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Riparian buffer strips: their role in the conservation of insect pollinators in intensive grassland systems

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Abstract: There is growing concern that the global decline of insect pollinators will adversely influence the stability of pollination in agricultural and terrestrial ecosystems. By enhancing habitat heterogeneity and ecological connectivity, riparian buffer strips have the potential to promote insect pollinators in intensively managed landscapes. Insect pollinators and flowering plants were investigated on a range of riparian margins, and their adjacent grassland fields, to determine the main physical and botanical attributes driving pollinator diversity.
Irrespective of whether they were fenced or not, riparian margins had richer plant assemblages and supported more pollinators than grassland fields. While the erection of fences did not enhance the richness or diversity of flowers, fenced riparian buffer strips supported more even and diverse assemblages of bumblebees and a greater number of butterflies than unfenced riparian margins. More bumblebees and butterflies were recorded in wide buffer strips (i.e. over 5 m wide) than in unfenced margins or narrow buffer strips (i.e. ≤ 3.5 m wide) and butterfly assemblages in wide buffer strips were richer and more diverse. There was a strong positive relationship between floral resources and the abundance, richness and diversity of bumblebee and butterfly assemblages. Pollinators only foraged on a small number of the flower species present and impacts of fencing and buffer strip width could not solely be attributed to the area and/or species richness of flowers.
Fenced riparian buffer strips, particularly when over 5 m wide, have the potential to provide resources for insect pollinators in intensively grazed systems. Management to enhance floristic diversity (to provide a more continuous supply of pollen and nectar) and tussock forming grasses (to provide shelter for pollinators and nesting locations for bumblebees) could further increase their value to insect pollinators. In grassland systems, restricted grazing is easier to implement than mowing. It is, however, important that grazing management does not unduly interfere with other ecosystem services derived from riparian buffer strips (e.g. diffuse pollution mitigation). Widespread fencing of watercourses at the catchment level could result in the simplification of these inherently dynamic and complex habitats. Buffer strips should therefore be strategically placed to optimise benefits such as ecological connectivity and diffuse pollution mitigation.

Highlights

- This research evaluates riparian buffer strips as a resource for insect pollinators
- Riparian margins (i.e. fenced and unfenced) supported more insect pollinators than grassland fields
- Insect pollinators were more abundant in wide buffer strips than in narrow buffer strips
- Impacts of riparian management could not solely be explained by differences in flower abundance
- Management to promote flowering plants may enhance the biodiversity value of buffer strips

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Riparian buffer strips: Their role in the conservation of insect pollinators in intensive grassland systems

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Abstract

There is growing concern that the global decline of insect pollinators will adversely influence the stability of pollination in agricultural and terrestrial ecosystems. By enhancing habitat heterogeneity and ecological connectivity, riparian buffer strips have the potential to promote insect pollinators in intensively managed landscapes. Insect pollinators and flowering plants were investigated on a range of riparian margins, and their adjacent grassland fields, to determine the main physical and botanical attributes driving pollinator diversity.

Irrespective of whether they were fenced or not, riparian margins had richer plant assemblages and supported more pollinators than grassland fields. While the erection of fences did not enhance the richness or diversity of flowers, fenced riparian buffer strips supported more even and diverse assemblages of bumblebees and a greater number of butterflies than unfenced riparian margins. More bumblebees and butterflies were recorded in wide buffer strips (i.e. over 5 m wide) than in unfenced margins or narrow buffer strips (i.e. $\leq$ 3.5 m wide) and butterfly assemblages in wide buffer strips were richer and more diverse. There was a strong positive relationship between floral resources and the abundance, richness and diversity of bumblebee and butterfly assemblages. Pollinators only foraged on a small number of the flower species present and impacts of fencing and buffer strip width could not solely be attributed to the area and/or species richness of flowers.

Fenced riparian buffer strips, particularly when over 5 m wide, have the potential to provide resources for insect pollinators in intensively grazed systems. Management to enhance floristic diversity (to provide a more continuous supply of pollen and nectar) and tussock forming grasses (to provide shelter for pollinators and nesting locations for bumblebees) could further increase their value to insect pollinators. In grassland systems, restricted grazing is easier to implement than mowing. It is, however, important that grazing management does not unduly interfere with other ecosystem services derived from riparian buffer strips (e.g. diffuse pollution mitigation). Widespread fencing of watercourses at the catchment level could result in the simplification of these inherently dynamic and complex habitats. Buffer strips should therefore be strategically placed to optimise benefits such as ecological connectivity and diffuse pollution mitigation.

Keywords

Pollination, plant-pollinator interactions, bees and butterflies, vegetated buffer strips, agri-environment schemes, biodiversity

1. Introduction

The post war intensification of agricultural practices and the associated loss of landscape heterogeneity have adversely affected biodiversity across a range of taxa (Benton et al. 2003; Tscharntke et al. 2005). There is growing concern that this loss of biodiversity will have an adverse impact on ecosystem functioning, resulting in a degradation of ecosystem services (Albrecht et al. 2012; Flynn et al. 2009). Evidence is mounting that insect pollinators (including honeybees, wild bees, butterflies and hoverflies) are declining globally and with losses being biased towards species with specific habitats, diets and functional traits, the stability of the pollination services they deliver is under threat (Potts et al. 2010; Vanbergen and The Insect Pollinator Initiative, 2013). With insect pollinators enhancing yields in almost 70% of crops, accounting for approximately 35% of agricultural production, declines pose a genuine threat to global food security (Klein et al. 2007). Furthermore, insect pollinators are responsible for the pollination of the many wild plants and thus play a vital role in the maintenance of terrestrial ecosystems (Biesmeijer et al. 2006; Ollerton et al. 2011).

Within intensively managed agricultural landscapes, natural or semi-natural components provide important nesting and foraging sites for insect pollinators and proximity to such habitats has been found to increase pollinator species richness, crop visitation rates and pollination success (Blaauw and Isaacs, 2014; Garibaldi et al. 2011; Garibaldi et al. 2014; Petersen and Nault, 2014; Ricketts et al. 2008). There has been considerable research on the role that field margins play, especially when managed for conservation, in providing foraging and nesting sites for insect pollinators within intensively managed agricultural landscapes (Carvell et al. 2007; Kells and Goulson, 2003; Feber et al. 1996; Potts et al. 2009; Pywell et al. 2011; Scheper et al. 2013). This research has, however, focussed primarily on field margins that are not exclusively riparian (e.g. arable buffer strips, wildflower strips and grassland field margins) and comparable research looking specifically at riparian field margins is lacking. Riparian margins occur in the transitional zone (i.e. ecotone) between aquatic and terrestrial habitats and are typically subjected to disturbance by watercourses which results in the formation of functionally distinctive and dynamic ecosystems that support many specialist species. The properties of riparian margins are thus unique and consequently research findings from non-riparian field margins are unlikely to be directly transferrable to riparian field margins. Furthermore, in grassland situations, buffer strips are generally established by erecting fences adjacent to watercourses to exclude livestock with the resultant vegetation being typically left unmanaged. The resultant vegetation is tall and dense and while having a tendency to be species poor; it can be structurally diverse encompassing flower heads, seed heads and grassy tussocks (Cole et al. 2012a; Stockan et al. 2012; Woodcock et al. 2009). Arable riparian buffer strips, in contrast, are frequently established without the use of fences and disturbance (e.g. annual cutting) is relatively common. As a result of differences in establishment and management, findings from arable buffer strips are not directly transferrable to grassland buffer strips.

Previous pollinator research on field margins has concentrated on how the presence of margin establishment (e.g. natural regeneration verses different seed mixtures) and management (e.g. cutting verses no cutting) influences insect pollinators (Carvell et al. 2007; Feber et al. 1996; Holland et al. 2015; Potts et al. 2009; Pywell et al. 2004; Pywell et al. 2005; Pywell et al. 2011) with few studies focussing specifically on the impact of margin width (Bäckman and Tiainen, 2002; Field et al. 2005). With increasing pressure on agricultural land to meet growing demands for food (Garnett et al. 2013), there is a need to ensure that the area of land taken out of production is kept to a minimum and the resultant loss of yield is balanced with the benefits gained. Furthermore, landscape context can significantly influence the benefits derived from agri-environment measures with greater benefits to insect pollinators occurring in landscapes with intermediate levels of heterogeneity (Scheper et al. 2013). It is therefore important to increase our understanding of how field margin width influences biodiversity and also to consider the spatial location and landscape context of margins to ensure that the ecosystem services derived are optimised.

Fenced riparian buffer strips are a key agri-environment measure primarily aimed at protecting watercourses from diffuse pollution and their prevalence in intensively managed agricultural catchments is likely to become more widespread (McCracken et al. 2012). There is therefore a need to formulate management prescriptions that capitalise on the range of potential benefits that riparian buffer strips can deliver (e.g. biodiversity, pollination, protection of watercourses and ecological connectivity). The impact of fencing riparian field margins is taxa specific and while some groups including phytophagous invertebrates (Cole et al. 2012a), woodland carabids (Stockan et al. 2014) and flightless carabids (Cole et al. 2012b), are favoured by fencing, other groups including Linyphiidae spiders (Cole et al. 2012a) and vascular plants (Feehan et al. 2005; Stockan et al. 2012), are adversely affected. As insect pollinators are strongly driven by floral resources (Potts et al. 2009; Scheper et al. 2013), adverse effects of fencing on flowering plants is likely to have knock-on effects on pollinators. Management prescriptions for riparian buffer strips aimed at enhancing floristic diversity must be tailored to meet regulations that restrict certain agricultural practices adjacent to watercourses (e.g. cultivation and the application of agro-chemicals) and to ensure that they do not conflict with other functions that riparian buffer strips deliver (e.g. mitigating diffuse pollution). Advancing understanding of pollinator ecology within intensive grassland systems will assist in the formulation of agri-environment prescriptions for riparian field margins that promote insect pollinators and enable landowners to capitalise on the benefits derived from land taken out of production.

