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Potential benefits of commercial willow Short Rotation Coppice (SRC) for farm-scale plant and invertebrate communities in the agri-environment

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ABSTRACT

The cultivation of bioenergy crops (BECs) represents a significant land-use change in agri-environments, but their deployment has raised important issues globally regarding possible impacts on biodiversity. Few studies however, have systematically examined the effect of commercial scale bioenergy plantations on biodiversity in agri-ecosystems. In this study we investigate how the abundance and diversity of two key components of farmland biodiversity (ground flora and winged invertebrates) varied between mature willow Short Rotation Coppice (SRC) and two alternative land-use options (arable crops and set-aside land). Although the abundance of winged invertebrates was similar across all land-uses, taxonomic composition varied markedly. Hymenoptera and large Hemiptera (>5 mm) were more abundant in willow SRC than in arable or set-aside. Similarly although plant species richness was greater in set-aside, our data show that willow SRC supports a different plant community to the other land-uses, being dominated by competitive perennial species such as *Elytrigia repens* and *Urtica dioica*. Our results suggest that under current management practices a mixed farming system incorporating willow SRC can benefit native farm-scale biodiversity. In particular the reduced disturbance in willow SRC allows the persistence of perennial plant species, potentially providing a stable refuge and food sources for invertebrates. In addition, increased Hymenoptera abundance in willow SRC could potentially have concomitant effects on ecosystem processes, as many members of this Order are important pollinators of crop plants or otherwise fulfil an important beneficial role as predators or parasites of crop pests.

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1. Introduction

Increased use of organic farming practices, genetically modified crops and the implementation of agri-environment and other biodiversity enhancement schemes have brought about wide-scale changes to farming throughout the developed world [1,2]. More recently, the cultivation of dedicated non-food bioenergy crops (BECs) for power generation and biofuel production has raised concerns about potential effects on biodiversity in the agricultural environment [3–5]. Current emphasis centres on biodiversity loss in developing nations, but there have been significant shifts towards the cultivation of BECs in Europe [6], North America [7], and Australasia [8]. Although a number of plant species are utilized as BECs, it is the use of perennial grasses and fast growing woody crops – the so called "second generation crops" that pose the greatest changes in farm practices and have the largest potential to impact on biodiversity in the agri-environment [4,9].

Willow (*Salix* spp.) Short Rotation Coppice (SRC) is one of the most widely planted BECs in Europe [6,10]. It has been cultivated in the UK since the late 1980s, but the area of land dedicated to willow SRC has increased dramatically in recent years from under 1000 ha in 1999 to over 5000 ha in 2007 based on planting grant applications [11]. Long-term predictions suggest that 27 000–70 000 M ha of woody crops could be required by 2050 to meet bioenergy commitments, representing 11–29% of land cover in the UK [4].

Most research to-date suggests that SRC willow has positive effects on biodiversity [4]. However, these studies often focus on charismatic groups of species such as song birds [12,13] and butterflies [9,14], or potential pest species such as canopy invertebrates [15,14]. Moreover, few studies have examined how SRC affects species composition or abundance in comparison to the common alternative forms of land-use in the agri-environment (see [14]). This prevents any realistic assessment of the biodiversity implications of SRC expansion in Europe and beyond.

A further problem associated with many earlier studies on biodiversity within SRC plantations is that study sites were often located within small, non-commercial research-scale plantations, under 3 ha in area and managed in a way inconsistent with commercial SRC plantations (e.g. different harvesting cycles, greater mix of willow cultivars/clones per field, and greater range of age classes). Cunningham et al. [14] was one of the few studies to address this issue by selecting only large commercial sites. However, all sites were newly established (maximum plantation age of 4 years), and therefore, failed to reflect the true nature of mature willow SRC fields that may remain in use for up to 25 years [16].

The aim of this study was to compare biodiversity impacts of mature, commercial, large-scale willow SRC plantations with that observed in the two main alternative land-use options in the UK, arable and set-aside. Set-aside (land taken out of food production) was, until 2008, required under EU Common Agricultural Policy (CAP) in order to regulate food production. However, under the provisions of the CAP, set-aside could be used for the production of BECs, and thus it was particularly susceptible for conversion [17]. Currently, set-aside requirement is set at zero percent in the EU [18]. Consequently, BECs may now be an attractive option for any low grade farmland that, in the past, land owners often used to meet set-aside requirement.

