or distinctiveness. However, it should be realised that genetically similar (or even identical) hawthorn plants have the potential to display different phenotypes due to minor genetic differences, heritable epigenetic differences and genotype X environment interactions. Indeed, a previous study (Jones et al. 2001) has shown morphological, phenological and disease susceptibility differences between European hawthorns, which were likely to also be very similar at the genetic level.

3.4 Road Landscaping and Ecosystem Services (Invasion Resistance and Biocontrol)

While there was no manipulative research into biocontrol by carabid beetles in WP2, the measure of potential consumption was used as proxy for potential biocontrol. There were no significant effects ($p<0.001$) of soil slope treatments on potential consumption by carabid beetles (Fig. 3.6a). Mean carabid beetle potential consumption was highest in the margin, followed by the verge and the field. Similarly, there was no significant effect of the rock/scree slope treatments on carabid-beetle potential consumption (Fig. 3.6b).

There was a significant effect of rock/scree slope habitats on potential consumption by carabid beetles ($p<0.001$) (Fig. 3.6b). As in the case of soil slopes, mean carabid beetle potential consumption was significantly higher in the margin compared to the verge and field (Fig. 3.6b).

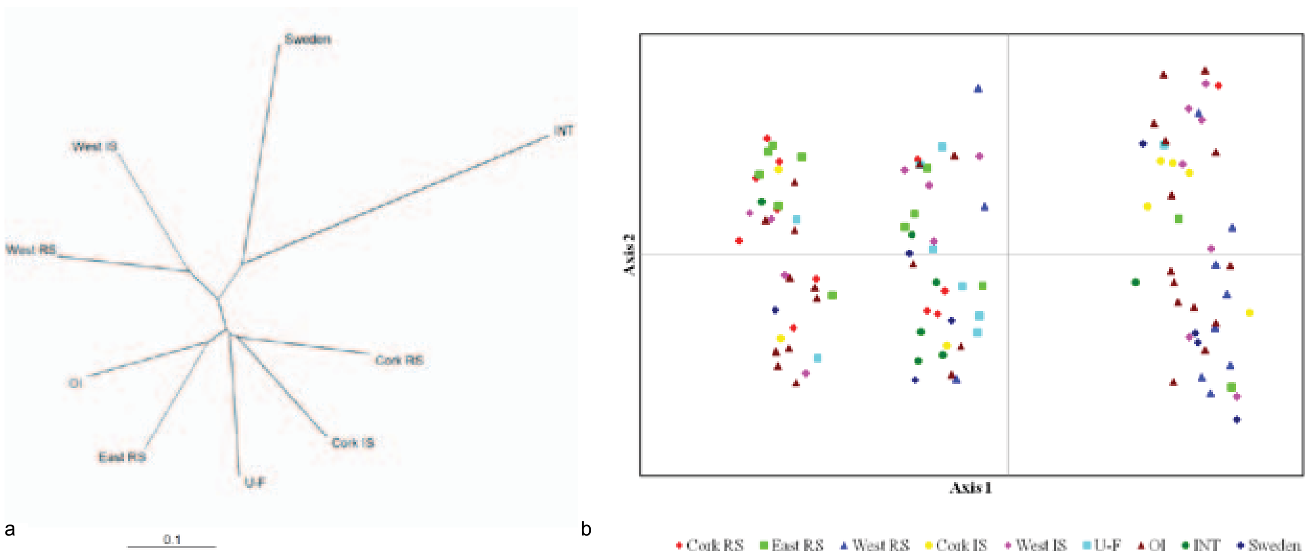


Figure 3.8. (a) Dendrogram displaying very low levels of differentiation between the groups. (b) Principal coordinate analysis of 111 individuals of *C. monogyna* grouped according to nine locations (Cork RS, East RS, West RS, Cork IS, West IS, U-F, OI, INT and Sweden). The axes indicate the genetic dispersion of the genotypes evaluated. The first two coordinates explain 30.88% and 22.23% of the total variance. The displayed structure does not support distinct groups, indicating that the total population is highly mixed.

In the third treatment, again, there was no significant effect of wider verge treatment on potential consumption (p=0.178) (Fig. 3.6c). However, there was a significant effect of wider verge habitats on potential consumption (p=0.001) by carabid beetles where mean carabid beetle potential consumption was significantly higher in the margin compared to the verge and field (Fig. 3.6c). The results on the ecosystem service of biocontrol as measured by potential consumption indicated the importance of the margin in all treatments as being different from the biocontrol services of the surrounding landscape.

3.5 Conclusion

This study has significantly increased the body of research on impacts of road landscaping on biodiversity in Ireland, providing the empirical evidence required to improve the national road-development process, and to maximise biodiversity conservation on future road developments. Opportunities exist in the planning, construction and implementation processes of road developments to improve on current best practice as detailed in the *Guide to Landscape Treatments for National Road Schemes in Ireland* (NRA, 2006) and NRA EACG. It is clear that the construction of the roads investigated increased biodiversity over that of the surrounding improved agricultural grasslands. The comparison of horticultural landscape treatments with those of more ecological treatments revealed that there was no difference between such treatments in terms of biodiversity. However, the landscape treatments that were investigated were ‘young’ in terms of the development of their plant and animal communities so the results should be interpreted in this light. Further, while there was no difference between horticultural and more ecological treatments, it is recommended that the latter, as detailed in the *Guide to Landscape Treatments for National Road Schemes in Ireland* (NRA 2006), continue to be used as best practice. This is because they recommend lower herbicide and fertiliser inputs, the use of plant material of Irish provenance, have lower development and maintenance costs, and are equally beneficial for biodiversity.

Recommendations are provided from an evaluation of the national road-development process and the NRA EACG to identify potential improvements in biodiversity conservation for future road development.

3.6 Recommendations for Decision-makers

1 Few differences in vascular plant, carabid beetle or pollinating insect biodiversity were found between the pre- and post-NRA guidelines. We therefore recommended that the treatments in the *Guide to Landscape Treatments for National Road Schemes in Ireland* (NRA 2006) continue to be implemented and improved. Such specifications are of higher value than earlier horticultural approaches because they are more sustainable. This is because they recommend lower herbicide and fertiliser inputs, the use of plant material of Irish provenance, have lower development and maintenance costs, and are equally beneficial for biodiversity.

2 No differences in soil nutrient concentrations were found between the pre- and post-NRA guidelines landscaping treatments. It is recommended that the use of subsoils (lower nutrient contents) over top soils always be prioritised when developing landscaping treatments because they are known to promote plant diversity as opposed to the reduced diversity of fast-growing weeds of agricultural crops that are typical of high nutrient agricultural soils.

3 With respect to carabids, in terms of habitats, however, it was clear that the margin habitat (hedgerow) was significantly different from the road verge and the adjacent field habitats. This indicates that the installation of hedgerows, as part of the road corridor, adds to carabid beetle biodiversity over that of the pre-existing habitats or that of the road verge or adjacent field. Currently, hedgerow whips on roads are usually installed as a double staggered row. In the light of the added contribution that the hedgerow habitat makes to the biodiversity of the road corridor it is recommended that the width of hedgerows be increased so as to produce a wider (2–3m) hedgerow. Such an increase in the width of hedgerows will not only increase the abundance of such a habitat in terms of biodiversity, but will also improve the stock-proofing that keeps stock away from the carriageway. Given that most of the current stock-proofing is provided by wooden post and rail fencing, supplemented with hawthorn (mainly), it is certain that in time the wooden fencing will decay, so investing in thicker hedging is recommended.

4 No differences in the genetic structure were detected between hawthorn populations on recently installed hedgerows on the N22/N25 road margins and those of older populations that were further from the N22/25, indicating all studied populations likely belong to a single genepool. However, an earlier study has demonstrated phenotypic differences (phenology, spinyness and disease resistance) which would favour the use of native provenances over imported material. We therefore, as a precaution, recommend the planting of native provenances and further research to investigate phenotypic variation.