This research aimed to determine the main physical and botanical attributes of riparian field margins, and their adjacent grassland fields, that influence the taxonomic structure and diversity of butterfly and social bumblebee (i.e. excluding subgenus *Psithyrus*) assemblages in intensive grassland systems. Butterflies and social bumblebees were selected as they are easily identified in the field and while they both rely strongly on nectar, they have very different lifecycles and habitat requirements and are thus sensitive to different factors (Potts et al. 2009; Holland et al. 2015). The main factors driving diversity in these two key groups of pollinators were assessed to determine if fenced riparian buffer strips supported more foraging pollinators than unfenced riparian margins, and, if so, to determine if wider riparian buffer strips were superior to narrow buffer strips.

2. Methods

2.1. Study sites

Two lowland regions of Scotland dominated by productive ryegrass, *Lolium perenne* L., swards were selected for study over a two year period (2010 and 2011); Ayrshire (N55°32'50", W4°22'00") and Kirkcudbrightshire (N54°51'35", W4°01'48"; Cole et al. 2012a). Agricultural management in both geographical locations is typically intensive livestock grazing and/or cutting for silage. A total of 26 sampling sites on 14 farms were surveyed over the two year period, 14 sites in Ayrshire and 12 in Kirkcudbrightshire. Sites were chosen to represent the range of riparian margins occurring within the two study areas. Sites were classified into one of three riparian management types: Unfenced margin sites (i.e. no fences between fields and watercourses, n=9), Narrow fenced buffer strips sites (i.e. fences erected 1 to 3.5 m from the watercourse, n=9) and Wide fenced buffer strip sites (i.e. fences erected more than 5 m from watercourses, n=8) (Table 1). At each site, paired transects were established, one adjacent to the watercourse (termed margin transects: Unfenced margin, Narrow buffer strip and Wide buffer strip) and one approximately 20 meters from the watercourse in Unfenced sites, or from the fence in the case of Buffer strip sites, into the adjacent grassland field (termed field transects: Unfenced field, Narrow field and Wide field).

2.2. Insect pollinator and botanical sampling

Pollinators were monitored using standardised transect walks 100 m in length and 2 m on either side, and 2 m in front (i.e. transect area: 100 m by 4 m), of the observer (Pollard and Yates, 1993; Potts et al. 2009). Transect walks were conducted between 10.45 hrs and 16.00 hrs under conditions described as suitable by the Butterfly Monitoring Scheme Standards (temperature 13-17°C with at least 60% clear sky, or over 17°C and not raining and a maximum wind speed of 4 on the Beaufort Scale: Pollard and Yates, 1993). These conditions are also deemed suitable for recording bumblebees (Potts et al. 2009). Transects were walked at a constant rate of approximately 10 m min^{-1}.

All adult butterflies and foraging bumblebees entering transects were identified to species level and quantified. Due to difficulties in differentiating between workers of *Bombus lucorum senso lato* (i.e. species complex of *Bombus lucorum*, *Bombus cryptarum* and *Bombus magnus*) and workers of

Bombus terrestris based solely on morphological features, analyses were conducted on the aggregated data for these species (Wolf et al. 2010). During transect walks all dicotyledonous plants observed in flower within the transect area were identified to species level and their abundance quantified using the Domin Scale as a measure of resource availability. In 2011, plant-pollinator interactions were assessed by recording the plant species on which pollinators were observed foraging.

In Ayrshire pollinator transect walks were conducted in five sampling periods: Mid June, Late June, July, Early August and Late August. In Kirkcudbrightshire in 2010 and 2011 transect walks were conducted in Mid June and July, and in 2011 sampling was also conducted in Late August.

2.3. Collection of physical attributes and spatial data

Table 1 describes the physical and spatial data collected at the study sites. *Buffer age* and *Land use* were determined via interview with the land manager. With the exception of *Buffer area* and *Buffer perimeter* which were determined via ArcGIS (ArcGIS Version 10: Environmental Systems Research Institute, CA), data on margin attributes were collected by direct measurements in the field.

Surrounding land cover data were derived from the Ordnance Survey MasterMap data, Forestry Commission Native Woodland Scotland Survey, and agricultural land cover data derived from the Scottish Government's Land Parcel Identification System. These datasets were integrated using ArcGIS and the resultant spatial dataset was classified into five broad land cover categories: semi-natural habitat, manmade structures, gardens, intensively managed grassland and arable/horticultural. Ellipses were drawn around each 100 m transect at two distinct spatial scales (i.e. 100 m and 500 m) and the percentage area of these five land covers calculated at each spatial scale. An upper scale of 500 m was selected as it this scale has been deemed suitable in detecting landscape effects across a wide range of taxa (Batáry et al. 2012; Concepción et al. 2008; Goulson et al. 2010) and it prevented undue overlap of adjacent ellipses in the study area.

2.4. Analyses

2.4.1. Summarising plant-pollinator interactions

Plant-pollinator interaction data were collected in 2011. To determine seasonal variation in the utilisation of different flower species, data were first summed for all observed plant-pollinator interactions in Mid June, July and Late August (data were summed for each sampling period across Unfenced margins, Narrow buffer strips and Wide buffer strips irrespective of geographical location). To determine how riparian management influenced plant-pollinator interactions, plant-pollinator interactions were also summed for Unfenced margins, Narrow buffer strips and Wide buffer strips for each geographical location (to enable direct comparison between the two geographical locations, data from Ayrshire was summed for the Mid June, July and Late August only). Plant-pollinator interaction graphs were produced using the bipartite package (Dormann et al. 2009) in R (R Core Team 2014).

2.4.2. Determining the impact of riparian management on diversity

To determine the impact of riparian management on bumblebee, butterfly and flowering plant diversity, four measures of diversity were calculated for each group:

(i) Abundance/Area: total number of bumblebees/butterflies or % area of transect consisting of plants in flower

(ii) Species richness: total number of species sampled

(iii) Diversity: Shannon diversity index

(iv) Evenness: reciprocal of Berger-Parker diversity index (i.e. 1/Berger-Parker)

Prior to all analyses Domin cover-abundance values for flowering plants were converted to percentage cover following Currall (1987).

For response variables based on counts (i.e. species richness and butterfly and bumblebee abundance), Generalised Linear Mixed Models (GLMMs) were fitted in Genstat 16 using Residual Maximum Likelihood (REML), a log link function and assuming Poisson distributed errors. For all other response variables (i.e. Area of flowers log transformed, Shannon diversity log transformed for butterflies and 1/Berger-Parker angular transformed) Linear Mixed Models (LMMs) were fitted using REML.

Descriptions of the fixed and random effects investigated are provided in Table 1. The hierarchical structure for random effects was, in descending order, *Farm*, *Site* (only included in models fitted to data from all transects) and *Transect*. For LMMs the residual was *Sample* (i.e. data derived from a specific transect on a specific sampling period) and for GLMMs the dispersion was estimated to allow for both over and under dispersal in response variables. This structure enabled the greatest precision of comparison between transects at a specific site and sampling date. To allow for similarity between repeated samples from different sampling periods, interactions between these random effects and year were also included.

GLMMs and LMMs were conducted at two levels. Initial simple GLMMs/LMMs were conducted (referred to as "Simple models") on the complete dataset. Bumblebees and butterflies were rarely recorded in field transects (i.e. Unfenced field, Narrow field and Wide field) so scarcity of data in these transects meant that fitting more complicated models to the full datasets was not feasible. Data derived from field transects were therefore removed and more complex models (referred to as "Complex models") were fitted to data from margin transects only (i.e. Unfenced margin, Narrow buffer strip and Wide buffer strip).

For all response variables the Simple models fitted were:

Year + Sampling period + Geolocation + Coarse management + Detailed management

Modelling the data in this way allowed both geographical locations to be modelled simultaneously despite differences in sampling intensity. This model also allows us to detect effects of *Coarse management* (i.e. differences between Fields, Fenced buffer strips and/or Unfenced margins) and then *Detailed management* (e.g. do Wide buffer strips differ from Narrow buffer strips?).

Complex models were then conducted omitting data derived from field transects. For flower response variables the following fixed effects were fitted:

Year + *Sampling period* + *Geolocation*+ *Fencing* + *Buffer width* + *Geolocation* x *Fencing* + *Geolocation* x *Buffer width*

Fitting fixed effects in this order allows testing for effects of *Fencing* (i.e. Do Unfenced margins differ from Fenced buffer strips?) and then testing for effects of *Buffer width* (i.e. Do Wide buffer strips differ from Narrow buffer strips?). As a consequence of the physical constraints of Narrow buffer strips, transects in Narrow buffer strips consisted of both fenced and unfenced habitat while transects in Wide buffer strips consisted solely of fenced habitat. To help determine the relative importance of *Percentage fenced* within Narrow buffer strips initial modelling included this variable immediately following the inclusion of *Buffer width*. *Percentage fenced* was not significant for any of the response variables investigated and therefore it was omitted from the final models.

For bumblebee and butterfly response variables the Complex models were as above, except with floral resource variables (i.e. *Area of flowers* and *Flowering plant species richness*) incorporated before and after margin management effects:

(i) *Year* + *Sampling period* + *Geolocation* + *Fencing* + *Buffer width* + *Geolocation* x *Fencing* + *Geolocation* x *Buffer width* + ***Area of Flowers*** + ***Flowering plant species richness***

(ii) *Year* + *Sampling period* + *Geolocation* + ***Area of flowers*** **+** ***Flowering plant species richness*** + *Fencing* + *Buffer width* + *Geolocation* x *Fencing* + *Geolocation* x *Buffer width*

Incorporating floral resource variables before and after margin management effects helps to determine if effects of *Fencing* and *Buffer width* were solely attributable to differences in floral resources.

2.4.2. Determining drivers of bumblebee and butterfly assemblages

To determine the main environmental factors driving bumblebee and butterfly assemblage structure Canonical Correspondence Analyses (CCAs: ter Braak, 1986) were conducted on the species data without downweighting rare species and including year as a block to deal with repeated measures. As a consequence of the low numbers of pollinators observed in field transects, CCA was only conducted on the margin data. Prior to analyses, bumblebee and butterfly counts were summed across sampling dates for a specific transect and year and log transformed to give an overall indication of assemblage structure for that year.