Vascular plant abundance and diversity were investigated as they represent a significant biodiversity component within the agri-environment [19]. In addition, vascular plants provide shelter and food for a range of other species, making them critical to species diversity at the community level [20]. We also assigned plant species to life-history groupings based on [21] C-S-R strategy scheme, to make the results of this study comparable across geographic regions and provide an insight into the ecological processes affecting plant community development [21,22]. We assessed the abundance and diversity of winged invertebrates since this group of organisms has received remarkably little attention in previous studies of SRC yet comprises the bulk of terrestrial biodiversity and provides crucial ecosystem services as pollinators and predators of farm pests [23].

2. Methods

Field sites were selected primarily on criteria designed to ensure that sites represented mature commercial plantations. These criteria included:

- Commercial plantations managed in accordance with current Department for Environment, Food and Rural Affairs (DEFRA) guidelines [16]
- Individual fields greater than 5 ha in size
- Sites at least 5 years old, which had completed at least one harvest cycle
- Control fields of arable land and set-aside available close to plantations
- Plantations and control fields to be uniform in shape (i.e. standard field layout rather than narrow strips or convoluted in shape).

In total, three sites were selected in north Nottinghamshire, UK. SRC plantations ranged from 5 ha to 9 ha, and were established between 1998 and 2000 (Table 1). In all cases plantations consisted of a mix of 5 varieties of willow, containing approximately 30% Tora, with the remaining mix consisting of equal selection of three varieties from Ulv, Olof, Jorunn, Jorr, and a small amount <10% of Bowles Hybrid. Arable and set-aside fields were selected for their proximity and similarity (size and shape) to the SRC plantations. Arable fields which had been cultivated for cereal crops were selected, as cereals represent the highest proportion of arable land-use in Great Britain [24]. In all cases the arable fields had been cultivated with barley and had been harvested, between one and two weeks previously. The fields had however yet to be ploughed being stubble at the time of the study (August 2006) thus the ground flora was relatively undisturbed. The selected sites were relatively uniform in shape and all were previously arable land (Table 1).

2.1. Invertebrate diversity and abundance

Winged invertebrates were sampled using double-sided yellow sticky traps 22 cm × 41 cm (BC28211, Agrisense-BCS

Table 1 – Field site details giving grid references, field size, establishment year, (for willow year of planting for set-aside first year of registration) and date of last harvest. All sites were located in north Nottinghamshire and were selected based on criteria relating to age, and size of plantation, and location of plantation in relation to control fields. In all cases previous land-use was arable.

Site	Land-use (plots)	Location (WG84 DMS)		Size (ha)	Year established	Date of last harvest
		North	West			
1	Willow SRC	53:21:23.18	0:59:57.60	7.67	2000	2005
	Arable (barley)	53:20:42.22	0:59:42.28	20.01	N/A	July 2006
	Set-aside	53:19:44.93	0:58:56.42	3.82	2004	N/A
2	Willow SRC	53:25:59.40	0:48:6.62	9.00	1998	2004
	Arable (barley)	53:26:02.47	0:48:07.54	5.32	N/A	July 2006
	Set-aside	53:26:16.19	0:46:58.62	6.69	2004	N/A
3	Willow SRC	53:26:26.09	0:47:20.44	5.75	1998	2004
	Arable (barley)	53:26:28.25	0:46:57:12	10.00	N/A	July 2006
	Set-aside	53:26:22.62	0:47:03.05	5.87	2001	N/A

Ltd., Treforest Industrial Estate, Pontypridd, Mid-Glamorgan, UK). As described previously [25,26]. Yellow traps were selected over other colour options as they are considered to be effective over the widest range of invertebrate species [27]. To ensure samples were taken from an area as wide as possible, fields were divided into equal quarters. One side of the field was randomly selected and two transects along the center of the quarters (running from headland into to the crop at right angles crop edge). The third transect was then placed on the opposite side of the plantation at the intersection of the two remaining quarters. Sampling points were located along each transect in the headland, 5 m, 25 m, 50 m and 100 m into the cultivated area, apart from site 3 where the centre of the SRC was at 61 m, a central sampling point was used, both in the plantation and in the paired arable and set-aside fields.

As height has been reported to affect sticky trap efficiency [25] a set of three traps were installed at each sampling point, 0.10 m, 1 m and 2 m above ground level. This ensured that at least one trap in each land-use type was close to the vegetation canopy. Each set of three traps was suspended between two bamboo canes such that the 22 cm edge of each trap was parallel to the ground. To prevent vegetation adhering to the traps and thereby reducing their efficiency, each trap was surrounded by an open-ended tube made from galvanised wire netting (mesh size of 50 mm, Gardman, Moulton, Spalding, Lincolnshire, UK).