5 The current study was carried out in 2009 on sites that had been created between 2004 and 2007. The sites are therefore 'young' in terms of their developing vegetation and carabid beetle communities. This is particularly true of communities on natural recolonisation or rock/scree slopes which take longer to develop than those on soil. It is important, therefore, to replicate the study on a future occasion when more mature communities have developed since aspects of road corridor management, such as nutrient status of soils, presence of invasive alien species and increasing organic matter content of soils are all likely to have changed considerably, with consequent effects on the plant and carabid beetle communities.

6 The provisions of the NRA (2006) *Guide to Landscape Treatments* should continue to apply as best practice for landscaping on Irish roads, including the use of planting material that is of Irish provenance. While native biodiversity continues to be threatened by increasing agricultural intensification, it is important to avail of opportunities afforded by the construction of roads to establish native vegetation communities as part of the national contribution to biodiversity conservation. Such vegetation will host communities of other organisms with which they have evolved, thus contributing to wider biodiversity conservation and sustainability criteria.

7 The following are recommendations from the evaluation (Dolan et al. in review) of the national road development process and the NRA EACG to identify potential improvements in biodiversity conservation for future road development:

   a Implementation of best practice ecological and habitat survey methodologies as recommended by the NRA (2008) and The Heritage Council (Smith et al. 2011) should be mandatory;

   b Species-specific surveys required at the route-selection stage for species where mitigation and compensatory measures are not feasible;

   c The extent of information displayed in EIS Habitat Mapping needs to be consistent and readily accessible at all contractual stages to all relevant contractors, consultants and designers;

   d Audits of Environmental Operating Plans are required to ensure they meet the necessary standards;

   e Increased protection of badger setts, bat roosts and other species/habitats required during Advanced Site Clearance;

   f A review of best practice in relation to management of aquatic systems required to ensure increased protection and focus on wetlands located adjacent to new road projects;

   g Implementation of a native only/use of Irish provenance plant material landscape planting policy is strongly recommended;

   h Improved monitoring and data storage/ management in a national open access repository (e.g. NBDC) is required to ensure effective implementation of mitigation measures (e.g. mammal fencing).

4 Assessing and Reducing Impacts of Aquaculture on Marine Biodiversity

4.1 Context

Since the 1980s, the global expansion of capture fisheries has virtually stopped, while demand for fish has continued to increase rapidly. In response, world aquaculture production has increased by an average of 7% per annum and now produces half of the fish and shellfish consumed by humans (Food and Agriculture Organization of the United Nations [FAO] 2009). The Irish aquaculture industry began in the 1970s. In 2007, the total production of shellfish and finfish in Ireland was 48,350 tonnes – 37,112 tonnes of shellfish (mainly oysters and mussels) and 11,238 tonnes of finfish (mainly salmon). The value of the sector was €105.7 million and it employed 2000 people. The economic and social value of aquaculture is heightened by the fact that it is one of the few industries with a strong presence in Ireland's remote coastal communities. While the production of shellfish is increasing steadily, salmon production has shown a decrease from a maximum output of 23,312 tonnes in 2001 to 9,923 tonnes in 2008. Industry output in Ireland is focused on high-quality, low-volume niche markets. An increasing proportion (almost 50% in 2003) of Irish salmon is produced to Organic or Eco-Standards and sells at a premium (Browne et al. 2008). In 2008, 90% of Irish salmon production was independently accredited to either Organic or Eco-Standards and this pattern will continue into the future. The salmon-growing sites on the west coast of Ireland occur in naturally higher-energy, more exposed environments than the sea-lochs utilised by Scottish and Norwegian operators. Consequently, typical impacts associated with salmon farming, such as seabed anoxia and nutrient enrichment, are not as much of an issue in Ireland when compared with other jurisdictions.

Nevertheless, aquaculture can influence biodiversity and ecosystem functioning and services in a number of ways. The influences considered most important in Ireland are interactions with wild fisheries resources, physical damage to or replacement of habitat, organic and nutrient enrichment, as a vector for invasive species, and through interactions with seals and birds (Callier et al. 2011).

To ensure the sustainability of this industry, it is essential to better understand the interactions between aquaculture, biodiversity, ecosystem services and society. Changes to biodiversity, for example in terms of the numbers and identities of species present in an area, can affect the functioning of ecosystems, altering rates of production, nutrient cycling, etc., which in turn can influence the benefits to society that ecosystems provide. A key challenge is to find the balance between the benefits of aquaculture and maintaining conservation status in coastal Natura 2000 sites.

4.2 Summary of Findings

4.2.1 Direct Impacts of Caged Salmon Farms on Biodiversity and Ecosystem Functioning

The extent of salmon farming's influence on the environment and the uptake of particulate and dissolved effluents by benthic organisms were assessed using community structure and stable isotope analyses (Callier et al. 2013). Sediment cores were collected along transects in two directions (perpendicular to [T1] and in the direction of [T2] the main residual current) at 0m, 25m and 200m from two salmon farms (Millstone and Cranford) located in Mulroy Bay, Republic of Ireland (Fig. 4.1). In addition, fouling communities were collected on artificial substrates, which were placed for 2 months at 1m depth at the same distances. The extent of measurable change in benthic communities depended on residual current direction. At both farms, communities living below the cages had low diversity (Fig. 4.1), and were dominated by opportunistic species. Variation in isotopic signatures of the food sources was sufficient to identify variation in the organisms' diet. Intra-specific variation in isotopic value in benthic invertebrates was mostly explained by distance from cages. Organisms collected beneath the cages were depleted in δ13C compared to individuals collected at 200m. A shift in δ13C was observed in species present at more than one distance, including the bristleworm