In addition to the flower resource variables *Area of flowers* and *Flowering plant species richness*, sixteen continuous variables (log transformed to normalise and to make relationships linear where required) and two categorical variables (i.e. *Land use* and *Geolocation*) were included in CCAs (Table 1). To reduce problems associated with multi-collinearity the continuous variables *100m buildings* and *500m buildings* were omitted from CCAs.

3. Results

3.1. Overall Trends

Over the two sampling years 91 plant species, 498 butterflies (consisting of 13 species) and 791 bumblebees (consisting of five species) were identified (Appendix 1). While a total of 85 flowering plant species were recorded in 2011, pollinators were only recorded foraging on 21 species with 86.8% of plant-pollinator interactions occurring on just seven plant species. The relative importance of plant species changed as the season progressed with most interactions being observed on *Symphytum×uplandicum* Nyman, *Stachys sylvatica* L. and *Trifolium repens* L. in Mid June; *S. sylvatica* and *Cirsium palustre* L. in July; and *Stachys palustris* L., *Cirsium arvense* (L.) Scop., *S. sylvatica* and *Centaurea nigra* L. in Late August (Fig. 1).

The relative importance of different plant species differed between Unfenced margins, Narrow buffer strips and Wide buffer strips (Fig. 2). To allow comparison between the two geographical locations these summaries are based on the Mid June, July and Late August data only. In Wide buffer strips the relative importance of these plant species differed in the two geographical areas with the dominant species in Ayrshire being *Symphytum×uplandicum* (35% of observed interactions), *C. nigra* (25%) and *C. arvense* (15%) while in Kirkcudbrightshire *S. sylvatica* (55%) and *S. palustris* (34%) were the dominant species. In Narrow buffer strips, most pollinators were observed foraging on *Cirsium* spp. (63% in Ayrshire with species including *C. palustre*, *Cirsium vulgare* (Savi) Ten. and *C. arvense*, and 62% in Kirkcudbrightshire with species including *C. palustre* and *C. arvense*). Pollinators in unfenced margins in Ayrshire were most frequently recorded foraging on *T. repens* (50%) and *C. arvense* (25%) while those in Kirkcudbrightshire were most frequently recorded foraging on *S. sylvatica* (30%) and *T. repens* (26%).

GLMMs and LMMs conducted on the full dataset (i.e. including field transects) and the reduced data set (i.e. excluding field transects) found highly significant effects of *Sampling period* for all response variables and significant effects of *Year* for some response variables. While this indicates seasonal and annual fluctuations in flower and pollinator assemblages, such fluctuations are outside the focus of this paper and are not considered further.

3.2. Impact of riparian management on flower diversity

Simple models (fitted to all data) found highly significant effects of *Coarse management* (Table 2a, Appendix 2) with Field transects having fewer flowers and flower species, and less even and diverse assemblages than Margin transects (i.e. both Unfenced margins and Fenced buffer strips). More complex models (applied to margin transects only) indicated that Fenced buffer strips and Unfenced margins were similar with respect to the number of flower species and the diversity and evenness of flower assemblages. Fenced buffer strips were, however, found to have a significantly higher *Area of flowers* than Unfenced margins.

No significant effect of *Buffer width* was found for the number of flower species, or the diversity and evenness of flower assemblages, indicating that these response variables did not differ between Narrow and Wide buffer strips. *Buffer width* significantly influenced the Area of flowers with the mean area being greater in Wide than Narrow buffer strips. The lack of significant interactions between *Buffer width* and *Geolocation* indicates effects were consistent across geographical locations. While it is feasible that the greater area of flowers in Wide buffer strips could simply be due to these buffer strips having a higher percentage of fenced transect, initial models that included the variable *Percentage fenced* indicated this was not the case.

3.3. Impact of riparian management on bumblebee diversity

There was a highly significant effect of *Coarse management* (Table 2b, Appendix 3) on all bumblebee response variables. Fewer bumblebees and bumblebee species were recorded in Field transects than in margin transects, and Fenced buffer strips had more even and diverse bumblebee assemblages than Unfenced margins. These findings were supported by the more complex models which found *Fencing* to clearly enhance the diversity and evenness of foraging bumblebees. Effects of *Fencing* on diversity and evenness were significant following the inclusion of floral resource variables (i.e. *Area of flowers* and *Flowering plant species richness*) indicating that *Fencing* effects were not solely driven by the *Area of flowers* being greater in Fenced buffer strips. Effects of *Fencing* on the frequency of bumblebee visits (i.e. bumblebee abundance) were marginally significant, however, they became insignificant when floral resource variables (i.e. *Area of flowers* and *Flowering plant species richness*) were included in the model prior to testing for effects of *Fencing*, indicating that effects of *Fencing* on bumblebee abundance were largely driven by differences in floral resources. *Fencing* did not influence bumblebee species richness. No significant interaction was found between *Fencing* and *Geolocation*, indicating that effects were consistent across geographical locations.

Complex models indicated that all bumblebee response variables differed between Wide and Narrow buffer strips. In both geographical locations, a greater number of bumblebees were recorded in Wide buffer strips than Narrow buffer strips. In Ayrshire, Wide buffer strips also supported a higher number of bumblebee species, and more even and diverse bumblebee assemblages than Narrow buffer strips. A similar trend was not, however, found in Kirkcudbrightshire and significant interactions between *Buffer width* and *Geolocation* were detected in models for bumblebee evenness, species richness and diversity (Table 2b, Appendix 3).

Bumblebee abundance, species richness and evenness showed a significant positive relationship with the *Area of flowers*, but no significant effects of *Flowering plant species richness* were found after adjusting for *Area of flowers*. *Area of flowers* differed between Wide and Narrow buffer strips. However, when floral resource variables were included in models prior to the inclusion of *Buffer width*, significant effects of *Buffer width* were still detected indicating that effects of *Buffer width* were not simply due to wider margins having a greater *Area of flowers.*

3.4. Drivers of bumblebee assemblage structure

Canonical correspondence analyses of the bumblebee assemblage data yielded eigenvalues of 0.088, 0.006, 0.162 and 0.152 for axes 1-4 respectively. Only two of the 21 variables included in the analyses were significant and thus only the first two axes are pertinent to the interpretation of results. Axis one accounted for 15%, while axis two accounted for 1%, of the total variation in bumblebee assemblage structure. *Bank height* ($F = 5.62$; $P < 0.005$) and *Area of flowers* ($F=2.38$; $P < 0.05$), significantly influenced bumblebee assemblage structure (Fig. 3). *Bombus pratorum* (L.) and *Bombus hortorum* (L.) were both associated with higher bank heights and riparian field margins with a greater *Area of flowers.* While no significant influence of *Buffer width* (inputted as a continuous variable) was detected, there was a tendency for Wide buffer strips to have higher axis 1 scores than Unfenced margins or Narrow buffer strips (Fig. 3). As *Buffer width* and *Area of flowers* were confounded, the lack of significance of the former could be due to the inclusion of the latter in the analyses.

3.5. Impact of riparian management on butterfly diversity

Significant effects of *Coarse management* were detected for all butterfly response variables (Table 2c, Appendix 4). Butterflies were more frequently observed and assemblages were richer, and more even and diverse in transects adjacent to watercourses than in Field transects. Complex models indicated that abundance of butterflies was greater in Fenced buffer strips than Unfenced margins. Effects of

Fencing on butterfly species richness were only detected when floral resource variables were included in the model prior to effects of *Fencing*, and even then effects were only marginally significant. *Fencing* did not impact the diversity or evenness of assemblages.

A significant effect of *Buffer width* was detected for all butterfly response variables when included before floral resource variables. In both geographical locations butterflies were recorded more frequently, and assemblages were richer, more even and diverse, in Wide than Narrow buffer strips. No significant interaction was detected between *Geolocation* and either *Fencing* or *Buffer width* indicating that effects of these factors were consistent across geographical locations.

All butterfly response variables showed a strong positive relationship with *Area of flowers*, and the number of butterfly species was also positively influenced by *Flowering plant species richness* in models where this variable was included following margin attribute variables. Following the inclusion of floral resource variables, significant effects of *Buffer width* were still detected for abundance, species richness and diversity indicating that differences between Wide and Narrow buffer strips were not simply driven by differences in floral resources. When floral resources were included in the model before *Buffer width* effects of *Buffer width* were not detected for evenness indicating that evenness was driven by wider margins having a greater area of flowers.

3.6. Drivers of butterfly assemblage structure

CCA of the butterfly assemblage data found eigenvalues of 0.165, 0.160, 0.112 and 0.552 for axes 1-4 respectively. Only three environmental variables significantly influenced butterfly assemblage structure and axes 1-3 explained 6.0%, 5.9% and 4.1%, respectively, of the total variation in assemblage structure. *Geolocation* ($F = 2.67$; $P < 0.005$), *Area of flowers* (F-ratio= 2.73; $P < 0.001$) and *Buffer width* (inputted as a continuous variable rather than as a categorical variable: $F = 2.67$; $P < 0.05$) significantly influenced the structure of butterfly assemblages (Fig. 4).

Pararge aegeria L. and *Pieris brassicae* L. were associated with Kirkcudbrightshire and *Anthocharis cardamines* (L.) was associated with Ayrshire. Transects in Ayrshire were conducted earlier in the season and thus captured the flight period of this early emerging butterfly. A significant effect of *Buffer width* (inputted as a continuous variable) was detected and Unfenced margins, Narrow buffer strips and Wide buffer strips are clearly separated along axis 1, with Wide buffer strips, having the highest axis 1 scores while Unfenced margins had the lowest scores. *Anthocharis cardamines*, *Aglais io* L., *Vanessa atalanta* (L.) and *Aphantopus hyperantus* (L.) were associated with wider buffer strips and with a higher *Area of flowers*. While *Coenonympha pamphilus* (L.) was only recorded in unfenced margins, it is important to note that this species was only recorded on two occasions. *Pieris napi* L. and *Aglais urticae* L. were the most common species and were ubiquitous occurring in all transect categories.