Traps were installed in each site over a 3-day period in August 2006, with each land-use (willow, arable, or set-aside) taking a full day to set up. Each trap was left in place for 144 h, before being collected, wrapped in cling film and frozen at −20 °C. All invertebrates over 5 mm in length were identified to Order. For invertebrates less than 5 mm in size, each side of the trap was divided into a 2 × 2.1 cm grid and all individuals within 10 randomly selected squares per side (5% of the total trap area) were identified to Order using a dissection microscope. Thus results for some Orders were divided into two size classes; referred to as 'large', (over 5 mm) and 'small' (under 5 mm). All individuals present on a given trap (regardless of size) were counted to give a total winged invertebrate abundance per trap.

Statistical analyses were performed in Minitab version 15 after normalising residuals with a square root transformation. The effects of land-use, distance into the crop, and trap height on the abundance of winged invertebrates were examined using the following split-plot nested ANOVA model (henceforth referred to as model 1):

$$\text{Abundance} = H_3|D_5|T'_3(F'_1(B'_3|L_3))$$

where prime identifies a random factor, subscript refers to number of factor levels, "|" to "cross-factored with", and "(" to "nested in" [28]. H = height, D = distance into crop (headland, 5 m, 25 m, 50 m, and 100/61 m), T′ = transect, F′ = field, B′ = blocking factor site, and L = land-use. With a single field for each of the nine B′ * L combinations, fixed main effects and their interactions were each tested against their respective interactions with site (which were not themselves testable because fields were not replicated for each land-use within the three site blocks). Although the low site replication gave few error d.f. for testing the land-use main effect, power to detect an effect was improved indirectly by the error variation being estimated from replicate transects. Larger numbers of error d.f. were available for testing land-use interactions with other treatment factors.

2.2. *Ground flora*

To account for the planting pattern in Willow SRC plantations a 2 m × 2 m quadrat was used to allow sampling of both a section of the tramlines (1.5 m gap between double rows of willow stools, used for machinery access) and intra-stool area [29]. Within each quadrat, the cover of each component species was recorded based on the Domin scale, excluding Bryophytes [30]. Floral surveys were conducted during August 2006.

Fields were divided into equal quarters and transects positioned in the center of each quarter (giving four transects) Within each transect, sample points were the same as the winged invertebrates but with an additional sampling point included at the edge of the cultivated area. The number of quadrats were set to allow 80 m^2 of cultivated area to be surveyed, an area equivalent to that recommended for surveying the herb layer in National Vegetation Classification (NVC) surveys and similar to that used in previous studies [14,15].

A sample of above ground plant biomass was also taken from three (randomly selected) ground flora transects. For each sample 0.25 m^2 of above ground biomass was collected

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from each quadrat, dried at 80 °C for 48 h (until no additional weight loss was seen) and weighed. Plant species recorded within each quadrat were designated attributes for three plant strategies: life history (annual or perennial), life form (grass or forb), and establishment strategy (C-S-R) [21]. Establishment strategies were then further grouped into four groups, C competitive species, CSR generalised species, S stress tolerant species, R ruderal species (following [22]). Prior to analysis of ground flora diversity, plant strategies, and dominant species, Domin cover values were transformed into percentages using the protocol described by Godefroid et al. [31].

Following square root transformation to ensure homogeneity of variances, the effects of land-use and distance into the crop on plant species richness, diversity and biomass were examined using the following split-plot nested ANOVA (henceforth referred to as model 2):

$$\text{Richness} = D_6|T'_4(F'_1(B'_3|L_3))$$

$$\text{Diversity} = D_6|T'_4(F'_1(B'_3|L_3))$$

$$\text{Biomass} = D_6|T'_3(F'_1(B'_3|L_3))$$

As for model 1, fixed main effects and their interactions were each tested against their respective interactions with the random variable site.

Due to variation in the total cover between land-uses, direct comparisons between plant strategies based directly on percentage cover were inappropriate. Therefore, the level of cover for a given plant strategy (Si) was calculated as a fraction of total cover within each quadrat (equation (1)) [22].

$$S_i = A_i/T \tag{1}$$

where A_i is the total cover per quadrat of a given strategy division (e.g. annual, perennial, e.t.c), and T is the total floral cover per quadrat.