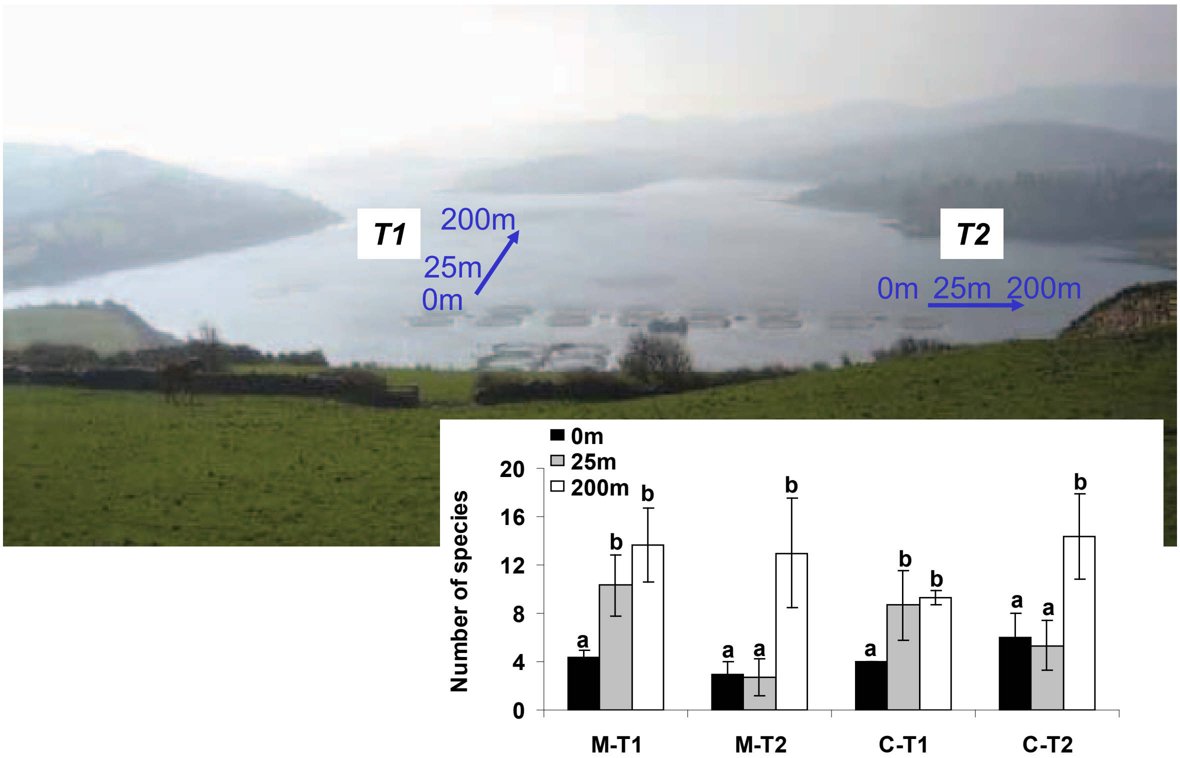


Figure 4.1. Millstone farm, Mulroy Bay showing Marine Harvest salmon farm and arrangement of sampling stations along transects T1, perpendicular to residual current and T2, downstream from farm. Inset is a graph showing average number of species (species richness) per core (*n* = 3) sampled at stations along transects T1 at Millstone farm (M) and Cranford farm (C) – located elsewhere in Mulroy Bay. Bars representing means that are not statistically different from each other are denoted by the letters a or b; bars with different letters above them are statistically different from each other. Compared to control sites 200m from the cages, species richness is significantly reduced immediately under the cages (0m) in all transects. Along T2, reduced species richness is also apparent 25m downstream from the cages. Along T1, species richness at stations 25m from the cages is not different from that at control stations 200m from the cages. Multivariate analysis of community structure revealed comparable spatial patterns of difference.

(*Malacoceros fuliginosus*), the catworm (*Nephtys hombergii*), nematode worms and the Red speckled anemone (*Anthopteura balii*). Fouling communities collected on artificial structures – mainly composed of tunicates (*Ascidiella aspersa*) – showed higher δ15N values at fish-cage sites compared to 200m sites. The study demonstrated that fish effluents were assimilated and became a food source for native organisms with repercussions for trophic structure. Sedimentary and fouling organisms, potential sinks for fish effluents, may play an important role in the carrying capacity of ecosystems for aquaculture.

4.2.2 Indirect Effects of Aquaculture

This body of work focused on the Pacific oyster, *Crassostrea gigas*. Native to Japan, the Pacific oyster has been introduced for aquaculture to many parts of the world and has become one of the world's main aquaculture species (FAO 2012). In many intertidal habitats outside aquaculture areas it has established permanent, self-sustaining and also invasive populations worldwide (Reise 1998; Ruesink et al. 2005; Troost 2010). In Europe, there are invasive populations along the Atlantic and North Sea coasts, for example in Germany (Reise 1998; Diederich et al.

2005), the Netherlands (Fey et al. 2010) and France (Cognie et al. 2006). Recent studies indicate that the northern boundaries of distributions of this species are expanding; they have been found in England and Wales (Couzens 2006), Northern Ireland (Guy & Roberts 2010) and Scandinavia (Wrange et al. 2010).

Pacific oysters are habitat generalists. Their colonisation process generally starts with settlement onto pieces of hard substratum, for example shell fragments, stones, mussel beds, aquaculture racks or harbour walls. They can be found in a wide range of habitat types, from coastal sheltered soft-sediment environments to exposed rocky shores (Ruesink et al. 2005; Cognie et al. 2006; Troost 2010) and they are tolerant of a wide range of environmental conditions (Enríquez-Díaz et al. 2008). Growth of oysters occurs between 3 and 35°C, but temperatures for spawning range between 16 and 34°C (Mann et al. 1991; Ruiz et al. 1992) and increasing summer temperatures have been associated with the spread of Pacific oysters in Europe (Diederich et al. 2005; Fey et al. 2010).

In locations around the world, wild Pacific oyster populations have established soon after their farming had commenced (Brandt et al. 2008; Troost 2010). Pacific oysters were introduced to Ireland in 1973 for aquaculture and they are now extensively farmed around the north, the west and south coast (Browne et al. 2008). Recently, there have been reports of individuals being found in the wild, but the extent and distribution of these populations was hitherto known. Given their potential rate of spread, there is an urgent need to characterise its pattern of establishment at an early stage and determine which factors are associated with its presence or absence.

Invasive oyster populations can have substantial impacts, including saturation of the carrying capacity of estuaries, change in phytoplankton composition and food webs, spatial competition with other species and alteration of habitat heterogeneity (Ruesink et al. 2005; Cognie et al. 2006; Troost 2010). Before the current study, the potential impacts of Pacific oysters on biodiversity in Ireland had not yet been characterised and indeed there had been little experimental research in other parts of their invaded range. Their impacts on ecosystem functioning and the mechanisms underlying those impacts had not previously been studied anywhere.

4.2.2.1 Oyster Escape, Establishment and Future Spread

Documenting the establishment and spread of invasive species requires extensive coordinated sampling programmes. Identifying the factors promoting or inhibiting local establishment of an invasive species can improve capacity to predict further spread and underpin strategies to limit spread. Here, a structured sampling programme was used to assess the current distribution of feral populations of Pacific oysters in Ireland (Kochmann, 2012; Kochmann et al. 2013). In a direct collaboration between UCD, the Loughs Agency, the Marine Institute, Queen's University Belfast (QUB) and Bord Iascaigh Mhara (BIM), 69 sites were sampled in 2009 using a standardised protocol combining semi-quantitative and quantitative approaches. Sites were chosen to represent a variation in proximity to aquaculture and a range of environmental variables. Oyster populations were found at 18 locations (Fig. 4.2). Highest densities occurred in Lough Swilly and Lough Foyle with up to 9 individuals/m^2 and lower densities were found in the Shannon Estuary and Galway Bay. Analysis of size frequency distributions revealed that several recruitment events had occurred, probably within the previous 6–10 years. Logistic regression indicated that feral oysters were positively associated with the presence of hard substrata or biogenic reef, long residence times of embayments and large intertidal areas. There was also a tendency for oysters to occur disproportionately in bays with aquaculture, but >500m from it. Small-scale analysis within sites showed that oysters were almost exclusively attached to hard substrata and mussels. The approach taken here provides a rigorous repeatable methodology for future monitoring and a detailed basis for the prediction of further spread.