4. Discussion

This research highlights that while intensively managed grassland fields provide poor foraging resources for insect pollinators, their adjacent riparian margins (both fenced and unfenced) provide a greater area and diversity of flowers with positive implications for the abundance, richness and diversity of butterflies and bumblebees. Riparian field margins are typically less intensively managed than adjacent agricultural land as a consequence of environmental legislation, aimed at protecting watercourses, restricting many agricultural practices adjacent to watercourses (e.g. cultivation and the application of many agro-chemicals).

4.1. Impact of riparian management on insect pollinators and flowering plants

The ability of riparian buffer strips to deliver multiple benefits (e.g. promoting biodiversity, enhancing the ecological status of the watercourse and improving ecological connectivity) is highly dependant on their structure, location and management (Cole et al. 2012b; McCracken et al. 2012; Stockan et al. 2012). In this study, neither the erection of fences, nor the width of the resultant buffer strips, enhanced floristic diversity or richness. Previous research has found the erection of fences can result in a decline in flowering plant species and this can be attributed to the lack of disturbance by grazing livestock resulting in vigorous plant species shading out lower growing species (Feehan et al 2005; Stockan et al. 2012). Furthermore, the width of non riparian field margins has been found to have no influence on plant species richness (Field et al. 2005; Fritch et al. 2011). Vegetation in fenced margins, however, is typically taller with more structural components including flower heads, grassy tussocks and seed heads (Woodcock et al. 2009). Increased structural components can promote a range of phytophagous insects, their predators and parasitoids (Cole et al. 2012a; ÓhUallacháin et al. 2013; Woodcock et al. 2009). The current study found that while fencing did not influence the diversity or richness of plants in flower, fenced buffer strips, especially wider buffer strips, contained a greater area of flowers than unfenced riparian margins.

In agreement with previous research, bumblebee and butterfly assemblages in riparian field margins were strongly driven by floral resources (Bäckman and Tiainen, 2002; Field et al. 2005; Potts et al. 2009; Scheper et al. 2013). Fenced buffer strips supported a greater number of bumblebees and butterflies and more diverse assemblages of foraging bumblebees with the long tongued *Bombus hortorum* being associated with riparian margins with high concentrations of flowers. When compared with unfenced riparian margins, the higher abundance of bumblebees in fenced buffer strips could solely be attributed the greater abundance of flowers present. However, neither the greater diversity of bumblebees, nor the greater abundance of butterflies in fenced buffer strips could entirely be attributed to either a greater abundance or richness of flowers. The number of key floral species, which will be specific to both season and geographical location, has been found to be a better predictor of pollinator assemblages than the abundance or richness of flowers (Bäckman and Tiainen, 2002; Haaland et al. 2011; Pywell et al. 2011). In this study the majority of plant-pollinator interactions (87 %) occurred on just seven plant species, indicating their value as resources for insect pollinators (i.e. *Symphytum×uplandicum, S. sylvatica, S. palustris, T. repens, C. palustre*, *C. arvense* and *C. nigra*). The abundance of these key flower species, rather than the total abundance of flowers, is likely to be a more important determinant of insect pollinator populations in the study area. With the exception of *C. arvense* and *T. repens*, flowers of these species were more abundant in fenced buffer strips than unfenced riparian margins.

Contrary to previous findings that margin width does not significantly influence butterfly species richness (Field et al. 2005), wide buffer strips (i.e. over five meters wide) supported greater abundances of butterflies and assemblages were more diverse and richer than narrow buffer strips. Furthermore, the butterfly species *A. cardamines*, *A. io, V. atalanta* and *A. hyperantus* were associated with wide buffer strips. In agreement with the findings Bäckman and Tiainen (2002), wide buffer strips also supported greater abundances of bumblebees. Bäckman and Tiainen (2002), found that margin width did not influence the richness or diversity of bumblebee assemblages, and in the current study positive effects of buffer strip width on bumblebee diversity, evenness and species richness were only detected in one geographical location (i.e. Ayrshire). Landscape complexity can influence the biodiversity value of field margins (Power et al. 2012; Scheper et al. 2013). However, in the current study, landscape complexity was similar in the two geographical locations and the structure of bumblebee assemblages was not influenced by measures of landscape complexity (e.g. percentage of semi-natural habitat, or percentage of grassland).

Habitat quality has been shown to be a more important predictor of pollinator richness in field margins than landscape complexity (Kennedy et al. 2013). However, positive effects of buffer strip width on pollinators could not be solely attributed to the greater abundance of flowers observed in wider buffer strips. While the richness and diversity of flower assemblages did not differ between wide and narrow buffer strips, there were clear differences between the plant species that pollinators were observed foraging on. This indicates that margin width influenced the composition of floral assemblages and both composition and seasonal flowering patterns have been identified as key factors influencing the value of non-riparian field margins to insect pollinators (Carvell et al. 2007; Feber et al. 1996; Haaland et al. 2011; Holland et al. 2015). From a land-manager's perspective it is important to note that plant-pollinator interactions in narrow buffer strips were dominated by agriculturally injurious weeds belonging to the genus *Cirsium* (including *C. arvense* and *C. vulgare*). Furthermore, pollinators in narrow buffers strips were never recorded foraging on plant species identified as providing key resources early in the season (i.e. *Symphytum*×*uplandicum*, *S. sylvatica* and *T. repens*), indicating the importance of wide buffer strips, and indeed unfenced riparian margins, in providing resources early in the season. The availability of early season resources may increase the survival of newly founded bumblebee nests (Osborne et al. 2008; Westphal et al. 2009). Plant-pollinator interactions in wide buffer strips differed between the two geographical locations. In Kirkcudbrightshire interactions were dominated by a single genus (i.e. *Stachys* spp.), whereas in Ayrshire pollinators were regularly found foraging on a wider suite of species (i.e. *Symphytum*×*uplandicum*, *C. arvense* and *C. nigra*). The greater diversity and richness of bumblebees in wide margins in Ayrshire may therefore be the result of these margins providing a greater diversity of key plant species.

Bumblebees and butterflies both rely strongly on a continuous supply of nectar throughout the season but additional resource requirements differ. Bumblebees require a continuous supply of pollen and the availability of suitable nesting and hibernating sites (Potts et al. 2009; Pywell et al. 2005), while butterflies are driven by the availability of larval food-plants and shelter (Holland et al. 2015; Pywell et al. 2004; Pywell et al. 2011). Potts et al. (2009) found that while bumblebees were virtually absent from grassy field margins, adult butterflies were more abundant, and such field margins supported greater densities of butterfly larvae. The higher richness, diversity and abundance of butterflies in wide buffer strips may have been driven by a higher abundance of larval food plants. While the butterfly *Aphantopus hyperantus*, which has grass feeding larvae, was associated with wider buffer strips, there was no evidence that wider buffer strips supported a greater diversity of grasses. However, two of the species associated with wider buffer strips (i.e. *A. io* and *V. atalanta*) have larvae that feed on *Urtica dioica* L. which was more abundant in these buffer strips. Wider buffer strips may also have more tussock forming grass species, a greater structural diversity of vegetation and provide a greater barrier against the perturbations of the adjacent intensively managed agricultural fields. As a consequence, they are likely to provide more stable microclimates that provide shelter and overwintering sites for a range of invertebrates (Cole et al. 2012b; Woodcock et al. 2009) including butterflies (Pywell et al. 2004), and nesting opportunities for bumblebees (Kells and Goulson, 2003; Osborne et al. 2008).

While the findings of this study indicated that fenced riparian buffer strips, particularly wide buffer strips, provide important foraging resources (and potentially also other resources such as shelter, larvae food plants and nesting sites), it is important to note that it does not necessarily follow that pollinators in the wider landscape will be increased as a result of buffer strips. Furthermore, bumblebees and butterflies only form a component of the pollinator assemblage and other important pollinators (e.g. hoverflies and solitary bees) that differ in their ecology may respond differently to riparian management.

4.2. Considerations for riparian management

This research indicated that buffer strip width positively influenced the diversity and abundance of insect pollinators in riparian field margins. Wider buffer strips are also likely to be superior at delivering a range of other ecosystem services, including providing food for foliage gleaning birds, enhancing the ecological status of the watercourse, providing overwintering habitat for polyphagous predators and improving ecological connectivity (Cole et al. 2012a, 2012b; Collins and Rutherford, 2004; Greenwood et al. 2012).

The floristic diversity of riparian margins was not enhanced simply by the erection of fences, indicating riparian buffer strips may be under delivering as a foraging habitat for insect pollinators. Enhancing floristic diversity in buffer strips would ensure a more continual supply of nectar and pollen throughout the season, thus benefitting a wider range of pollinator species (Carvell et al. 2007; Pywell et al. 2011). Furthermore, increasing the abundance of tussock-forming grass species (e.g. *Dactylis* and *Deschampsia* spp.) would provide butterfly larval host-plants, nesting sites for bumblebees and shelter for butterflies (Holland et al. 2015; Kells and Goulson, 2003; Potts et al. 2009; Pywell et al. 2004). Seed banks in intensive grassland systems, however, tend to be impoverished and the establishment of diverse floral assemblages on nutrient enriched soils can be difficult (Fritch et al. 2011; Wood et al. 2015).

Management to enhance botanical diversity (e.g. planting seed mixtures) or facilitate natural regeneration (e.g. scarification or rotovation) following the erection of fences may benefit insect pollinators (Carvell et al. 2007; Fritch et al. 2011; Potts et al. 2009; Jönsson et al. 2015). There is, however, concern that planting diverse wild flower margins may detract pollinators from pollinating the natural flora (Holland et al. 2015; Mitchell et al. 2009). Furthermore, the cultivation of riparian field margins can result in sedimentation and bank destabilisation and watercourses can facilitate the dispersal of non native invasive species (Pysek and Prach, 1993). Management practices that enable natural regeneration without cultivation (e.g. restricted grazing or mowing) are therefore more appropriate for riparian b. Mowing field margins early in the season, particularly when accompanied with vegetation removal, can help enhance the abundance of pollen and nectar bearing species and extend their flowering period through reducing soil fertility and supressing nitrophilic perennial weeds and scrub encroachment resulting in increased abundances of foraging pollinators (Schippers and Joenje, 2002; Pywell et al. 2011). While mowing is a realistic option in arable landscapes where buffer strips can be established without fencing, in grassland situations grazing is a more viable management option, due to the difficulties in manoeuvring machinery in the confinements of fenced field margins. Grazing disturbance can increase the longevity of botanical diversity within field margins, thus benefitting insect pollinators (Carvell, 2002; Fritch et al. 2011). Allowing livestock access to riparian buffer strips, however, increases the risk of faecal contaminants entering the watercourse and thus grazing management should be implemented outside of the bathing season to minimise risk to human health (McCracken et al. 2012).