To improve normality of residuals, the fraction of cover at each sampling location (i.e. headland, 0 m, 5 m, 25 m, 50 m, and 100/61 m) was averaged across all four transect per field given mean value per distance. Means were then arcsine transformed prior to analysis. Due to limited floral cover in arable land a limited number (maximum of three) sampling location had no cover. In these cases values were replaced with average values from the remaining two sites of same land-use. All strategies with the exception of S+ which, due to rarity was not suitable for statistical analysis, were examined using the following split-plot nested ANOVA (henceforth referred to as model 3).

$$\text{Strategy} = D_6|F'_1(B'_3|L_3)$$

Data manipulation was conducted in MS-Excel 2007 and statistical analysis in Min-tab 15.

3. Results

3.1. *Winged invertebrates*

The abundance of winged invertebrates was significantly influenced by both trap height and distance into the crop within the different land-use types (Tables 2–4), In contrast to arable and set-aside land, in which abundance decreased with height, invertebrate abundance in willow SRC increased from 0.10 m to 1 m, and remained high at 2 m (Table 4). Invertebrate abundance within willow SRC headlands was also higher than in the other land-uses, and higher than in the crop area of the willow SRC (confirmed by removal of willow data $F_{4,8} = 0.15$, $P = 0.960$, and headlands data $F_{3,6} = 0.72$, $P = 0.577$, Table 3). Invertebrate abundance in the other land-uses however, was not affected by distance into the crop as confirmed by the removal of the willow data ($L\chi D$ interaction: $F_{4,8} = 1.43$, $P = 0.31$).

3.2. *Distribution of winged invertebrate Orders*

Fourteen arthropod Orders were observed across all sites, however, statistical analysis was only applied to the seven most abundant Orders (Table 2). The remaining Orders were excluded due to low sample sizes. The abundance of large Hymenoptera, small Hymenoptera and large Hemiptera were higher in willow SRC than in the alternative land-uses (Tables 2 and 3). The remaining Orders showed similar abundance in all land-uses (Table 2). In many cases however, land-use had a significant effect as part of an interaction with height and/or distance. For example, small Diptera (<5 mm) and large Coleoptera, although common in the headlands of SRC, were much less abundant in the SRC crop than within the other land-uses (Table 4). Thysanoptera were also more abundant in SRC headlands, (Table 4) but their abundance within the crop remained similar between the land-uses even with the exclusion of the headland data ($F_{2,4} = 3.37$, $P = 0.139$).

Height and land-use interactions were also apparent for Hymenoptera, small Diptera, and Lepidoptera (Tables 2 and 4). For the most part, the effects of height on these Orders were largely in accord with the effect on total winged invertebrate abundance (Table 3). Lepidoptera however, showed a markedly different pattern, with a single peak in abundance at 0.10 m in set-aside, compared to a uniformly low abundance at all other locations (Table 3). Large Diptera and small Hemiptera were affected only by height (Tables 2 and 3), with similar overall abundance in each land-use type.

3.3. *Ground flora species richness, biomass and diversity*

Interactions between land-use and distance were present for species richness, ground flora biomass and diversity (Table 5). *Post hoc* testing showed species richness, biomass and diversity to be similar in the headlands of all three land-uses ("L" effect for Species Richness: $F_{2,4} = 1.42$, $P = 0.342$; biomass: $F_{2,4} = 1.11$, $P = 0.415$; diversity: $F_{2,4} = 2.87$ $P = 0.169$). Within the cultivated area (≥25 m), however, species richness was highest in set-aside land followed by willow SRC and finally arable land (L effect: $F_{2,4} = 17.45$, $P = 0.011$, Fig. 1A). At all distances ground flora biomass was similar in willow SRC and set-aside (Table 5, Fig. 1B), but much reduced in the cultivated area of arable land (Fig. 1B). Within the cultivated area the Shannon diversity index was highest in set-aside land, with willow SRC and arable land showing surprisingly similar levels of

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Table 2 – Comparison of the effect of land-use, distance into the cultivated areas (headland, 0 m, 5 m, 25 m, 50 m and 100 m/61 m) and heights of sticky trap (0.1 m, 1 m and 2 m) on total winged invertebrate abundance and of the nine most abundant Orders (ANOVA model 1). Orders are arranged in order of abundance on traps, with most abundant Orders on the left.