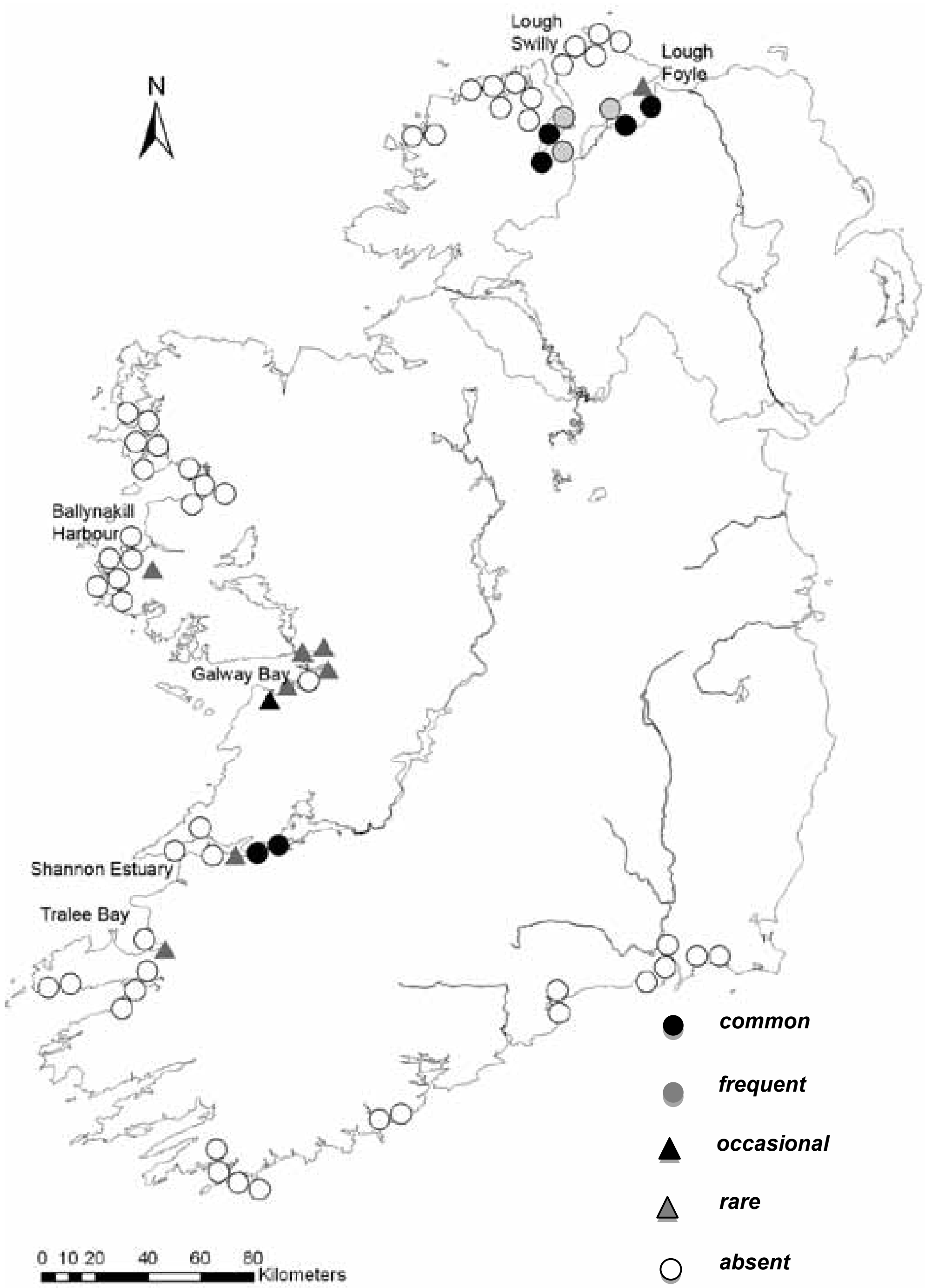


Figure 4.2. Sampling sites and abundances of feral Pacific oysters in Ireland in 2009. Sites are categorised on the semi-quantitative SACFOR scale on the basis of timed searches. Names of the embayments where oysters were found are given.

Biotic interactions can play a key role in promoting or inhibiting the spread of invasive species. Here, we tested the influence of predation and macroalgae on growth and survival of juvenile Pacific oysters. A field experiment was set up in July 2011 at two intertidal macroalgae-dominated boulder shores where only single individuals of oysters occur. After 10 months, the condition of oysters was not significantly decreased in the presence of macroalgal canopy; however, shell growth was significantly reduced by at least 3mm in less than 4 months, but only at one site. Although predation had a strong negative effect on oyster survival (mean oyster size 16mm) in a pilot experiment conducted in July 2010, no effect of predators was detected in the present study (mean oyster size 36mm). Trapping of shore crabs (*Carcinus maenas*), which are considered one of the main potential predators of Pacific oysters in their introduced range, revealed the presence of significantly larger crabs at sites where oysters were not found. More crabs (>35mm carapace width) were found at shores where oysters are rare but numbers were not significantly different from other shores. Our results suggest that pre-settlement and recruitment processes might better explain abundance patterns of Pacific oysters in intertidal habitats than post-recruitment growth and survival.

Human-mediated introduction of non-native species into coastal areas via aquaculture is one of the main pathways that can lead to biological invasions. To develop strategies to counteract invasions it is critical to determine whether populations establishing in the wild are self-sustaining or based on repeated introductions. In this study, temporal genetic variability of farmed and wild oysters from the largest enclosed bay in Ireland was assessed to reconstruct the recent biological history of the feral populations using seven anonymous and seven expressed sequence tag (EST)-linked microsatellites (Kochmann et al. 2012). There was no evidence of EST-linked markers showing footprints of selection. Allelic richness was higher in feral samples than in aquaculture samples (p=0.003, paired t-test). Significant deviations from Hardy-Weinberg (HWE) due to heterozyote deficiencies were detected for almost all loci and samples, most likely explained by the presence of null-alleles. High genetic differentiation was found between aquaculture and feral oysters (largest pairwise multilocus FST 0.074, p<0.01) and between year classes of oysters from aquaculture (largest pairwise multilocus FST 0.073, p<0.01), which was also confirmed by the strong separation of aquaculture and wild samples using Bayesian clustering approaches. A ten-fold higher effective population size (Ne) – and a high number of private alleles – in wild oysters suggest an established self-sustaining feral population. The wild oyster population studied appears demographically independent from the current aquaculture activities in the estuary and alternative pathways of introduction and establishment are discussed.

4.2.2.2 Effects of Oysters in Wild on Biodiversity and Ecosystem Services

An experiment was used to separate the effects of cover, physical structure and biological activities of Pacific oysters on the development of assemblages (Green 2012; Green & Crowe 2013). Increasing cover of living (biologically active) and dead (physical structure only) oysters were added to the tops of new boulders and deployed within an intertidal boulder field. After 14 months, diversity, evenness and assemblage structure were affected by Pacific oysters, with patterns differing depending on the cover and state of oysters. Boulders with Pacific oysters, regardless of their cover or state, supported assemblages with more species, greater Shannon-Wiener diversity and evenness, but boulders with the least cover of living oysters had the greatest diversity and evenness. Assemblage structure also differed depending on the cover and state of oysters with differences driven by changes to the establishment of several key species. These included the honeycomb worm, *Sabellaria alveolata*, which constructs reefs protected by the EU Habitats Directive and which mainly established on the underside of boulders, and was nonetheless greatly reduced by increasing cover of oysters on their upper surfaces, regardless of their state.

To test the impacts of Pacific oysters on biodiversity and ecosystem functioning in different habitats, experimental plots with increasing cover of oysters were set up in mussel-beds and mud-flats within two estuaries, Lough Foyle and Lough Swilly and were sampled after 4 and 15 months (Green 2012; Green & Crowe 2013). At both times and within each estuary, species richness, diversity (calculated using the Shannon-Wiener index) and total number of individuals increased, with increasing cover of oysters within mud-flat habitats. In mussel-bed habitats, however, species richness, Shannon-Wiener diversity and total number of individuals peaked with medium cover of oysters at one estuary and significantly decreased with the greatest cover of oysters at the other estuary. At both estuaries at each time, assemblage structure differed between habitats and among covers of oysters with a reduction in β-diversity as assemblages became more homogenous with the increasing cover of oysters in mud-flat habitats. These responses were primarily underpinned by increases in the density or cover of several taxa, including a grazing gastropod (*Littorina littorea*), a non-indigenous barnacle (*Elminius modestus*) and a primary producer (*Fucus vesiculosus*) with increasing cover of oysters. The response of many species differed between locations and over time, suggesting that some effects are context dependent.

Measurements of ecosystem functioning were made only in Lough Swilly (Green 2012; Green & Crowe 2013). Pacific oysters significantly altered several biogeochemical properties and processes, and some of its effects differed between habitats. Sediment-water fluxes of NH_4^+ and $Si(OH)_4$ and benthic turnover rates increased with increasing cover of oysters in mud-flats but decreased at the greatest cover of oysters in mussel-beds. Community respiration (CO_2 flux) increased with the greatest cover of oysters in both habitats. Biodiversity increased with increasing cover of oysters in mud-flats but decreased with the greatest cover of oysters in mussel-beds. The relationship between assemblage structure and functional variables was assessed using distance-based linear models (DISTLM). A total of 28.8% of the total variation in assemblage structure was accounted for by 9 variables in distance-based redundancy analysis, and 18% of this variation was explained by variation in NH_4^+. Pacific oysters can alter biodiversity and benthic turnover rates of important limiting nutrients, and therefore may affect ecosystem services provided by estuarine ecosystems.