5. Conclusions

While intensively managed grassland fields offered little in the way of foraging resources for insect pollinators, their adjacent riparian field margins (both fenced and unfenced) were floristically more diverse and supported richer more abundant assemblages of insect pollinators. Pollinators were more abundant and assemblages were richer and more diverse in wide riparian buffer strips (i.e. over 5 m wide) when compared with narrow buffer strips (i.e. less than 3.5 m wide) or unfenced riparian margins. While bumblebee and butterfly assemblages in riparian buffer strips were strongly driven by floral resources, effects of buffer strip width could not be solely attributed to differences in the abundance or richness of flowers. This indicates that wide buffer strips provide additional resources for insect pollinators, such as early season floral resources, butterfly larval host-plants and more stable microclimates that provide shelter, bumblebee nesting and overwintering sites. The floristic diversity of wide buffer strips did not differ from unfenced margins or narrow buffer strips, indicating that their value could be further increased through management (e.g. restricted grazing or mowing) to open up the vegetation structure and prevent scrub encroachment. The widespread fencing of watercourses, especially when the resultant buffer strips are left unmanaged, could result in the homogenisation of these inherently complex and dynamic habitats. Fenced riparian buffer strips should therefore be strategically placed within the landscape to optimise benefits to ecological connectivity and diffuse pollution mitigation and thus enable land managers to capitalise on the benefits derived from land taken out of production.

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Table 1. Summary of the fixed and random effects investigated in GLMMs and LMMs* and the environmental variables considered in Canonical Correspondence Analyses (CCA). A description of each variable is provided and for categorical factors the levels of each factor is provided.

Environmental Variable	***Description***
GLMM/LMM Fixed Effects	
Coarse management	Broad site classifications: Field, Fenced buffer strip, Unfenced margin
Detailed management[†]	Description of transect category: Unfenced field, Wide field, Narrow field, Narrow buffer strip, Wide buffer strip
Geolocation	Location of sampling: Ayrshire, Kirkcudbrightshire
Year	Year of sampling: 2010, 2011
Sampling period	Period of sampling: Early June, Late June, July, Early August, Late August. .
Fencing	Factor determining if the watercourse was fenced: Fenced, Unfenced
Buffer width	Categorical variable buffer strip width: Narrow buffer strip, Wide buffer strip
Area of flowers	Percentage area of transect covered by flowers
Flowering plant species richness	Number of plant species that were in flower during transect walk
GLMM/LMM Random Effects	
Farm	Farm where site is situated
Site	Site (i.e. grassland field) with paired transect (e.g. Wide buffer strip and Wide field
Transect	A specific transect (e.g. Narrow buffer strip)
Sample	Unique sample derived from a specific transect on a specific sampling date
CCA Environmental variables	
Land use	Land use when sampling: Gazing, Silage/Silage with aftermath grazing
[§]*Buffer width*	Continuous variable indicating the distance in metres from fence to watercourse.
[§]*Opposite buffer width*	Distance in metres from fence to watercourse on the opposite side of the watercourse
Percentage fenced	Percentage of transect area that constituted fenced buffer strip habitat
[§]*Buffer area*	Area of fenced buffer strip including fenced area on opposite bank
Buffer perimeter	Perimeter of fenced buffer strip including fenced area on opposite bank
Buffer age	Time in years since fence was erected
Watercourse width	Mean width in meters of watercourse along transect area
Bank height	Mean bank height in meters along transect area
[§]*100m arable*	% of 100m ellipse constituting arable and horticulture
[§]*100m gardens*	% of 100m ellipse constituting gardens
100m grassland	% of 100m ellipse constituting grassland
100m semi-natural habitat	% of 100m ellipse constituting natural or semi-natural environment (e.g. road verges, deciduous woodland, scrub)
100m manmade	% of 100m ellipse constituting manmade structures (e.g. roads, buildings)
500m arable	% of 500m ellipse constituting arable and horticulture
[§]*500m gardens*	% of 500m ellipse constituting gardens
500m grassland	% of 500m ellipse constituting grassland
500m semi-natural habitat	% of 500m ellipse constituting natural or semi-natural environment (e.g. road verges, deciduous woodland, scrub)
500m manmade	% of 500m ellipse constituting manmade structures (e.g. roads, buildings)

* Generalised Linear Mixed Models (GLMMs) were fitted to response variables based on counts (i.e. species richness and butterfly and bumblebee abundance) and Linear Mixed Models (LMMs) to all other response variables (i.e. Area of flowers, Shannon diversity and 1/Berger-Parker).

† As *Coarse management* is included in models prior to the inclusion of *Detailed management* Unfenced margin does not contribute to the testing of the effect of *Detailed management* and thus it is omitted from levels of this factor.

[§] Log transformed.

ble 2. Results of Simple and Complex GLMMs/LMMs conducted on flower (a), bumblebee (b) and butterfly (b) response variables giving numerator and ranges for denominator degrees of freedom. For bumblebee and butterfly Complex models F-values are derived from models with floral resource variables in after margin variables (top) and models with floral resource variables in before margin variables (bottom). The direction of significant effects for *Area of flowers* and *Flowering plant species richness* were positive. Fixed effects that were not significant in any model are omitted as are effects of *Sampling period* which were always highly significant.

(a) Flower response variables

Simple models	Area	Species	Shannon	1/Berger
Year $_{(1, 16\text{-}36)}$	0.00	8.27**	3.35	8.62**
Course management $_{(2, 29\text{-}38)}$	61.5***	87.0***	76.7***	33.3***
Detailed management $_{(3, 32\text{-}41)}$	4.11*	3.78*	4.18*	6.57**
Complex models				
Year $_{(1, 5\text{-}19)}$	0.98	14.0**	0.39	0.75
Fencing $_{(1, 14\text{-}21)}$	8.25*	2.43	1.83	1.77
Buffer width $_{(1, 12\text{-}20)}$	19.5***	0.22	0.64	3.29

(b) Bumblebee response variables

Simple models	Abundance	Species	Shannon	1/Berger
Year $_{(1, 15\text{-}325)}$	9.50**	2.74	0.29	0.10
Geolocation $_{(1, 10\text{-}25)}$	7.36*	6.65*	1.48	2.49
Coarse management $_{(2, 32\text{-}39)}$	22.6***	31.8***	23.0***	25.4***
Detailed management $_{(3, 39\text{-}56)}$	4.32**	2.90*	3.41*	3.29*
Complex models				
Year $_{(1, 8\text{-}161)}$	7.12*	0.81	0.21	0.06
Fencing $_{(1,18\text{-}22)}$	4.44*	4.05	10.7**	12.8**
	3.76	3.63	10.63**	12.6**
Buffer width $_{(1,15\text{-}19)}$	11.1**	9.10*	7.50*	7.96*
	8.18*	6.56*	6.35*	6.51*
Geolocation x Buffer width $_{(1,16\text{-}20)}$	1.64	5.56*	4.98*	5.45*
	1.26	5.05*	4.72*	5.14*
Area of flowers $_{(1, 154\text{-}170)}$	4.14*	2.03	0.25	0.37
	8.31**	6.24*	2.98	3.98*

(c) Butterfly response variables

Simple models	Abundance	Species	Shannon	1/Berger
Year $_{(1, 6\text{-}352)}$	15.1***	18.3***	6.22*	5.91*
Coarse management $_{(2, 32\text{-}133)}$	49.3***	35.7***	20.7***	23.9***
Detailed management $_{(3, 31\text{-}65)}$	4.22*	3.39**	5.76**	5.19**
Complex models				
Year $_{(1, 5\text{-}167)}$	19.6**	11.8***	4.94*	4.88
Fencing $_{(1, 22\text{-}29)}$	6.35*	3.92	1.48	0.97
	5.51*	4.71*	1.11	0.58
Buffer width $_{(1, 14\text{-}21)}$	12.8**	12.5**	12.0**	8.88**
	5.99*	6.38*	6.02*	4.24
Area of flowers $_{(1, 84\text{-}160)}$	5.90*	2.28	4.78*	4.16*
	14.7***	9.43**	11.9***	9.61**
Flowering plant species	2.28	5.69*	2.61	1.27
richness $_{(1, 53\text{-}86)}$	1.19	3.74	1.20	0.46

***P<0.001, **0.001≥P<0.01, *0.01≥P<0.05

Figure legends

Fig. 1. Plant-pollinator interaction graphs indicating effects of *Sampling period* on the frequency of visits to different flower species. Graphs are based on data summarised for all riparian margin transects (i.e. excluding field transects) collected during Mid June, July & Late August.

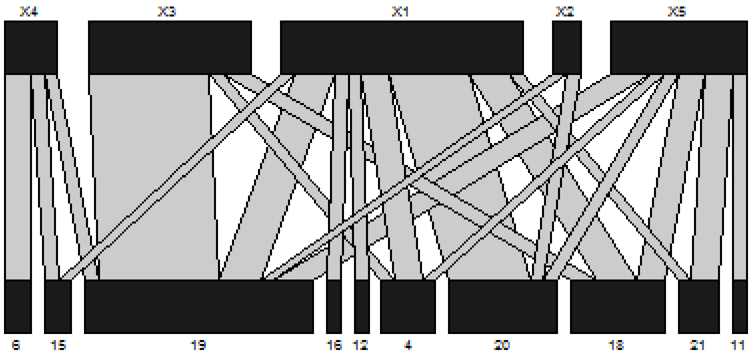
Fig. 2. Plant-pollinator bipartite interaction graphs indicating effects of riparian management on the frequency of visits to different flower species. Graphs are based on data summarised across *Sampling Periods* for each for the three riparian management category in the two geographical areas. Codes for flowering plants and pollinators are provided in Fig 1.

