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Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

STRIVE

Report Series No.21

AG-BIOTA – Monitoring, Functional Significance and Management for the Maintenance and Economic Utilisation of Biodiversity in the Intensively Farmed Landscape

STRIVE

Environmental Protection Agency Programme

2007-2013

Agriculture and Food Development Authority

SSTI Strategy for Science, Technology and Innovation

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage 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.

The EPA is an independent public body established in July 1993 under the Environmental Protection Agency Act, 1992. Its sponsor in Government is the Department of the Environment, Heritage and Local Government.

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- Office of Environmental Enforcement
- Office of Environmental Assessment
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet several times a year to discuss issues of concern and offer advice to the Board.

EPA STRIVE Programme 2007–2013

AG-BIOTA – Monitoring, Functional Significance and Management for the Maintenance and Economic Utilisation of Biodiversity in the Intensively Farmed Landscape

(2001-CD/B1-M1)

STRIVE Report

End of Project Report available for download on http://erc.epa.ie/safer/reports

Prepared for the Environmental Protection Agency

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DISCLAIMER

The EPA STRIVE Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Project Statement

This Synthesis Report provides a summary overview and statement of the main findings of the Ag-Biota Project. As such, this account relies very strongly on the full version of the final Ag-Biota Report for the provision of all necessary information regarding methods of study and data analysis, detailed provision and interpretation of results, and all supporting literature. The End of Project Ag-Biota Report is available from the EPA's website at: http://erc.epa.ie/safer/reports.

Table of Contents

Executive Summary

Agriculture accounts for about 62% of Ireland's land area. Due to the intensification of agricultural methods, there has been a drastic change in the farmed landscape since the second half of the last century, and a widely perceived decline in Irish biodiversity similar to that experienced across much of Western Europe. This integrated study, informally known as the 'Ag-Biota' Project, was funded as a 5-year 'capability development' project starting in 2001, to develop capacity and expertise in biodiversity research within the context of agriculture. The Project had four specified objectives:

1. To develop research capacity and methodologies for biodiversity monitoring within agro-ecosystems
2. To identify and investigate key aspects of agricultural practice that influence biodiversity
3. To develop a better understanding of the benefits and utilisation of natural populations within agricultural production systems
4. To address fundamental ecological questions regarding the functional value of biological diversity.

Seven key achievements of the Project are:

1. The identification and use of four potentially important bio-indicator groups reflecting the impacts of agriculture on biodiversity at different scales (Chapter 2):
   (i) At the field level, parasitoid wasps, which have importance in natural pest regulation and are shown to reflect wider biodiversity and ecological change in agricultural grasslands (Sections 2.2, 2.5, 3.2, 3.3, 3.4, 3.5)
   (ii) Bumblebees, which have importance as pollinators, and are shown to have undergone significant decline over recent decades (Sections 2.3.1, 2.3.2, 2.5)
   (iii) Birds, whose incidence in farmland is shown to reflect the management of field boundaries, farm habitat diversity and the intensity of grassland husbandry, which may not necessarily always be detrimental to biodiversity (Sections 2.3.3, 2.5)
   (iv) Aquatic invertebrates in the rivers and streams draining Irish farmland, which reflect the wider impact of agricultural practice on water quality (Sections 2.4, 2.5).
2. Demonstration of the particular significance of parasitic and pollinator taxa as 'front-line' indicators of biodiversity loss at lower trophic levels within agro-ecosystems (Section 2.5.1).
3. Demonstration that surrogate indicators based on aspects of farm management and condition can be reflective 'drivers' of likely change in the status of biological populations within farmland. This insight has subsequently informed wider EU-funded research focused on the development of agri-environmental policy evaluation (Sections 2.3.4, 6.2, 6.3).
4. Development and application of research tools, including simulation models, real-time polymerase chain reaction (PCR), stable isotope methods and novel statistical designs for studying the ecology of specific populations, trophic relationships and the value of mixed-species communities within the agro-ecosytem (Sections 4.2.2, 4.3, 4.4, Chapter 5).
5. Demonstration of clearly reduced plant and arthropod diversity in agricultural grasslands under intensive management practice (Chapter 3, Section 4.2.1), and of the potential agronomic value and indispensable functional benefits of biodiversity in pasture swards (Sections 4.2.2, 5.4).

   The data also suggest, however, that the increased grassland management intensity associated with dairy farming is not necessarily always 'bad' for all aspects of biodiversity (Section

2.2.3) and actually may have unexpected positive benefits (Section 2.3.3). This points to the necessity for a more flexible approach to the design of agri-environmental measures (Section 6.3).

6. Demonstration of the wider ecological impacts of intensive grassland management practice, including the decreasing efficiency of soil nitrogen utilisation, and of the decreased efficacy of atmospheric nitrogen fixation by white clover in pastures as inorganic fertiliser use is increased, and demonstration of the functional dependency of the pasture ecosystem on earthworm diversity in maintaining critical soil processes (Section 5.3.1) and in ameliorating the impact of high stocking rates on soil structure (Section 4.5).

   However, the grassland agronomy field experiments that were available for these studies were not originally designed to investigate biodiversity issues *per se*. Thus, whilst the studies provide an important evidence base supporting many aspects of current Rural Environment Protection Scheme (REPS) measures regarding grassland management, they also highlight areas for further improvement (Section 3.5.1).

Conclusion

7. Finally, Ag-Biota's work highlights an obvious, but so far unrealised, need for a nationally co-ordinated programme of integrated research in grassland agronomy that is central to the interests of the agricultural industry. Such a programme would successfully utilise and integrate the ecological benefits of biodiversity within our main agricultural sector with the economic and social benefits that would also accrue (Section 6.4).

   This would enable the agriculture industry to address both its wider commitment to halt the general loss of biodiversity within the Irish countryside and simultaneously resolve many of the major agri-environmental, and potentially animal health, issues associated with increasingly intensive production methods.

1 General Introduction

1.1 Background

Agriculture accounts for about 62% of total land use in Ireland. Due to intensification of the industry, there has been a drastic change in the farmed landscape since the second half of the last century, and a widely perceived decline in Irish biodiversity similar to that experienced across much of Western Europe. Intensification of agriculture through increased machinery use, loss of hedgerows and increase in chemical usage has been associated with a general reduction in landscape diversity. It has been suggested that between 1970 and 2000 the diversity of species in European farmland declined by 23%. Aside from its intrinsic and cultural values, biodiversity has a functional value in the provision of services, e.g. food and fuel. This functional role includes the support of nutrient cycling and regulation of climate and hydrological services, many of which are poorly understood but central to sustainable agro-ecosystems. The reversal of biodiversity loss and restoration of greater diversity within the farmed landscape is a politically sensitive issue because of fears that such an aim could only be achieved at the cost of reduced production and a loss in competitiveness. However, there is scope to reintroduce biodiversity in agricultural habitats without necessarily compromising productivity and indeed, with greater knowledge of the functional value of natural populations and ecosystem processes within agro-ecosystems, there is likely to be positive agronomic merit in the development of less artificial and more environmentally sustainable production systems that benefit from an increased utilisation of the ecological advantages of biological diversity.

1.2 Overall Aims

This integrated study, informally known as the ‘Ag-Biota’ Project, was funded as a 5-year ‘capability development’ project starting in 2001, to develop capacity and expertise in biodiversity research within the context of agriculture.

The overall aims of the project were laid in four defined work packages, or Actions:

Action 1: *Development of methods for monitoring the current and likely future status of biodiversity in the agro-ecosystem*

The project undertook a 5-year programme of standardised monitoring for a wide selection of taxonomic groups at scales appropriate to those groups (individual fields, farms or landscape). Initially, this monitoring was done at a relatively small number of farm sites with the intention of identifying the most useful bio-indicator groups likely to be informative in longer-term assessment of the changing impact of farming on biodiversity within the countryside. Subsequently, once candidate indicator groups had been identified, the scale of monitoring was increased with the aim of confirming the utility of the chosen groups as useful bio-indicators, and beginning the process of collating and analysing information relevant to the current baseline status of the chosen groups. Summary results and conclusions from this Action are reported in Chapter 2.

Action 2: *Identification of the key factors that define or limit biodiversity within contrasting farming systems*

The project also sought to make use of a range of existing agronomic field experiments at Teagasc Research Centres to assess the influences and relative merits of contrasting grassland husbandry practices on biological diversity. As the ecological benefits of alternative farming systems in Ireland remain relatively unquantified in any objective sense, the data provided by these quantitative studies provide much-needed information to support the formulation of policy regarding the future development and promotion of optimum production systems. Summary results and conclusions from this Action are reported in Chapter 3.

Action 3: *Ecology of populations in agro-ecosystems: developing tools for the practical management and utilisation of biodiversity*

A fundamental objective of the project was also the development and improvement of knowledge concerning the practical utilisation of specific natural populations, and of the functional value of such populations within farm systems. Essentially, this requires the development of a greater understanding of the ecological roles of plant and animal populations within production systems and in many cases an improved understanding of their agronomic significance and potential benefits. Summary results and conclusions from this Action are reported in Chapter 4.

Action 4: *Functional significance of altered biodiversity*

If the benefits of biological diversity in managed farm systems are to be fully realised, it is necessary to understand the importance of maintaining biological diversity within natural systems. The project therefore sought to investigate experimentally the ecological and functional significance of multiple species community structures on two very important integrating ecosystem functions, namely primary productivity and decomposition. Novel experimental approaches and designs that are statistically more efficient than previous methods were developed and used to assess the relative functionality of multi-species community structures. Summary results and conclusions from this Action are reported in Chapter 5.

2 Developing Methods for Monitoring Biodiversity in the Agro-Ecosystem

2.1 Background

Following the signing of the Convention on Biological Diversity (CBD), which agreed to integrate biodiversity policy into all economic sectors, the European Commission published a Biodiversity Action Plan (BAP) for Agriculture (COM(2001)162 vol. III) as part of a strategy to halt the global decline in biodiversity by 2010. Amongst the recommendations of a subsequent meeting of the European Platform for Biodiversity Research Strategy (EPBRS) in Ireland in 2004, there was agreement on the urgent need to develop monitoring systems to evaluate the performance of the Common Agricultural Policy (CAP) in terms of halting biodiversity loss. One of the primary aims of the Ag-Biota Project was therefore to develop appropriate monitoring protocols with which to assess the impact of changing farm practices on biodiversity. There is currently a great need for, but little agreement on, the selection of suitable biological indicators that can be used to validate agri-environmental policy.

2.2 The Biodiversity of Populations at Field Level

Approximately 80% (3.4 million ha) of agricultural land in Ireland is devoted to grass-based farming systems, including grazed pasture and the production of grassland forage (hay and silage). In comparison, non-grass arable crops comprise only about 9% (0.4 million ha) of agricultural land use. The intensification of grassland management through changes in grazing, fertiliser usage and other chemical inputs, has led to widespread landscape degradation and a loss of biodiversity across Europe. The greatest changes in Irish land use between 1990 and 2000 include a 35% increase in the area of CORINE ‘arable land’ classes, which include land used for the production of grass-based silage. This increase was principally at the expense of natural grasslands and grazed heathland (–1% approx.), pasture and mixed farming (–4% approx.) and wetlands (–6% approx.). Similarly, an 11% increase in the land area used for silage production has been reported during the period 1994–2004, and a corresponding 54% decrease in the land area devoted to hay production during the same period. From an agri-environmental perspective, it is therefore important to understand how changing grassland husbandry practices impact on biological diversity.

2.2.1 Methods

Arthropods are amongst the most abundant living things on the planet and constitute much the greatest proportion of species richness and biomass in terrestrial habitats, including managed grasslands. The Project therefore undertook initial studies at 10 paired farm sites in 2002, using a Vortis insect suction sampler to assess arthropod diversity in individual monitored grasslands, with the aim of identifying likely bio-indicators of wider diversity within agricultural grassland. Using information from this initial study, in 2005 the Project subsequently undertook a much more extensive study of arthropod populations in individual grassland fields on a random sample of 50 principally livestock farms in counties Carlow, Cork, Kilkenny, Laois, Meath, Waterford, Wexford and Wicklow in south-east Ireland, stratified by farm (livestock) typology and selected from the National Farm Survey database (Fig. 2.1).

In addition, the project obtained a third grassland arthropod data set by monitoring populations in 36 individual plots of a grass field margin experiment located at the Teagasc Johnstown Castle Research Centre.

2.2.2 The bio-indicator value of parasitoid Hymenoptera

Analysis of relationships between the diversity of major arthropod groups and wider foliage arthropod diversity, using data provided by the initial study of 10 paired grassland sites, suggested that parasitic Hymenoptera were the group with greatest bio-indicator potential. This was confirmed by the subsequent analysis of

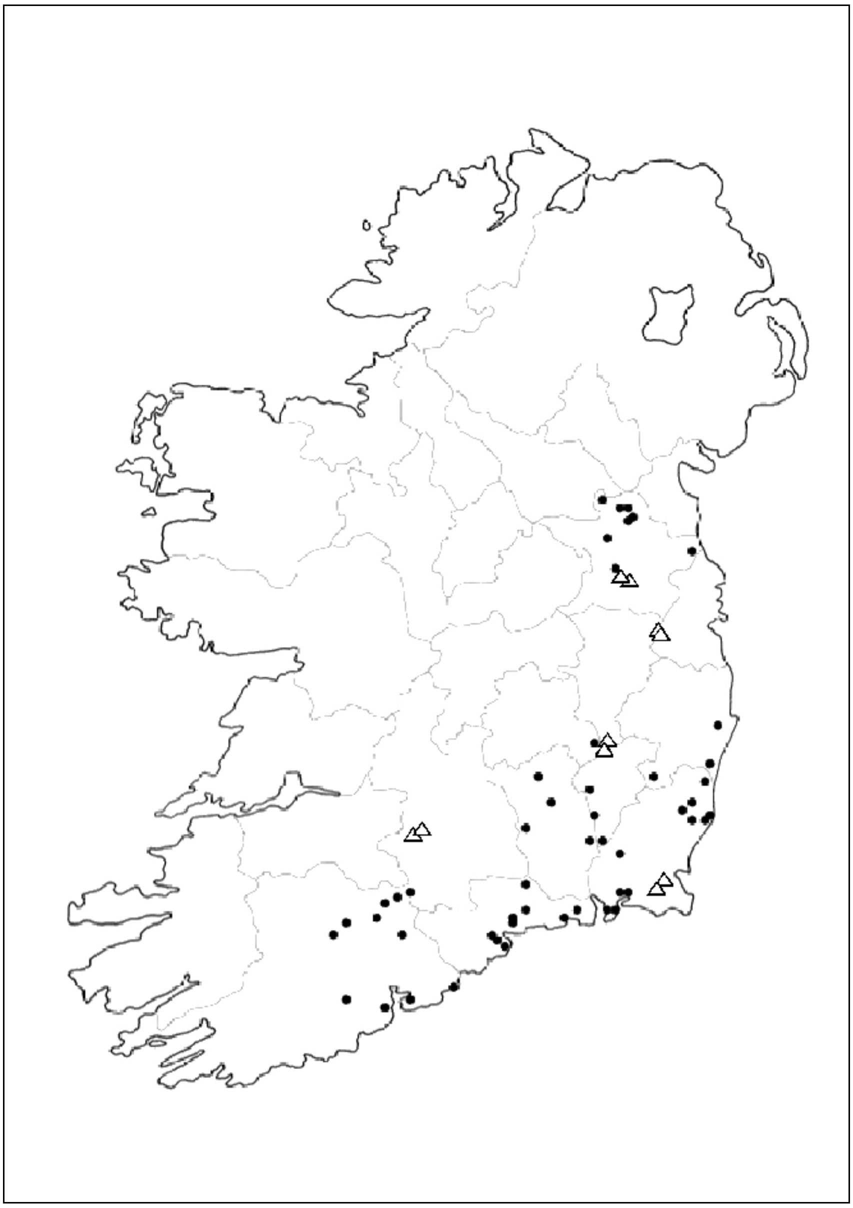
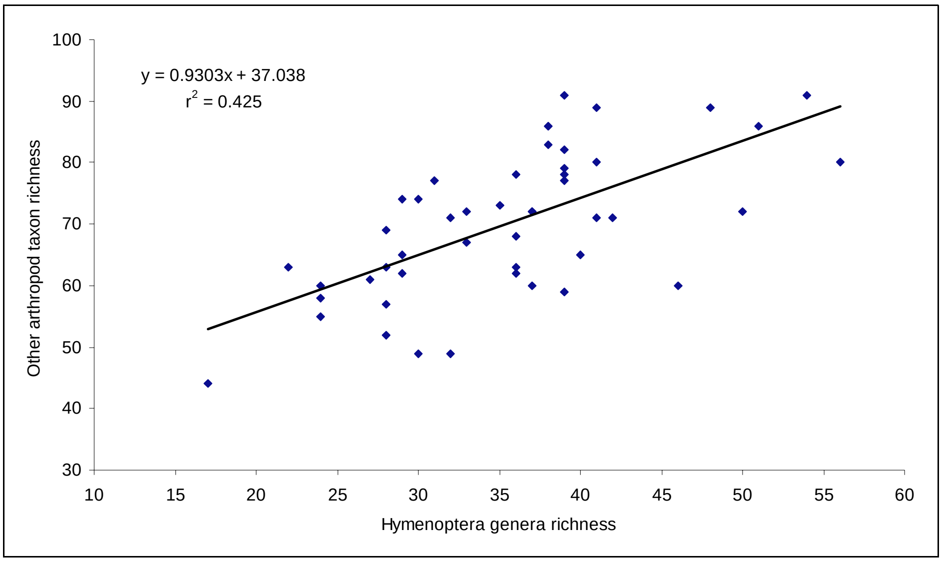


Figure 2.1. Location of the original 10 paired grassland sites monitored in 2002 (open triangles) and additional 50 commercial farm sites (closed circles) sampled during 2005.

additional data sets collected from the survey of 50 commercial farm sites and the Teagasc conservation field margin experiment, which consistently showed that the taxon (Genus) richness and abundance of parasitoid wasps was most positively correlated with total overall arthropod diversity (Fig. 2.2).

The consistency of this relationship in agricultural grassland provides support for the hypothesis that, because of their unique and specialised biology as parasites of other arthropods, parasitoid wasps are very good indicators of the diversity of other potential host arthropod taxa. The sampling and quantification of total parasitoid abundance (total numbers of individuals) is a relatively straightforward and practicable option for routine monitoring. There is therefore a very reasonable prospect that parasitoid abundance could be used as a field-level bio-indicator to track ongoing changes in wider arthropod diversity, at least within the context of agricultural grassland, which comprises the greater proportion of the Irish countryside. Whilst monitoring overall parasitoid abundance might be used to document the loss or

(a)



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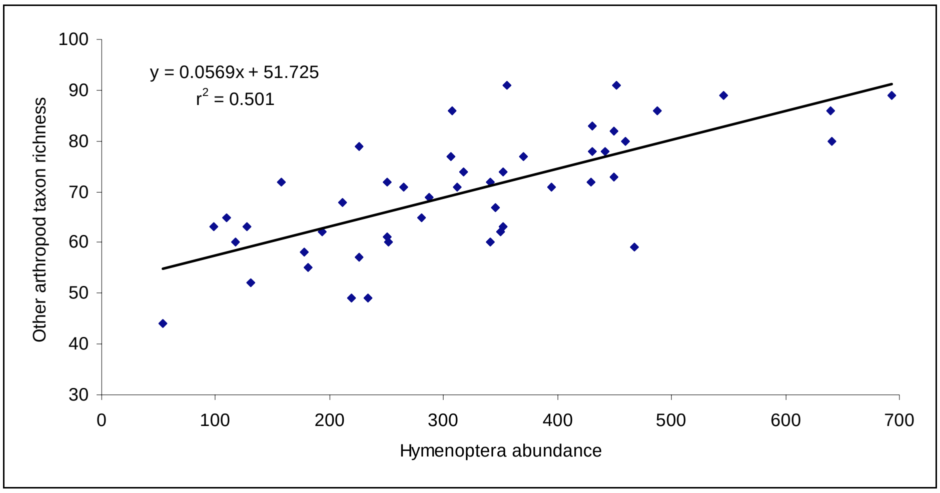


Figure 2.2. The relationship between the total taxon richness of all other arthropods (excluding parasitoid Hymenoptera) and (a) hymenopteran parasitoid genera richness and (b) total abundance of parasitoid individuals collected in Vortis suction samples from agricultural grassland swards on the 50 commercial farms.

improvement in wider arthropod biodiversity, it would contribute little to explaining the likely causes of such change. However, these studies have also shown that knowledge of the detailed composition and community structure of parasitoid populations, particularly with respect to the relative incidence of parasitoid guilds with different host group affinities, can provide a detailed insight into the underlying ecological processes causing change in wider arthropod community structure. To gain this insight, however, requires a much more detailed understanding of the biologies and relative abundance of individual parasitoid taxa identified to the level of genera (see also Chapter 3).

2.2.3 Relationships between grassland arthropod populations and farm management

The Project also quantified the relationships between farm system parameters and grassland arthropod abundance and diversity. A significant negative relationship was observed between mean total farm nitrogen input (inorganic and organic) and adjusted arthropod taxon richness (taxon numbers in samples corrected for sample differences in the abundance of individuals) (Fig. 2.3).

As total farm nitrogen input level is perhaps the simplest measure of grassland management intensity, this is clear evidence of the negative relationship between the intensity of grassland management and the diversity of arthropod populations at field level. The variance in sward height and the number of plant species present in swards were both significantly greater on non-dairy, compared with dairy livestock farms, and both these factors were positively associated with greater adjusted taxon richness in samples. A positive relationship between the botanical and structural diversity of swards, and arthropod diversity is expected on theoretical grounds, but the present study is the first unequivocally to demonstrate such a relationship in Irish agricultural pastures, lending support to policy directed at increasing botanical sward diversity in agricultural grassland.

However, a more intriguing manifestation of the relationship between farm management intensity and biodiversity was revealed by analysis of the relationship between the unadjusted taxon density and total abundance of arthropod populations in samples collected from dairy and non-dairy (dry livestock) farms (Figs 2.4 and 2.5, respectively).

Both the absolute taxon density ($p = 0.028$) and total abundance ($p < 0.001$) of arthropod populations were significantly greater in samples from dairy, compared with non-dairy farms. The comparison of dairy *versus* non-dairy grassland encapsulates many different aspects of management intensity, including nutrient input levels, stocking rate and the intensity of grazing management, which were all greater on dairy compared with non-dairy livestock farms. The data therefore strongly suggest that greater input levels and management intensity on dairy farms promotes significantly greater, but less biologically diverse, grassland arthropod populations.

Comparison of sward arthropod community structure, using non-metric multidimensional scaling (NMDS) analysis, also indicated that compositional differences in arthropod communities in the 50 surveyed grasslands were primarily related to four environmental variables: sampling date, sward plant species diversity, sward height variance, and total farm nitrogen levels (Table 2.1, Fig. 2.6).

As shown by the use of generalised linear model (GLM) methods, the effect of increased plant diversity

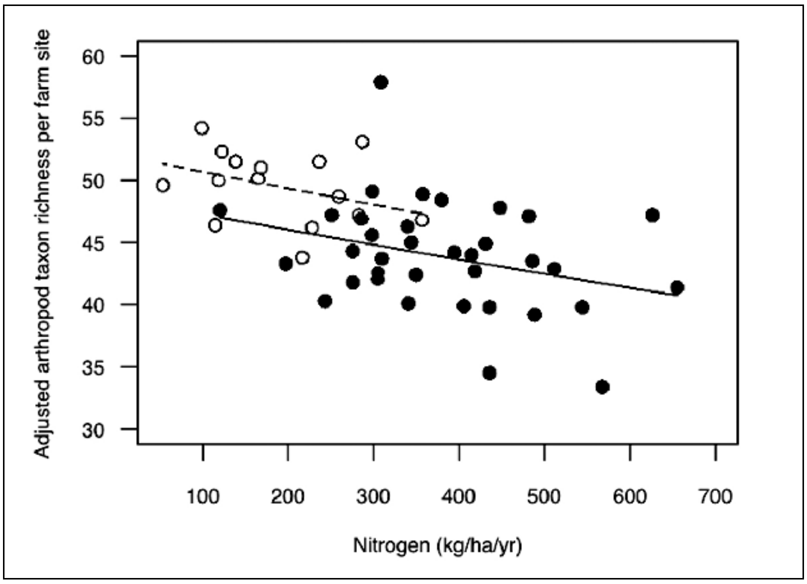


Figure 2.3. Multiple regression model prediction of the relationship between adjusted arthropod taxon richness (excluding Diptera) and the total farm input level of nitrogen to grassland on mixed dry-livestock (non-dairy) farms (open circles/dashed line) and on dairy farms (solid black circles/line).

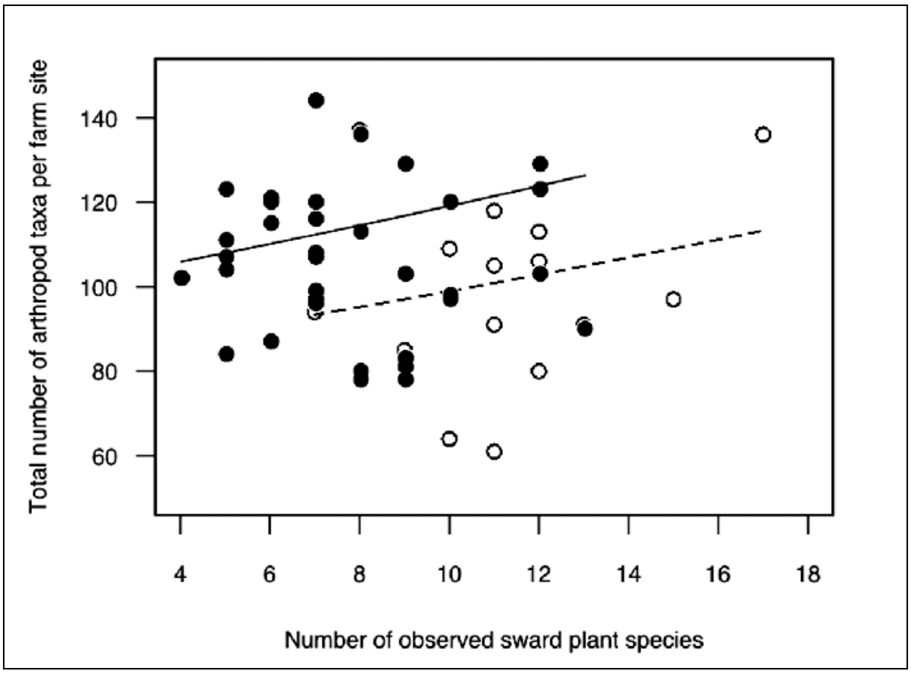


Figure 2.4. Multiple regression model prediction of the relationship between taxon density of arthropods and species density of sward plants on dairy (solid black circles/line) and non-dairy farms (open circles/dashed line).

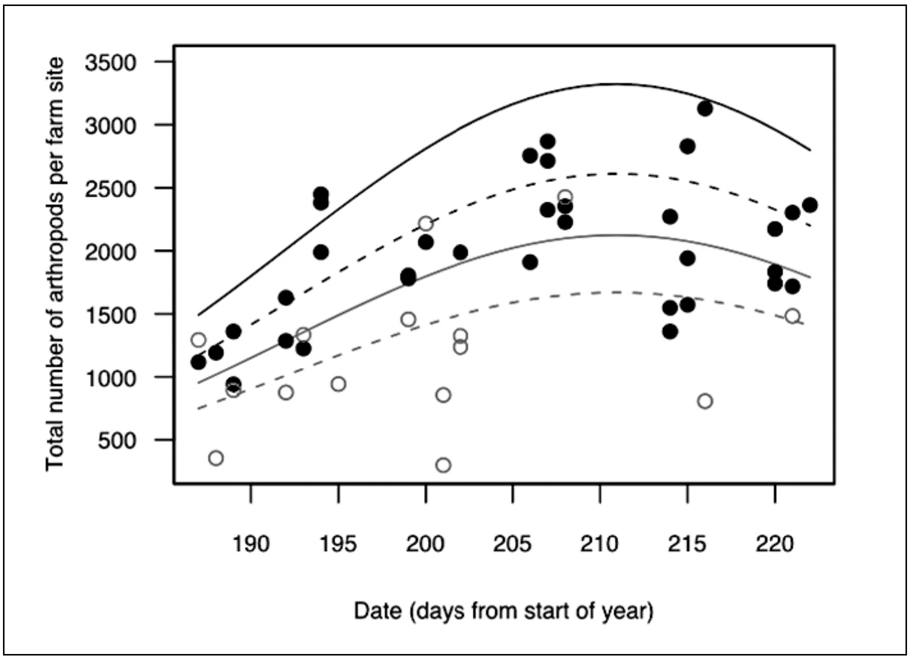


Figure 2.5. Multiple regression model prediction of the relationship between total arthropod abundance (total numbers of individuals, including Diptera) and the date of sampling (187 = 6 June; 222 = 10 August) on mixed dry-livestock (non-dairy) farms (open circles/grey lines), and dairy farms (solid black circles/black lines). Fitted lines show catch predictions for low (6 cm) and high (18 cm) values of observed grass height variance (dashed and continuous lines, respectively).