The effects of different percentage covers of invasive Pacific oysters on ecosystem processes and associated microbial assemblages in mud-flats were tested experimentally in the field at Lough Swilly (Green 2012; Green et al. in review). Pore-water nutrients (NH_4^+, NO_2^- and NO_3^-), sediment chlorophyll content, microbial activity, total carbon and nitrogen and community respiration (CO_2 and CH_4) were measured to assess changes in ecosystem functioning. Assemblages of bacteria in general as well as functional groups including methanogens, methanotrophs and ammonia-oxidisers were assessed in the oxic and anoxic layers of sediment using terminal restriction length polymorphism on the 16S, mcr*A*, mxa*F* and amo*A* genes respectively. Effects of Pacific oysters differed with cover. At the highest cover, there was significantly greater total microbial activity, chlorophyll content and CO_2 (13 fold greater) and CH_4 (6 fold greater) emission from the sediment compared to mud-flats without any Pacific oysters. At the lowest cover, Pacific oysters increased the concentration of total oxidised nitrogen and altered the assemblage structure of ammonia oxidisers and methanogens. At any cover of Pacific oysters, concentrations of pore-water NH_4^+ were greater than in areas of mud-flat without Pacific oysters. Invasive oysters may alter ecosystem functioning not only directly, but also indirectly by affecting microbial communities vital for the maintenance of ecosystem processes.

4.3 Conclusion

Aquaculture is an important industry for Ireland, particularly in the context of remote rural communities, where it brings considerable economic and social benefits. Irish aquaculture has a number of features that make its impacts on the environment generally less than in some other jurisdictions. Nevertheless, it has the potential to influence native biodiversity and ecosystem processes in important ways. Such impacts can affect not only the conservation status of coastal marine habitats, but can also reduce the capacity of marine ecosystems to deliver vital ecosystem services, including provisioning services such as aquaculture itself. The significance of its impacts varies considerably with environmental context and must also be considered in the context of social and economic imperatives, as well as policy and legislative frameworks, particularly those derived from EU directives, such as the Habitats Directive, the Marine Strategy Framework Directive and the Water Framework Directive.

Effective management of aquaculture is needed to reduce its environmental impacts and safeguard its long-term sustainability. Some statutory measures are in place and there are also some effective voluntary programmes, such as ECOPACT and CLAMS, which enjoy a high level of support from industry. Effective management must also be underpinned by good scientific understanding. A range of recommendations is made above, based on the research completed during the SIMBIOSYS project. A number of key research gaps are also identified. These should be filled with a nationally coordinated programme of integrated research developed and executed in cooperation with the full range of relevant stakeholders.

4.4 Recommendations for Decision-makers

1 In environmental decision-making and spatial planning for bays involving aquaculture, it should be noted that the extent of influence of salmon cages on benthic assemblages is very narrow (<25m) perpendicular to the main direction of current flow in comparatively high-energy areas such as Mulroy Bay, but greater (25–200m) downstream from the cage.

2 Stable isotopes were an effective tracer of salmon farm wastes into biota and enabled us to reveal assimilation of salmon waste by benthic species, which underwent a shift in their diet. Further use of this approach could yield additional insights into changes in trophic structure and may help inform decisions about the compatibility of aquaculture with other activities in Natura 2000 sites.

3 Increased biomass of suspension feeders (e.g. tunicates) as part of 'fouling communities' could decrease levels of particulate and dissolved material in the surrounding environment. This could potentially be used as a mitigation strategy, in which substrata could be deployed in highly sensitive environments, where small reductions in nutrient loading could be critical. Further research would be required to assess the effectiveness of this approach on a larger scale.

4 Further consideration should also be given to using Integrated Multi-Trophic Aquaculture in Ireland. This is an approach with potential to both diminish environmental impacts and increase profitability. Benthic polychaetes could potentially be used to consume waste under fish cages, for example, and in turn be harvestable themselves.

5 Pacific oysters can pose a considerable threat to native biodiversity and ecosystem functioning. The current study showed that they may negatively impact the establishment of a protected biogenic habitat (*Sabellaria* reefs). At their highest cover, Pacific oysters can decrease biodiversity, increase the homogenisation of habitats, increase the emission of gaseous carbon and decrease the turnover rate of important limiting nutrients, possibly leading to a reduction in provisioning services, such as aquaculture production. Experience in other countries has also included negative effects on bird populations and on recreation and tourism.

6 Action should be taken at an early stage to restrict (or eliminate where possible) the spread of Pacific oysters in Ireland before dense reefs are formed. The task would already be very challenging, but if large populations become established, the challenge would be far greater.

7 In developing management strategies, surveillance should be focused on areas with hard substrata or biogenic reef, long residence times of embayments and large intertidal areas. Pacific oysters also tend to occur disproportionately in bays with aquaculture, but >500m from it. Management efforts should also be targeted towards areas of particular conservation or economic value, for example areas designated for *Sabellaria* reefs, areas important for aquaculture.

8 Risk of spread of Pacific oysters from aquaculture could be greatly reduced by the use of triploid oysters. This approach has already been adopted by many farmers and presents a win-win solution as triploid oysters also grow faster than diploids.

9 Genetic evidence indicates that feral Pacific oysters are likely to be spawning, such that their populations are self-sustaining. Management measures must therefore focus on feral populations as well as aquaculture operations.

10 At present in some areas, feral populations of Pacific oysters are being harvested in some habitats (F. O'Beirn, pers. comm.), which will contribute considerably to their control and should be encouraged. However, this would cease if populations become too dense: once they have formed dense reefs, they are not harvested commercially because individuals with distorted shells have limited commercial value.

11 Pacific oysters can impact biodiversity even when dead, albeit to a lesser extent, so management action should include the removal of oyster shell material where feasible. It should be noted, however, that shell material can be important for the promotion of native oyster production.

12 A coordinated sampling programme should be established to monitor the spread of Pacific oysters and test effectiveness of any control measures adopted. The methodology developed in the current project is rigorous, repeatable and cost effective.

13 Statutory measures and existing voluntary programmes such as CLAMS and ECOPACT provide a good framework for the development and implementation of further improvements to the management of aquaculture activities with the broader view of reducing and managing environmental impacts.

14 The understanding of impacts of aquaculture in Ireland could be improved by the development of a coordinated monitoring programme and research to understand: (i) changes to communities and ecosystem processes in the water column (which have been less well studied than those on the sea bed); (ii) the extent of influence of individual aquaculture installations and how their influence combines and interacts with other local and global pressures; (iii) the resistance and resilience of coastal ecosystems and the carrying capacity of Irish embayments, and (iv) how ecological changes induced by aquaculture translate into changes in the provision of ecosystem services.

5 Impacts of Wind Energy on Biodiversity: a Review[1]

In response to climate change, the EU has set a target to achieve 20% of energy from renewable sources by 2020. Consequently, Ireland has set targets of 40, 10 and 12% of energy coming from renewable sources for electricity, transport and heat, respectively. Wind energy is expected to contribute to over 90% of these targets given Ireland's large onshore and offshore wind potential, with over 2000MW of installed capacity to date. However, the potential impacts of these wind farm developments on Ireland's biodiversity remain largely unquantified.

In this assessment we used a review of the literature to identify the potential positive and negative impacts of wind farms on Ireland's marine and terrestrial biodiversity. We also combined spatial analysis techniques with national datasets to reveal the extent to which wind resources and current and future wind farm developments overlap with habitats and species of conservation value.

To maximise effectiveness, wind farms should ideally be sited in open, exposed areas where mean wind speeds are high, with developments therefore most suited to upland, coastal and offshore areas. To date wind farms in Ireland have mostly been developed at onshore locations, but offshore developments may significantly increase in the future. This means that a wide range of species and habitats of high conservation value are or will be potentially influenced by wind energy developments.

Results of the literature review highlight little published information on the impacts of wind developments on Ireland's biodiversity and ecosystem services. Accessibility to existing monitoring datasets and grey literature proved challenging.

The international literature suggests that birds (onshore and offshore), bats (onshore), and marine mammals (offshore) are the groups most vulnerable to the direct impacts of wind turbines. The four principal impacts on birds are: (i) collision; (ii) displacement due to disturbance; (iii) barrier effects; and (iv) habitat loss, with consequences for direct mortality, or changes to behaviour, condition and breeding success. The effects of a wind farm on birds are highly variable and depend on a wide range of factors, including the specification of the development, the topography of the surrounding land, the habitats affected and the number and species of birds present.