Fig. 3. Biplot derived from canonical correspondence analysis of the bumblebee log abundance data with sampling transects categorised by riparian management and significant (at the 5% level) environmental variables.

Fig. 4. Biplot derived from canonical correspondence analysis of the butterfly log abundance data with sampling transects categorised by riparian management and significant (at the 5% level) environmental variables.

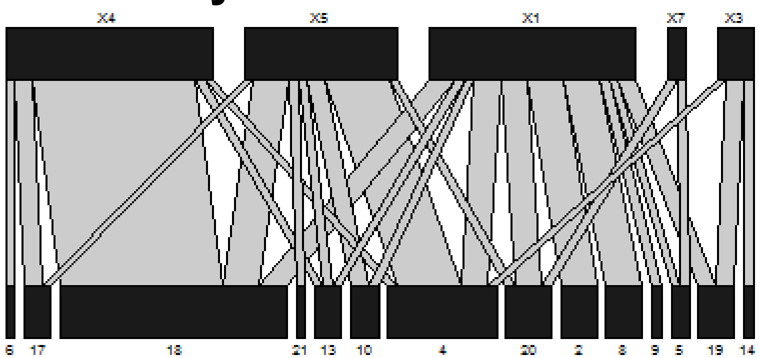
Figure 1

Mid June



Code	Pollinator Species
X1	*Bombus terrestris* L & *Bombus lucorum* (L.)
X2	*Bombus lapidarius* L.
X3	*Bombus pratorum* (L.)
X4	*Bombus hortorum* (L.)
X5	*Bombus pascuorum* (Scopoli)
X6	*Pieris napi* L.
X7	*Aglais urticae* L.
X8	*Inachis io* L.
X9	*Lycaena phlaeas* (L.)

Mid July



Code	Flower Species
1	*Angelica sylvestris* L.
2	*Cirsium arvense* (L.) Scop
3	*Centaurea nigra* L.
4	*Cirsium palustre* (L.) Scop
5	*Cirsium vulgare* (Savi)
6	*Digitalis purpurea* L.
7	*Epilobium hirsutum* L.
8	*Filipendula ulmaria* (L.)
9	*Heracleum sphondylium* L.
10	*Lotus pedunculatus* Cav.
11	*Lathyrus pratensis* L.
12	*Rosa canina* L.
13	*Rubus fruticosus* L. agg.
14	*Rhinanthus minor* L.
15	*Silene dioica* (L.)
16	*Scrophularia nodosa* L.
17	*Stachys palustris* L.
18	*Stachys sylvatica* L.
19	*Symphytum x uplandicum* Nyman
20	*Trifolium repens* L.
21	*Vicia cracca* L.

Late August

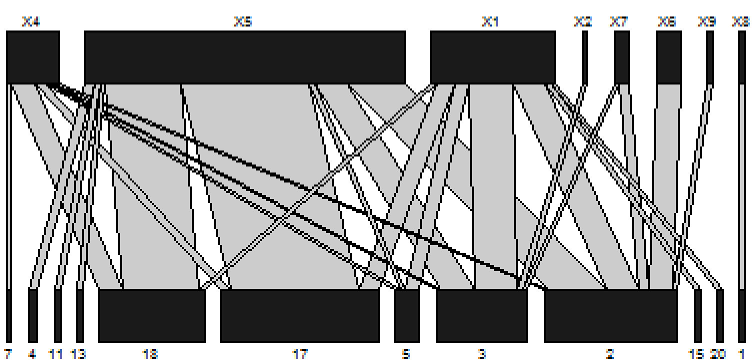


Figure 2

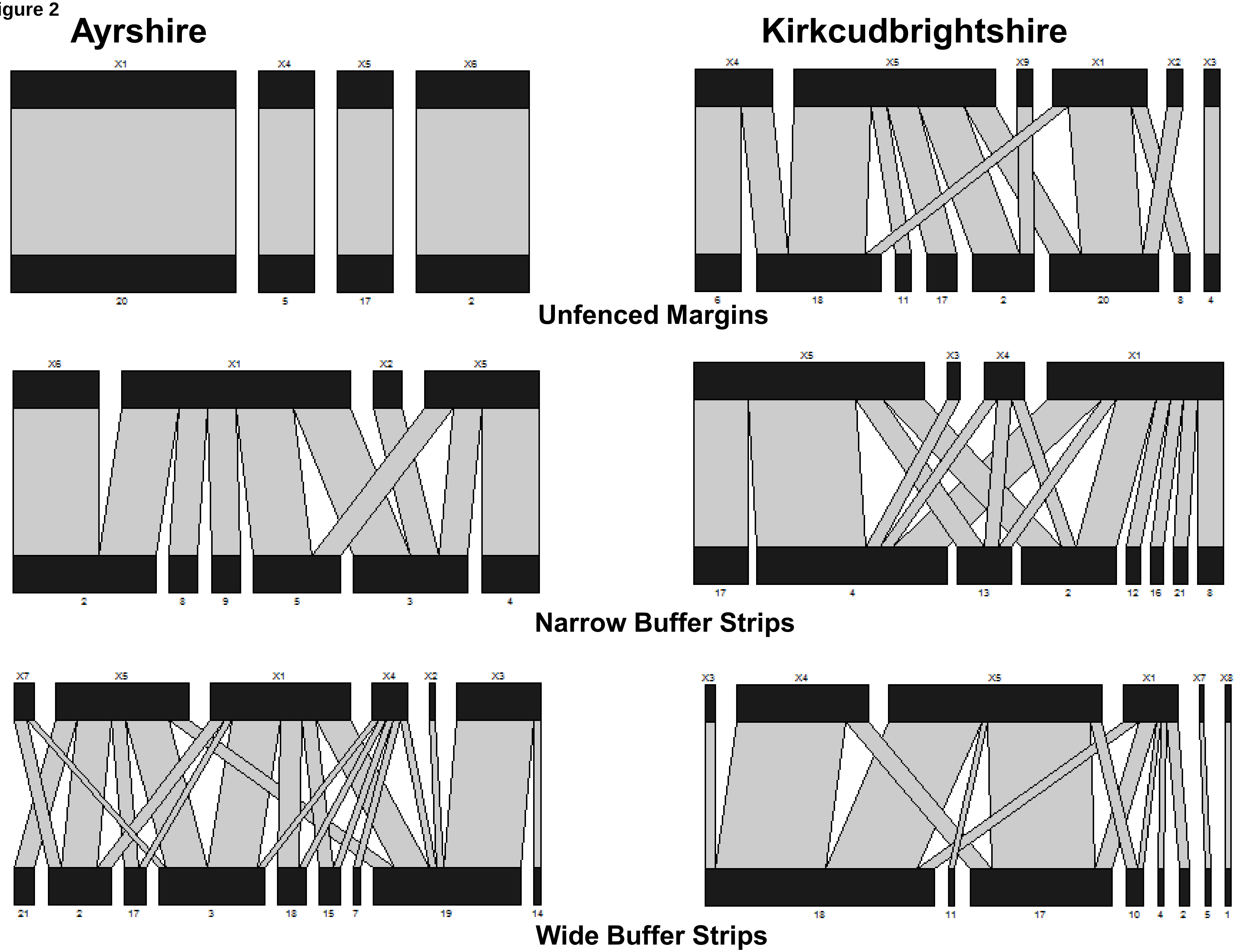
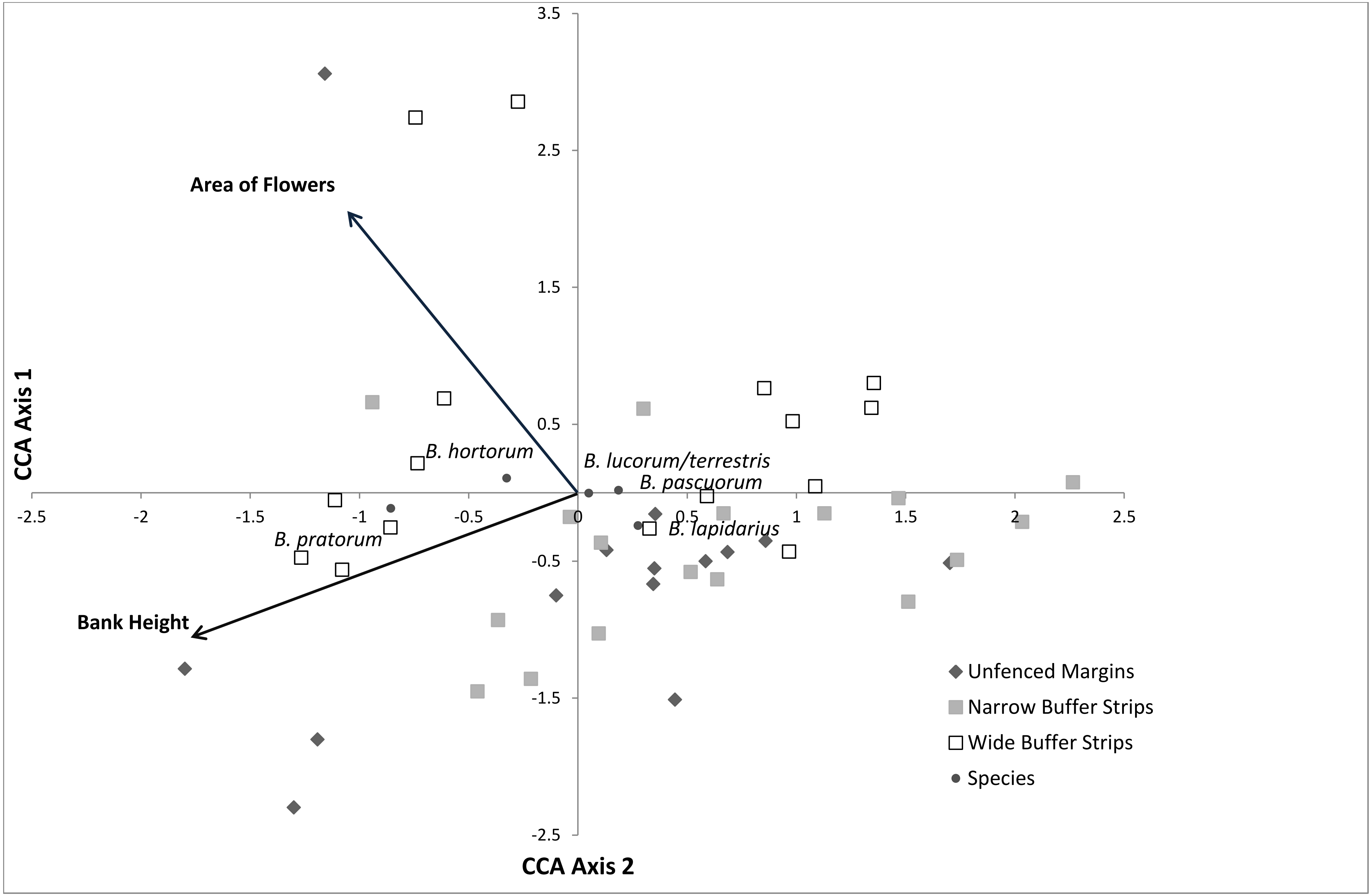
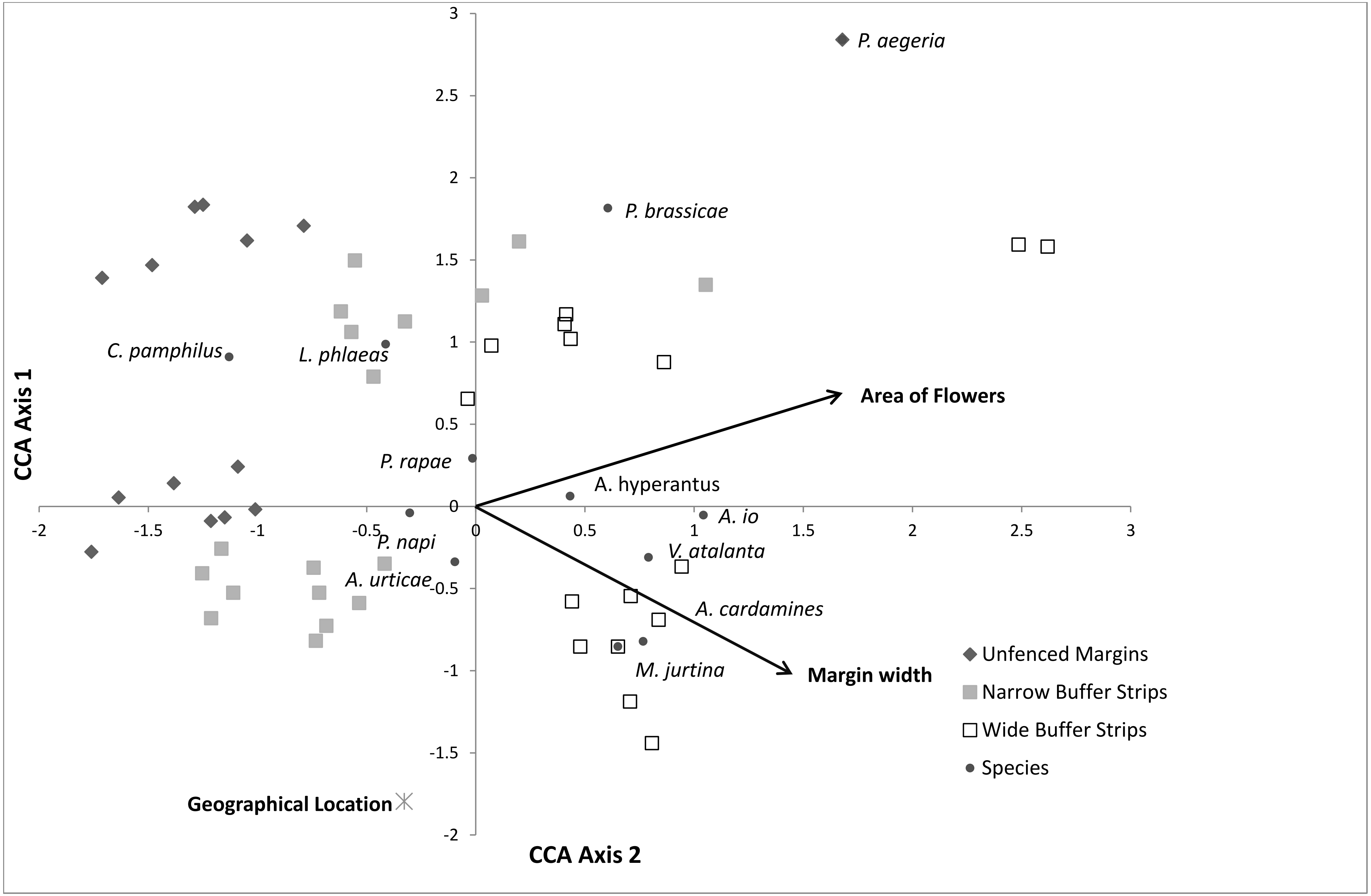