Table 2.1. Correlation value (R^2) and significance (p values) of the continuous variables tested as possible environmental vectors in a non-metric multidimensional scaling (NMDS) model of total arthropod community structure in sampled grasslands on the 50 commercial farm sites. (Emboldened values indicate significant variables, $p \leq 0.05$.)

NMDS model for	Environmental vectors							
	Sample date	**Proportion of non-crop habitats**	**Sward plant species count**	**Mean grass height**	**Sward height variance**	**Shannon Index – habitat diversity**	**Total farm N input level**	**Latitude**
Community structure of sward arthropods	**0.623 (<0.001)**	0.106 (0.153)	**0.356 (<0.001)**	0.085 (0.257)	**0.293 (0.001)**	0.018 (0.840)	**0.349 (0.001)**	0.146 (0.056)

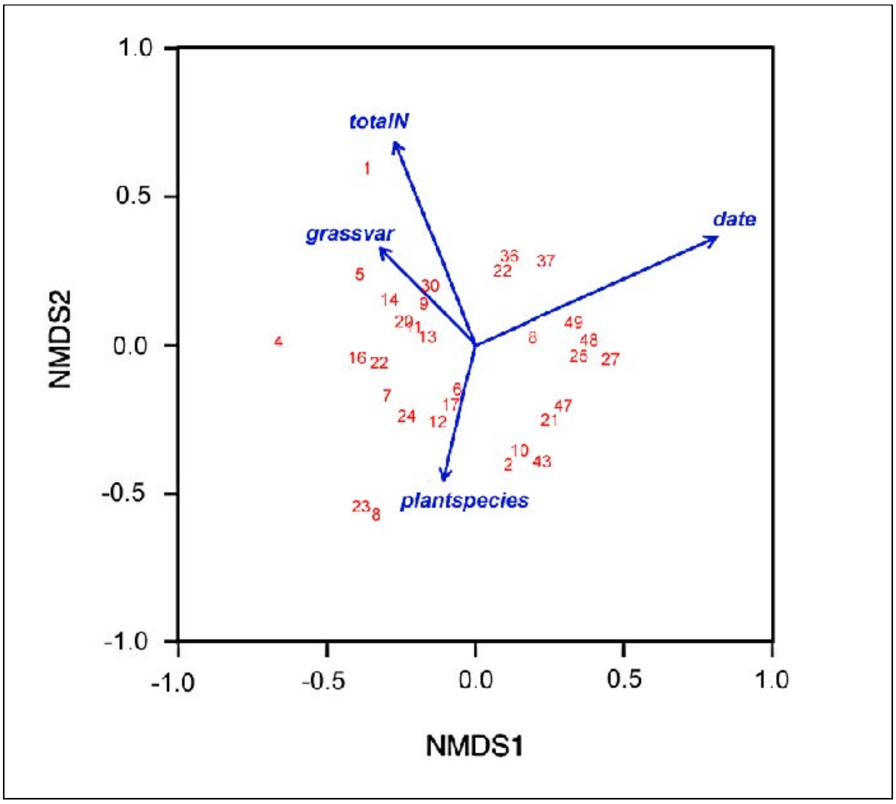


Figure 2.6. The non-metric multidimensional scaling (NMDS) ordination of total arthropod community structure in grasslands at the 50 commercial farm sites with fitted significant ($p < 0.05$) environmental vectors. R^2 = 0.851 for the linear fit of ordination distances on community dissimilarity; red numbers refer to the ordination of individual farm sites; for clarity only peripheral farm sites are indicated.

on arthropod populations in agricultural grasslands is significant and positive, with increased opportunities for arthropod taxa in more speciose swards. In a similar way, an increase in sward height variance is likely to positively affect niche opportunities for arthropod taxa. An important implication of this finding is that the fauna of very intensively grazed grasslands can be expected to have a simplified community structure, dominated by a relatively small number of taxa that directly benefit from cycles of intensive rotational grazing. Not surprisingly, dung-breeding and detritivorous dipteran families, aphids and parasitoid genera associated with these host groups were found to be some of the best indicators of fields on dairy farms with very intensive pasture management (Table 2.2).

Table 2.2. Vegetation arthropod taxa with significant ($p < 0.05$) indicator values (IV) for the comparison of dairy and dry livestock farms in the 50-site survey; 'good' indicators with IV scores ≥70 are emboldened.

Order	Taxon	Associated with	Indicator value	p value
Araneae	*E. atra*	Dairy farms	67.3	0.0004
	L. tenuis	Dairy farms	66.1	0.0014
Diptera	**Chironomidae**	**Dairy farms**	**70.5**	**0.0458**
	Drosophilidae	**Dairy farms**	**70.8**	**0.0320**
	Lonchopteridae	**Dairy farms**	**74.2**	**0.0002**
	Opomyzidae	**Dairy farms**	**71.1**	**0.0010**
	Phoridae	Dairy farms	65.5	0.0036
Hemiptera	*Myzus* sp. B	Dairy farms	66.3	0.0410
	***Rhopalosiphum* sp.**	**Dairy farms**	**80.7**	**0.0004**
Coleoptera	*Acrotona* sp. A	Dairy farms	52.2	0.0302
	Acrotrichis atomaria	Dairy farms	67.8	0.0288
	Aloconota gregaria	Dairy farms	68.3	0.0022
	Amischa analis	Dairy farms	65.1	0.0218
	Amischa decipiens	**Dairy farms**	**73.8**	**0.0064**
	Atomaria apicalis	Dairy farms	61.8	0.0092
	Atomaria atricapilla	Dairy farms	62.6	0.0022
	Atomaria nitidula	Dairy farms	56.5	0.0074
	Bembidion lampros	Dairy farms	56.5	0.0260
	Corticarina fuscula	Dairy farms	53.3	0.0118
	Enicmus histrio	Dairy farms	59.7	0.0080
	Philonthus carbonarius	Dairy farms	66.4	0.0012
	Stenus formicetorum	Dairy farms	59.4	0.0134
	Tachyporus chrysomelinus	Dairy farms	61.3	0.0038
Hymenoptera	*Aphanogmus*	Dairy farms	61.4	0.0382
	Aphidius	**Dairy farms**	**79.6**	**0.0002**
	Dacnusa	Dairy farms	67.2	0.0124
	Kleidotoma	Dry livestock farms	57.4	0.0408
	Meraporus	Dry livestock farms	56.5	0.0028
	Phaenocarpa	**Dairy farms**	**76.2**	**0.0004**
	Rhoptromeris	Dry livestock farms	65.2	0.0056
	Trichopria	**Dairy farms**	**79.7**	**0.0002**

These findings highlight a possible deficiency in current Rural Environment Protection Scheme (REPS) policy with respect to grassland management. Currently, it is possible for farmers to manage their grassland according to REPS specifications by reducing only the level of nitrogen use and stocking rates, with no requirement to modify very intensive grazing patterns. However, the clearly observed relationship between sward structure and arthropod diversity suggests that if sward utilisation by intensive rotational grazing remains unchanged, the net effect of the current REPS core Measure 2 to enhance biodiversity in grassland farming is likely to be less than might be achieved if the pattern of intensive cyclical grazing were also changed.

2.3 Bio-Indicators at the Farm Scale

2.3.1 'Aesthetic' arthropods

In addition to the very wide range of functional benefits derived from the multitude of arthropod populations in agro-ecosystems, a relatively small number of arthropod species are appreciated and valued for aesthetic reasons, and have a high profile in the eyes of the general public as subjects of conservation interest and indicators of environmental well-being. Bees (Hymenoptera: Aculeata: Apoidea) are one such group with a high status in public affections, and are one of the few insect groups that most people can instantly recognise. They feature in poetry, art, literature and other media, and are evocative of high environmental quality. They may therefore act as a vehicle for engaging and informing the wider public on conservation issues and generating enthusiasm, support and involvement for conservation measures.

Line-transect counts and yellow pan traps (Fig. 2.7) were used to survey current bee populations on moderately-to-intensively managed lowland grass-based farms in south-east Ireland, and in the generally more extensively managed Burren region of Co. Clare. Comparisons were also made with historic observations of bee incidence on farmland in the 1970s and 1980s.

While bumblebees as a group are still readily found on typical farmland, these studies reveal that both their abundance and diversity on moderately-to-intensively

Figure 2.7. Yellow window pan trap as used in the sampling of bee populations.

managed farms may have declined by at least 50% compared with historical data and with current populations in the Burren region (Table 2.3). Bumblebee assemblages on typical farmland have undergone a substantial reduction in species composition over the last three decades, and are now almost entirely dominated by only two taxa, the *Bombus terrestris*/*lucorum* group and *B. pascuorum* (Fig. 2.8). The 'cuckoo' bumblebee species (*Psithyrus* spp.), in particular, appear to have been very seriously affected by the changing status of overall bumblebee populations, and are now almost entirely absent from most typical farms (Table 2.3).

Psithyrus spp. lay their eggs in the nests of specific conventional bumblebee species, which then rear them as 'parasites'. The incidence of *Psithyrus* spp. is therefore likely to be strongly influenced by the abundance of their particular host species (in much the same way as the incidence of parasitoid wasps reflects the incidence of their host guilds), and their marked

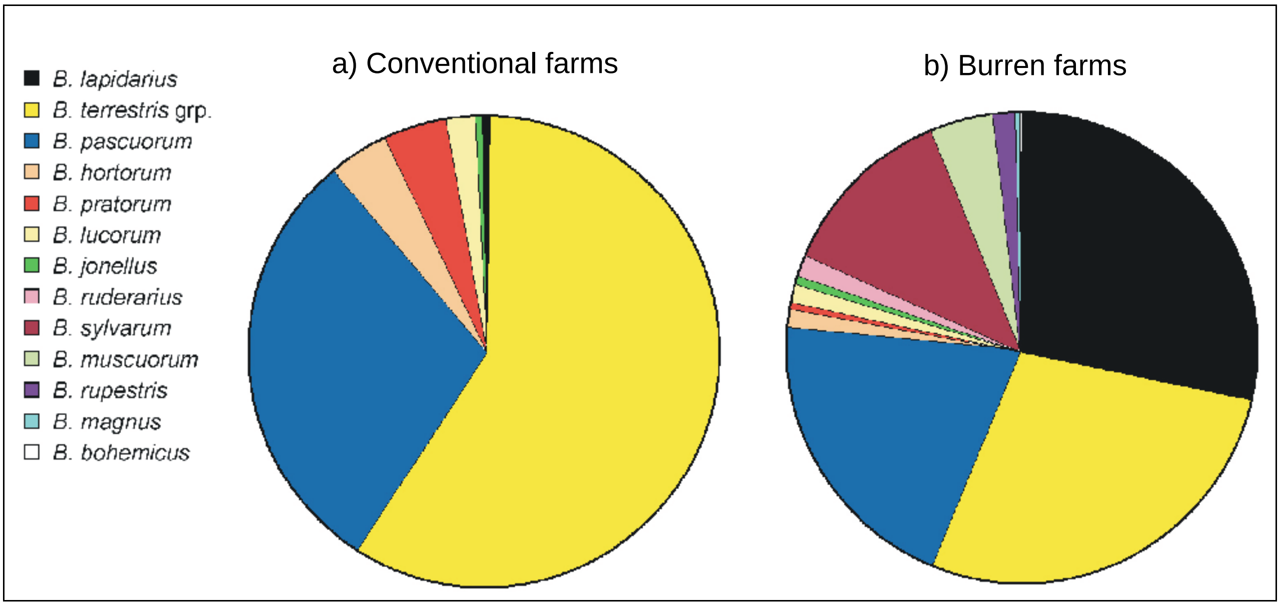


Figure 2.8. Current relative abundance of bumblebee species in (a) typical intensive agricultural farmland and (b) in the more extensively farmed Burren region.

Table 2.3. The frequency of incidence of bumblebee species observed in typical farmland, on extensive Burren farms and recorded in historical data from the period 1972 to 1988. (*Indicates species that are likely to have been under-recorded in the historical survey. Red text indicates 'problematic' IUCN categories.)

Survey	IUCN status	Typical farmland 2003–2004 (28 sites)	Burren farms 2004 (11 sites)	National records 1972–1988 (119 sites)
'Free-living' bumblebees				
Bombus cryptarum **(Fabricius)**	DD	Not distinguished from the *B. terrestris*/*lucorum* group		
B. distinguendus **Morawitz**	EN	Not observed	0.18	0.10
B. hortorum **(L.)**	LC	0.54	0.55	0.34*
B. jonellus **(Kirby)**	LC	0.04	0.36	0.10
B. lapidarius **(L.)**	NT	0.11	0.82	0.22
B. lucorum **(L.)**	LC	Not distinguished within *B. terrestris/lucorum* group		
B. magnus **Vogt**	DD	Not distinguished within *B. terrestris/lucorum* group		
B. monticola **Smith**	LC	Not observed – distribution restricted to upland eastern areas		
B. muscuorum **(L.)**	NT	Not observed	0.73	0.26
B. pascuorum **(Scopoli)**	LC	0.89	1.00	0.45*
B. pratorum **(L.)**	LC	0.57	0.18	0.24
B. ruderarius **(Müller)**	VU	0.04	0.45	0.13
B. sylvarum **(L.)**	EN	Not observed	0.82	0.06
B. terrestris **(L.)/*lucorum*** **(L.) group**	LC	1.00	1.00	0.39*
Parasitic 'cuckoo' bumblebees				
Bombus (Psithyrus) barbutellus **(Kirby)**	EN	Not observed	Not observed	0.17
B. (P.) *bohemicus* **Seidl**	NT	0.07	Not observed	0.20
B. (P.) *campestris* **(Panzer)**	VU	Not observed	Not observed	0.13
B. (P.) *rupestris* **(Fabricius)**	EN	Not observed	0.45	0.06
B. (P.) *sylvestris* **(Lepeletier)**	LC	Not observed	Not observed	0.07
B. (P.) *vestalis* **(Geoffroy in Fourcroy)**	EN	Not observed and may not be part of Irish fauna		

Key to International Union for Conservation of Nature (IUCN) categories: CR, critically endangered; EN, endangered; VU, vulnerable; DD, data deficient; NT, near threatened; LC, least concern.

rarity in comparison with historic data provides the clearest evidence of overall decline in conventional bumblebee populations. The evidence for the high indicator value of parasitic taxa (both parasitic bumblebees and parasitoid wasps) at the apex of trophic community structures within agro-ecosystems is undoubtedly one of the most ecologically meaningful insights to have been gained in the current studies.

2.3.2 The bio-indicator value of bees

The high public profile of bees and evidence of their significant decline make bumblebees a potentially very important indicator group. Furthermore, they are sensitive to environmental change, particularly relating to the abundance of flowering plants at the farm and landscape level, and can therefore provide an indication of environment quality at wider scales. Survey methods and identification are relatively simple, and non-destructive, for bumblebees, allowing their use as bio-indicators of the changing environmental influence of agriculture to become routine. Their species composition and total abundance or density can provide relatively simple measures of responses to agri-environmental conservation measures. However, a better understanding of natural bumblebee population fluctuations is needed to fully exploit this potential. Pan-trap surveys on 50 commercial farms in south-east Ireland (see Section 2.2.1) also showed that solitary bee species are a relatively species diverse group within Irish farmland and, like bumblebees, they may have indicator potential signalling the changing status of floral resources within the wider countryside. However, unlike bumblebees, the accurate identification of solitary bee species can be problematic requiring destructive trapping, and much less is known about their individual ecologies and distributions. However, given their greater species diversity in farmland, and similar functional value as pollinators, solitary bees, like bumblebees, may have considerable potential as an indicator group for farm habitat quality, and the abundance and variety of flowering plants at the field or farm scale. Nevertheless, it would be a considerable challenge to develop non-destructive survey methods with which their populations could be routinely monitored.

2.3.3 The bio-indicator value of birds

Results from other studies have shown that an extensively managed and diverse agriculture can promote the highest diversity and abundance of farmland birds. This view is reinforced by the work showing that agricultural mosaics of low-intensity cultivation maintain the highest diversity of endangered bird species. It is likely that changes in agricultural practices within Irish agricultural ecosystems over the last 20–30 years, including a tendency towards increased field uniformity and size, have reduced landscape heterogeneity with adverse effects on farmland birds. Understanding the influences of landscape change is therefore critical to understanding the likely causes of biodiversity loss in farmland birds. The current project undertook a series of detailed bird population surveys, initially on the original Ag-Biota farm sites, and subsequently on the 50 commercial farm sites studied by the project (see Section 2.2.1).

2.3.3.1 Relationships between farmland habitats and birds

The initial monitoring of Ag-Biota sites revealed a significant positive relationship ($p = 0.018$) between the diversity of discrete habitat types that can be recognised at farm level, and the numbers of bird species observed in standardised farm-wide surveys (Fig. 2.9).

This suggests that habitat richness quantified at farm level can be used as a significant predictor of change in bird species richness, and supports the hypothesis that bird diversity may be enhanced by measures seeking to increase habitat heterogeneity at a farm level. Bird populations may therefore be a potentially useful bio-indicator group reflective of the ongoing influence of landscape change at the farm level. This conclusion will be tested further by ongoing analysis of the much more extensive database that is now available following the subsequent monitoring of bird populations in the study of 50 commercial farm sites.

The habitat classification system used in the current study was based very largely on that originally proposed by Fossitt (2000), but with a number of important modifications. Fossitt's system was primarily

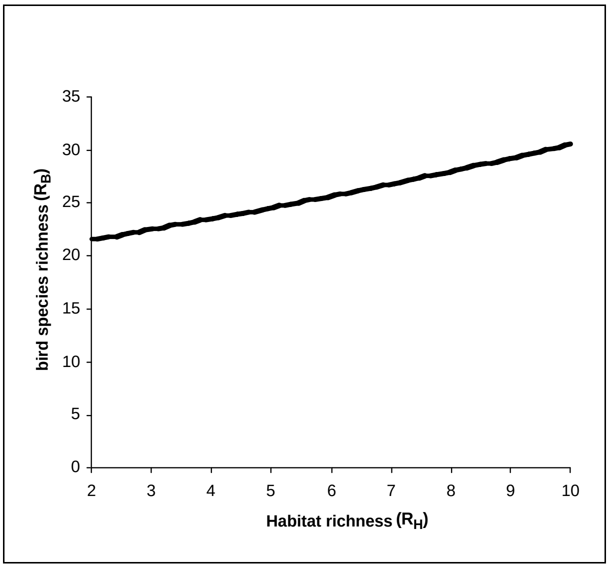


Figure 2.9. Regression model predictions for the relationship between observed bird species richness (R_B) during surveys of the original Ag-Biota monitoring sites and farm habitat richness (R_H).

developed to describe the very wide range of Irish semi-natural habitat types. As such, its usefulness in classifying ecologically significant habitats specifically within farmland is quite limited. For example, Fossitt's classification of grassland habitats is largely based on parent soil type, topography and the presence or absence of 'agricultural management', with the result that the majority of lowland Irish grassland falls into a single category of 'improved' grassland, with no differentiation to reflect the age of the sward since last cultivation and reseeding, or the current sward type and the intensity of its management. This is probably much too broad a categorisation to reflect the true ecological and biodiversity value of a land-use type covering such a large proportion of the country. It is therefore concluded that a more detailed classification of farmland habitat types, based on ecological considerations such as seasonal discreteness, functional and biodiversity value, is urgently needed if the relationship between changing agricultural management practice and farmland biodiversity is to be better understood (see also Section 2.3.4).

2.3.3.2 Relationships between field boundary characteristics and birds

Ag-Biota bird surveys also highlighted significant relationships between the ecological quality of field boundaries, quantified by Field Boundary Evaluation and Grading System (FBEGS) scores (Collier and Feehan, 2003), and bird species richness and diversity within the same field boundaries. In the surveys done at the original Ag-Biota monitoring sites, the total FBEGS Index score was found to be a useful indicator of total observed bird species richness in both the breeding and the winter season. These positive relationships were largely confirmed and elaborated on by the follow-up study of 50 commercial farm sites. In this much larger survey, a very strong link was found between the total FBEGS Index and both the species richness and Shannon diversity of bird populations in the same boundaries during the breeding season (Table 2.4, Fig. 2.10).

However, these relationships were much more tenuous in the winter season, when a more detailed analysis of relationships between bird population statistics and individual FBEGS component scores showed that only the Associated Features component of the FBEGS Index was a consistently good predictor of the total diversity and abundance of birds, and the species richness and abundance of habitat generalists in the same field boundaries over the winter period (Table 2.5, Fig. 2.11).

In the breeding season, however, more than one of the component parts of the FBEGS Index was found to make an important contribution to predicting bird diversity statistics, and an important conclusion of the current study is that when more than one component part of the FBEGS Index has a significant influence in determining bird populations, the overall Index appears to 'capture' in a synergistic way a useful integrated measure of field boundary quality from the perspective of wider bird diversity. The importance of this finding is that it suggests that the FBEGS method could provide a useful and practical additional tool for monitoring and evaluating the consequences of longer-term changes in farmed landscapes from the perspective of overall bird populations.

A further insight from the 50-site survey of commercial

Table 2.4. Summary statistics for generalised linear models describing the relationship between the Field Boundary Evaluation and Grading System (FBEGS) Index for field boundaries surveyed on the 50 commercial farm sites in 2006 and observed breeding season bird population statistics for the same field boundaries.

Explanatory variable	Response variable	Parameter estimate	$F_{1,48}$	p value
Total FBEGS Index	Total breeding season bird species richness	0.0531	32.55	<0.0001
	Shannon Index for total breeding season birds	0.0546	51.63	<0.0001
	Total breeding season bird abundance	0.0777	99.89	<0.0001
	Breeding season species richness, habitat generalists	0.0550	33.29	<0.0001
	Breeding season species richness, farmland specialists	n.s.	n.s.	n.s.
	Breeding season abundance of habitat generalists	0.0790	98.7	<0.0001
	Breeding season abundance of farmland specialists	n.s	n.s.	n.s.

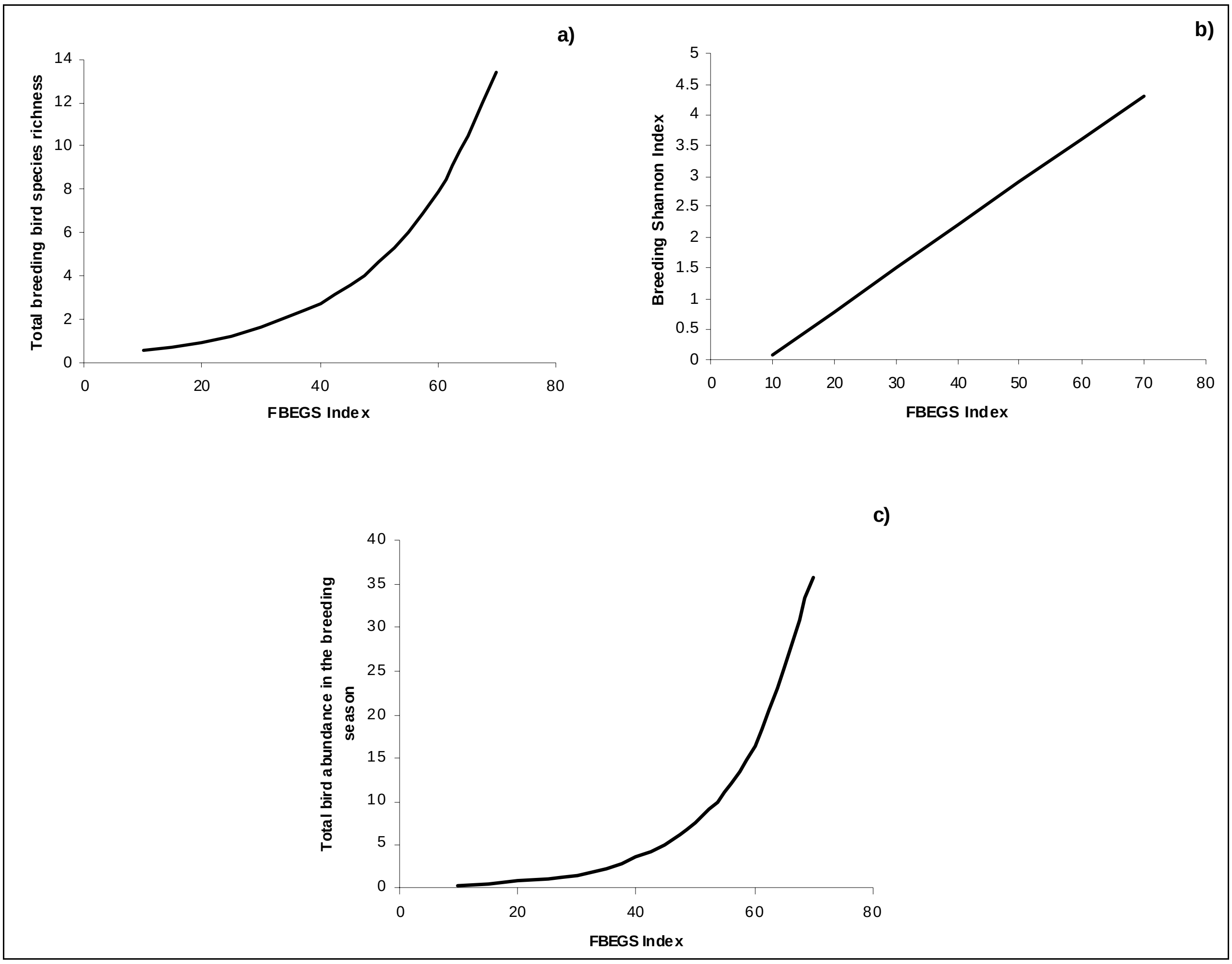


Fig. 2.10. The relationships between the total Field Boundary Evaluation and Grading System (FBEGS) Index and (a) the total bird species richness, (b) the Shannon index, and (c) the abundance of total breeding season bird populations observed in the same field boundaries on the 50 commercial farm sites in 2006.

Table 2.5. Summary statistics for generalised linear models describing the relationships between Field Boundary Evaluation and Grading System (FBEGS) component scores for field boundaries surveyed on the 50 commercial farm sites in 2006 and observed winter bird population statistics for the same field boundaries.