Less research on the impacts of wind-farm construction, operation and decommissioning has focused on bats. The principal impacts on bats are (i) collision, (ii) barotrauma, (iii) habitat loss (avoidance), and (iv) barriers to migration/commuting, with consequences for direct mortality, or changes to behaviour, condition and breeding success.

For marine species, including marine mammals, fish and invertebrates, positive impacts include habitat creation, with turbines functioning as artificial reefs benefiting epibenthic invertebrate and algae and fish assemblages. Wind farms also act as no-take zones for fish and fish-aggregation devices. Negative impacts on marine species include habitat change and loss, construction- and operation-induced noise, artificial structures providing habitats for non-indigenous species, electromagnetic fields affecting fish orientation, and construction (pile diving) impacts on the foraging, orientation and communication of harbour porpoises and bottlenose dolphin.

Some key areas for future research in Ireland include: (i) the development of bird/bat sensitivity maps; (ii) studies focused on population-level impacts to disentangle wind farm impacts from other threats and pressures; (iii) species-specific studies concerning the behavioural responses of different species based on lifecycle characteristics, population dynamics, ecology and abundance in response to construction, operational and removal phases of wind farms. This will establish species-specific sensitivities to several types of large-scale wind farms; (iv) identify migration routes/corridors and stepping stones of bats in Ireland; (v) cumulative effects on onshore and offshore wind farms on birds and bats; and (vi) preliminary research into impacts on Ireland's marine species and

1 Full review available from: http://www.tcd.ie/research/simbiosys/images/SIMBIOSYS%20Wind%20Energy%20Sectoral%20Review.pdf

habitats in advance of increased offshore wind farm developments.

Little published research was found concerning impacts on habitats. Habitats (particularly peatland, heath, upland, coastal and marine habitats in Ireland) are directly influenced, predominantly during the construction phase and through longer-term habitat loss. No studies to date have focused on impacts on the provision of ecosystem services or the indirect impacts of wind farms on habitats and species. Habitat ecological and physical integrity, habitat fragmentation and the facilitation of invasive species remain largely under-researched.

Long-term sustainability of the sector will be dependent on quality research, appropriate monitoring, greater consideration of cumulative impact assessments facilitated by clearer guidance, and appropriate spatial planning. Our spatial analyses reveal the extent to which wind resources and current and future wind farm developments overlap with habitats and species of conservation value. We put forward recommendations on the sustainable future planning and management of wind farms in Ireland, helping to ensure the direct benefits of GHG emission reduction are maximised without compromising the protection of biodiversity in Ireland.

6 Sectoral Impacts on Marine Systems: a Review[2]

Ireland's coastal waters are very important to its society and its economy. A wide range of activities impinge on them, with the potential to affect biodiversity and the provision of ecosystem services. As such, EU and national legislation provide for these activities to be regulated to ensure the long-term sustainability of this valuable resource. Effective implementation of this legislation requires a sound knowledge of the nature and relative importance of impacts caused by different activities.

Our assessment of potential impacts on coastal marine ecosystems of pressures associated with sectoral activities involved a systematic review of the literature and consultation with appropriate experts (Crowe et al. 2012). Relevant research often focuses on pressures, such as pollution, habitat loss and hydrological changes rather than on the sectors of activity that introduce them. The first step was therefore to map pressures to sectors of human activity, such that the overall effects of particular sectors could be interpreted from available research findings. We then categorised the resistance of each habitat to potential impacts of each pressure on extent and quality and assessed the likely time to recovery (resilience). Our findings are summarised and presented in more detail as a series of summary tables, which include clarification of the extent, nature, quality and applicability in an Irish context of the evidence that underpins each entry (see Crowe et al. 2012).

Pressures that result in habitat loss or change or direct physical disturbance clearly have the most direct and irreparable impacts on the extent of habitats, particularly sedimentary habitats. Such pressures are exerted by sectors such as fisheries and aquaculture, the construction industry, with lesser influences of the shipping, leisure, tourism and energy sectors.

Sedimentary habitats also have limited resistance to changes in water flow and/or tidal emergence regimes, which are also caused by physical installations, such as those associated with aquaculture, construction, shipping and the energy industry.

Exposed rocky reefs are comparatively resistant to physical pressures, but less so to chemical contaminants or biological pressures such as harvesting and non-indigenous species. Sheltered reefs on the other hand are also vulnerable to physical pressures such as siltation. If pressures are removed and there is an appropriate source of larvae, most rocky substrata can be recolonised and tend to recover within 10 to 15 years.

The addition of inorganic nutrients and organic matter leading to eutrophication and deoxygenation causes changes to many of the habitats, particularly muddy sands, seagrass and sheltered rocky reefs. These are derived from agricultural and industrial discharges, sewage and aquaculture, which need to be considered as cumulative sources in a given estuary or embayment and associated catchment.

Shipping, leisure boating and aquaculture are the main sources of non-indigenous species, some of which become invasive and cause substantial changes to marine ecosystems with little scope for recovery.

In Ireland, perhaps the most extensive industries with potential to influence coastal marine biodiversity are agriculture, fisheries and aquaculture. These activities occur in many Special Areas of Conservation (SACs) and Special Areas of Protection (SAPs), and finding an acceptable balance between their important economic and social benefits and the achievement of conservation objectives presents a significant challenge.

We emphasise that the summary tables should serve as a guide only and that their applicability to any site-specific assessment process should be informed by appropriate expert judgement. We argue that the knowledge-base to anticipate cumulative and combined impacts of multiple pressures is not sufficiently well developed for most pressures and receiving environments. We therefore recommend a precautionary approach assuming additive or synergistic effects of multiple pressures where there is uncertainty.

2 Full review available from: http://www.tcd.ie/research/simbiosys/images/SIMBIOSYS%20Marine%20Impacts%20Sectoral%20Review.pdf

Key areas for future research include:

- The introduction and spread of invasive non-indigenous species and the resistance of ecosystems to their effects;
- The influence of sectoral activities on maërl and seagrass;
- Assessment of the compatibility of aquaculture activities with the conservation objectives of SACs and SPAs to inform the development of management plans;
- Links between changes in biodiversity, ecosystem functioning and the provision of ecosystem services to assess how sectoral activities may influence the flow of economic and societal services from ecosystems;
- How multiple sectoral pressures combine to affect ecosystems and how their effects may be modified by global climate change and changes to the pH and carbonate chemistry of the oceans;
- Resilience – the capacity of ecosystems to recover after impact;
- Tipping points into alternative states from which recovery may be unlikely;
- Carefully designed long-term sampling to detect changes in biodiversity and ecosystem functioning and interpret them in relation to sectoral activities and the pressures they exert. Such programmes could be built around compliance monitoring required under the Habitats Directive, Water Framework Directive and Marine Strategy Framework Directive.

7 General Conclusions

7.1 Summary of Key Messages

Overall, the SIMBIOSYS Project has identified three key messages from across the different WPs:

1 Different Management Approaches affect Different Aspects of Biodiversity: Different taxa were found to respond in different ways to human activities, with some species benefiting, some suffering and some not affected at all. Even within ecological guilds, there were subtle differences in responses among taxa (e.g. within the pollinator groups in the energy crops). In addition, the response of species depends on environmental context (e.g. in the salmon fisheries, the impacts varied spatially from the source). In addition, if we focus just on taxonomic diversity or species richness, we overlook the fact that not all species are equally important, either in an ecological or economic sense. For example, some species on roads that add to the biodiversity of plants may be non-native and so have adverse effects on other aspects of the ecosystem; or some species of carabid beetle in crops may be better at controlling crop pests than others. Thus, just demonstrating effects on biodiversity in different sectors of activity is not enough: we need to determine what this means for the ecosystem and for us in terms of delivery of ecosystem services.

2 Positive Relationship between Species Richness and Services across Land-use Types/ Systems: Like other studies before us, we have found support for a positive relationship between species richness and ecosystem functioning, which leads to the delivery of ecosystem services. For example, for both the pollinators and the carabids in the energy crops, increases in species richness were associated with increases in potential service provision of pollination and predation respectively. Importantly, this relationship was apparent, regardless of the management pressures.