Ayrshire
Kirkcudbrightshire
X1
X4
X5
X6
20
5
17
2
X4
X5
X9
X1
X2
X3
6
18
11
17
2
20
8
4
Unfenced Margins
X6
X1
X2
X5
2
8
9
5
3
4
X5
X3
X4
X1
17
4
13
2
12
16
21
8
Narrow Buffer Strips
X7
X5
X1
X4
X2
X3
21
2
17
3
18
15
7
19
14
X3
X4
X5
X1
X7
X8
18
11
17
10
4
2
5
1
Wide Buffer Strips

Figure 3



3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
Area of Flowers
Bank Height
CCA Axis 1
CCA Axis 2
B. hortorum
B. lucorum/terrestris
B. pascuorum
B. lapidarius
B. pratorum
Unfenced Margins
Narrow Buffer Strips
Wide Buffer Strips
Species

Figure 4

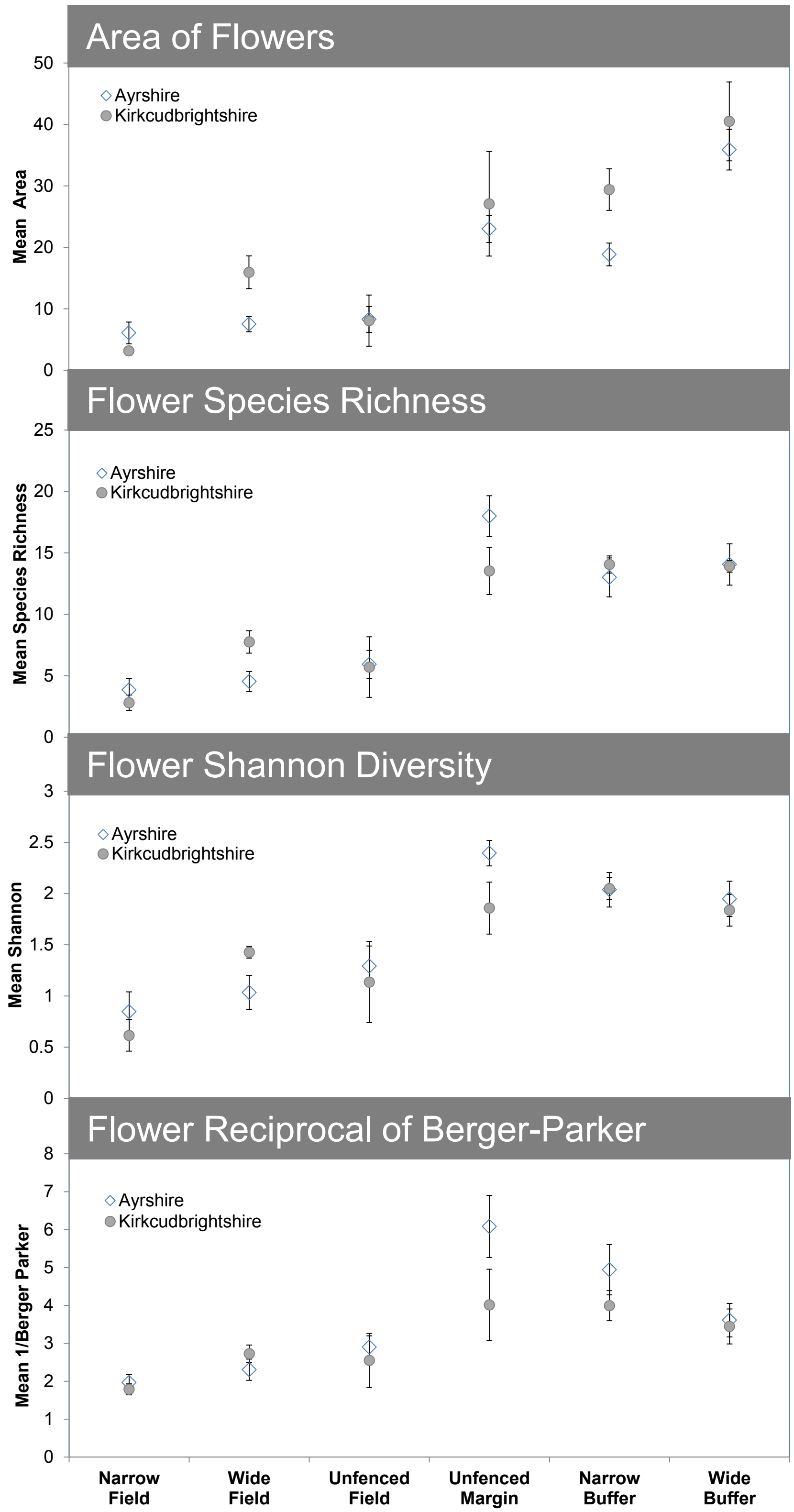

P. aegeria
P. brassicae
C. pamphilus
L. phlaeas
P. rapae
A. hyperantus
A. io
P. napi
V. atalanta
A. urticae
A. cardamines
M. jurtina
Area of Flowers
Margin width
Geographical Location
CCA Axis 1
CCA Axis 2
Unfenced Margins
Narrow Buffer Strips
Wide Buffer Strips
Species
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
2.5
3