Response variable	Significant terms in the minimally adequate FBEGS Component Model	Parameter estimate	$F_{1,48}$	p value
Total winter bird species richness	Associated Features score	0.0732	7.63	0.008
Shannon Index for total winter birds	Associated Features score	0.0745	7.34	0.009
Total winter bird abundance	Associated Features score	0.1147	56.15	<0.0001
Species richness of habitat generalists	Associated Features score	0.0734	7.44	0.009
Abundance of habitat generalists	Associated Features score	0.1027	43.19	<0.0001
Abundance of farmland specialists	Associated Features score	0.4438	24.34	<0.0001

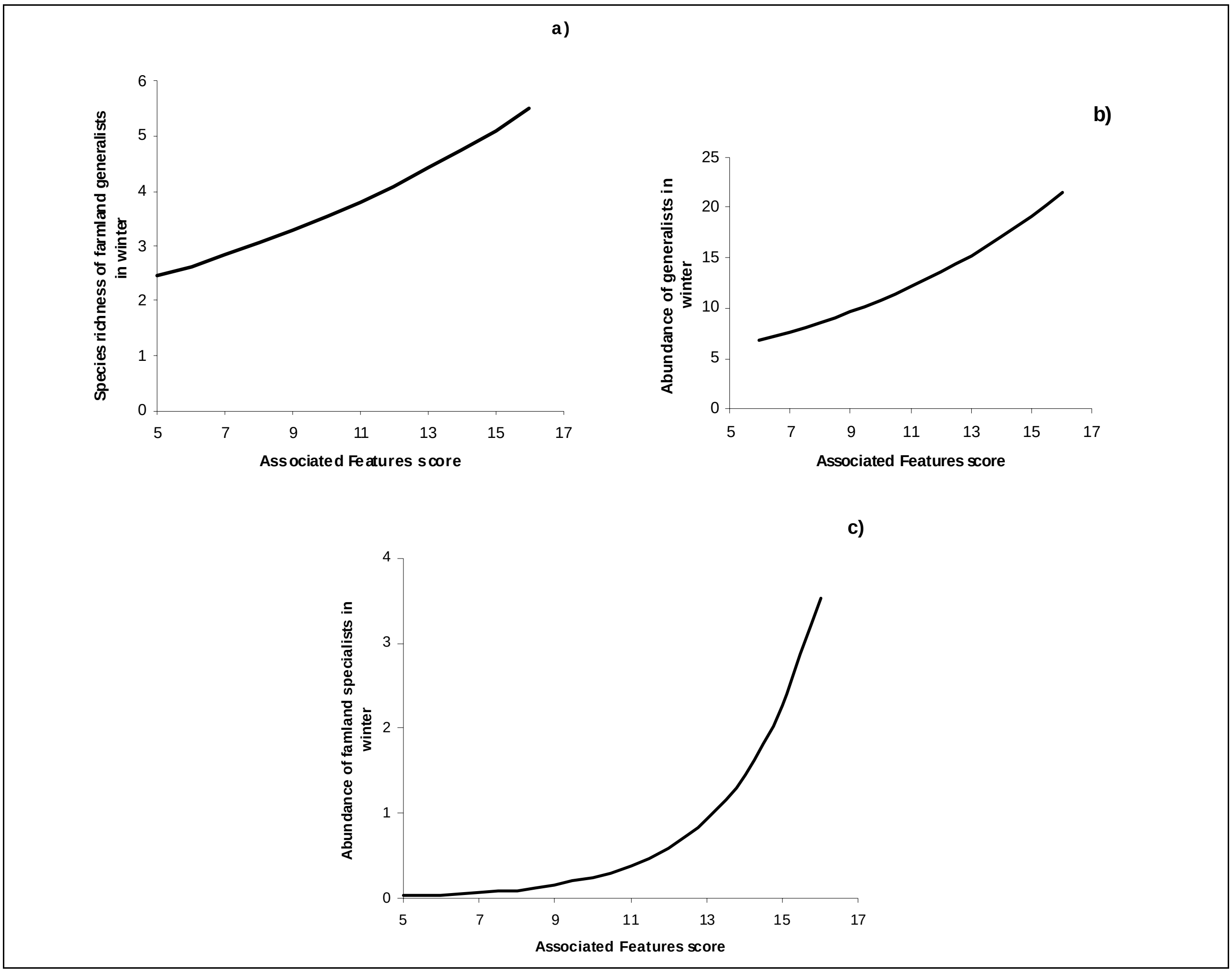


Figure 2.11. The relationships between the Associated Features component score of the Field Boundary Evaluation and Grading System (FBEGS) Index and (a) the winter species richness of habitat generalist bird species, (b) the winter abundance of habitat generalist bird species, and (c) the winter abundance of farmland specialist bird species observed in the same field boundaries on the 50 commercial farm sites in 2006.

farms, was the discovery of significantly greater FBEGS indices and both the species richness and abundance of breeding birds in field boundaries on dairy farms compared with non-dairy farms. (Figs 2.12 and 2.13, respectively).

These are extremely important findings since they suggest, firstly, the existence of a positive relationship between field boundary quality and bird populations and, secondly, establish that breeding bird populations in field boundaries on relatively intensively managed

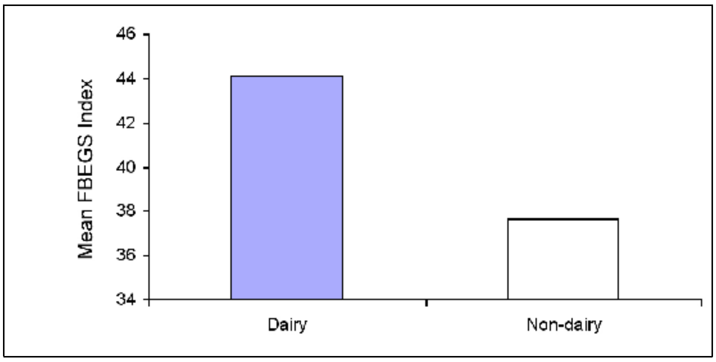


Figure 2.12. Generalised linear model predictions of the mean Total Field Boundary Evaluation and Grading System (FBEGS) Index for permanent field boundaries on dairy and non-dairy farm types using data collected from 50 commercial farm sites in 2006.

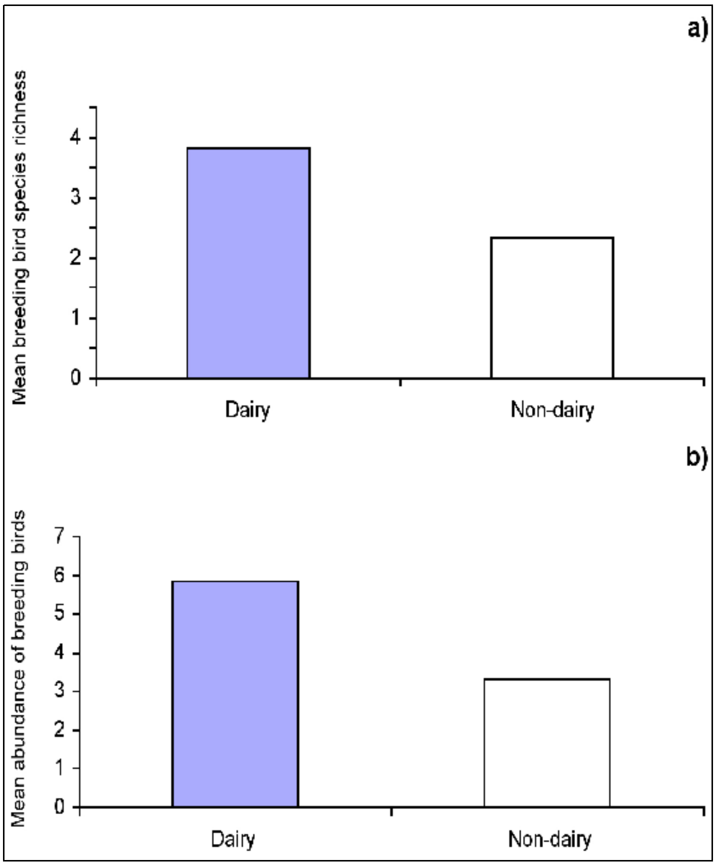


Figure 2.13. Generalised linear model predictions of (a) mean bird species richness, and (b) mean total abundance of breeding season bird populations within field boundaries on dairy and non-dairy farm types using data collected from 50 commercial farm sites in 2006.

dairy farms are greater compared with much less intensively managed non-dairy farms. Much further analysis of the 50-site data set regarding relationships between habitat structures, FBEGS scores, farming practices and bird populations remains to be done. However, it is already apparent from these initial analyses that a greater intensity in farm husbandry is not necessarily always detrimental for all aspects of farmland biodiversity.

2.3.4 *The significance of farm habitat and management data*

Changes in Irish land cover classes identified through CORINE assessments made in 1990 and 2000 include a 35% increase in the land area classified as 'arable land', which includes land used for silage production, a 31% increase in artificial surfaces, and a 23% increase in the area of afforested land. These increases have principally been at the expense of areas under permanent pasture, mixed farmland and wetland habitats. However, little attention has been afforded to identifying the composition and ecological quality of habitats and their management status at a farm scale.

The current Project's survey of 50 commercial farm sites, totalling 2,577.1 ha in south-east Ireland, indicates that about 15% of land on such farms (7.83 ha per farm) is currently maintained as 'non-cropped' habitat, including an extensive network of hedgerows, accounting for approximately 9% of the total surveyed land area, or about 9 km/km^2 (Table 2.6).

Table 2.6. Relative incidence of major habitat types[1] recorded on the 50 commercial farm sites.

Category	Habitat type (code according to Fossitt, 2000)	Total area (ha)	Mean area (ha) per farm ± SE	No. of farms on which recorded
'Cropped'	Intensive grassland (GA1, in part)	1,086.00	21.72 ± 2.11	40
	Less intensive, high agronomic quality grassland (GA1, in part)	656.26	13.23 ± 1.77	44
	Cereals – winter – spring – stubble (BC1)	55.60	1.1 1 ± 0.95	5
		34.07	0.68 ± 0.44	5
		175.30	3.50 ± 1.39	13
	Bare ground (BC3, in part)	27.47	0.55 ± 0.31	7
	Total	**2,098**	**41.96 ± 2.63**	**–**
'Non-cropped'	Field boundaries + associated herbaceous margins (WL1 mostly)	230.46	4.61 ± 0.33	50
	Scrub (WS1)	33.03	0.66 ± 0.17	25
	Deciduous woodland (WD1)	31.96	0.64 ± 0.16	26
	Riparian woodland (WN5)	37.55	0.75 ± 0.15	24
	Total	**391.74**	**7.83 ± 0.69**	**–**
'Other'	Built ground (BL3, in part)	84.28	1.68 ± 0.12	50
	Total	**87.32**	**1.75 ± 0.13**	**–**

[1] This table includes only summary data for habitats accounting for a mean of at least 0.5 ha per farm. Other recorded habitats included: Wet (*Juncus*-dominated) (GA1, in part), Wet (non-*Juncus*), Transitional grassland (GA1, in part), Wet grassland (GS4), Dry calcareous & neutral grassland (GS1, in part), Coniferous plantation (WD4), Mixed woodland (WD2), Wet deciduous woodland (WN6), Deciduous plantation (<10 years) (WS2, in part), Mixed forestry (<10 years) (WS2, in part), Wetlands, e.g. ponds (FL8), Saltmarsh (CM1 and CM2), Heath (HH1) and Historical features; see the full Ag-Biota Report for further details.

These estimates serve to underline the much higher density of hedgerow habitats present on Irish farmland compared with other European countries. This finding is a strong endorsement of specific agri-environmental measures targeting the protection and maintenance of this important part of the Irish landscape, and in conjunction with the Project's findings regarding the significant relationships between field boundary structure and bird populations (Section 2.3.3.2), is a strong incentive to optimise hedgerow management.

Less optimistically, the data collected from a total of 251.72 km of field margins adjacent to field boundaries indicate that over 22% of margins are dominated by nitrophilous plant species, suggesting an elevated nutrient status probably arising from the misapplication of fertiliser and/or slurry very close to field edges (vegetation types 3 and 4 in Table 2.7). Over 31% of field margins also showed the presence of other shrubby and/or woody species, indicating poor vegetation management (vegetation types 2, 4 and 6 in Table 2.7).

Coupled with high nutrient status, soil poaching caused by grazing animals was noted in approximately 1.5% of field margins (vegetation type 5 in Table 2.7). The survey of field margins also revealed that bracken (*Pteridium aquilinum*), an essentially weed plant species with virtually no biodiversity value, formed the dominant flora in almost 1% of field margins studied (vegetation type 6 in Table 2.7) and in total only 52% of field margins were well managed, with no evidence of nutrient enrichment or inappropriate vegetation management (vegetation type 1 in Table 2.7).

A detailed analysis of habitat composition on surveyed farms showed a strong distinction between dairy and other, exclusively drystock, farm typologies (Fig. 2.14). From this analysis, it can be concluded that farming intensity as indicated, on the one hand, by dairy status with associated high input levels and, on the other hand, by non-dairy and REPS status, is a primary driver of habitat composition on Irish livestock farms. This analysis also revealed a significant positive association between the proportion of field boundary habitat on a farm and REPS status (Fig. 2.15). Assuming of course that the surveyed REPS farms were not already different from the wider farm population when they joined the scheme, this is perhaps evidence of a significant positive influence of REPS policy on the retention of field boundaries.

Analysis of management practices also revealed that REPS farms, in general, had a significantly smaller total utilisable agricultural area (UAA) than non-REPS farms and that, on both REPS and non-REPS farms, there is a significant **negative** association between stocking rate and UAA (Fig. 2.16).

This suggests that, irrespective of their REPS status, smaller farms are more intensively stocked than larger farms, which is significant from a policy perspective because it contradicts any assumption that larger farms are more intensively managed.

Table 2.7. Relative incidence of vegetation types within the 1.5-m wide field margins surveyed on the 50 commercial farm holdings.

Field margin vegetation type	Total length (km) recorded on the 50 surveyed sites	Linear proportion (%) of total field margins
1. Grass and herb margins	131.05	52.06
2. *Rubus* and *Ulex* margins	57.44	22.82
3. *Galium* and/or *Urtica* margins	34.16	13.57
4. Mixed woody and nutrient-responsive spp. margins	22.73	9.03
5. Bare ground margins	3.97	1.58
6. Bracken (*Pteridium aquilinum*) margins	2.37	0.94

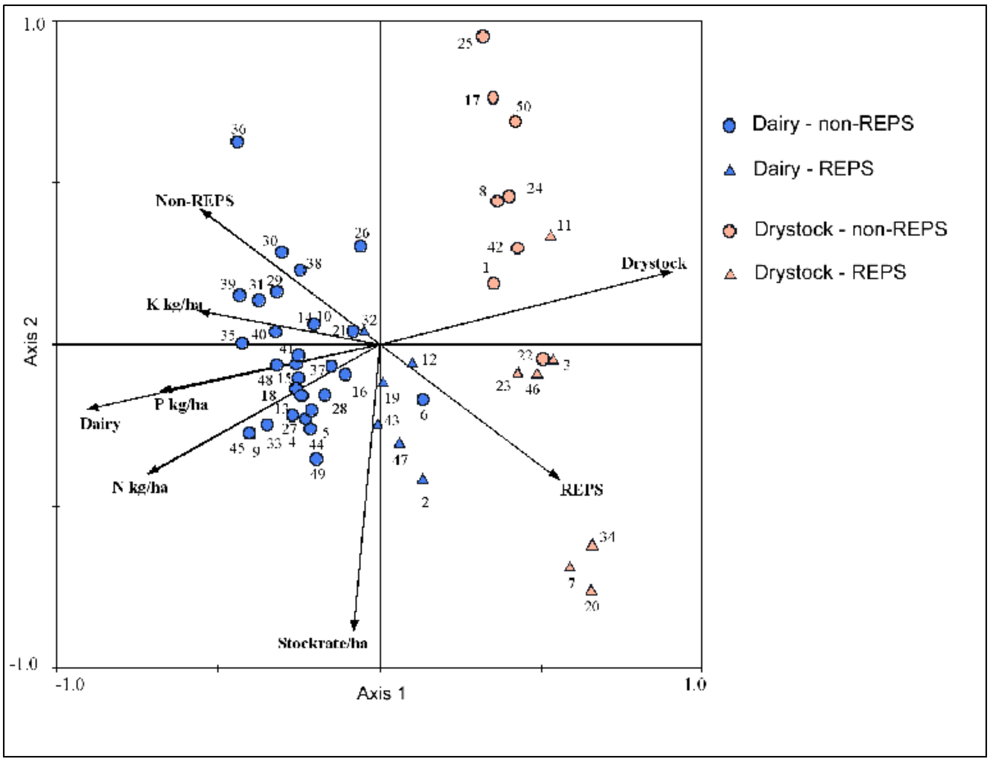


Figure 2.14. Summary of the final farm site redundancy analysis (RDA) ordination based on the relative incidence of habitat types; symbol colour and shape denote dairy *vs* non-dairy, and Rural Environment Protection Scheme (REPS) *vs* Non-REPS farm types, respectively.

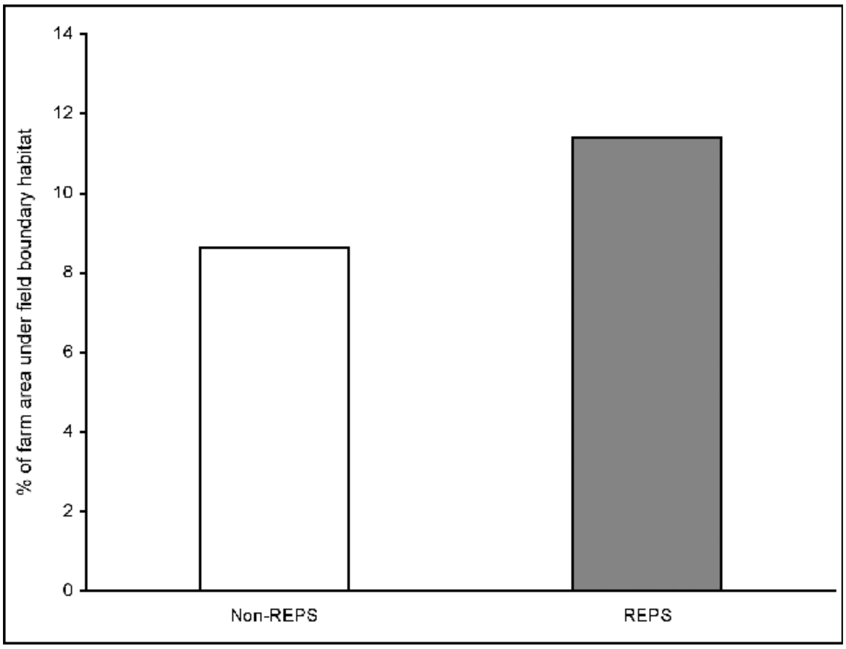


Figure 2.15. Multiple regression model estimates for the significantly different proportion of field boundary habitat on Rural Environment Protection Scheme (REPS) and non-REPS farms in the 50-farm site survey ($p < 0.001$).

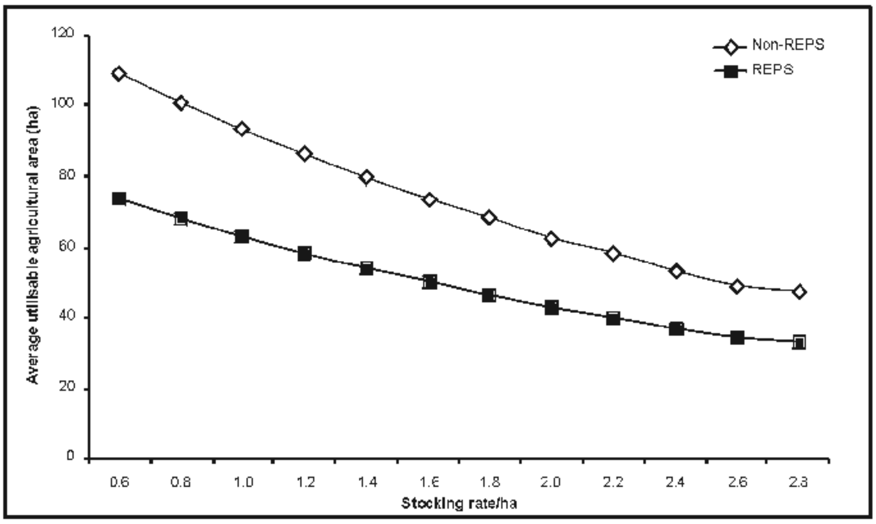


Figure 2.16. Multiple regression model predictions for the significantly different relationships between total utilised agricultural area (UAA) and stocking rate (livestock units, LU/ha), on Rural Environment Protection Scheme (REPS) and non-REPS farms.

2.4 Biodiversity at the Landscape Level

2.4.1 The bio-indicator value of aquatic invertebrates

Degradation of the ecological quality of freshwater systems, particularly as a consequence of intensive agricultural practices has received much attention and is the subject of extensive environmental legislation including the EU Habitats and Water Framework Directives. Maintaining the integrity of freshwater habitats has long been recognised as being dependent on the conceptual realisation that rivers are a product of the landscape through which they flow. Agricultural landscapes under intensive land-use practices are shown in this monitoring programme to impact on the ecological integrity of freshwater habitats. In comparison to similar reference sites, streams draining predominantly agricultural land were similar in alpha diversity, but sustained relatively greater invertebrate abundance. The invertebrate communities in agricultural streams were dominated by a small number of species, with only two to seven taxa representing up to 80% of the total aquatic invertebrate population. In contrast, reference streams had a markedly greater degree of evenness in relative abundance, with about 13 taxa represented in 80% of all individuals (Fig. 2.17).

The most notable differences between agricultural and reference streams were in the composition of the invertebrate communities. Reference streams were consistently dominated by pollution-sensitive taxa, both in terms of taxon richness and relative abundance (Table 2.8).

In comparison, most agricultural streams were dominated by pollution-tolerant taxa with a much lower number and relative abundance of pollution-sensitive and EPT (Ephemeroptera + Plectoptera + Trichoptera) taxa. As a consequence, catchments draining predominantly agricultural land are likely to have lost sensitive taxa, and proximity to refugia in the landscape will largely determine the probability and rate of their recovery. Aquatic invertebrate diversity within agricultural streams is a likely subset of the most tolerant taxa in reference sites, which have increased from a rare to common status. The analysis of the incidence of functional feeding groups in agricultural and reference streams suggests that despite a reduction of their ecological quality, as indicated by widely recognised biological metrics, the ecological functioning of streams in predominantly agricultural landscapes is largely maintained by a markedly greater abundance and diversity of tolerant taxa that have similar functional roles to the taxa that have been replaced. The concern would be, however, that further

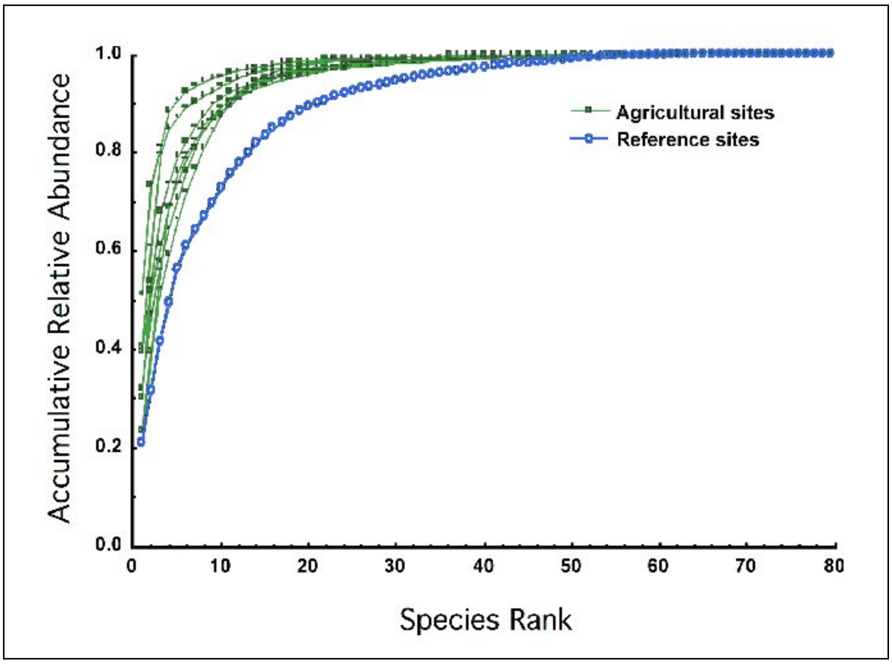


Figure 2.17. Mean relative abundance rank order plot comparing the accumulative abundances of taxa recorded at seven agricultural sites compared to reference streams.

Table 2.8. Mean water quality and risk assessment metrics for streams draining predominantly agricultural catchments in 2002–2005 and comparable reference sites sampled in 2004–2005.

Site	Total no. taxa	Q value	BMWP	ASPT	No. sensitive taxa	No. EPT taxa	% EPT (±SE)	SSRS
JC1	31	Q3	89	5.4	3	11	4 (2.3)	At risk
JC2	43	Q4–5	182	6.7	12	24	58 (2.6)	Not at risk
SH1	38	Q3	130	5.2	5	14	28 (1.1)	At risk
OP1	46	Q3	148	5.5	8	18	11 (1.2)	At risk
OP5	32	Q3	86	5.1	4	9	14 (2.2)	At risk
GR2	43	Q3	136	5.4	7	16	45 (16.5)	At risk
L1	30	Q2–3	91	4.9	3	9	5 (1.5)	At risk
Mean for reference sites[1]	41	Q5	164	6.8	14	24	75 (1.6)	Not at risk

[1]Six streams monitored to represent comparable reference conditions.
BMWP, biological monitoring working party; ASPT, average score per taxon; EPT, Ephemeroptera + Plectoptera + Trichoptera; SSRS, Small Stream Risk Score.

agricultural intensification could lead to such levels of depletion in sensitive taxa that population refugia, which might normally permit recolonisation within agricultural regions, will be lost from entire catchments. This emphasises the importance of long-term baseline monitoring programmes providing species-level ecological information concerning aquatic invertebrate populations that can be specifically linked to ongoing changes in farming practice and other forms of landscape use with river basement systems.

2.5 Assessing the Sectoral Impact of Agriculture on Biodiversity

2.5.1 Selection of bio-indicators

As already pointed out, at the start of the Ag-Biota Project it was not clear **what** should be monitored, or **how** monitoring could be done. During an initial phase of the Project, a strategic programme of monitoring was undertaken for a wide range of populations within farmland at levels from individual field to the wider landscape, whilst adopting the basic working assumptions that, firstly, no single bio-indicator group was likely to fulfil the need to assess the many potential impacts of agriculture and, secondly, that different indicator groups were likely to be most appropriate at different scales. Both of these assumptions have been borne out, and the initial studies identified a provisional list of four potentially key bio-indicator groups for Irish agriculture (Table 2.9).

Table 2.9. Potential key bio-indicator groups at different scales identified by the project for assessment of the impact of agriculture on biological diversity.

Monitoring scale	Key bio-indicator group
Field	Parasitoid Hymenoptera
Farm	Bumblebees/Butterflies
Farm	Birds
Landscape	Aquatic invertebrates

2.5.1.1 Parasitic and pollinator taxa as ecological indicators

Within agro-ecosystems, it has been argued that greatest priority must be given to functionally relevant biodiversity within cultivated areas, i.e. biodiversity within field systems under the influence of cropping practice. Parasitoid wasps occupy such a position but, uniquely, because of their highly specialised biologies, they are also highly diverse and abundant, even in intensive agro-ecosystems. Within the current studies, multiple data sets illustrated the overall value of this insect group as sensitive indicators of wider diversity within the most widespread habitat type in the Irish countryside, namely managed grassland. The value of parasitoids as bio-indicators lies not only in the close relationships between their abundance and diversity and that of other arthropod taxa, but also in the insight provided by a knowledge of their host ranges. Uniquely, the latter can reveal the underlying ecological influences affecting overall arthropod diversity. The indicator value of parasitoid populations is now the subject of ongoing studies.

At a farm scale, bumblebees are identified as a key indicator group on the basis that not only were they of particularly important functional value as pollinators, but also because this project's data suggest that they have suffered a particularly marked decline in incidence on farmland over recent decades. Solitary bees may also be of significant indicator value, since these studies also suggest that these indigenous wild pollinators may be as abundant as bumblebees on farmland. However, lack of a suitable non-destructive sampling methodology and knowledge concerning their distributions currently limits their indicator value. Further studies on the incidence of both these pollinator groups are considered a high priority. Until such studies are done, it is difficult to know, for example, precisely why bumblebee populations have declined in recent times, and whether solitary bee populations are undergoing similar decline. This project's data already show that 'cuckoo' *Psithyrus* bumblebees have undergone the most obvious decline in recent years. Whatever the cause, the identification of parasitic bumblebee species as the most sensitive indicators of a wider general decline in bee populations is yet another insight into the particular value of parasitic taxa as 'front-line' indicators of the loss of biological diversity at lower trophic levels within agro-ecosystems. This is a key finding of this Project.

2.5.1.2 Birds as indicators

Birds are also identified as a key indicator group at the farm and wider farmed landscape level. Of particular interest is the Project's demonstration of the underlying relationship between the previously largely theoretical FBEGS Index and bird populations within the assessed field boundaries. This is another key finding and clearly demonstrates that surrogate management-based indicators that reflect the application of sound ecological knowledge **can** be reflective of the actual state of biological diversity. These studies also provide evidence of the significantly greater ecological quality of field boundaries, as measured by FBEGS scores, and greater abundance (as opposed to diversity) of grassland arthropod populations on dairy compared with other livestock farm types. This very probably underpins the additional finding that breeding bird populations within field boundaries are also significantly greater on dairy farms (Fig. 2.18). Such potential complexity in the relationships between agricultural practice and biodiversity provides a salutary lesson that intensive farming is not necessarily '**bad**' for all aspects of biodiversity.

2.5.1.3 Aquatic invertebrates as indicators

At a wider farmed landscape level, aquatic invertebrate populations have been shown to be highly sensitive to the degradation of water quality, and the current Project very much confirms the potential utility of information concerning ongoing change in aquatic communities within intensively farmed catchments. These studies also clearly illustrate how baseline monitoring of the composition of aquatic invertebrate fauna can provide a valuable yardstick for assessment and evaluation of the ongoing impact of agri-environmental policy. However, further studies are required across gradients of land-use intensity and different landscape mosaics in order to identify the potential causal mechanisms underlying biotic change, and to determine if thresholds exist for the maintenance of ecological functioning within the aquatic system in terms of the intensity of farming and landscape spatial composition. Such studies have already begun within a newly Department of Agriculture, Fisheries and Food (DAFF)-funded project, 'Agri-Baseline' (Stimulus Research Fund 2006), which is utilising the knowledge gained by the current Ag-Biota Project in the further development of biodiversity monitoring within the context of agriculture (see Section 6.2).