3 Biodiversity and Society: Win-win Solutions: The SIMBIOSYS project has found evidence for some sustainable ‘win-win’ solutions to balancing biodiversity and human activity. For example, with regards to road landscaping, lower-input treatments were no less species rich; in the energy crops, a reduction in agrochemical inputs is cheaper for the farmer and better for natural enemies of crop pests; and in aquaculture, using triploid oysters which are virtually sterile means they cannot ‘escape’ from farms, and in addition they grow much more quickly. In many cases, identifying more cost-effective, sustainable approaches for managers also benefits biodiversity, and thus the provision of some ecosystem services, but this relationship is not widely appreciated.

In general, management to promote biodiversity can also enhance delivery of some ecosystem services, but possibly at a cost to others. For example, if a farmer manages a *Miscanthus* crop to increase delivery of provisioning services (i.e. crop yield), he or she will also increase carbon sequestration, but may reduce the diversity of carabid beetles that provide pest population regulation. The scale of management is important too. For example, patches of *Miscanthus* in a landscape of mixed heterogeneous farming may benefit communities of bees, but if the landscape is covered with *Miscanthus* this may have negative impacts. As a result, activity needs to be appropriate to the management goals and at an appropriate scale. Decisions need to be made about what are the most important services in a particular situation. Managers need to be clear about what they want to achieve in terms of biodiversity and services and then, with an understanding of what the consequences of their actions are, decisions can be made about how to achieve these goals and what the impacts may be. Importantly, biodiversity protection should not just occur in designated protected areas, but also in highly managed and exploited habitats such as those studied in this project.

One of the shortcomings of the SIMBIOSYS project (and other similar studies elsewhere) is that the project was only a few years long, with most field data coming from one to two seasons. As a result, year-to-year variations cannot be accounted for. In addition, the industries focused on in SIMBIOSYS are in their infancy relative to other sectors in Ireland. We chose to study them because they were rapidly expanding sectors, but this means they are also young sectors: energy crops were recently planted, road treatments recently implemented, and although oyster farming is not new, the escape of oysters is just starting to occur. Therefore, we could not test long-term impacts, and cannot make long-term predictions.

Furthermore, the spatial extent of impacts are largely unknown: energy crops currently occur as relatively small patches in agricultural landscapes, road treatments are not implemented on all routeways, and oysters are currently only in isolated bays. If these sectors continue to expand in Ireland, impacts may differ in magnitude. In addition, we do not know how activity in other sectors may affect the growth of the sectors studied in SIMBIOSYS. Nor do we know how biodiversity and services will respond to multiple pressures, both from the environment and from people and their activities, for example with future climate change, invasion by other non-native species, or changes in policy. Therefore, although we have achieved a great deal during the SIMBIOSYS project, there is still a lot to do in terms of understanding the influence of human activity on biodiversity, ecosystem functioning and the delivery of ecosystem services.

7.2 Summary of Outputs

The SIMBIOSYS project has brought together expertise from principal investigators from four universities (TCD, UCD, UCC and NUIG), employed six postdoctoral researchers, involved twenty national and international academic collaborators, and benefited from interaction with many key stakeholders (Table 7.1). This has enabled the training of six PhD students (one funded externally, but linked to the SIMBIOSYS project infrastructure) and eight research assistants/technicians, as well as many other MSc and undergraduate students (not directly funded by the project). This illustrates the value of a relatively long term (>3 years) integrated large-scale research project: value for money can be achieved through the addition of various undergraduate and postgraduate research projects during the life of the project – in particular to tackle smaller questions which were not apparent at its initial conception. In addition, this illustrates the importance of collaborative research: various external experts were involved with aspects of the project, enabling us to ensure that our work is at the forefront of international cutting-edge research.

The national and international relevance of our findings is illustrated by the number of presentations and reports that have been delivered during the project, and the number of international peer-review publications which have already been published, are in press, or are in the process of being submitted (Table 7.1). Because the academic publishing process can take some time, we expect this number of journal papers to increase over the 12–18 months following the end of the project. Publication updates will be posted on the EPA website as the full technical report, and on the SIMBIOSYS project website. Sectoral reviews were carried out for the main experimental WPs (energy crops, road landscaping and aquaculture) as well as for coastal marine ecosystems and the potential impacts of wind energy; the full text of these reviews is available for download from: http://www.tcd.ie/research/simbiosys/outputs/sectoral-reviews/

Table 7.1. Summary of outputs to date (June 2013) from the SIMBIOSYS project.

Output metrics	Number
Researchers:	
Principal investigators	7
Postdoctoral researchers	6
Research assistants	7
Research technician	1
PhD students	6
MSc students	6
Undergraduate students/internships	8
Collaborators:	
Irish collaborators	11
International collaborators	9
Papers, conferences & reports:	
Peer-reviewed journal papers	17
Sectoral reviews and work-package final Reports	6
Project progress reports	8
Peer-reviewed conference papers	2
Conference paper presentations	37
Conference poster presentations	20
PhD theses	6*
MSc theses	6
Policy reports	3
Other presentations	8
Newspaper articles	2

* Five completed, one awaiting submission (June 2013).

7.3 Summary of Recommendations for Stakeholders/Decision-makers

Recommendations are given for each of the work-packages at the end of Sections 2, 3 and 4. These recommendations are summarised by WP in Table 7.2.

Table 7.2. Summary of recommendations for stakeholders and decision-makers in each sector.

Recommendation	Policy environment
Workpackage 1: Energy crops	
Converting arable or grassland to *Miscanthus* production can be recommended in terms of soil organic carbon dynamics.	Teagasc; Department of Agriculture, Food and the Marine (DAFM)
Immediately replant large patches within *Miscanthus* crops that were not planted due to problems with the machinery, and avoid planting areas that have a tendency for water-logging. Do not replant small patches.	Teagasc; DAFM
Appropriate management and promotion of flower-rich field margins and hedges within agricultural areas to provide forage and nesting resources to sustain pollinator populations; and specific agri-environmental schemes implemented (and appropriately monitored) to promote all pollinator groups.	Teagasc; DAFM
Maintain diversity of crop types within the landscape in agricultural areas rather than large monocultures.	Sustainable Energy Authority of Ireland (SEAI); Local Authorities; Teagasc; DAFM
Reduce use of neonicotinoid pesticides as seed treatment for oilseed rape, to avoid adverse effects on bumblebees, the primary pollinators of oilseed rape; and reduce intensity of pest management in oilseed rape to encourage carabid predators as biocontrol agents.	Teagasc, DAFM
Workpackage 2: Road landscaping	
Continue to implement the NRA (2006) *Guide to Landscape Treatments for National Road Schemes in Ireland* and seek to improve it in the light of recent research and practice.	National Roads Authority (NRA); Local Authorities; Department of Arts, Heritage and the Gaeltacht (DAHG); National Parks and Wildlife Service (NPWS); Road Safety Authority (RSA); Department of Environment, Community and Local Government (DECLG)
Increase the width of hedgerow planting on road margins so as to increase the extent of new habitat component contributed by roads over and above that of adjacent agricultural grassland.	DECLG; DAFM; DAHG (NPWS); Local Authorities; NRA; RSA;
Carry out further research into phenotypic variation in hawthorn and, in the meantime, as a precaution, implement/strengthen the use of an Irish provenance plant material landscape planting policy.	DAFM; DAHG (NPWS); Teagasc; Environmental Protection Agency (EPA); NRA; Local Authorities;
Repeat the current survey of plant and animal communities at decadal intervals so as to determine the sustainability of the developing communities and their contribution to biodiversity conservation. Commence monitoring of M/N7 plots at decadal intervals.	NRA; EPA; Local Authorities
Workpackage 3: Aquaculture	
In environmental decision-making and spatial planning for bays involving aquaculture, it should be noted that the extent of influence of salmon cages on benthic assemblages is very narrow (<25m) perpendicular to the main direction of current flow in comparatively high-energy areas such as Mulroy Bay, but greater (25–200m) downstream from the cage.	DECLG via Marine Institute (MI); EPA, DAHG (NPWS); DAFM; Local Authorities
Further use of stable isotopes as an effective tracer of salmon farm wastes into biota to yield additional insights into changes in trophic structure and inform decisions about the compatibility of aquaculture with other activities in Natura 2000 sites.	DECLG via MI, Bord Iascaigh Mhara (BIM), DAHG (NPWS)
Further consideration should also be given to using Integrated Multi-Trophic Aquaculture in Ireland. It is an approach with potential to both diminish environmental impacts and increase profitability. Benthic polychaetes could potentially be used to consume waste under fish cages, for example, and in turn be harvestable themselves.	DECLG via MI, BIM, DAFM