Appendix 1: Table

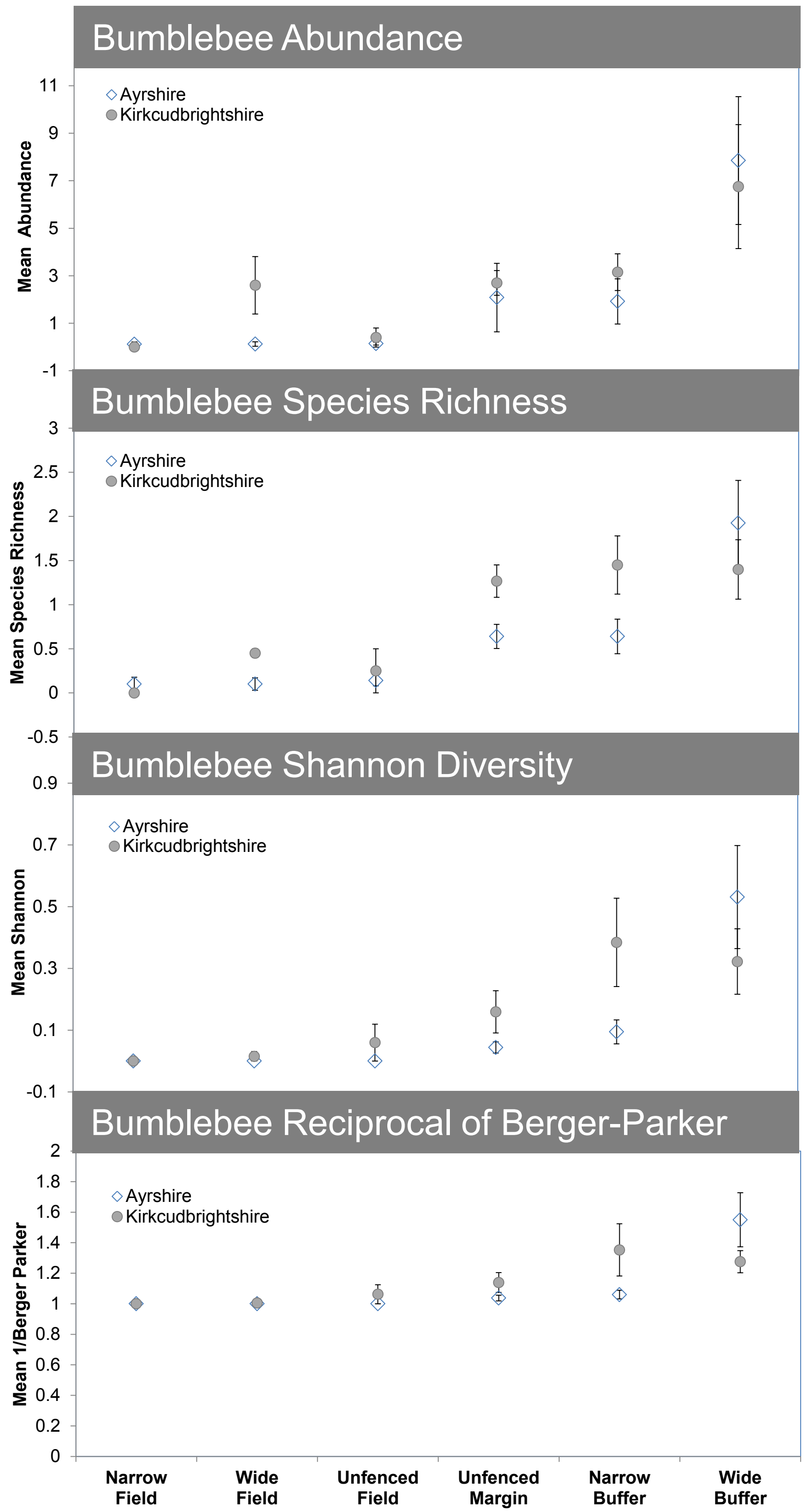
Appendix 1. Species inventory of insect pollinators recorded in the two geographical locations.

Bumblebee species	***Ayrshire***	***Kirkcudbrightshire***
Bombus terrestris L. & *Bombus lucorum* (L.) spp. complex	266	171
Bombus pascuorum (Scopoli)	115	87
Bombus hortorum (L.)	55	34
Bombus pratorum (L.)	40	6
Bombus lapidaries L.	9	8
Total	**485**	**306**
Butterfly Species		
Pieris napi L.	192	35
Aglais urticae L.	98	5
Aphantopus hyperantus (L.)	60	20
Pieris rapae L.	29	19
Inachis io L.	5	2
Vanessa atalanta (L.)	6	2
Lycaena phlaeus (L.)	1	7
Anthocharis cardamines (L.)	6	0
Vanessa cardui L.	2	0
Pieris brassicae L.	0	3
Maniola jurtina (L.)	2	1
Coenonympha pamphilus (L.)	1	1
Pararge aegeria L.	0	1
Total	**402**	**96**

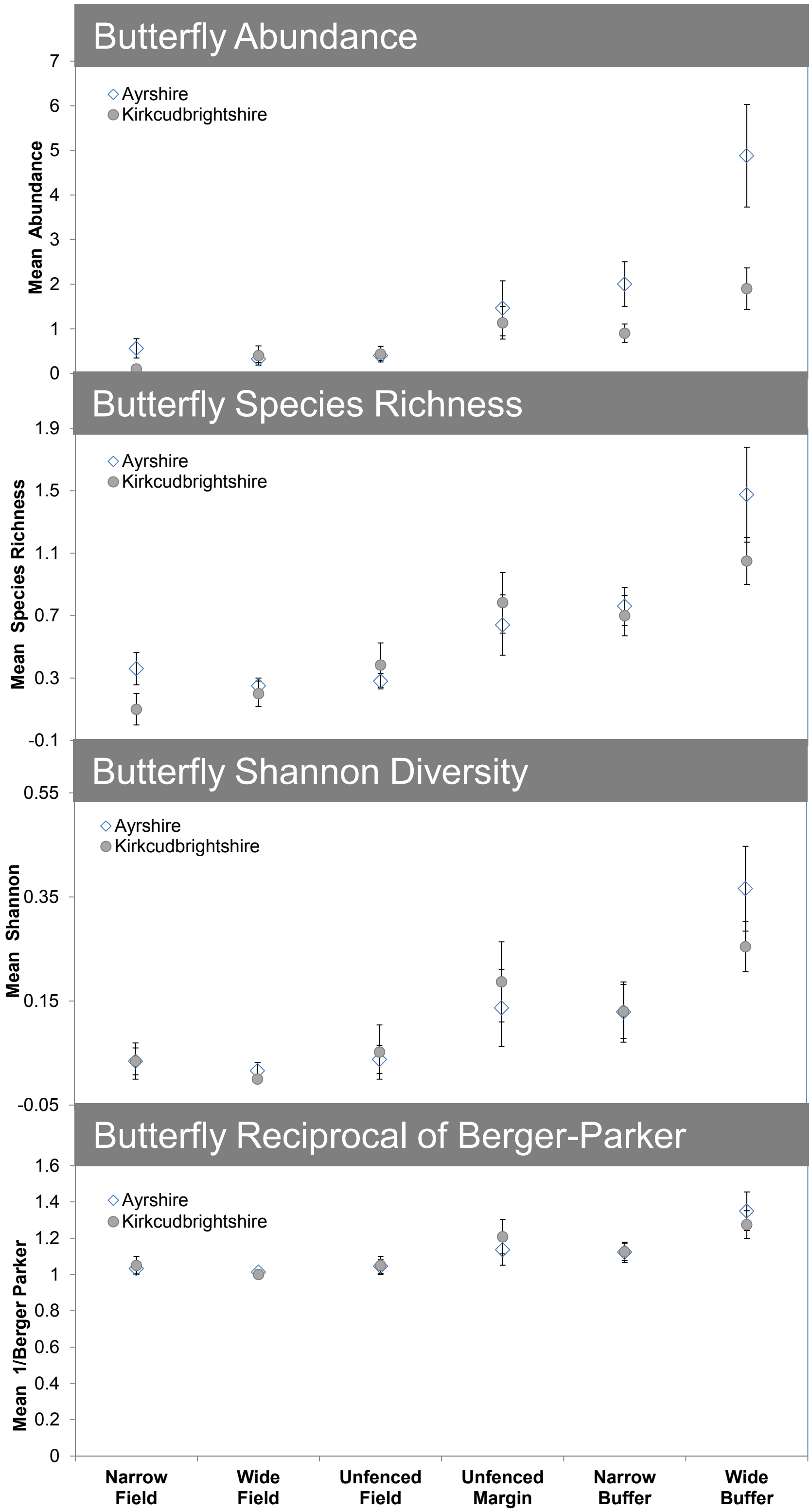
Appendix 2-4 Figures



Appendix 2: Influence of riparian management on flower area, species richness, Shannon diversity and 1/Berger-Parker evenness. The raw data sampled for each transect at different times were averaged before forming the means and SEMs presented for each transect category within each geographical location.



Appendix 3: Influence of riparian management on bumblebee abundance, species richness, Shannon diversity and 1/Berger-Parker evenness. The raw data sampled for each transect at different times were averaged before forming the means and SEMs presented for each transect category within each geographical location.



Appendix 4: Influence of riparian management on butterfly abundance, species richness, Shannon diversity and 1/Berger-Parker evenness. The raw data sampled for each transect at different times were averaged before forming the means and SEMs presented for each transect category within each geographical location.