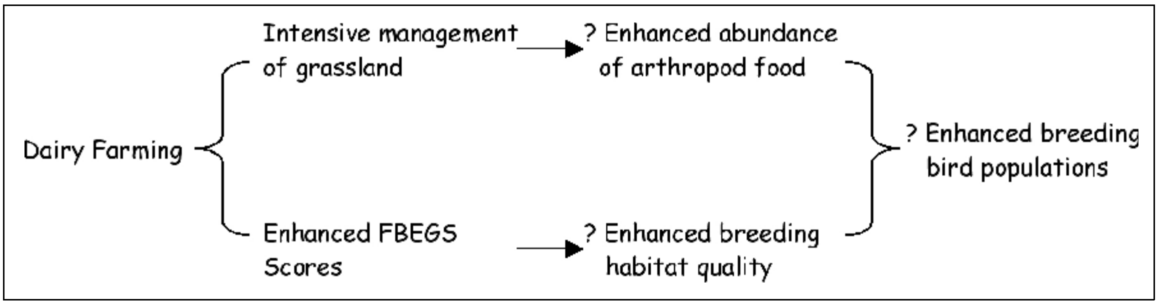


Figure 2.18. Suggested relationships between dairy farming, grassland arthropod abundance, field boundary quality, and breeding bird populations (FBEGS, Field Boundary Evaluation and Grading System).

3 Factors Determining Biodiversity in Grassland Farm Systems

3.1 Background

Grasslands are potentially very species-rich habitats, and maintaining even relatively intensively managed permanent pastures is likely to be more beneficial to biodiversity than many other types of land use. One of the most important priorities is therefore to understand how the management of this nationally dominant habitat type is likely to impact on biological diversity. Increased grassland management intensity has generally been found to decrease arthropod biodiversity, and practices such as fertiliser and pesticide use, grazing, cutting, ploughing and reseeding are likely to reduce biological diversity. Heavy grazing produces short swards that reduce foraging and habitat opportunities for many invertebrates, whilst low stocking rates can favour groups like spiders, whose incidence is strongly dependent on vegetation structure. This Project therefore made use of a number of pre-existing grassland husbandry experiments with a formally replicated design, which were available at the Teagasc Grange and Johnstown Castle Research Centres, to assess the likely influence of specific grassland husbandry practices on biological diversity.

3.2 The Grange Grassland Management Experiment

This experiment was set up to compare the agronomic performance of two contrasting suckler beef production systems of different management intensity:

1. A conventional standard suckler beef system with 0.65 ha/cow unit (cow plus progeny to slaughter plus replacements) and 225 kg N/ha/year

2. A REPS-compatible suckler beef system with 0.82 ha/cow unit and 88 kg N/ha/year.

The experiment was set out on two large adjacent pastures in 1997, which had previously been used for intensive beef production receiving *circa* 225 kg N/ha/year. The treatments were managed with separate, self-contained suckler herds, which were grazed between April and November on four replicated field plots per treatment. Each treatment replicate (plot) was subdivided into three nested grazing paddocks, which were grazed rotationally on an approximate 21- to 28-day cycle in a fixed sequence, such that only two replicate blocks of the experiment were in use at any one time. Vortis suction samples were collected from experimental plots in June and August 2003, and similarly in 2005.

3.2.1 Summary results

In both years of sampling, GLM analyses indicated significant treatment effects on arthropod populations. In 2003, there was a greater abundance and taxon density of arthropods in the sward of the REPS-compatible system compared with the higher management intensity system. In 2005, both arthropod abundance and taxon density showed a similar treatment difference in August, but not in June when overall populations were generally smaller (Table 3.1, Fig. 3.1). Similarly, a positive effect of sward height on arthropod abundance was substantially greater in the REPS-compatible compared with the conventional treatment. A significant treatment interaction between sample date and sward height resulted in a significantly greater slope estimate for the relationship between sward height and arthropod abundance in June compared with August samples, suggesting that the positive effect of grass height on arthropod abundance was greater earlier in the season when, from a phenology perspective, arthropod populations in grassland tend to be less abundant. This implies that the observed positive influence of the REPS-compatible treatment on arthropod abundance later in the growing season occurs despite a relative decline in the importance of sward height, i.e. the effect of the experimental treatment regimes at Grange cannot be entirely explained by their relative effects on sward structure, as measured by mean sward height. Collectively, the data from the Grange experiment clearly indicate that, as well as strong effects of sample season and sward height, there were real treatment differences in the abundance and taxon density of

Table 3.1. Summary of the best fitting lmer-based generalised linear model describing total arthropod taxon density in the plots of the suckler beef system experiment at the Teagasc Grange Research Centre in 2005. (Only the significant terms of a systematically refined minimally adequate model derived from an initially maximal model containing treatment and mean sward height as fixed effects, and block and plot as random effects are shown.)

Response variable	Terms in the minimally adequate model	Parameter estimate	Standard error	z	p value
Arthropod taxon density	Intercept (August, conventional treatment)	3.592	0.124	29.032	<0.001
	Date (June)	–0.298	0.182	–1.634	0.102
	Treatment (REPS-compatible)	0.269	0.063	4.242	<0.001
	Mean sward height	0.025	0.011	2.227	0.026
	Date (June) × treatment (REPS-compatible)	–0.239	0.096	–2.491	0.013
	Date (June) × sward height[1]	0.008	0.022	0.355	0.722

[1]Indicates a non-significant term in the fitted model, which could not be removed without causing a significant dis-improvement in model fit as quantified by the ANOVA function and AIC (Akaike's information criterion) values (change from 52.8 to 60.0).

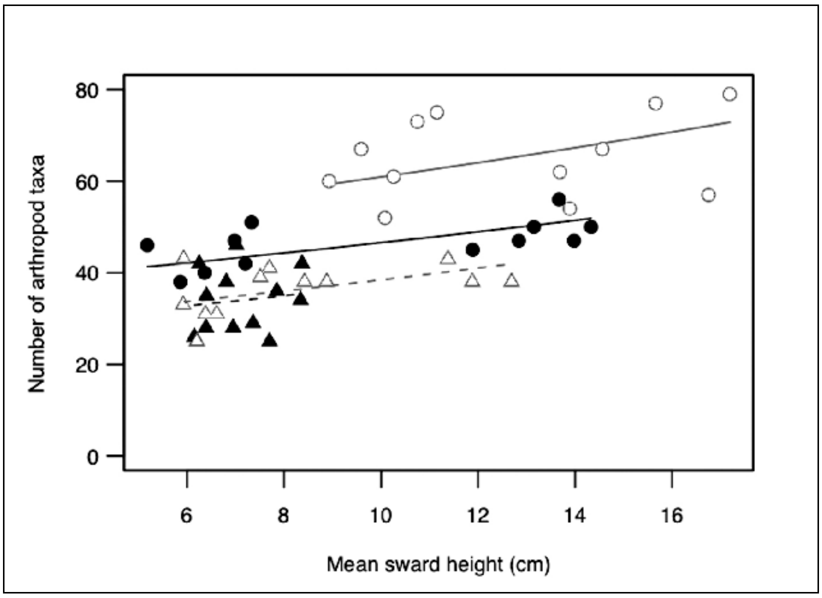


Figure 3.1. Multiple regression model prediction of the relationships between arthropod taxon density and mean sward height in the suckler beef system experiment at the Teagasc Grange Research Centre in 2005. (Triangles and broken lines represent observation and prediction of populations in June samples, and circles and solid lines August samples; open symbols represent the less intensive REPS-compatible treatment, and solid symbols the more intensive conventional treatment.)

sward arthropods. These differences were apparent despite the fact that both treatments were subjected to a relatively very intensive use of the sward through short-term rotational grazing.

Further evidence of faunal differences between the Grange treatments was provided by NMDS analysis of arthropod community structure in the experimental paddocks, which indicated significantly different communities in the REPS-compatible and conventional treatment paddocks (Fig. 3.2).

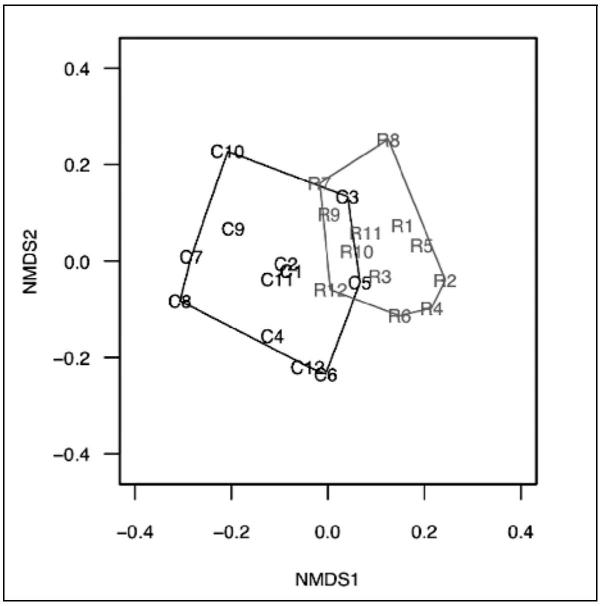


Figure 3.2. Non-metric multidimensional scaling (NMDS) ordination of total arthropod community structure in the Grange suckler beef system experiment, using pooled Vortis sample data collected from individual grazing paddocks in 2003 and 2005. (Conventional paddocks (C) are shown in black and REPS-compatible paddocks (R) in grey.)

A more detailed analysis of the relative incidence of different groups remains to be made in order to better explain this community structure effect. In this regard, a first step has already been made by Anderson and Purvis (2008), who analysed the data for parasitoid wasp populations collected during the current study. This analysis revealed a greater predominance of parasitoid taxa associated with concealed plant-mining and galling insect hosts and egg parasitoids in plots of the REPS-compatible system, and a greater prominence of aphid parasitoids (*Aphidius* and *Trioxys*) in the more intensive system.

3.3 The Tower Field Nitrogen Input Experiment at Johnstown Castle

The Tower Field experiment was established at the Teagasc Research Centre, Johnstown Castle, Co. Wexford (latitude 52° N, longitude 6° W) in 2001, originally to study the effects of different nitrogen fertiliser rates on N_2O emissions. Prior to the start of the experiment, the Tower field site had been very intensively managed for commercial beef production, with a uniform pasture sward dominated by perennial ryegrass for more than 10 years, and with inorganic fertiliser applied at a rate of *circa* 350 kg N/ha. Experimental treatments were arranged in a randomised block design, with three large replicated plots of each of the following fertiliser rates:

1. 0 kg N/ha/year (0 N)
2. 225 kg N/ha/year (225 N)
3. 390 kg N/ha/year (390 N).

As well as having very different fertiliser inputs, the three experimental treatments also differed in stocking density, which for the 0, 225 and 390 kg N treatments equated to 1, 2.4 and 3.0 livestock units per hectare, respectively. The plots of each treatment were subdivided by electric fencing into three grazing paddocks, which were grazed by a separate self-contained herd on a 21-day grazing cycle. In 2002, it became necessary to drop one of the three 0-N paddocks from the experiment because of excessive waterlogging. As a consequence, when arthropod samples were collected on six occasions grouped into two sampling periods (12, 18 and 25 May, and 28 July, 4 and 9 August 2004) only two replicates of the 0-N treatment were available.

3.3.1 *Summary results*

In comparison with the Grange experiment, the information gained from the Tower Field experiment concerning the influence of management intensity on arthropod diversity was less clear and proved more difficult to interpret. As in the Grange experiment, arthropod populations increased as the growing season progressed from early to late summer. The Tower Field data also showed significant relationships between both faunal abundance and taxon density, and sward height. However, in contrast to the Grange experiment, there were few consistent treatment differences at Tower Field in terms of the observed total abundance, taxon density or taxon richness of foliage arthropods. This may be explained by the different discriminatory power of the two pre-existing experiments or, alternatively, the explanation may lie in the past history of the two experimental sites – the experiment at Grange having run for 6 years before sampling began was preceded by relatively modest management intensity (*circa* 225 kg N/ha/year); in contrast, the Tower Field experiment had been maintained for 2 years prior to sampling and the site had previously received a very intensive input of *circa* 350 kg N/ha/year. It seems very likely therefore, that a high level of residual soil fertility may have remained in the Tower Field plots at the start of this study, despite the adoption of a 0-N treatment regime.

Despite the lack of treatment effects on univariate population statistics in the Tower Field experiment, NMDS ordination of arthropod community composition within individual paddocks showed strongly significant treatment differences (Fig. 3.3). This ordination clearly implies that ecological conditions in the plots of the 0-N treatment had already changed during the relatively

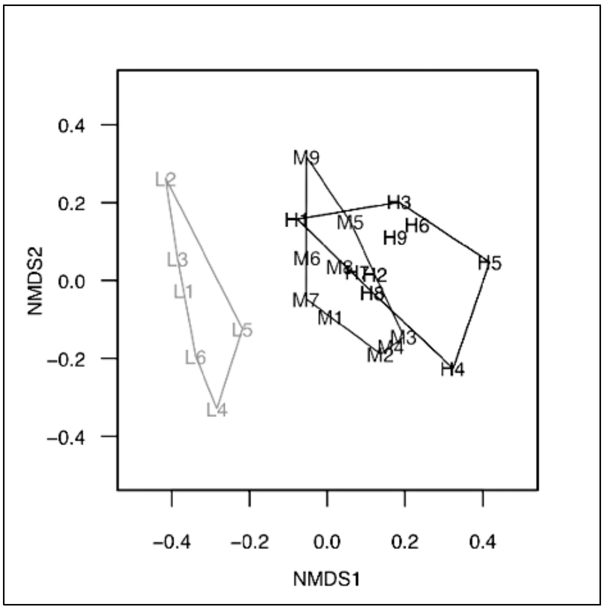


Figure 3.3. Non-metric multidimensional scaling (NMDS) ordination of foliage arthropod community structure in the Tower Field experiment, using pooled Vortis sample data collected from individual grazing paddocks in 2004. (0-N paddocks (L) are shown in light grey, 220-N paddocks (M) in dark grey and 390-N paddocks (H) in black.)

short lifespan of the experiment, altering the community structure of the foliage fauna in comparison to the higher nitrogen treatments. As in the Grange experiment, the fauna of plots with more intensive management were characterised by a greater prominence of aphid parasitoids and parasitoids of dung-breeding Diptera.

3.4 The Field Margin Experiment, Johnstown Castle

The REPS has gone some way to recognising the potential benefits of modifying the management of grass field margins by the inclusion of specific measures for their maintenance. These measures are designed essentially to create a ‘buffer’ between the intensively managed field and adjacent habitats close to the field edge, such as hedgerows and woodland. REPS Measure 2 has for some time required the implementation of a sustainable grassland management plan that includes the maintenance of an untilled, unploughed and unsprayed margin of at least 1.5 m width whenever grass fields are re-sown. Other REPS measures, 4, 5 and 6, also specifically target the protection of such narrow field margins adjacent to the field boundary. New supplementary measures in the latest variant of REPS 4, available to farmers since late 2007, include biodiversity options such as the retention of traditional hay meadows (Option 2A), maintenance of species-rich grasslands (Option 2B), and the use of clover in re-sown swards (Option 2C). All of these supplements to the basic REPS are aimed at improving biodiversity within agricultural grassland systems. However, to date, very little research has been undertaken to validate the effectiveness of the longer-term REPS measures to protect field margins. Also, no experimental work has been done to date to document the potential advantages of the more recent Supplementary Measures that pertain to grassland management (listed above). However, a longer-standing fenced field margin experiment at Teagasc, Johnstown Castle, was available to this project. The primary objective of this experiment was to investigate the optimum means to establish and maintain a protected field margin around the edge of intensively managed dairy paddocks from the perspective of botanical diversity.

All traditional field hedgerows and their associated herbaceous margins had been removed from the vicinity of the experiment during a process of grassland management intensification in the 1970s and 1980s. The result was the subdivision of the site into a large number of rotationally grazed paddocks fenced with electric fencing and dominated by perennial ryegrass (*Lolium perenne* L.), which were grazed by a dairy herd on a standard 21-day rotation, with each paddock conserved and cut once for silage in alternate years. In February 2002, a field margin experiment was established by physically fencing off strips of varying (1.5 m, 2.5 m and 3.5 m) width at the margins of existing paddocks. These strips were subsequently divided into three 30-m long plots to accommodate three replicates of the following treatments in a fully randomised block design:

1. Fenced only (FO): the existing grass sward within the strip simply fenced off from the adjacent paddock

2. Rotavated and Fenced (ROT): the existing vegetation removed with a glyphosate-based herbicide and the strip rotavated and left to revegetate naturally after being fenced off

3. Rotavated, Reseeded and Fenced (RS): the existing vegetation removed with glyphosate-based herbicide and the strip rotavated and reseeded with a selected grass and wildflower seed mixture before being fenced off.

Once established, these fenced margin treatments (1–3) were protected from all cattle grazing and normal nutrient inputs that continued as normal on the adjacent paddocks. Unfenced control (UC) margin strips (Treatment 4) of similar length (30 m) and width (1.5 m, 2.5 m or 3.5 m) were marked out at paddock margins within each of the three replicate blocks. Vegetation arthropod populations within all marginal plots were sampled four times, in June and August 2004 and 2005, respectively, using a Vortis suction sampler.

3.4.1 Summary results

Arthropod populations were generally more abundant in the plots in 2005 compared with 2004 and, possibly as a consequence, arthropod abundance and diversity in the fenced margin treatments were more evidently greater than in the unfenced grazed margins in the second year of sampling (Fig. 3.4).

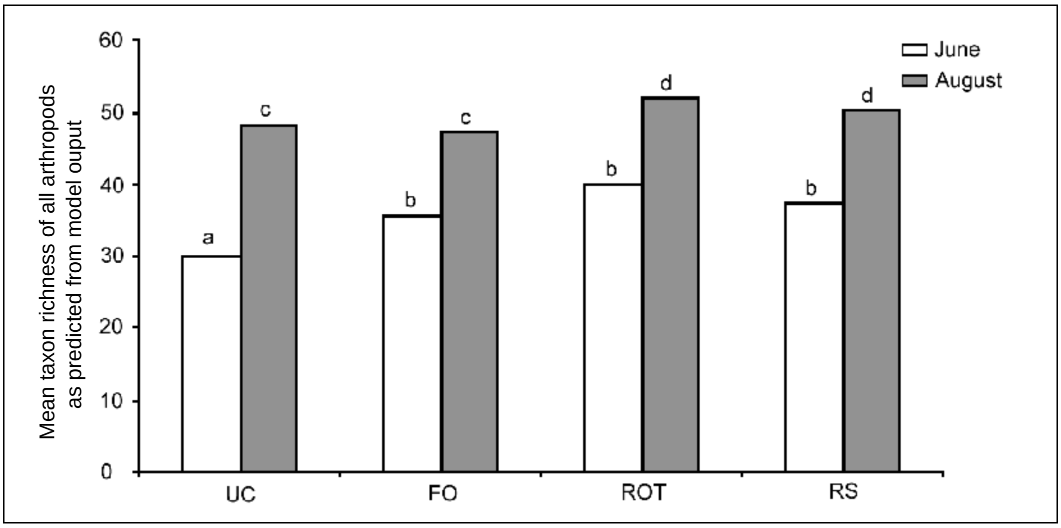


Figure 3.4. Multiple regression model prediction of the total numbers of foliage arthropod taxa in Vortis suction samples collected in 2004 and 2005 from the different treatments of the field margin experiment at the Teagasc Johnstown Castle Research Centre. (Open bars indicate estimates for catches in June, and grey-filled bars estimates for August catches; different letters above bars indicate significant treatment effects within sampling dates ($p < 0.05$). UC, Unfenced control; FO, Fenced only; ROT, Rotavated and Fenced; RS, Rotavated, Reseeded and Fenced.)

The effect of sward structural change associated with fencing was even more clearly apparent in comparisons of arthropod communities, with strong evidence of divergent community structures for all major arthropod groups (Figs 3.5–3.8), with a majority of taxa clearly benefiting from the fencing of margins (Table 3.2).

Only a small number of taxa were clearly more associated with the intensively utilised sward of unfenced margins. These included predictable groups, such as specifically grass-feeding aphids and leafhoppers, a range of essentially detritivorous taxa closely associated with cattle dung and associated microflora, erigonine spiders dependent on short grassland vegetation for the production of their ground-level webs, some dung-associated predatory Coleoptera, and a number of parasitoid wasp genera known to be parasites of the aforementioned groups.

Within the wider parasitoid community, the idiobiont/koinobiont dichotomy provides strong indications concerning the biological and ecological attributes of host groups, and is a useful way to interpret and better understand patterns in host–parasitoid interactions. The larval development of koinobiont parasitoids is closely adapted to that of their hosts, which are generally found living in exposed habitats. In order to ensure their own survival, koinobiont parasitoids maintain the activity and mobility of their host for as long as possible following initial parasitism, and so avoid likely predation of their own larval stages. In contrast, idiobionts are more generalist parasitoids that lack developmental adaptations to prolong the survival of their hosts, which are usually killed on initial parasitism. The idiobiont developmental strategy is well adapted to hosts that are not likely to become victims of predation following parasitism, and dominate in well-concealed plant-mining herbivore communities.

In the current study, the abundance and taxon richness of idiobionts were substantially greater in the fenced margins compared to the unfenced margins, whilst neither the abundance nor the diversity of koinobiont taxa were significantly influenced by the fenced margin treatments (Table 3.3, Fig. 3.9).

This suggests that the greatest advantage of a conserved field margin in an agricultural grassland, at least in the short-term, is a marked increase in the abundance and diversity of well-concealed cryptic plant-mining insect populations associated with

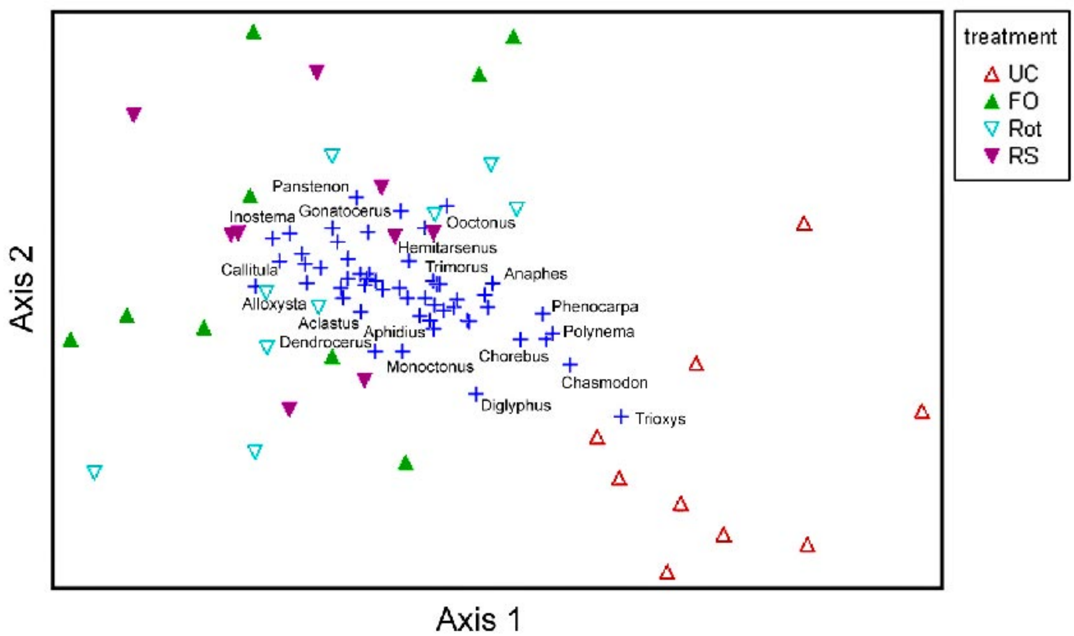


Figure 3.5. Non-metric multidimensional scaling (NMDS) ordination of total parasitoid Hymenoptera populations collected from the plots of the field margin experiment at Johnstown Castle. Crosses indicate the ordination of specific taxa, which for clarity may not all be labelled. (UC, Unfenced control; FO, Fenced only; Rot, Rotavated and Fenced; RS, Rotavated, Reseeded and Fenced.)

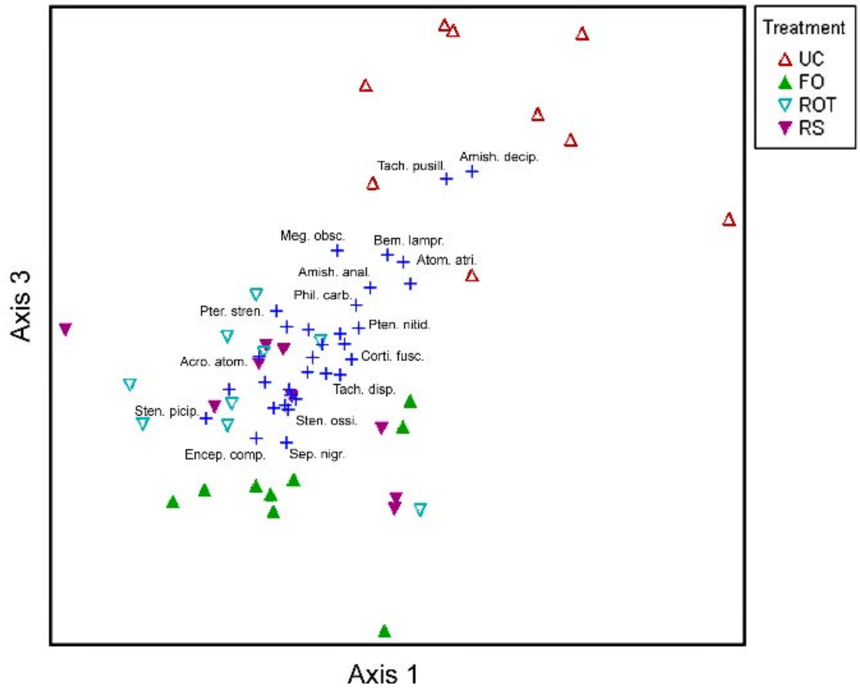


Figure 3.6. Non-metric multidimensional scaling (NMDS) ordination of Coleoptera populations collected from the plots of the field margin experiment at Johnstown Castle. Crosses indicate the ordination of specific taxa, which for clarity may not all be labelled. (UC, Unfenced control; FO, Fenced only; ROT, Rotavated and Fenced; RS, Rotavated, Reseeded and Fenced.)

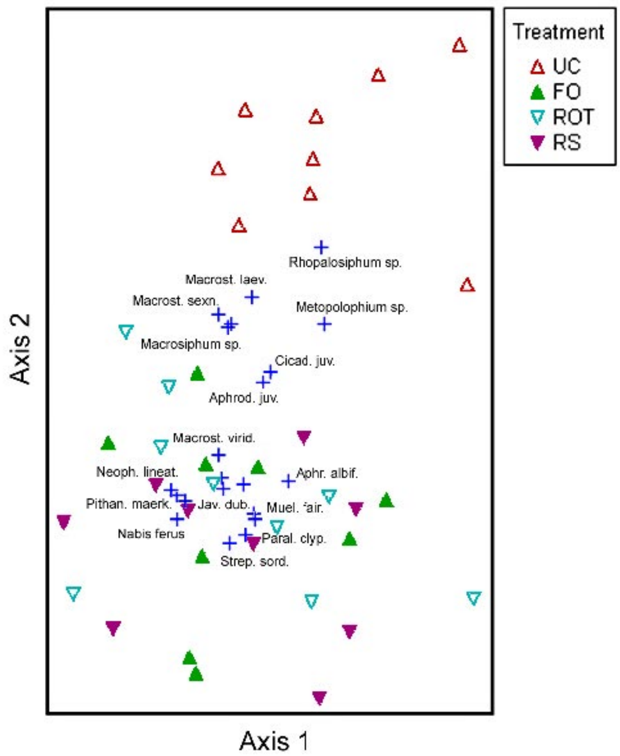


Figure 3.7. Non-metric multidimensional scaling (NMDS) ordination of Hemiptera populations. Crosses indicate the ordination of specific taxa, which for clarity may not all be labelled. (UC, Unfenced control; FO, Fenced only; ROT, Rotavated and Fenced; RS, Rotavated, Reseeded and Fenced.)