Cont. overleaf

Recommendation	Policy environment
Action should be taken at an early stage to restrict the spread of Pacific oysters in Ireland before dense reefs are formed. Surveillance should be focused on areas with hard substrata or biogenic reef, long residence times of embayments and large intertidal areas. Oysters also tend to occur disproportionately in bays with aquaculture, but also >500m from it. Management efforts should also be targeted towards areas of particular conservation or economic value, e.g. areas designated for Sabellaria reefs, and areas important for aquaculture.	DECLG via MI, BIM, DAHG (NPWS), DAFM , Loughs Agency
Risk of spread of oysters from aquaculture could be greatly reduced by the use of triploid oysters. This approach has already been adopted by many farmers and presents a win-win solution as triploid oysters also grow faster than diploids.	DECLG via MI, BIM, DAFM, Loughs Agency, DAHG (NPWS)
Management measures must focus on feral populations of oysters as well as aquaculture operations because feral oysters are likely to be spawning, such that their populations are self-sustaining. Harvesting of feral oysters should be encouraged before reefs become too dense and shells become distorted.	DECLG via MI, BIM, DAFM, Loughs Agency, DAHG (NPWS)
Oysters can impact biodiversity even when dead, albeit to a lesser extent, so management action should include removal of oyster shell material where feasible. It should be noted, however, that shell material can be important for the promotion of native oyster production.	DECLG via MI, BIM, DAFM, Loughs Agency, DAHG (NPWS)
A coordinated sampling programme should be established to monitor spread of oysters and test effectiveness of any control measures adopted. The methodology developed in the current project is rigorous, repeatable and cost effective.	DECLG via MI, BIM, DAFM, Loughs Agency, DAHG (NPWS), EPA, Northern Ireland Environment Agency
Statutory measures and existing voluntary programmes such as CLAMS and ECOPACT provide a good framework for the development and implementation of further improvements to management of aquaculture activities with the broader view of reducing and managing environmental impacts.	MI, BIM, DAFM, Loughs Agency, DAHG (NPWS)

7.4 Further Research

Several areas for further research have been highlighted by the project. We recommend that these specific areas for further research, where not already included, should be added to the National Platform for Biodiversity Research (NPBR) research recommendation list. These are summarised below:

7.4.1 Carbon Sequestration by Miscanthus

Our research showed large differences on a regional scale in the amount of soil carbon sequestration. While part of the variation can be explained by former land-use, initial soil organic carbon stocks, and soil pH, as well as the patchiness, further drivers of the variation are still unknown. Furthermore, the processes by which these factors influence soil carbon sequestration are not yet fully understood. It is therefore important to conduct further research on the processes driving soil carbon sequestration.

7.4.2 Impacts of Energy Crops on Biodiversity and Ecosystem Services

Further research includes:

1. Long-term, multi-season impacts and effects of introducing oilseed rape into new areas versus expanding planting in existing landscapes;
2. Impacts of growing energy crops at higher density and on a larger spatial scale;
3. Impacts of growing energy crops on marginal/semi-natural land;
4. The distribution, pollination efficiency and other ecological requirements of the cryptic bumblebee complex;
5. Impacts of other mass-flowering and/or bioenergy crops.

7.4.3 Road Landscaping

Given that the results and conclusions of the current study were developed from road communities that had only developed over a short period of time, it is important to document the long-term changes in these road communities. Species diversity/abundance, soil organic matter, soil nutrients and the ecosystem services that are provided need to be evaluated over decadal periods so as to determine whether their biodiversity importance and ecosystem services increase or whether they revert to habitats dominated by agricultural weeds from the adjacent grasslands. Such studies should seek to increase the groups investigated beyond flowering plants and carabids and should extend to other ecosystem services, such as carbon fixation and erosion control. Separately, the installation of 800m-long trial plots, containing different vegetation and soil treatments on the M/N7, may be the largest experiment of its kind in the field of road landscaping and will require monitoring of the developing communities at intervals; therefore, provision needs to be made to schedule and finance such monitoring. The management of plant communities so as to promote resistance to invasive alien species is a developing field with distinct possibilities for improving the sustainability of management practices on roads, while, promoting biodiversity conservation. From an economic and conservation perspective, research should seek to improve the sustainability of road corridors.

7.4.4 Aquaculture

Further research is required on the effectiveness of increasing biomass of suspension feeders (e.g. Tunicates) as part of ‘fouling communities’ as a mitigation strategy to decrease levels of particulate and dissolved material in the surrounding environment, particularly in highly sensitive environments.

The understanding of impacts of aquaculture in Ireland could be improved by the development of a coordinated monitoring programme and research to understand: (i) changes to communities and ecosystem processes in the water column (which have been less well studied than those on the sea bed); (ii) the extent of influence of individual aquaculture installations and how their influence combines and interacts with other local and global pressures; (iii) the resistance and resilience of coastal ecosystems and the carrying capacity of Irish embayments; and (iv) how ecological changes induced by aquaculture translate into changes in provision of ecosystem services.

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Acronyms and Annotations

AMOVA	Analysis of Molecular Variance
AWMSI	Area Weighted Mean Shape Index
BIM	Bord Iascaigh Mhara
DAFM	Department of Agriculture, Food and the Marine
DAHG	Department of Arts, Heritage and the Gaeltacht
DECLG	Department of Environment, Community and Local Government
DISTLM	Distance-based linear models EST Expressed sequence tag
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse gas
HWE	Hardy-Weinberg
IAG	Improved agricultural grassland
MI	Marine Institute
MPFDI	Mean Patch Fractal Dimension Index
NPWS	National Parks and Wildlife Service
NR	Natural recolonisation
NRA	National Roads Authority
NREA EACG	National Roads Authority Environmental Assessment and Construction Guidelines
NUIG	National University of Ireland Galway
PIs	Principal investigators
QUB	Queen’s University Belfast
RSA	Road Safety Authority
SEAI	Sustainable Energy Authority of Ireland
SGSM	Standard grass seed mix
SSR	Simple Sequence Repeats
TCD	Trinity College Dublin
UCC	University College Cork
UCD	University College Dublin
WP	Work-package

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil, Pobal agus Rialtais Áitiúil.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail;
- scardadh dramhuisce;
- dumpáil mara.

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

Science, Technology, Research and Innovation for the Environment (STRIVE) 2007-2013

The Science, Technology, Research and Innovation for the Environment (STRIVE) programme covers the period 2007 to 2013.

The programme comprises three key measures: Sustainable Development, Cleaner Production and Environmental Technologies, and A Healthy Environment; together with two supporting measures: EPA Environmental Research Centre (ERC) and Capacity & Capability Building. The seven principal thematic areas for the programme are Climate Change; Waste, Resource Management and Chemicals; Water Quality and the Aquatic Environment; Air Quality, Atmospheric Deposition and Noise; Impacts on Biodiversity; Soils and Land-use; and Socio-economic Considerations. In addition, other emerging issues will be addressed as the need arises.

The funding for the programme (approximately €100 million) comes from the Environmental Research Sub-Programme of the National Development Plan (NDP), the Inter-Departmental Committee for the Strategy for Science, Technology and Innovation (IDC-SSTI); and EPA core funding and co-funding by economic sectors.

The EPA has a statutory role to co-ordinate environmental research in Ireland and is organising and administering the STRIVE programme on behalf of the Department of the Environment, Heritage and Local Government.

Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

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SSTI Strategy for Science, Technology and Innovation

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government