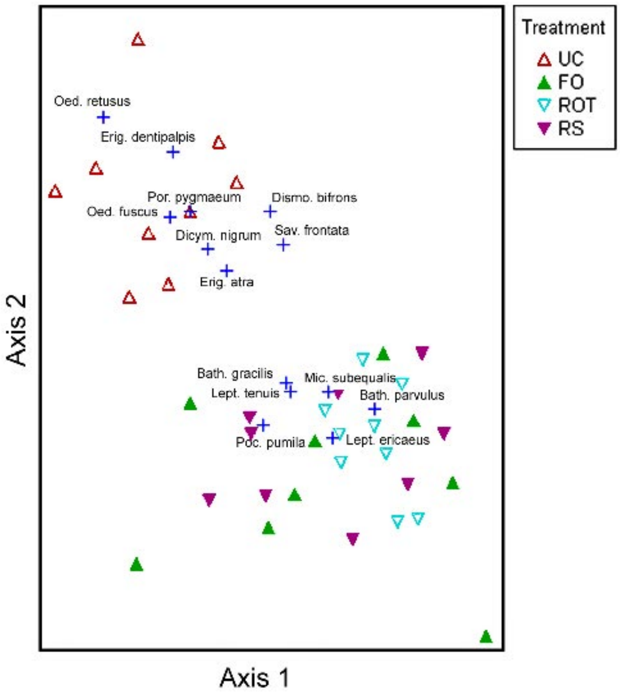


Figure 3.8. Non-metric multidimensional scaling (NMDS) ordination of spider populations. Crosses indicate the ordination of specific taxa, which for clarity may not all be labelled. (UC, Unfenced control; FO, Fenced only; ROT, Rotavated and Fenced; RS, Rotavated, Reseeded and Fenced.)

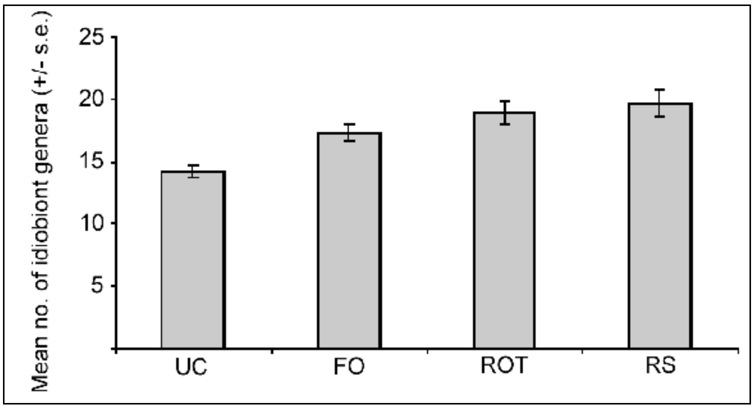


Figure 3.9. Mean taxon density of idiobiont parasitoid wasps in the field margin experiment at the Teagasc Johnstown Castle Research Centre. (UC, Unfenced control; FO, Fenced only; ROT, Rotavated and Fenced; RS, Rotavated, Reseeded and Fenced.)

increased plant structural diversity, including elongated stems, flowers, seed heads, etc.

One of the most distinctive indicator groups for the fenced paddock margins was the guild of lepidopteran parasitoids (Fig. 3.10). However, virtually no adult Lepidoptera were collected from any of the experimental margins during the study, and it is very likely that the majority of lepidopterous parasitoids observed in the fenced margins were parasites of well-concealed plant-mining 'micro-lepidopteran' larvae. The observation of associated parasitoids is probably the only feasible way that such cryptic biodiversity can be demonstrated.

The fencing of paddock margins is a relatively simple practice that even the most intensive grassland farmers in Ireland might readily undertake at minimal

Table 3.2. Significant indicator value (IV) scores for the incidence of foliage arthropod taxa in the unfenced (UC) and fenced paddock margins of the field margin experiment at Teagasc, Johnstown Castle. IVs were calculated by pooling all Vortis sample data collected from individual plots in 2004 and 2005, and contrasting incidence in unfenced (grazed) *vs* all fenced margins. IVs are listed for 'Good indicators' with significant IVs (p = 0.05) greater than 70%.

Order	Taxa	Associated with	IV	p value
Araneae	*Erigone atra*	UC margins	88.6	0.0002
	Oedothorax fuscus	UC margins	98.0	0.0002
Diptera	Chironomidae	UC margins	74.5	0.0034
Hemiptera	*Aphrodes* juveniles	UC margins	80.8	0.0012
	Cicadellidae juveniles	UC margins	75.8	0.0050
	Javesella dubia	Fenced margins	88.2	0.0002
	Macrosteles adults	UC margins	75.9	0.0052
	Metopolophium spp.	UC margins	72.0	0.0006
	Muellerianella fairmairei	Fenced margins	90.3	0.0002
	Paraliburnia clypealis	Fenced margins	90.6	0.0002
	Rhopalosiphum spp.	UC margins	95.4	0.0002
	Pithanus maerkeli nymph	Fenced margins	90.3	0.0006
	Sipha glyceriae	Fenced margins	83.3	0.0004
	Sitobion fragariae	Fenced margins	76.4	0.0006
Coleoptera	*Acrotrichis atomaria*	Fenced margins	76.3	0.0038
	Amischa analis	UC margins	89.3	0.0002
	Amischa decipiens	UC margins	95.8	0.0002
	Sepedophilus nigripennis	Fenced margins	96.3	0.0002
	Stenus fulvicornis	Fenced margins	76.0	0.0004
	Stenus ossium	Fenced margins	88.2	0.0002
	Tachyporus pusillus	UC margins	90.0	0.0002
Hymenoptera	*Anagyrus*	Fenced margins	70.4	0.0012
	Chasmodon	UC margins	77.5	0.0002
	Gonatocerus	Fenced margins	70.9	0.0016
	Inostemma	Fenced margins	92.2	0.0002
	Mesopolobus	Fenced margins	70.4	0.0010
	Panstenon	Fenced margins	93.7	0.0002
	Polynema	UC margins	86.5	0.0002

Table 3.3. Summary of significant differences in the taxon density of parasitoid wasp guilds in the field margin experiment at the Teagasc Johnstown Castle Research Centre.

Guild	df	F	p value
Idiobionts	3,6	34.571	<0.001
Koinobionts	3,6	3.279	0.102
Parasitoids of (taxonomic host groups):			
Hemiptera (other than aphids)	3,6	13.391	0.005
Lepidoptera larvae	3,6	7.000	0.022
Parasitoids of (ecological host groups):			
Gall-forming insect larvae	3,6	7.724	0.018
Insect and spider eggs	3,6	16.337	0.003

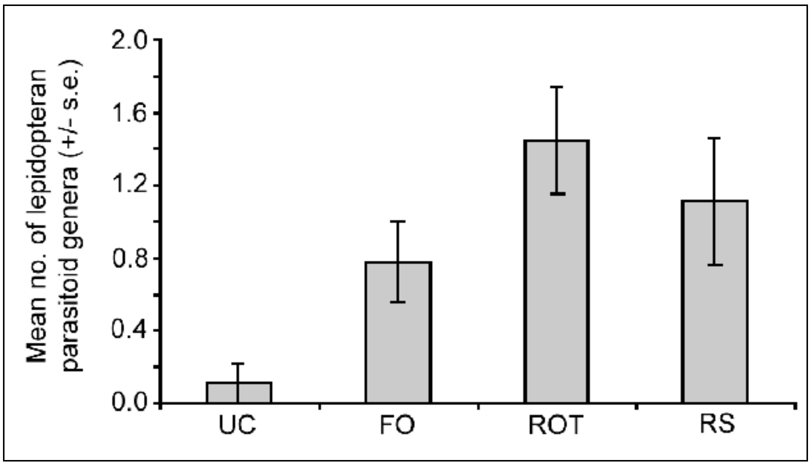


Figure 3.10. Mean taxon density of parasitoids of lepidopterous larvae in the field margin experiment at Teagasc, Johnstown Castle. (UC, Unfenced control; FO, Fenced only; ROT, Rotavated and Fenced; RS, Rotavated, Reseeded and Fenced.)

cost to their production system. It is therefore important that the Johnstown Castle field margin experiment is continued, in order to document the timescale necessary to realise the full benefits of the treatments designed to increase the botanical, as well as the structural, diversity of such margins. Ongoing analysis of faunal data from this experiment will also prove invaluable in helping to evaluate the likely longer-term benefits of optional Measures 2a and 2b in REPS 4 relating to the conservation of traditional hay meadows and the maintenance of species-rich grassland, respectively.

3.5 Conclusions Concerning the Impact of Grassland Management on Biodiversity

Taken together, the evidence from all three Teagasc field experiments (the Grange, Tower Field and paddock margin experiments) tells a rather similar story of management effects on foliage arthropod abundance, diversity and altered community structure. Characteristic and predictable groups, such as aphids and dung-breeding Diptera and their associated parasitoid taxa, were much more evident in the most intensively managed treatments, while a generally much greater diversity of fauna and, in particular, a greater incidence of parasitoids of well-concealed plant-mining and gall-forming insects, and insect and spider eggs, being found in more extensive treatments. The degree to which such treatment differences were apparent was generally a reflection of the relative contrast in the 'intensity' of the management systems being compared. Thus, by far the clearest discrimination of arthropod populations was observed in the comparison of experimental field margin treatments, in which populations in all the fenced treatments differed very clearly from those in the unfenced control margins. Within the Grange and Tower Field experiments, all treatment plots were intensively grazed and differences between the nutrient input treatments were often smaller. However, within each experiment, an overall negative relationship between management intensity and faunal diversity was still evident. Overall, these studies suggest that a full evaluation of the biodiversity benefits of reducing the intensity of grassland husbandry will almost certainly require longer-term experimental comparisons. This is a recurring finding of the current study (see also Section 4.2), and suggests that the full benefits of adopting REPS measures with respect to grassland management may take time to become fully evident.

3.5.1 Implications for REPS policy

Collectively, the results from monitored Teagasc experiments are very revealing, and clearly support previous work showing the importance of sward structure on arthropod populations in relatively intensively managed agricultural grasslands. However, the significance of this dimension of grassland management was maximally evident only in the field margin experiment at Johnstown Castle. Because the management treatments in the Tower Field (Johnstown Castle) and Grange experiments did not depart from the widely practised custom of maximising grass utilisation by intensive rotational grazing in electrically fenced paddock strips, they essentially provided only a measure of reduced nutrient input levels and consequently reduced stock numbers. Undoubtedly, this is likely to have limited the potential biodiversity benefits that might be achieved by additionally reducing the frequency and intensity of grazing. Thus, whilst the current studies provide an important evidence base supporting many aspects of current REPS measures regarding grassland management, they also highlight areas for improvement.

As the Grange beef system experiment clearly illustrates, it is possible for farmers to manage their grassland according to REPS specifications (reducing only nitrogen use and stocking rates), and so achieve demonstrable improvements in biodiversity by doing so. However, the scale of treatment effects observed in the field margin experiment, despite its relatively short timescale, suggests that if the pattern of intensive grass utilisation by rotational grazing remains unchanged, the net effect of the current REPS core Measure 2 in enhancing biodiversity is likely to be substantially less than might be otherwise achieved. In this context, the adoption of new optional measures (Options 2a and 2b) in REPS 4 to maintain traditional hay meadows and species-rich grasslands is very much welcomed. However, to exploit the full potential of biodiversity within grass-based agriculture will require a dedicated programme of longer-term grassland husbandry research to achieve an optimised and sustainable model for grassland production systems customised to particular agronomic conditions (see Chapter 6).

4 Ecology of Populations in Agro-Ecosystems: Developing Tools for the Practical Management and Utilisation of Biodiversity

4.1 Background

An understanding of the fundamental ecology of plant and animal populations (both beneficial and detrimental) within production systems is essential for the development and integration of practical management strategies that utilise the ecological benefits of biodiversity in agriculture. Whilst much is known about some of the more detrimental effects of certain intensive practices on particular pest and beneficial taxonomic groups, the longer-term practical and agronomic consequences of farming-induced changes throughout much of our countryside remain relatively unknown and unstudied. In this part of the Ag-Biota work programme, the project undertook a number of individual Ph.D. and M.Sc. studies to better understand the agronomic value of specific populations within the Irish agro-ecosystem and to increase knowledge of the potential benefits of natural populations in the development of more environmentally and agronomically sustainable farming systems.

4.2 Integrating Botanical Diversity and Management of Agricultural Grassland

In Ireland, the introduction of decoupling, the Nitrates (91/676/EEC) and related Water Framework (2000/60/EC) Directives and the adoption of the REPS have been some of the most important changes in agricultural legislation. It is through such legislation that new agricultural policies target more sustainable production levels, and provide the necessary financial incentives for farmers to deliver ‘public good’ services, such as clean water, air and biodiversity. The policy framework is expected to increase farmer interest in the benefits that a more biodiverse grassland sward has to offer, in contrast to past concentration on *Lolium* monocultures. Previous, often theoretical, and frequently disputed claims have been made that more species-rich swards can be more productive due to resource complementarity between different species. The research presented here contributes to current knowledge concerning plant species coexistence in production grasslands, and seeks to assess the influence of farm management practice in the enhancement and maintenance of botanical sward diversity.

4.2.1 The potential to restore grassland biodiversity by extensification of husbandry

Species-rich grasslands used to be common in Ireland but, with the intensification of agriculture, plant species richness in typical agricultural pastures has markedly declined. This is a common trend throughout Europe. There have been numerous examples of declining biodiversity following intensification of farming practices. Conversely, it is generally assumed that biodiversity will positively respond to re-extensification of farm practices. This assumption is widely incorporated into policies and agri-environmental schemes, including the REPS. However, a reduction of inputs, such as pesticides and fertiliser usage through agri-environmental schemes, is not guaranteed to provide the ecological conditions necessary for a corresponding improvement in biodiversity. The objective of this part of these sward biodiversity studies was to explore the regeneration potential for botanical diversity within typical Irish agricultural grasslands, by tracking sward changes in three pre-existing Teagasc field-scale experiments at the Johnstown Castle Research Centre, Co. Wexford (52°17' N, 06°30' W), the Solohead Research Station, Co. Tipperary (52°30' N, 08°12' W), and the Grange Research Centre, Co. Meath (53°32' N, 06°31' W). At all three locations, field-scale treatments were laid out in a randomised block design and individual husbandry treatments were managed with self-contained herds of grazing cattle (Table 4.1).

Table 4.1. Details of monitored Teagasc field experiments to assess the potential restoration of sward diversity by extensification of grassland husbandry. (LU, livestock units.)

Location	Previous land use and fertiliser rate (kg N/ha)	Experimental fertiliser rates (kg N/ha)	Experimental stocking rates (LU/ha/year)	No. of field-scale replicates	Duration of experiment (years)	Soil characteristics
Johnstown Castle Co. Wexford	Intensive beef (approx. 350)	0 225 390	1.0 2.4 3.0	2 3 3	4	Moderately drained gley
Solohead Co. Tipperary	Intensive dairy (approx. 250)	80 175 225 350	1.75 2.1 2.5 2.5	5 5 5 5	3	Moderately drained grey–brown podzolic
Grange Co. Meath	Intensive beef (approx. 200)	100 225	1.9 2.4	4 4	5	Moderately drained gley/grey–brown podzolic

4.2.1.1 Summary results

The total numbers of plant species observed at all locations changed little during the course of the experiments, indicating that either the rate of change in sward species richness resulting from a reduction in management intensity was very slow and not detectable within the experimental time frame, or there simply was no change. However, significant increases in species number per quadrat were detected at all sites (Fig. 4.1), and the reduction of nutrient inputs changed the relative dominance of the most abundant species (Fig. 4.2).

Taken together, these observations suggest that reduction of fertiliser use and overall management intensity led to a decrease in former species dominance, most obviously that of perennial ryegrass (*Lolium perenne*). This may indicate a potential for colonisation of the sward by additional species. However, the lack of evidence for ‘new’ species within the sward suggests that in formerly intensively managed pastures the colonisation of additional species is likely to be very slow. Reseeding may therefore be the most effective option for increasing botanical biodiversity in such pastures within a reasonable time span.

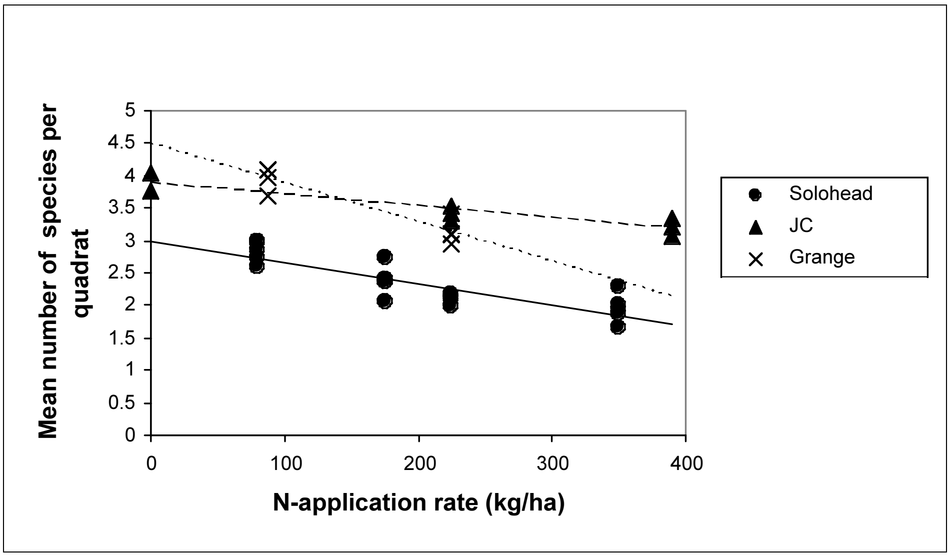


Figure 4.1. Linear regression trends between nitrogen application rate and the number of plant species recorded in quadrat samples from the Johnstown Castle (JC), Solohead and Grange experiments.

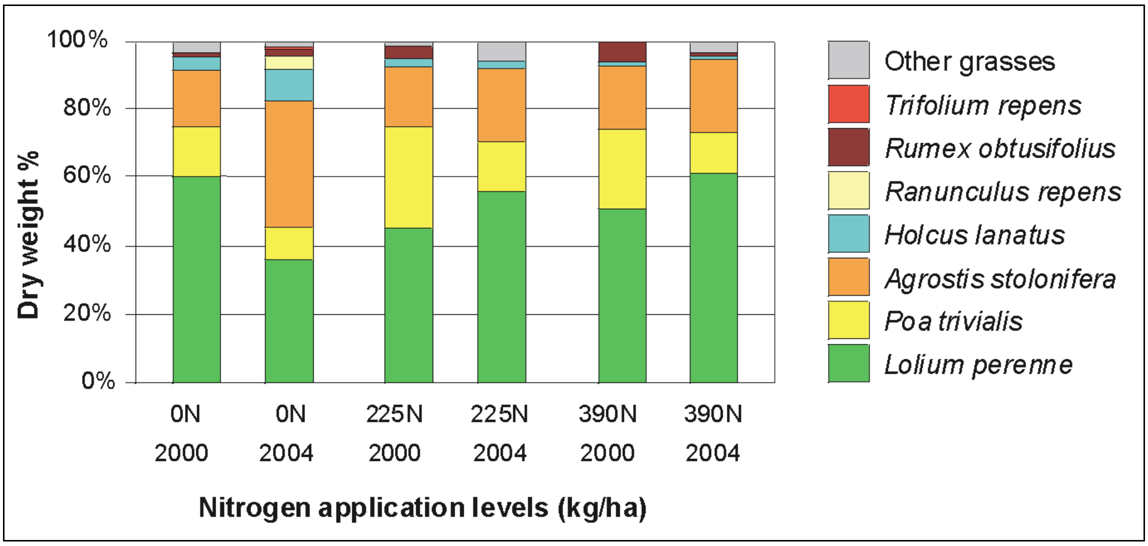


Figure 4.2. Mean botanical composition of the Tower Field plots at Johnstown Castle before (2000) and 4 years after (2004) the imposition of different nitrogen application rates (0 N, 225 N and 390 N) and matching stocking levels.

4.2.2 *The compatibility of sward mixtures*

One of the most direct measures to increase botanical diversity is to sow a diverse seed mixture. When recommending species mixtures, the likely persistence of any combination of species needs to be considered. When two species coexist at the same location, they share resources such as nutrients, water and light. Species can avoid or decrease the competition experienced from other species by spatial, temporal and physiological differences in the dynamics of their resource uptake; this is generally referred to as niche differentiation. Prediction of the potential for longer-term species coexistence requires quantification of the relative growth rate (RGR) of each species, and quantification of mutual competitive interactions over time, in order to extrapolate likely seasonal species dynamics. The separate effects of RGR and competitive interactions act simultaneously, and both are dynamic over time. Disentangling and quantifying these processes requires measurement of botanical composition on several occasions throughout the growing season, and non-destructive sampling methods are required to achieve this. The current project therefore undertook a small-plot field experiment growing common Irish pasture species in multi-species mixtures. Using repeated measurements of growth throughout the year, it was sought to empirically quantify the short-term processes of differential relative plant growth and intra- and inter-specific competition between the studied species. These empirically derived field data were subsequently used in the development of simulation models to evaluate the likely coexistence of species mixtures throughout the growing season and, in further development of the simulation model approach, sought to evaluate the influence of the spatial environmental heterogeneity that is created by grazing livestock on the outcome of seasonal population dynamics.

4.2.2.1 Summary results

The compatibility of species was quantified in three ways: (i) using empirically derived species-specific competition parameters, (ii) using seasonal Lotka–Volterra predictions, and (iii) using multi-year model simulations. Results only partially agreed. The three methodologies differ in the inclusion of maximum RGR parameters (ii and iii only), and whether they are static, i.e. seasonally fixed (i and ii) or dynamic, i.e. multi-year (iii). Of the three methodologies, multi-year simulations probably come closest to matching actual field conditions. However, which of the methodologies most closely corresponds to actual species persistence under field conditions can only be determined through the collection of long-term field data. However, the current study has been the first to demonstrate and quantify a dynamic seasonal influence on the direction of population attractors for plant species mixtures (Table 4.2, Fig. 4.3), and the models developed were able to integrate the influence of seasonally varying population dynamics and describe the likely long-term outcome of interactions for particular species mixtures (Fig. 4.4).

The extension of the developed simulation models to include the influence of spatial heterogeneity in environmental conditions created by grazing livestock was hindered by current lack of knowledge about species dispersal within mixed swards, and the general absence of quantified parameters for this process. Key questions in relation to the dispersal mechanism are (i) the specific rate at which a species biomass can disperse spatially, (ii) the spatial ordination of this dispersed biomass, and (iii) the required conditions for dispersal to occur. Because of these knowledge gaps, the influence of spatial heterogeneity on population dynamics in mixed swards remains largely unquantified. The dispersal of the vegetative biomass **within** swards occurs on a quite different scale to seed dispersal at a regional scale, and both processes are critically important to understanding how best to manage grasslands so as to increase their botanical diversity with maximum efficiency.

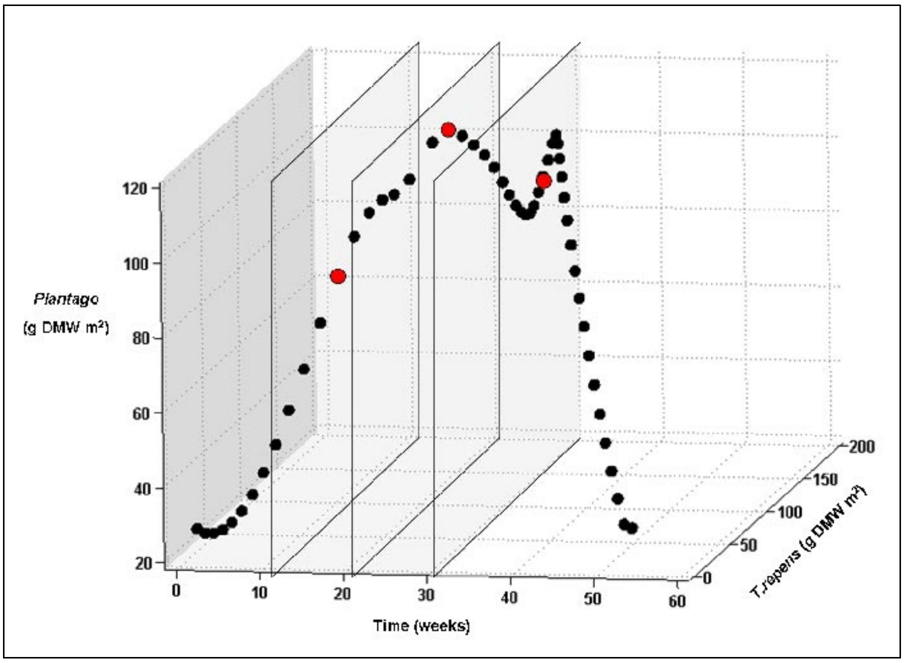
Although the total number of sward species was not observed to increase as fertiliser rates were reduced in the field experiments monitored in Section 4.2.1, the spatial aggregation of existing species was

Table 4.2. Predicted population outcomes for coexistence (C) or exclusion (E) in short-term (within season) Lotka–Volterra (LV) simulations, and in longer-term (3-year) model simulations of population dynamics in two-species grassland mixtures, with and without sward cutting.

Species combinations		Within-season LV predictions (Spring: Early: Late summer)	Longer-term model: No cutting	Longer-term model: 5 cuts per year
Lolium	*Agrostis*	C: C: C	C	C
	Phleum	C: E^1: E^1	E^1	E^1
	Plantago	C: C: E^1	C	C
	Trifolium pratense	C: C: C	C	C
	Trifolium repens	C: C: C	C	C
Agrostis	*Phleum*	C: C: E^1	E^1	C
	Plantago	C: C: C	C	C
	Trifolium pratense	C: C: C	C	C
	Trifolium repens	C: C: C	C	C
Phleum	*Plantago*	E^2: E^2: E^2	E^2	E^2
	Trifolium pratense	E^2: E^2: E^2	E^2	E^2
	Trifolium repens	C: C: C	C	C
Plantago	*Trifolium pratense*	E^2: E^2: E^2	E^2	E^2
	Trifolium repens	C: E^1: E^2	C*	E^1**
Trifolium pratense	*Trifolium repens*	E^2: E^2: C	E^2	E^2

E^1 and E^2 indicate that either the first or second listed species, respectively, was likely to be excluded.
*Indicates that the rate of population change was very slow, but headed towards coexistence.
**Indicates that the rate of population change was very slow, but headed towards exclusion.

a)



b)

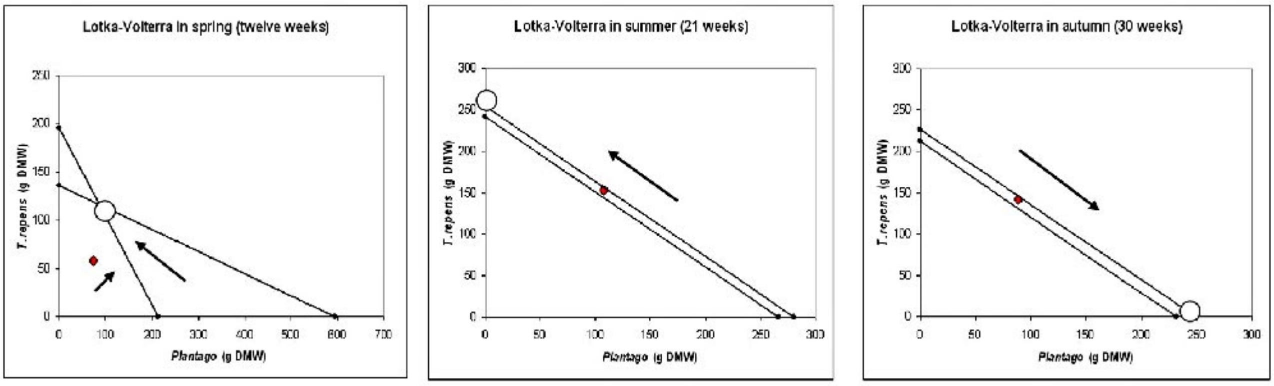


Figure 4.3. Simulated change in the abundances of *Plantago* and *Trifolium repens* grown in a mixture for the twelfth successive year: (a) the three parallelograms represent individual seasonal snapshots, the red dots indicating the biomass of each species in spring (Calendar Week 12), early summer (Week 21) and late summer (Week 30); (b) three snapshots illustrating the seasonally varying trajectory of species population dynamics; red dots represent species abundances moving towards a temporally moving population attractor (open circles) representing coexistence, and extinction of *Plantago* and *Trifolium repens*, respectively.

significantly altered. It is likely that higher fertiliser rates preferentially boost the vegetative growth rates of species such as *Lolium perenne*. The mechanisms that control the reverse process, however, are currently unclear, but are very likely to be strongly dependent on the mechanics of both vegetative growth and seed dispersal at field and regional scales, respectively. Fundamentally important questions regarding sward population dynamics can only be answered by longer-term, multi-year field studies that will enable more accurate simulation models to be developed. Such longer-term studies would also enable simulation models to take cognisance of the influence of longer-term, annual variations (for example, in climatic conditions) on sward species dynamics.

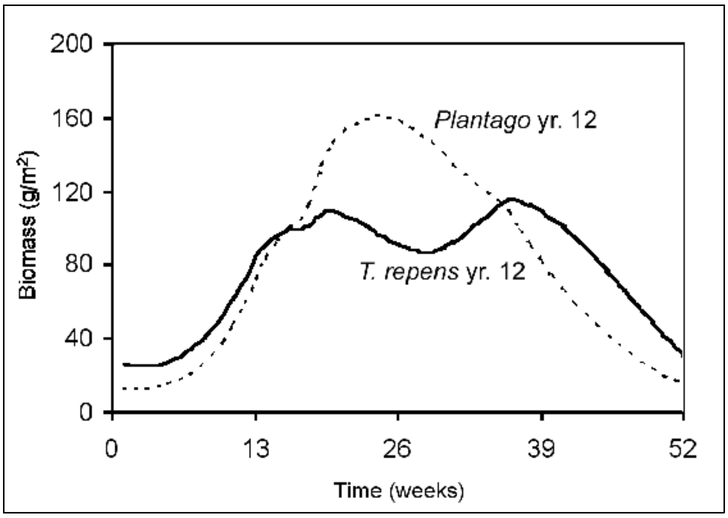


Figure 4.4. Model predictions of biomass for a mixture of *Plantago lanceolata* and *Trifolium repens* in the twelfth year of a simulation that predicted constantly varying cycles in relative abundance and long-term species coexistence.

4.3 Studies on the Ecology of Cereal Aphids, Predatory Arthropods and the Incidence of Barley Yellow Dwarf Virus

4.3.1 Background

Barley yellow dwarf virus (BYDV) is a major disease of cereals in Ireland, especially in early autumn and late spring-sown crops. Aphids are responsible for the transmission of 66% of the known 370 plant viruses with invertebrate vectors. Aphids are the sole vectors of BYDV, which cannot be transmitted mechanically. The two main vectors of BYDV in Britain are *Sitobion avenae* and *Rhopalosiphum padi*. Major yield losses in barley and wheat crops are mainly due to autumn infections, and in France 90% of cases are caused by *R. padi* carrying the PAV and occasionally the MAV strains of the virus. In Ireland, *S. avenae* is usually the most numerous vector species found on infected crops and MAV the dominant BYDV strain. Winged aphids migrating from volunteer cereal plants, maize crops and grasses in September and October initially infect newly emerging cereal crops. The extent of subsequent crop infection and yield loss greatly depends on the subsequent secondary spread of the virus throughout the winter and spring by the wingless offspring of the initial migrant aphids. In autumn-sown crops, early sowing (as early as late August in parts of the UK) tends to coincide with the peak in numbers of alate migrant aphids, and greatly increases the risk of infection. The primary objective of the current study was to develop appropriate tools to quantify BYDV incidence in host plants and aphid vectors, and to use the developed assays to investigate aspects of the ecology of BYDV in the field.

4.3.2 Development of diagnostic assays for the detection of barley yellow dwarf virus MAV strain

The study of BYDV in natural systems has been limited by the lack of efficient diagnostic techniques. Enzyme-linked immunosorbent assay (ELISA), introduced in 1979, has proven to be a versatile method for the detection of BYDV, especially when dealing with large numbers of samples. However, ELISA can lead to false negative results for aphids carrying less than 10^6 virus particles, and therefore it cannot be used to accurately determine whether or not individual aphids represent a virus threat. The ever-increasing availability of viral sequences has permitted the development of nucleic acid based (polymerase chain reaction, PCR) diagnostic methods that can distinguish between virus strains.

Reverse transcription PCR (RT-PCR) has proven to be a more sensitive technique than ELISA for virus detection, and has become one of the most important tools in medical and veterinary diagnosis and research. Such assays are particularly useful for the identification of virus reservoirs, and are gaining wider acceptance and use in the study of virus ecology because of increased sensitivity, increased speed and reduced risk of contamination. Real-time RT-PCR methods, in general, offer the additional advantage of being considerably easier to interpret than conventional RT-PCR, and the Taqman® one-step real-time RT-PCR protocol has particular advantages, including (i) fully automated reaction and simultaneous computerised analysis, (ii) products are detected through closed tubes, reducing the risk of cross contamination, (iii) no post-RT-PCR manipulations are required, (iv) the assay is rapid, allowing analysis of 96 samples at a time, and (v) the addition of a specific probe to the reaction can enhance sensitivity and specificity. The initial aim of this study was therefore to develop RT-PCR assay tools for the detection of BYDV MAV in plants, aphids and, if possible, in beneficial aphid predators as a first step towards the use of such tools in subsequent field studies of the ecology of BYDV and its vectors in Irish crops.

4.3.2.1 Summary results

Reliable and sensitive, yet practical, virus assays were developed using both conventional RT-PCR (Figs 4.5 and 4.6), and a real-time, one-step Taqman® (Figs 4.7 and 4.8) assay to detect BYDV in infected cereal plants and aphid vectors.

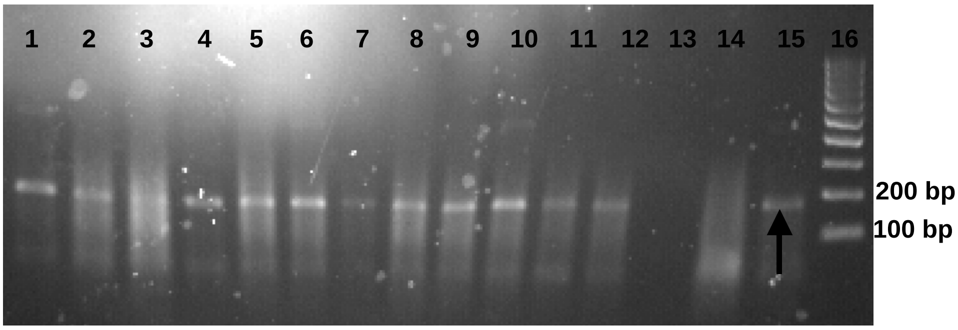


Figure 4.5. A conventional RT-PCR gel showing positive testing for barley yellow dwarf virus MAV in aphids and barley plants infected with field-sourced virus. Lanes 1 to 12 are known MAV-positive samples; Lanes 13, 14, 15 and 16 are a no template control, a negative control, a positive control and DNA markers, respectively.

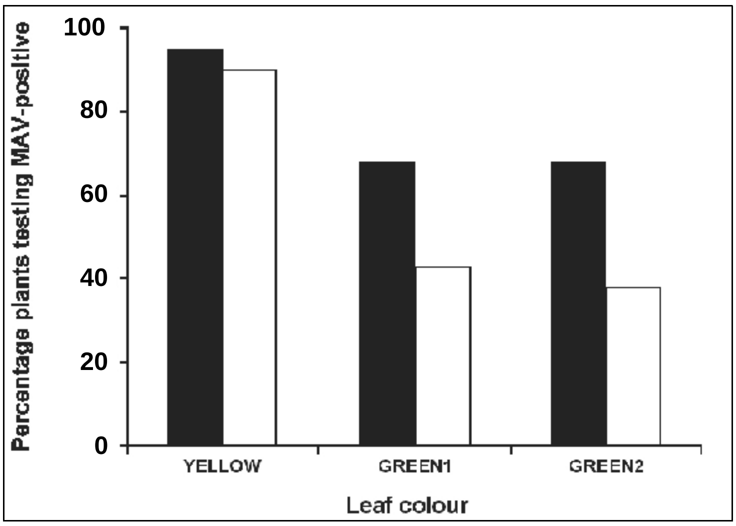


Figure 4.6. Comparative detection rates for barley yellow dwarf virus MAV (%) in field-collected symptomatic (yellow) and asymptomatic (Green1 and Green2) leaf samples using the developed conventional RT-PCR tool (black columns) and ELISA (white columns).

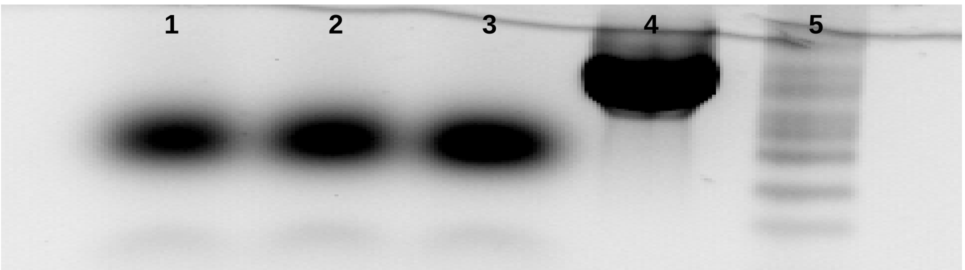


Figure 4.7. A gel from the developed Taqman® real-time RT-PCR assay showing *in vitro*-transcribed barley yellow dwarf virus-MAV (Lanes 1–3); Lanes 4 and 5 are a positive control and an RNA marker, respectively.

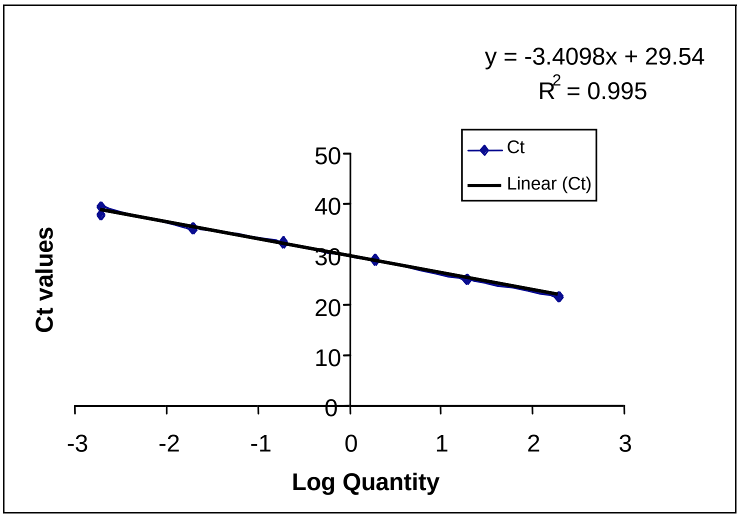


Figure 4.8. A standard curve for the developed Taqman® real-time RT-PCR assay based on 10-fold serial dilutions of MAV RNA control transcripts.

The Taqman®-based assay was found to successfully detect as little as 3.7×10^1 copies or 1.93 fg of the BYDV-MAV virus, which is 100 times more sensitive than the developed conventional RT-PCR assay, which was found to reliably detect 10^3 viral copies (193 fg).

Relatively little use has been made of RT-PCR methods in field-based ecological studies of BYDV, very largely because of the relative complexity of the conventional (multiple stage) technique, and perversely, the relatively high risk of false positives associated with extreme sensitivity. The developed Taqman® minor groove binder (MGB) probe method has been shown to have a number of significant advantages as an investigative tool for ecological studies, because of its substantially enhanced sensitivity and its use of a relatively simple one-tube closed reaction, which greatly reduced risk of false positives resulting from contamination. Both of the developed RT-PCR assays were based on detection of viral RNA, and were shown to be highly effective tools for studying the ecology of BYDV-MAV in both host plants and aphid vectors. However, attempts to detect the viral target in aphid predators recently fed virus-infected aphids were unsuccessful. This is unfortunate, but probably reflects the inherent instability of viral RNA when an infected aphid is killed and ingested.

4.3.3 *Subsequent use of the developed PCR methods in field studies of virus ecology*

Field studies showed that *R. padi* was the most prevalent BYDV vector present in potential virus reservoirs within the Irish countryside, such as grassland, arable field margins and maize crops. In old cereal stubbles, however, *S. avenae* was the most abundant aphid found. Use of the developed RT-PCR methodologies showed that the greatest virus threat, in terms of the average densities of virus-infected aphids per m^2, comes from *S. avenae* populations on cereal stubbles and from *R. padi* populations in extensively managed grassland (Fig. 4.9).

In two of the three study years, a higher general prevalence of aphids on newly emerged crops was associated with high populations of *S. avenae* on old cereal stubbles. In contrast, in the third year of the study, when a lower general prevalence of aphids was observed on newly emerged crops, the greatest potential virus reservoir threat came from *R. padi* populations on extensively managed grassland. In contrast, intensively managed grassland constituted a significantly smaller virus threat. It seems very likely

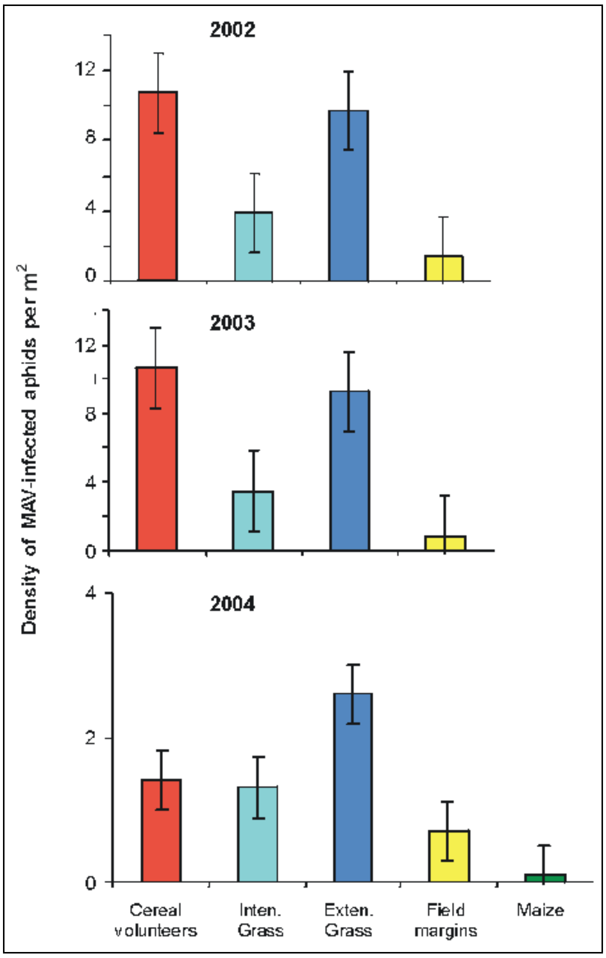


Figure 4.9. Estimated total densities of MAV-infected apterous aphids in different potential virus reservoirs in 2002, 2003, 2004, (± SE).

that in Ireland a high 'carry-over' of *S. avenae* populations *via* the 'green bridge' provided by remnants of past cereal crops may be the most important source of virus infection in years of high virus incidence on new crops. Such a conclusion needs to be validated, however, by further monitoring of aphid populations and virus incidence using the developed virus assay.

The area of maize sown in Ireland has increased substantially in the last decade due to its high nutritional value for livestock and the breeding of cultivars better suited to the Irish climate. However, the proportion of virus-infected *R. padi* found in this study was small, and it seems unlikely that maize is currently a significant source of virus infection.

4.4 Development and Use of Stable Isotope Techniques to Investigate the Functional Role of Invertebrates in Agricultural Ecosystems

4.4.1 Background

Stable isotope techniques, using light elements including carbon, nitrogen and sulphur, represent one of the major methodological advances in ecological research over the last two decades. The technique uses the fact that many biochemical processes are accompanied by systematic changes in the ratio between stable isotope pairs (e.g. $^{13}C/^{12}C$ and $^{15}N/^{14}N$). Until now, stable isotopes have been used to establish trophic differences and energy flows in aquatic and terrestrial food chains. At the level of individuals, analysis of tissues with different metabolic turnover rates can provide additional information on changes in the recent diet, or in the metabolism of the tested species. A closer examination of the carbon and nitrogen stable isotope signatures of individual animals can provide an insight into niche width and individual preferences. Further, the method has been used successfully at ecosystem scale to assess water availability and for measurements of anthropogenic N inputs into, e.g., agricultural ecosystems. In the current study, stable isotope techniques were used in field and laboratory studies to establish trophic relationships in carabid beetles during different stages of their development and to assess the potential of stable isotope analysis of ecosystem components (soil, plants, invertebrates) as an integrating, easily measurable indicator of farming intensity in Irish pasture systems.

4.4.2 Influence of management intensity, fertiliser use and stocking rate on isotopic signatures

4.4.2.1 Methods

Samples of soil, ryegrass (*Lolium perenne*), white clover (*Trifolium repens*) and predatory spiders (*Erigone atra*; Linyphiidae) were collected for isotopic analysis from 50 commercial farm pastures in the south and east of Ireland during summer 2005 (see Section 2.2.1 and Fig. 2.1 for further site details).

4.4.2.2 Summary results

Management intensity, as reflected by stocking rates and mineral fertiliser applications, was found to have a selective influence on the isotopic signatures of nitrogen in the tested pastures. In the samples of nitrogen-fixing white clover, a significant increase in $\delta^{15}N$ was measured when larger amounts of nitrogen fertiliser were applied (Fig. 4.10). This result clearly illustrates the declining fixation of atmospheric nitrogen by white clover and its greater reliance on soil N as fertiliser inputs increase.

For soil samples, a similar increase in the ^{15}N signature was observed in relation to increased fertiliser input, despite the fact that chemical fertilisers in general do not have an elevated $\delta^{15}N$ level (Fig. 4.11).

This observed increase in soil $\delta^{15}N$ suggests that soil processes that discriminate between N isotopes (e.g. nitrification, denitrification and ammonia volatilisation) are stimulated by an increased supply of readily available N, leading to relatively greater losses of ^{14}N and a relative retention and accumulation of ^{15}N in the soil N pool. In contrast, these results suggest that organic fertiliser inputs result in less N loss through processes such as nitrification, denitrification and ammonia volatilisation, and hence relatively less ^{15}N enrichment than the use of mineral fertilisers.

4.4.3 Isotopic signatures and species diversity

Correlations in isotopic signatures within different ecosystem levels can provide information about food sources as well as trophic relationships, since carbon is discriminated by approximately 1‰ and nitrogen by 3‰ at each trophic step.

A highly significant correlation was found between the carbon isotope signatures in grass and spider samples from the studied pastures (Table 4.3).

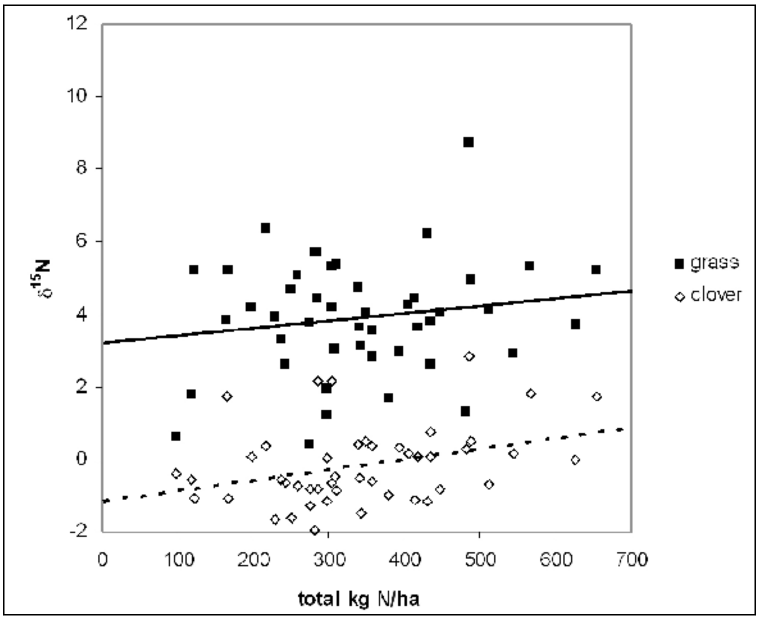


Figure 4.10. Linear correlation between total farm fertiliser input and nitrogen isotope signatures in ryegrass (n.s.) and clover (r = 0.345, p = 0.019) samples.

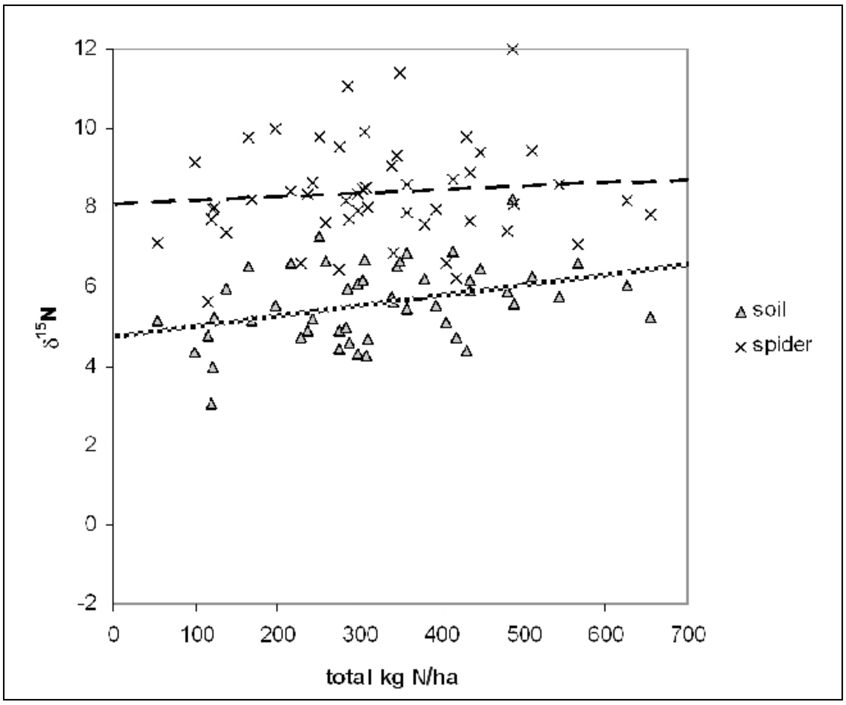


Figure 4.11. Linear correlation between total farm fertiliser input and nitrogen isotope signatures in soil (r = 0.374, p = 0.008) and spider (n.s.) samples.

Table 4.3. Summary of Pearson's correlation coefficients between the carbon and nitrogen signatures of soil, grass (*Lolium perenne*), clover (*Trifolium repens*) and spider (*Erigone atra*) samples.

	Soil	Grass	Clover	Spider
Soil	–	$0.027^{n.s.}$	$–0.101^{n.s.}$	$1.16^{n.s.}$
Grass	0.421**	–	0.312*	0.384**
Clover	0.397**	0.332**	–	$0.160^{n.s.}$
Spider	0.462**	0.393**	0.351**	–

Values above the diagonal show correlations of the $\delta^{13}C$ values.
Values below the diagonal show correlations of the $\delta^{15}N$ values.
n.s., not significant. *p < 0.05; **p < 0.01.

This is of particular interest, because plant-feeding prey species, such as sap feeders, have $\delta^{13}C$ values similar to their host plant, and the discovered correlation strongly suggests that aphids (Hemiptera) are common prey species for the tested spider species, *E. atra*, in these pastures. Collembola, which are a second potentially abundant food source for spiders, and members of the detrital food web, are likely to have a $\delta^{13}C$ value more similar to soil organic matter, which is the main basis of their nutrition. The data from these studies therefore suggest that aphids, rather than Collembola, may be the primary food source of grassland spiders and that, as grassland management intensity increases, aphids become a more significant element in spider diets, which is reflected in larger $\delta^{15}N$ values. This concurs with conclusions regarding the positive relationship between aphid populations and grassland management intensity inferred from the greater incidence of specialist aphid parasitoid populations in intensively managed swards (Sections 2.2.3 and 3.5).

Measurements of ^{15}N showed systematic isotopic patterns with significant correlations between all analysed components of the pasture system (Table 4.3), suggesting that external inputs of inorganic fertiliser are the main driver of nitrogen isotope values in agricultural pastures. The $\delta^{15}N$ values found in spiders were positively correlated with the abundance of Diptera collected in the same swards (Fig. 4.12), and this also implies an influence of management intensity because the total abundance of sward arthropods, including adult Diptera, was found to be significantly greater in dairy compared with non-dairy pastures (see Section 2.2.3, Fig. 2.5).

$\delta^{15}N$ in spiders was negatively correlated with increased plant species density and Simpson's Index for parasitoid Hymenoptera (Figs 4.13 and 4.14). As both the taxon density of sward plant species and arthropod diversity in general are affected negatively by stocking rate (see Section 2.2.3), this further illustrates a systematic influence of increased nitrogen fertiliser use within the pasture ecosystem. Taken in conjunction with results reported in Sections 2.2 and 3.2, all the isotope data paint a similar picture, suggesting a strong link between grassland management intensity, faunal and floral diversity, and modified relative taxon abundance and trophic relationships within the sward community.

4.5 Relationships between Earthworm Populations and Management Intensity in Cattle-Grazed Pastures

4.5.1 Background

Since earthworm abundance is largely determined by food supply, management practices that affect the nature and quantity of organic residues returned to the soil are likely to influence strongly earthworm population density and biomass. In the managed grassland context, the quality and extent of residue return depends on factors such as sward composition, the extent and type of grazing, the frequency of cutting, and the quantity and type of fertiliser applied. High levels of net primary production and return of high-quality organic residues to the soil can be expected to benefit earthworm populations in pasture. The current study reports the results from observations on earthworm populations in three grassland

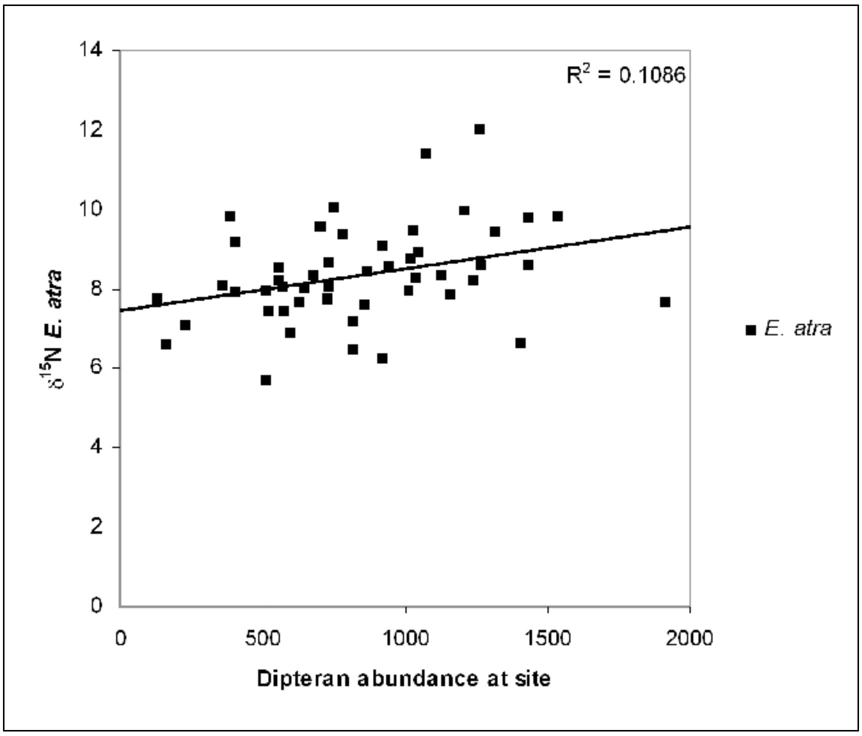


Figure 4.12. The relationship between $\delta^{15}N$ in spider (*Erigone atra*) samples and total abundance of Diptera collected in Vortis samples from pasture sites in the south-east of Ireland ($p = 0.020$; $n = 49$).

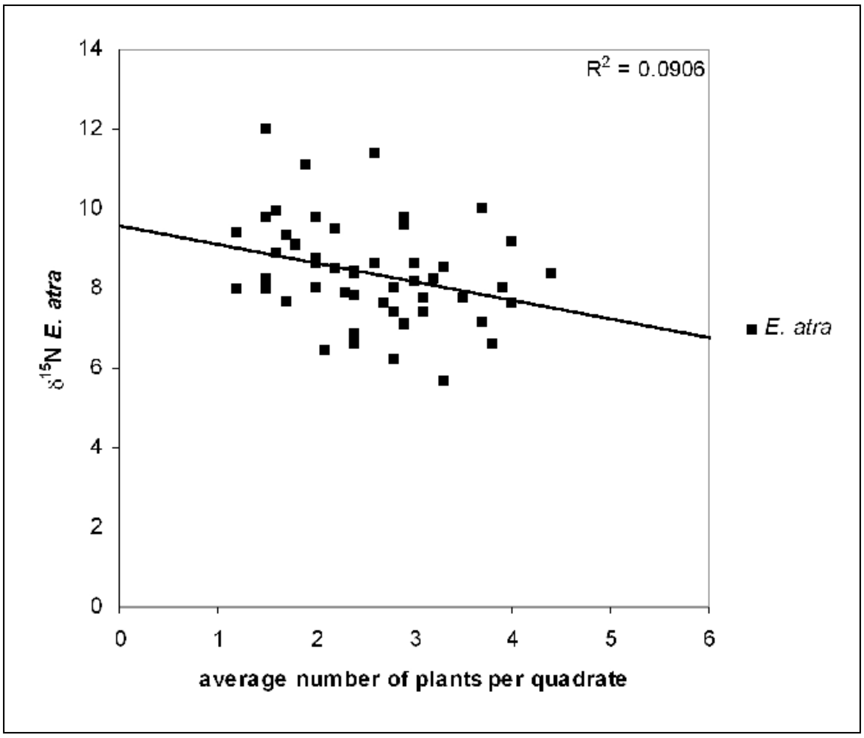


Figure 4.13. The relationship between δ^{15}N in spider (*Erigone atra*) samples and the mean number of sward plant species counted per m^2 at pasture sites in the south-east of Ireland ($p = 0.036$; $n = 50$).

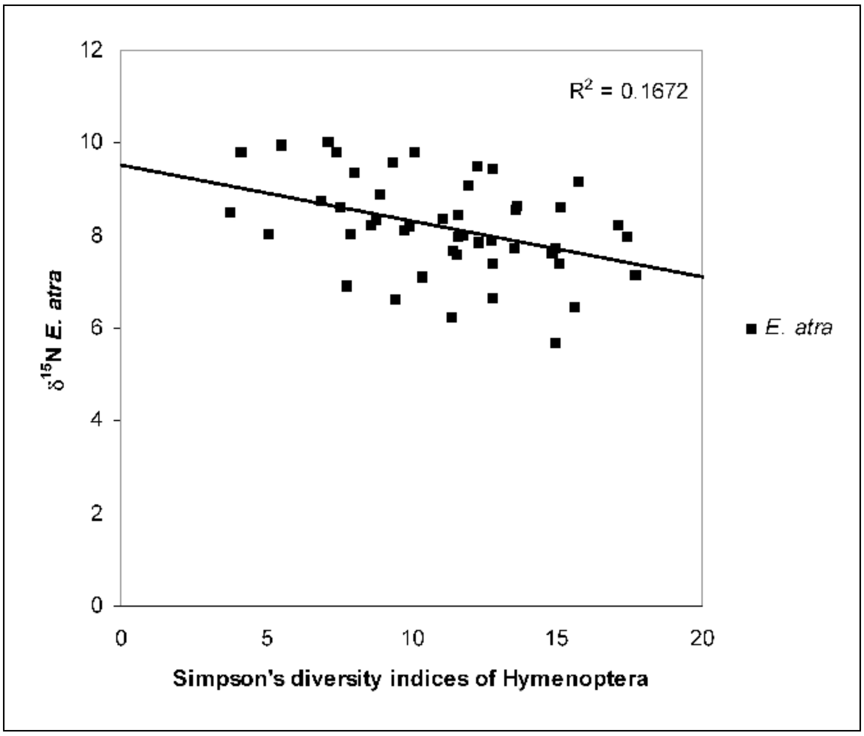


Figure 4.14. The relationship between δ^{15}N in spider (*Erigone atra*) samples and Simpson's Diversity Index for parasitoid Hymenoptera taxa collected at pasture sites in the south-east of Ireland ($p = 0.004$; $n = 47$).

management field experiments at the Teagasc Grange, Johnstown Castle and Solohead Research Centres (see Table 4.1 for details), with a view to documenting treatment effects on the abundance and functional value of earthworm populations.

4.5.2 *Summary results*

Overall positive relationships were found between both earthworm abundance and biomass, and nutrient input levels in the three experiments (Fig. 4.15). The overall earthworm response to grassland management is likely to reflect the balance between the beneficial effects of enhanced food supply and the negative effects of soil poaching at high stocking densities. Increased sward productivity and higher stocking density result in increased food supply in the form of plant litter and animal dung, which could be expected to lead to increased earthworm populations. It is known that trampling at high stocking levels can damage soil structure and adversely affect surface-dwelling earthworm populations, especially in heavy soils where significant poaching can occur during wet weather. Other studies have assessed the impact of cattle trampling on soil physical properties in two of the present field experiments (Johnstown Castle and Grange), and reported that areas to which cattle had

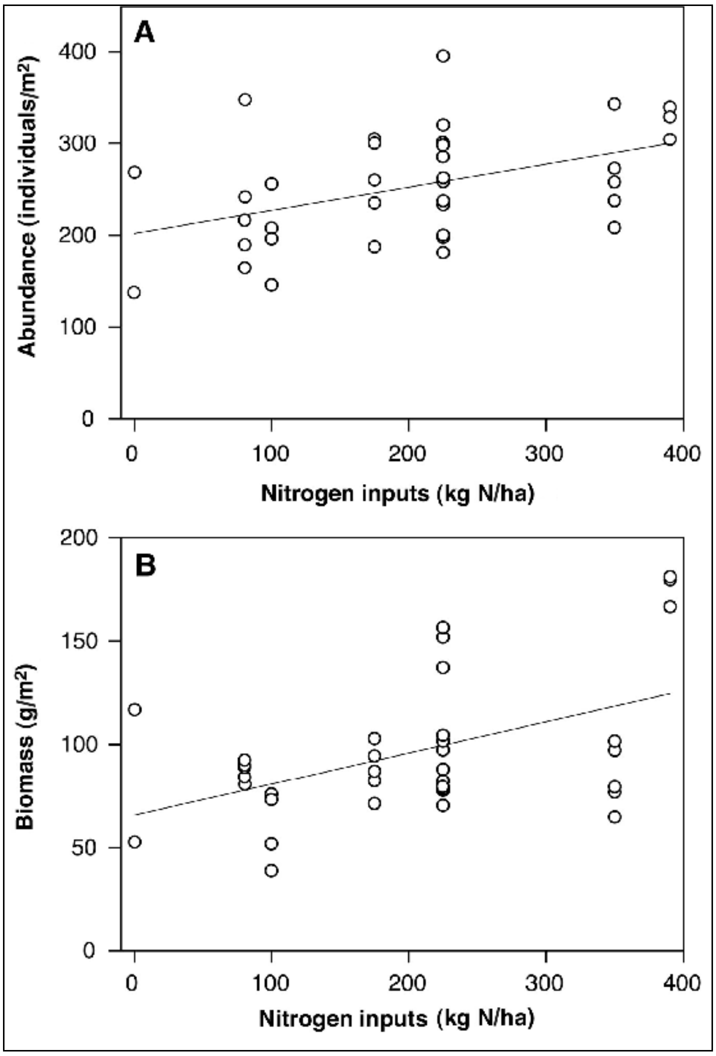


Figure 4.15. Overall relationships between total earthworm abundance (A) and biomass (B) and grassland management intensity as indicated by mineral N fertiliser use in 36 field plots at the three study sites (Solohead, Grange and Johnstown Castle). (For abundance: $Y = 202.81 + 0.25X$, $r^2 = 0.20$; F (Reg.) = 8.50, $p = 0.006$; ANCOVA F (N level) = 4.47, $p = 0.043$; F (Site) not significant ($p > 0.05$). For biomass: $Y = 65.58 + 0.15X$, $r^2 = 0.23$; F (Reg.) = 10.34, $p = 0.003$; ANCOVA F (N level) = 17.32, $p < 0.001$; F (Site) = 4.60, $p = 0.02$.)

free access had 57–83% lower macroporosity, 8–17% higher bulk density and 27–50% higher resistance to penetration than areas from which cattle were excluded. Nevertheless, despite signs of extensive poaching in many of the plots, it is noteworthy that earthworm populations were not adversely affected. Given their ability to alter soil physical conditions, the presence of high earthworm populations is potentially important in counteracting the effects of soil compaction at high stocking levels. In particular, the abilities of deep-burrowing species, such as *Aporrectodea longa* and *Lumbricus terrestris*, to ameliorate the effects of trampling at greater soil depths may be particularly significant, and the ability of the earthworm fauna to survive and even thrive may be critical to the sustainability of intensively grazed pasture systems.

4.6 Utilising Knowledge of Population Ecology within Agro-Ecosystems

In Action 3, the Ag-Biota Project has sought to improve understanding of the ecology of populations with the agro-ecosystem. The development and use of relatively new methodologies for ecological investigations, particularly the development of real-time PCR and stable isotope methods, and their application in the field is a particular milestone achieved by the Project. Very often methods developed by specialists in the laboratory remain little used by traditional ecologists, and the current Project has illustrated how such techniques can provide valuable tools for and insights into ecological investigations.

A better understanding of the relationship between landscape structure and patterns of crop disease may allow the design and implementation of new crop disease management strategies. In order to manage BYDV, many key aspects of the ecology of the virus, its vectors, and aphid natural enemies remain to be resolved. The current Project has developed understanding of a number of these issues, but perhaps its single most significant contribution has been the development of an investigative tool that will continue to be of use in further studies of the ecology of BYDV and its vectors in the field. In this sense, the Project leaves a valuable legacy in terms of methodology.

Stable isotope methods were used as a tool to study the ecology of specific populations within the agro-ecosystem, and to assess the potential of the technique as an integrating, easily measurable indicator of ecological information concerning the influence of farming intensity. In doing so, the wider ecological effects of intensification on the grassland system have been highlighted. These latter studies demonstrated a system-wide decline in the efficiency of nitrogen applied to grassland swards as inputs increase (higher nitrogen losses leading to ^{15}N enrichment over time), and also a decline in the ecological efficacy of symbiotically fixed atmospheric N_2 by white clover, as the use of mineral (but not organic) fertilisers increases. Nitrogen isotope ratios in predatory spiders were also correlated with wider measures of biodiversity: negatively with sward plant diversity and the diversity of parasitoids (both now understood to be good indicators of wider diversity), and positively with dipteran abundance (now understood to be indicative of increased grassland management intensity). Overall, these results show that nitrogen isotope data can integrate information and provide ecological insights into the effects of agricultural intensification that would not be achievable by other means.

In contrast, this assessment of the impact of intensive grassland management on earthworm populations confirms the central importance of these ‘ecosystem engineers’ as essential for the maintenance of soil structure and health, even under conditions of very high management intensity.

5 The Functional Significance of Altered Biodiversity

5.1 Background

Communities of species and their related biological, chemical and physical processes, collectively known as an ecosystem, drive the Earth's biogeochemical processes. The loss of species has led to concerns about the unpredictable risks that biological impoverishment could mean for the continued functioning of the biosphere. The question is whether the functioning of ecosystems will be impaired by the projected loss of species. Growing concern about declining biodiversity and new experimental evidence have encouraged investigation of the view that species diversity enhances the productivity and stability of ecosystems. These issues are of particular importance in agricultural systems because if management practices lead to the loss of biodiversity it is essential to assess whether such loss has consequences for the functionality of production systems. In this Project, two key integrating agro-ecosystem functions, primary productivity and decomposition, were assessed to address the question "*at what level of ecological hierarchy (species, feeding guild, trophic levels, etc.), does the loss of biodiversity bring about measurable changes in ecosystem performance*".

5.1.1 The need for a new experimental design

It is only relatively recently that the relationship between ecosystem function and biodiversity *per se* has been addressed experimentally. The majority of studies have involved the manipulation of above-ground species diversity, with the intention of determining whether species diversity alters stability at the population or ecosystem level, or alters ecosystem properties including productivity. One of the primary problems associated with field studies of functional biodiversity is the difficulty in establishing replicated communities similar in all environmental variables except species richness. It has become clear that it is not a simple matter to "*rigorously assess the ecosystem function of biodiversity in a manner that speaks plainly to the concerns of the public and policy makers*".

One typical approach in biodiversity experiments is to create a series of communities of varying species mixtures selected from a larger species pool, and to then monitor the differences in ecosystem function. There are inherent problems with this approach. The sampling effect, for example, can give rise to a situation where a high-diversity community appears more productive than a low-diversity one simply because the higher species richness of the latter increases the chance of it containing a highly productive species. This problem is rooted in the fact that all species contribute differently to a system. A random array of species may not contain functional groupings vital to a productive ecosystem. Experimentally, this has caused difficulties with past experimental designs based on replacement series, which are known to be flawed in many circumstances. Therefore, an alternative design is required.

5.2 Aims

In this study, a novel experimental design was used to examine the relationship between biodiversity and ecosystem function. The relationships between earthworm diversity and soil processes, such as nitrogen mineralisation, and between grassland plant diversity and primary productivity were examined. Many past studies have shown a relationship between species richness and primary productivity and nitrogen dynamics. The current study adds to these by additionally assessing whether community evenness and species identity within a particular functional group affects functionality.

5.3 Methods

The studies reported here use an innovative simplex experimental design that optimises the investigation of relationships between community structure and ecosystem function in experimental monoculture and multi-species communities (Fig. 5.1).

5.3.1 Earthworms as model organisms

There is more likely to be redundancy among coexisting species from the same phylogenetic unit.

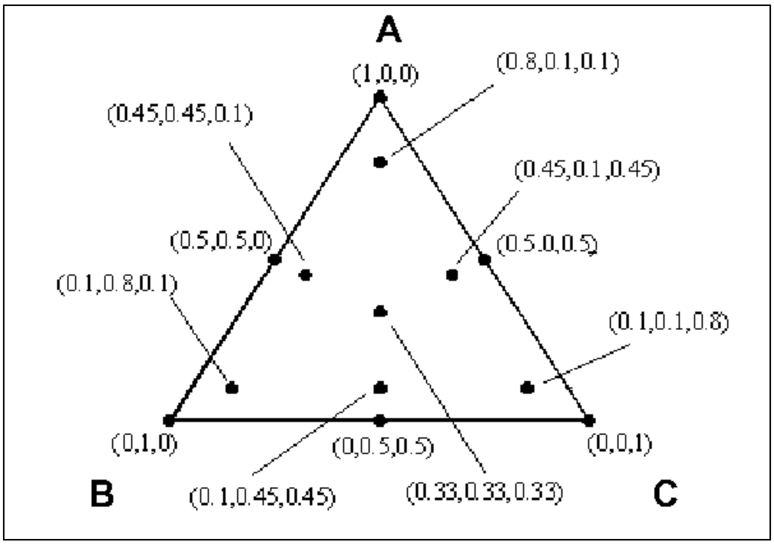


Figure 5.1. A simplex design for experimentation with a three-species assemblage of variable composition. (Points denote experimental species combinations; an assemblage with co-ordinates (0.1, 0.1, 0.8) consists of 10% Species A, 10% Species B and 80% Species C.)

Therefore, the most conservative test for the existence of a relationship between species richness and redundancy would involve investigation of the species that are closely related taxonomically. Earthworms were selected in this Project as the test organisms because (i) they belong to a single taxonomic unit, (ii) where they occur, they play an important role in determining rates of nutrient flow, due to their metabolic processes, their effects on microbial communities and their effects on the physical structure of soil through burial of organic material and the formation of casts, and (iii) because there have been conflicting reports suggesting that there is either considerable redundancy among the species or that the redundancy is overestimated.

5.3.1.1 Functional groups of earthworms

Earthworms are often perceived as soil organisms with relatively similar biologies and, in many respects, functionally equivalent. However, they are a much more heterogeneous and ecologically differentiated group than is normally assumed, and three distinct ecological groups have become widely recognised:

1. *Epigées*
   These species are generally forest dwellers, which are characteristically small with dark pigmentation and reside on the soil surface in leaf litter layers under the bark of decaying logs or in other concentrations of organic matter. They feed on accumulations of decomposing litter and ingest little or no soil.

2. *Anéciques*
   Anéciques dwell in permanent or semi-permanent burrow systems that may extend several metres into the soil. They are medium to heavily pigmented worms, and feed primarily on soil surface litter. Their ecological roles are strongly associated with their feeding and burrowing activities, which enhance water infiltration, fragment organic matter, increase soil porosity and aggregation, increase soil water holding capacity, increase nutrient availability to plant roots penetrating their burrow systems, and deposit faecal material (casts) containing organic matter from the soil surface within the soil, providing food to endogeic earthworms.

3. *Endogées*
   Endogées are unpigmented or lightly pigmented earthworms that burrow sub-horizontally within the top 10–15 cm of the soil, and derive nourishment by ingesting mineral soil containing organic matter. The functional roles of the endogées are similar to those of epigées, but they

are not important in the incorporation of surface plant litter. They aid in the mixing of soil layers, producing casts, which are water-soluble aggregates within which soil carbon is partially protected from oxidation, so they indirectly contribute to the retention of a soil carbon sink.

Earthworm experiments were done in mesocosms, comprising Plexiglas cylinders (15 cm diameter × 30 cm depth) containing 2.65 l of sieved, slightly alkaline, loam – clay loam topsoil obtained on the campus of University College Dublin. Earthworms were obtained from a meadow and sorted into the three distinct functional groups described above. The epigeic group consisted of *Lumbricus rubellus, Lumbricus castaneus* and *Satchellius mammalis*; the anecic group comprised *Lumbricus terrestris, Lumbricus friendi* and *Aporrectodea longa*; and the endogeic group consisted of *Aporrectodea caliginosa, Octolasion cyaneum, Allolobophora chlorotica* and *Aporrectodea rosea*.

Mesocosms were populated with two overall densities of earthworms per unit, and were provided with two levels of food supply, giving four combinations of biomass and food availability, with a total of 52 experimental communities (Fig. 5.2). An initial experiment, as described above, was run in naturally fluctuating ambient temperatures. In a second experiment, a similar experimental design was used with three earthworm species rather than mixed species populations within ecological groups. These species were *Aporrectodea longa* (anecic), *Aporrectodea caliginosa* (endogeic) and *Allolobophora chlorotica* (endogeic), and this second experiment was conducted in two contrasting temperature conditions (constant 10°C, 'naturally fluctuating' ambient).

Leachate from the mesocosms was routinely collected and its volume, pH and the concentrations of nitrate-N and ammonium-N measured over a 20-week period. The experiments were terminated at 30 weeks, when soil samples were taken from each mesocosm for the analysis of nitrate and ammonium-N concentrations.

Models based on Scheffé polynomials were created to determine how the proportions of the functional groups within earthworm communities affected functional parameters (soil nitrate concentration, concentrations of nitrate and ammonium in leachate, pH and volumes

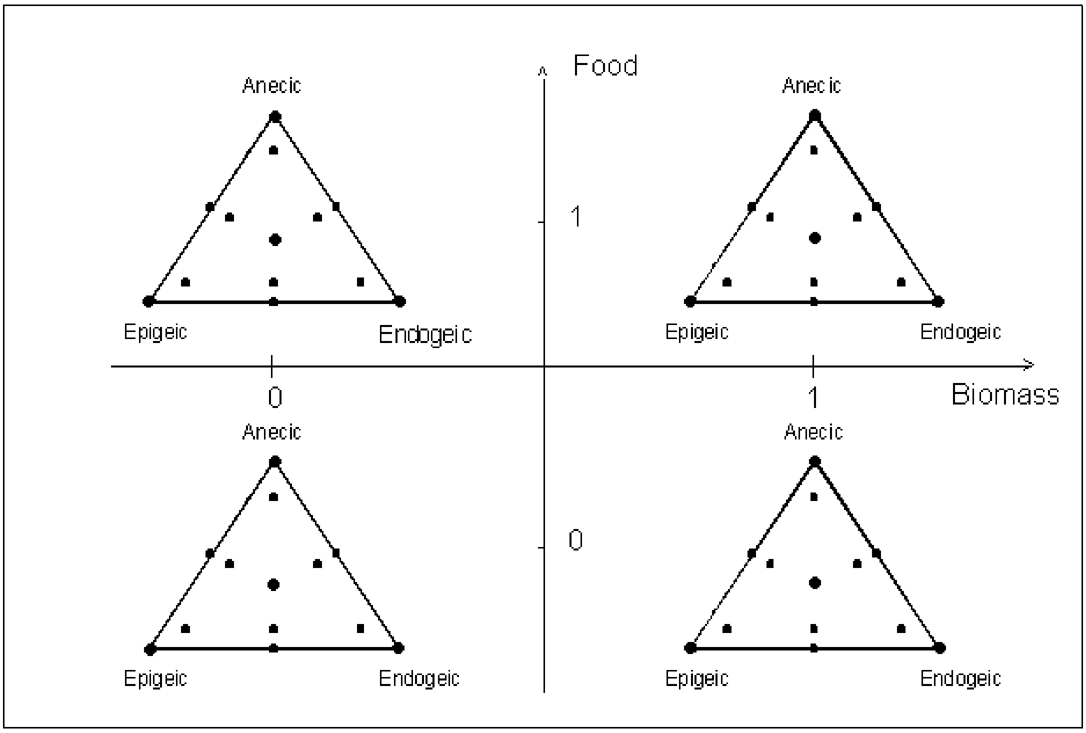


Figure 5.2. Design of the first experiment, showing combinations of earthworm community structure, biomass and food levels.

of leachate). Further details of analytical methods are given in the End of Project Ag-Biota report.

5.3.1.2 Summary results and discussion

In the initial experiment with mixed species populations of epigeic, anecic and endogeic groups, ammonium concentrations in leachate were generally higher in mesocosms dominated by anéciques and endogées; the opposite was true for nitrate-N, which was generally higher with epigées (Fig. 5.3).

This may indicate that nitrification was promoted by the epigées. However, it might also reflect the fact that the other functional groups produce casts, which retain nitrate. There was a significant synergy between the endogées and anéciques in terms of amounts of nitrate present in the soil. This suggests that the nitrate formed in the soil was being retained in the casts rather than being leached. Although generally containing high concentrations of ammonium, rapid nitrification in casts can result in stable levels of both nitrogen forms due to organic matter protection in dry casts. As nitrification is an acidifying process, the observation of significantly decreased pH when endogées were mixed with either anéciques or epigées supports this explanation.

In the second experiment, it was shown that earthworm communities containing all three species leached higher concentrations of nitrate-N, under conditions of high biomass and in the stable temperature regime (Fig. 5.4).

That the three species mixture can act in a way not shown by monocultures or binary mixtures suggests that each species is contributing something unique to the nitrogen mineralisation process. Given the results of the first study with mixed species ecological groups, this would be expected when considering the inter-functional group interaction (anecic and endogeic). However, the fact that a combination of two endogeics (*Aporrectodea caliginosa* and *Allolobophora chlorotica*) was required to produce increased levels of nitrate-N, suggests a lack of functional redundancy within the endogeic group.

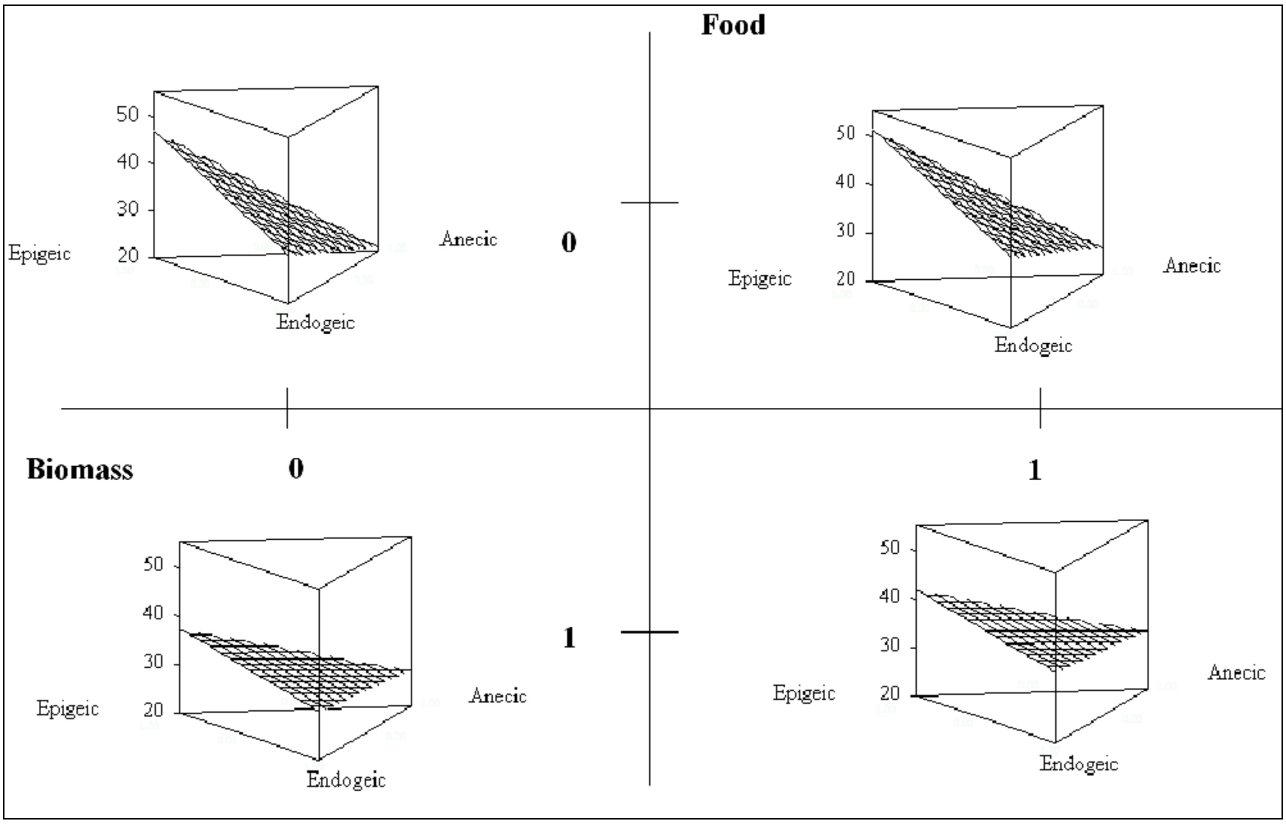


Figure 5.3. Response surface plots for predicted average nitrate-N (mg/l) in leachate.

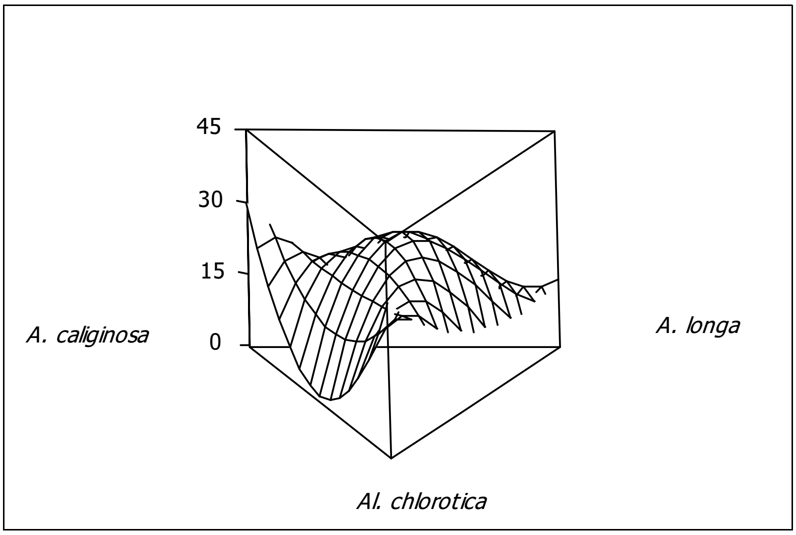


Figure 5.4. Predicted responses for leachate nitrate-N (mg/l) with a high initial earthworm biomass in a stable (10°C) temperature regime.

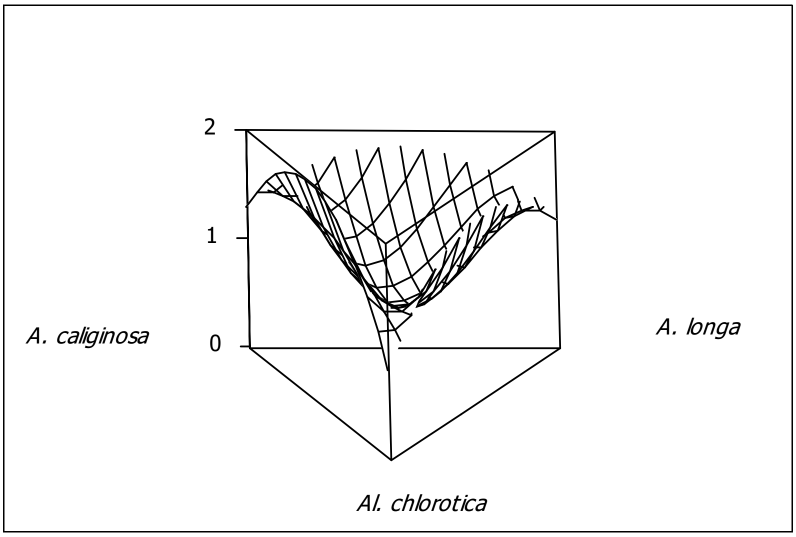


Figure 5.5. Predicted responses for ammonium-N (mg/l) in leachate with high initial earthworm biomass at a stable temperature of 10°C.

When the endogeic species *Aporrectodea caliginosa* was mixed in equal proportions with the other endogeic species, *Allolobophora chlorotica*, or the anecic species, *Aporrectodea longa*, there was a synergistic effect resulting in an increased concentration of ammonium-N in the leachate (Fig. 5.5). *Allolobophora chlorotica* and *Aporrectodea longa*, two obviously functionally dissimilar earthworm species, did not function synergistically in this fashion. This means that *Aporrectodea caliginosa*, while supposedly being functionally equivalent to *Allolobophora chlorotica*, caused a measurably different effect on the leaching of ammonium-N, a further example of the potential dissimilarity between supposedly functionally similar species.

Overall, the original hypothesis that earthworm community structure would significantly impact on nitrogen dynamics in the soil proved to be true when considering both the nitrogen in the soil and that in soil leachate. However, due to the design of the experiment a number of additional points can be made.

While both endogeics and anecics have been shown to have different effects on the nitrogen dynamics, depending on the conditions, the endogeic species are capable of having different functional effects. However, many of these effects only became apparent under the constant temperature regime. This demonstrates that significant functional differences can appear under changed 'unnatural' conditions, an important point with regard to the concept of 'ecosystem insurance'. The data illustrate that, as environmental conditions change, species that initially appear to be functionally identical may start to exhibit different functional roles. This is a very important result as it shows that the species within earthworm functional groups are **not** interchangeable and that there is therefore no redundancy in the study system. They show that the insurance hypothesis regarding the need to protect all biological diversity is applicable in this instance, both in terms of function and of differential responses to environmental conditions.

5.3.2 Grassland plants as model organisms

This study was carried out in association with COST Action 852, and involved collaboration with a wide range of international institutions (see Fig. 5.7 and the End of Project Ag-Biota Report for further details). At each site, two legume and two grass species were sown. One of the grass and one of the legume species were fast- and the other two were slow-establishing species. Five species groups were used: North European (NE), Mid-European (ME), Dry Mediterranean (DM), Moist Mediterranean (MM), and a fifth group (Other) consisted of three sites, each with its own species (Table 5.1).

A simplex design was used to define four monocultures and 11 mixtures of the four species (Fig. 5.8a). The 11 mixtures consisted of four mixtures

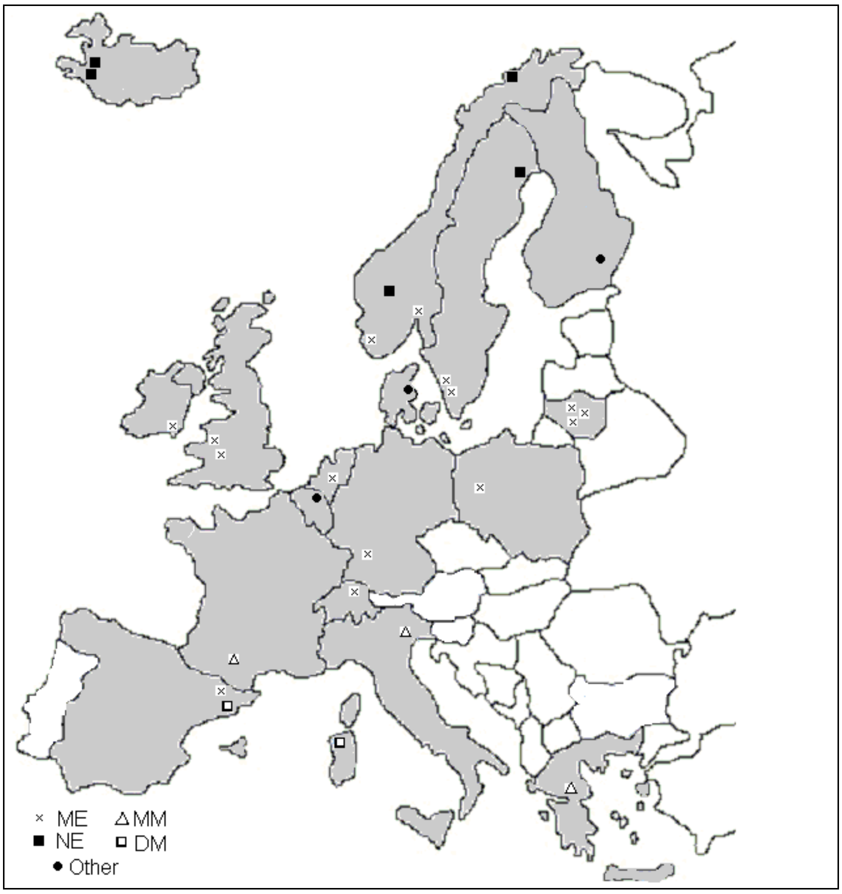


Figure 5.7. Location of European sites. The 28 sites are displayed according to the geographic species groups. They are Mid-European (ME), Northern European (NE), Moist Mediterranean (MM), Dry Mediterranean (DM) and the sites that used their own site-specific species (Other).

Table 5.1. Composition of species groups in the different geographical areas (Mid-European, Northern European, Moist Mediterranean and Dry Mediterranean).

Species	Functional group	Mid-European	Northern European	Moist Mediterranean	Dry Mediterranean
1	Grass – Fast	*Lolium perenne*	*Phleum pratense*	*Lolium perenne*	*Lolium rigidum*
2	Grass – Slow	*Dactylis glomerata*	*Poa pratensis*	*Dactylis glomerata*	*Dactylis glomerata*
3	Legume – Fast	*Trifolium pratense*	*Trifolium pratense*	*Trifolium pratense*	*Medicago polymorpha*
4	Legume – Slow	*Trifolium repens*	*Trifolium repens*	*Medicago sativa*	*Medicago sativa*
Number of sites		15	5	3	2

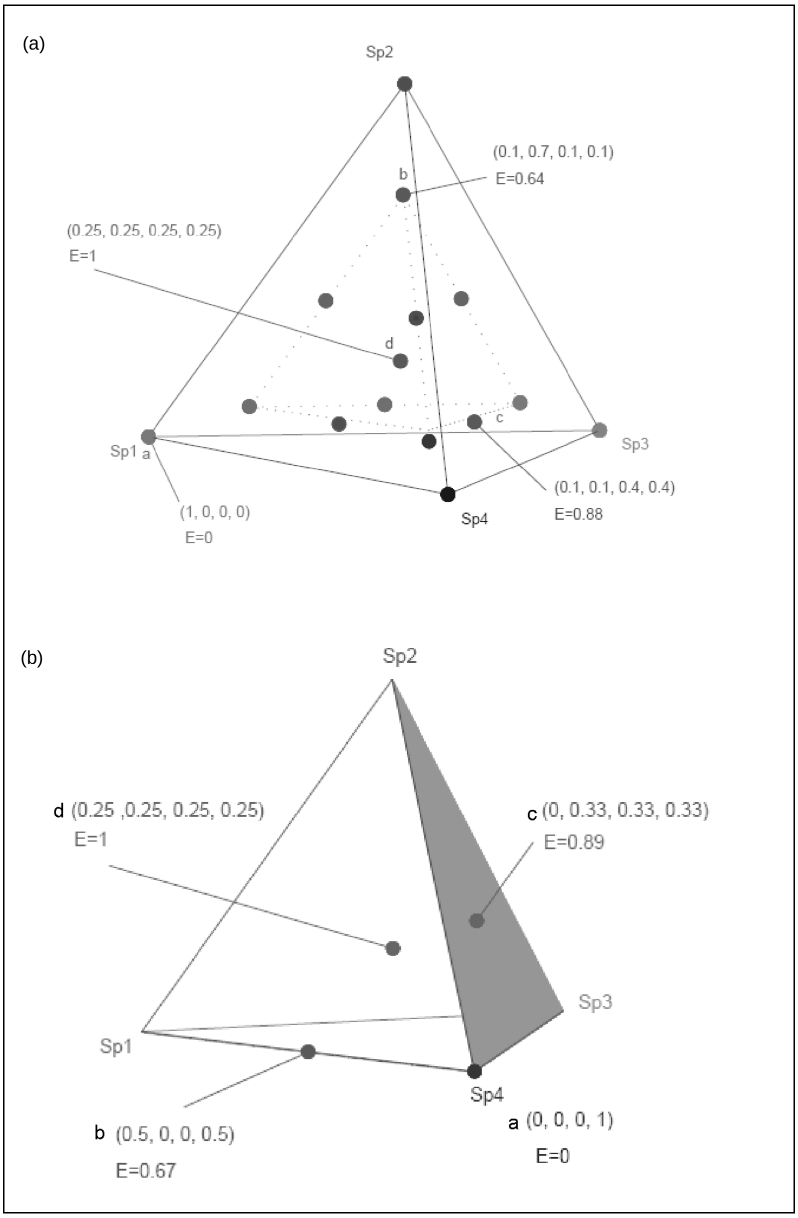


Figure 5.8. Graphical representation of (a) the four-species simplex design and (b) the relationship between sown evenness (*E*) and richness in the simplex.

dominated in turn by each species (sown proportions of 70% of dominant and 10% of each other species), six mixtures dominated in turn by pairs of species (40% of each of two species and 10% of the other two) and a centroid community (25% of each species). The monocultures and mixtures were sown at two levels of overall sown abundance (low being 60% of high). Species proportions at sowing were based on proportional seed biomass at establishment. Full details of the models used and data analysis are given the End of Project Ag-Biota Report.

5.3.2.1 Summary results and discussion

The yield of four-species mixtures exceeded that expected from monoculture performances. This diversity effect was consistent across a wide geographical scale, adding generality to the Project findings. The data also showed a consistently positive effect of increasing plant species evenness (Table 5.2).

In the combined analysis across sites, the diversity effect (*D*) defined as the difference between mixture performance and that expected from a simple (non-interacting) proportional combination of monocultures, differed between species groups. *D* was positively linearly related to evenness for NE ($p = 0.002$, five sites) and MM (but not significantly, $p = 0.108$, three sites) and the maximum diversity effect was 2.26 and 1.38 t/ha, respectively, at $E = 1$.

The models used in this study assume that all pairwise interactions between plant species contribute equally to the observed diversity effect; thus, the positive interaction between two grass species or two legume species was as strong as that between a grass and a legume. The study suggests that to obtain the practical benefit of the diversity effect in intensively managed agricultural grasslands, sowing rates and adaptive management must be used to maintain species evenness. Given that the diversity effect in these agricultural mixtures was related to evenness, the temporal persistence of the species in mixtures (to realise the diversity effect) is a significant issue, as are the effects of vegetation dynamics and abiotic factors in affecting persistence, hence the importance of greater understanding regarding species compatibility (Section 4.2.2).

5.4 Summary Conclusions

As indicated in Chapter 1, the primary objectives of this study were (i) to use and examine a novel experimental design to explore the relationship between biodiversity and ecosystem function, (ii) to examine the relationship between earthworm diversity and ecosystem functions such as nitrogen mineralisation, and (iii) to examine the relationship between plant diversity and primary productivity.

The conclusions are:

1. That the simplex experimental design is an efficient and appropriate design for such studies

2. That both earthworm functional group diversity and species identity are important in relation to function, i.e. that species within functional groups can have different functional properties and that redundancy does not necessarily exist within functional groups

3. That the above-ground biomass production of four-species mixtures (two legumes and two grasses) in grassland systems is consistently greater than that expected from monocultures, even at high productivity levels

4. That the additional performance of mixtures is driven by the number and strength of pairwise inter-specific interactions and the evenness of the community. In general, all pairwise interactions contributed equally to the additional performance of mixtures: the grass–grass and legume–legume interactions were as strong as those between grasses and legumes

5. That the combined analysis of plant diversity across geographical and temporal scales provides a generality of interpretation for the results that would not have been possible from experimentation and analyses at single sites.

Table 5.2. Estimates of the coefficient of evenness (δ) for 28 sites in Year 1 and 17 sites in Year 2 (coefficients in bold indicate significance at ≤5%). This estimates the maximum diversity effect in mixtures in t/ha. Also shown for each site for Year 1 are species group, mean mixture yield, and mean monoculture yield (mono).

Country	Species group	Mean mixture yield (t/ha)	Mean mono yield (t/ha)	Coefficient of evenness δ ± SE (t/ha)	
				Year 1	Year 2
Germany	ME	17.6	13.6	**4.84** ± 0.835	
Ireland	ME	16.6	13.6	**3.75** ± 0.515	**1.51** ± 0.641
Lithuania (Site a)	ME	5.7	5.5	0.34 ± 0.545	**1.84** ± 0.543
Lithuania (Site b)	ME	10.6	8.7	**2.44** ± 0.681	
Lithuania (Site c)	ME	11.0	9.1	**2.17** ± 0.464	
Netherlands	ME	11.5	8.4	**3.70** ± 1.069	**5.44** ± 1.375
Norway (Site a)	ME	13.7	7.8	**6.85** ± 0.602	**4.08** ± 0.402
Norway (Site b)	ME	11.7	9.9	**2.13** ± 0.36	**3.44** ± 0.579
Poland	ME	8.5	6.7	**1.77** ± 0.489	**2.66** ± 0.610
Spain (Site a)	ME	8.5	6.8	2.01 ± 1.217	
Sweden (Site a)	ME	10.4	7.9	**2.84** ± 0.582	**5.75** ± 0.548
Sweden (Site b)	ME	10.4	7.2	**3.72** ± 0.496	
Switzerland	ME	15.5	10.4	**5.64** ± 0.689	**7.46** ± 0.573
Wales (Site a)	ME	10.4	6.7	**4.37** ± 0.583	**2.21** ± 0.674
Wales (Site b)	ME	10.5	6.8	**4.68** ± 0.655	**4.05** ± 0.729
Iceland (Site a)	NE	5.4	4.3	**1.13** ± 0.533	0.49 ± 0.293
Iceland (Site b)	NE	2.3	1.3	**1.16** ± 0.262	**1.25** ± 0.239
Norway (Site c)	NE	11.3	7.1	**4.18** ± 0.481	
Norway (Site d)	NE	10.2	8.1	**2.40** ± 0.465	**2.04** ± 0.334
Sweden (Site c)	NE	9.1	7.2	**2.38** ± 0.32	
France	MM	9.5	8.1	1.71 ± 1.002	
Greece	MM	3.3	2.5	**0.92** ± 0.222	
Italy (Site a)	MM	9.3	8.0	**1.50** ± 0.712	
Italy (Site b)	DM	3.3	1.9	**1.62** ± 0.217	**0.91** ± 0.428
Spain (Site b)	DM	2.5	1.0	**1.70** ± 0.263	**3.57** ± 0.684
Belgium	Other	16.1	11.6	**5.18** ± 0.577	**9.14** ± 0.789
Denmark	Other	13.6	9.7	**4.57** ± 0.488	
Finland	Other	9.3	7.0	**2.65** ± 0.355	

ME, Mid-European; NE, Northern European; MM, Moist Mediterranean; DM, Dry Mediterranean; Other, the sites that used their own site-specific species.

6 Overall Discussion and Conclusions

6.1 Overall Project Aims

The Ag-Biota Project set out to develop a greater understanding of the relationships between Irish agriculture and biodiversity in its widest sense. At the start of the Project, relatively little work on this specific topic had been done. Even the question of specifying **how** to begin the process of monitoring and assessment of the sectoral impact of agriculture on biodiversity had not been addressed in an integrated way. The Ag-Biota Project has therefore focused very strongly on the generation of practical knowledge to inform REPS policy development, in addition to the acquisition of ecological knowledge and understanding regarding the intrinsic value of biodiversity in agricultural systems.

6.2 An Evaluation Strategy for Agri-Environmental Policy

The collection and quantification of a wide range of additional farm system, management and habitat information was an integral part of the monitoring studies, which had the overall aim of beginning the process of identifying the main agricultural 'drivers' of effects on biodiversity (Fig. 6.1). A key feature of this model is the 'feedback' process that enables policy refinement and the improvement of farming practice.

Clearly, assessment of the success, or otherwise, of agri-environmental policy with respect to biodiversity, and other environmental concerns, requires an unquestioned understanding of relationships between management practice and key state indicators reflective of effects on wider biodiversity. It is unrealistic, however, to expect that assessment can be based on the large-scale and **routine** collection of data relating to biological populations in extensive farm surveys. For this reason, it is necessary to develop the model outlined in Fig. 6.1, such that a detailed understanding of the highlighted linkages is developed to the point where one can reliably use surrogate assessments of changing farming practice in the creation of an evaluation methodology based on the routine collection of relevant farm statistics.

One of the most important aspects of the above model is the appropriate quantification of farmland habitats as a primary step in describing the effects of management practice on bio-indicator groups. It is apparent, however, that the most widely used Irish habitat classification system in current use (Fossitt, 2000), was not designed for, and so is not well suited to, the task of documenting ecologically discrete farmland habitats. This deficiency is most apparent in the ecological classification of agricultural grasslands, arable land types and field margins. The current study makes an important contribution in proposing new and more ecologically meaningful classification systems for the most widespread of these farmland features.

Purvis *et al.* (2009) outline the basis of a universally applicable agri-environmental evaluation method, the Agri-environmental Footprint Index (AFI). The conceptual framework for this method (Fig. 6.2) was directly informed by the current project's work in seeking to quantify the relationships between environmental state and farm management practice.

The current Project also fed directly into a DAFF-funded project, 'Agri-Baseline' (Stimulus Research Fund 2006), which is now surveying biological

Figure 6.1. A simple model for monitoring the impact of agriculture on biodiversity.

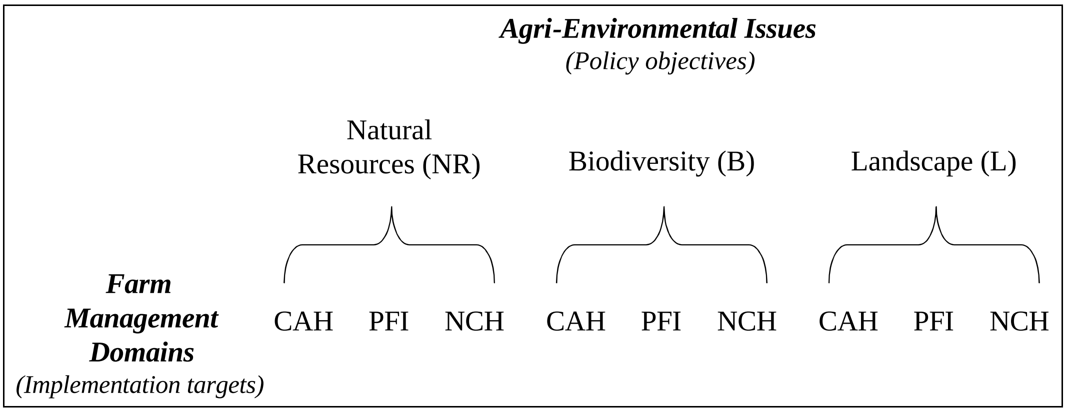


Figure 6.2. A conceptual framework for the agri-environment as developed by the Agri-Environmental Footprint Project. (CAH, farmer management of crop and animal husbandry; PFI, management of physical farm infrastructure; NCH, management of natural and cultural heritage features (Purvis *et al.*, 2009).)

indicators, farm management and REPS participation statistics for large samples of farms (Fig. 6.3).

Most importantly, within the Agri-Environmental (AE) Footprint Project, customised forms of the AFI using surrogate farm management criteria have been created for the evaluation of dry livestock farming in Sligo/Leitrim and dairy farming in Cork. This will make it possible in future work to validate the use of the AFI method by direct comparison of biological indicator data and AFI scores quantified for the same sample of farms currently being surveyed in the Agri-Baseline Project, in much the same way that the current Project has provided evidence of the potential utility of the largely conceptual FBEGS Index as a surrogate means to document possible effects on bird populations (Fig. 6.4).

6.3 Future Agri-Environmental Policy Design

Reduction of agricultural pressures on the environment and provision of agri-environmental (public good) services are the two primary facets of the 'multifunctional' model of European agriculture. It is clear, however, that restrictions on the intensity of husbandry systems are an almost universal feature of current EU AE schemes, including the REPS in Ireland. This clearly acts as a strong disincentive to voluntary participation in AE schemes in intensively farmed areas (Kleijn and Sutherland, 2003). As a consequence, only minimum regulatory thresholds for agri-environmental quality are likely to be attained in such regions (Downey and Purvis, 2005), and a valuable opportunity to recruit farmers as managers of

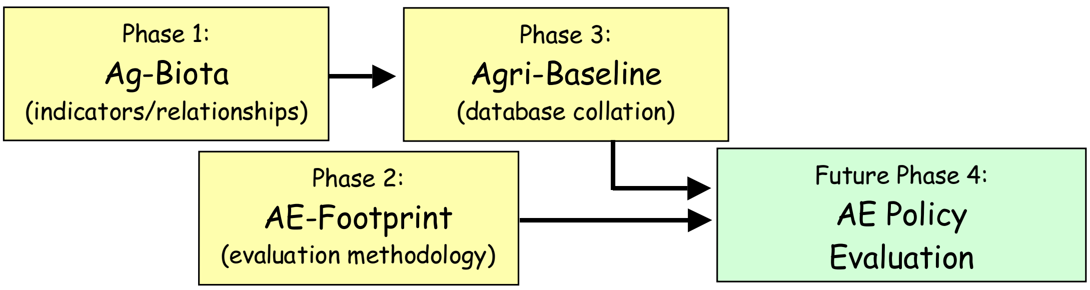


Figure 6.3. Strategic relationships between the current Ag-Biota Project, subsequent projects funded by the Department of Agriculture, Fisheries and Food (Agri-Baseline) and the EU (Agri-Environmental Footprint), and development of a possible, practicable future evaluation methodology for Irish agri-environmental policy.

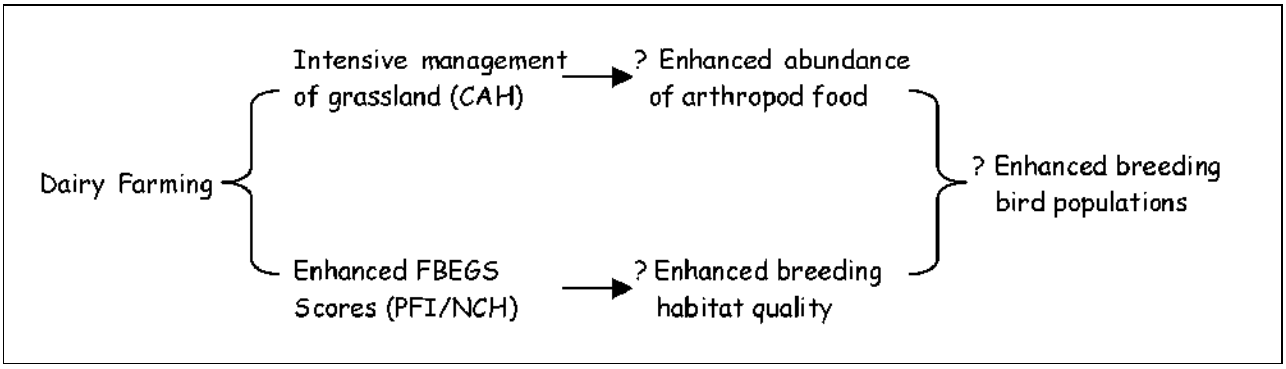


Figure 6.4. Suggested relationships between dairy farming, grassland arthropod abundance, field boundary quality, and breeding bird populations. (Note the importance of the dairy farmer's management of physical farm infrastructure (PFI) and natural and cultural heritage (NCH) features outside of the main production process (CAH), which is *not* an impediment to making a positive contribution to the agri-environment.)

the **non-production** dimensions of the agro-ecosystem is lost. The AE Footprint methodology (Purvis *et al.*, 2009) provides a conceptual framework for design and evaluation of AE schemes that recognises the importance of different farm management 'domains' (Fig. 6.2).

These environmental management 'domains' in agriculture relate to a farmer's management of crop and animal husbandry (CAH), physical farm infrastructure (PFI) and natural and cultural heritage (NCH) features on the farm. The relative environmental importance of these domains in addressing the major agri-environmental issues (protection of natural resources, biodiversity and landscape) differs in different farming contexts, and understanding this can facilitate the development of more innovative AE scheme structures customised to the very different multifunctional perspectives of intensive, extensive and marginal farming regions (Downey and Purvis, 2005). The current Project's finding of greater breeding bird populations on dairy farms compared with non-dairy farms (Fig. 6.4), if validated in independent surveys now being done by the Agri-Baseline Project, illustrates this point very well. A customised AE scheme structure for intensive dairy farming regions that gives priority to the management of wildlife habitats (NCH) and field boundaries (PFI), and less emphasis on limiting husbandry intensity (CAH) would be much more likely to actively engage dairy farmers, and so benefit at least some important aspects of biodiversity.

6.4 Key Role of Future Research in Meeting Obligations to Halt Loss of Biodiversity and Create a Sustainable Model for Irish Agriculture

The Ag-Biota Project represents a very considerable Irish investment in the creation of much needed knowledge concerning the impact, and potentially beneficial role, of a centrally important economic sector in maintaining biodiversity within the wider landscape. As such, it makes a very significant contribution towards Ireland's obligations under the Convention on Biological Diversity (CBD), and subsequent agreement by the Member States of the European Union, to halt the loss of biodiversity by 2010. This date is now imminent, and it is to be hoped that the current Project's work and findings will now stimulate an even more targeted and strategic approach towards the practical resolution of an extremely important global issue. It has been argued that within agro-ecosystems the greatest priority must be given to functionally relevant biodiversity that facilitates the production process (Büchs, 2003). Within Ireland, this effectively means paying much more attention to the influence of grass-based agricultural management on biodiversity, both within individual fields and in the wider countryside. The studies of existing grassland husbandry field experiments (Chapter 3) have provided clear evidence of a marked reduction in both plant and arthropod diversity in intensively managed pastures, and the studies of inter- and intra-specific relationships between sward plant species (Chapter 4) and the functional value of mixed populations (Chapter 5) provided further insights into the potential ecological benefits of mixed sward species. However, the existing field-scale grassland husbandry experiments that were available to the Project for monitoring were not originally designed to investigate biodiversity issues *per se*, and a further key conclusion of the studies must be that no dedicated, long-term and large-scale grassland husbandry experiments have yet been established with the express aim of investigating and quantifying the ecological benefits of biodiversity in grassland production systems.

Dedicated grassland husbandry experiments, which simultaneously seek to manipulate sward plant diversity, nutrient input levels and grazing intensities, are necessary to quantify the potentially beneficial interactions between husbandry practice and biodiversity in Ireland's main agricultural sector. Such an approach is surely central to, and an urgent requirement for, an improved understanding and development of biodiversity policy within Irish agriculture. The establishment of such long-term and regionally replicated field experiments would provide a suitable vehicle for a wide range of 'add-on' studies integrating other important agri-environmental issues. These would include optimum sward management for the efficient uptake and use of nutrients, avoidance of groundwater pollution, improvement in understanding of the relationship between sward structure, diet and rumen function in grazing livestock (with an almost entirely unexplored, but functionally critical rumen microbial biodiversity component), and potentially consequential reduction of greenhouse gas emissions and improvement in animal health and agronomic performance (Fig. 6.5).

Such a research model is central to the development of sustainable, grass-based agriculture in Ireland that successfully integrates and utilises the ecological benefits of biodiversity, but would surely require the joint collaboration of multiple research groups and funding agencies to facilitate the required investment in time and resources.

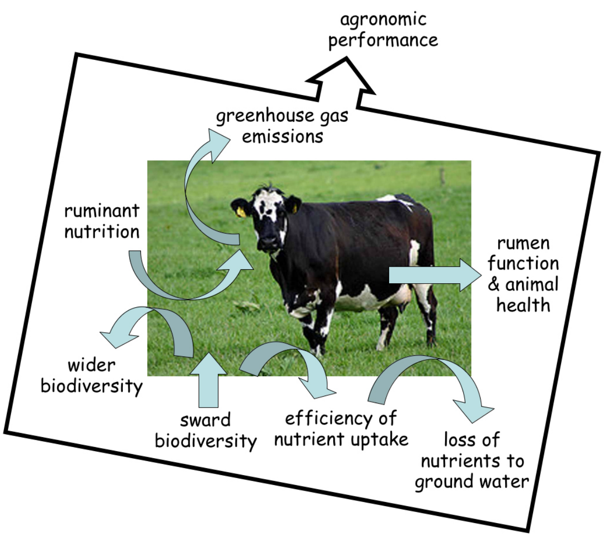


Figure 6.5. An integrated research model incorporating the conservation and utilisation of biological diversity in the development of sustainable grass-based agriculture.

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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 agus Rialtais Áitiúil a dhéanann urraíocht uirthi.

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.

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.

National Development Plan 2007 - 2013

Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

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.

Agriculture and Food Development Authority

SSTI Strategy for Science, Technology and Innovation

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