Q1

Factor	d.f.	Winged invertebrate abundance			Diptera >5 mm			Diptera <5 mm			Hymenoptera >5 mm			Hymenoptera <5 mm			Hemiptera >5 mm		
		MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*
L	2,4	20.97	0.04	0.958	473.92	4.82	0.086	86.49	4.18	0.105	64.92	13.27	0.017*	198.63	16.25	0.012*	42.17	14.94	0.014*
D	4,8	125.54	3.49	0.062	7.02	1.52	0.285	6.87	4.88	0.027*	4.00	11.70	0.002*	3.01	1.24	0.366	0.54	0.63	0.653
D*L	8,16	215.11	2.93	0.032*	7.02	0.73	0.661	20.55	7.30	0.001*	0.85	0.95	0.506	1.59	1.00	0.471	1.38	2.12	0.095
H	2,4	1662.5	28.22	0.004*	65.21	47.20	0.002*	68.38	11.13	0.023*	3.94	21.99	0.007*	7.29	5.41	0.073	5.06	18.90	0.009*
H*L	4,8	647.44	10.37	0.003*	21.61	1.82	0.218	25.74	5.36	0.021*	3.43	6.91	0.010*	5.61	4.30	0.038*	2.14	2.02	0.184
H*D	8,16	36.58	1.19	0.365	1.24	0.43	0.884	2.58	1.48	0.239	0.36	0.57	0.785	1.52	3.02	0.028*	0.15	0.26	0.969
H*D*L	16,32	41.74	1.81	0.075	3.56	1.21	0.314	2.21	2.29	0.023*	0.42	1.51	0.156	0.68	0.96	0.515	0.61	1.21	0.310

Factor	DF	Hemiptera <5 mm			Coleoptera >5 mm			Thysanoptera			Lepidoptera >5 mm			Psocoptera		
		MS	F	P	MS	F	P	MS	F	P	MS	F	P	MS	F	P
L	2,4	11.00	0.84	0.494	32.21	4.57	0.093	13.07	2.68	0.183	5.39	3.89	0.115	2.28	1.30	0.367
D	4,8	0.50	0.93	0.495	2.50	3.59	0.059	1.44	1.22	0.375	2.32	5.33	0.022*	0.83	3.07	0.083
D*L	8,16	0.64	0.46	0.866	1.62	4.88	0.003*	3.09	3.95	0.009*	0.32	1.51	0.231	0.09	0.19	0.989
H	2,4	7.26	53.07	0.001*	1.65	0.98	0.451	4.96	3.03	0.158	7.64	12.18	0.020*	0.66	1.14	0.405
H*L	4,8	1.19	1.64	0.255	2.50	2.70	0.108	0.50	0.89	0.511	3.29	25.69	0.001*	1.03	3.35	0.068
H*D	8,16	0.66	1.60	0.202	0.37	1.14	0.388	0.64	0.81	0.605	0.23	0.80	0.613	0.63	0.85	0.578
H*D*L	16,32	0.35	0.92	0.557	0.39	0.87	0.609	0.28	0.88	0.595	0.44	1.21	0.314	0.48	1.86	0.067

Results shown for fixed main effects (L = Land-use, D = Distance, H = Height) and their interactions; the un-replicated fields precluded testing of random effects F′, B′, T′ and interactions with them. Asterisk denotes $P < 0.05$.

Table 3 – Abundance of selected Orders within the different heights of sticky trap (0.1 m, 1 m and 2 m). Mean number of individuals given with standard errors in brackets, reflecting variation within land-uses (willow, arable and set-aside) between sites ($n = 3$).

Order	Height	Land-use		
		Willow SRC	Arable	Set-aside
All (total abundance)	0.1 m	1313.74 (107.95)	1761.77 (171.16)	1845.33 (309.89)
	1 m	1373.84 (69.43)	1299.43 (163.14)	1205.35 (138.65)
	2 m	1367.16 (95.72)	985.81 (66.76)	900.21 (62.25)
Large Diptera	0.1 m	76.02 (27.71)	22.07 (10.42)	58.75 (12.21)
	1 m	62.29 (15.78)	15.14 (3.91)	37.18 (9.73)
	2 m	61.86 (11.96)	20.84 (7.47)	21.80 (5.72)
Small Diptera	0.1 m	27.54 (1.03)	57.36 (10.51)	65.34 (19.25)
	1 m	27.25 (3.24)	40.13 (5.89)	42.63 (8.88)
	2 m	27.42 (4.47)	29.01 (2.88)	28.31 (3.99)
Large Hymenoptera	0.1 m	3.70 (0.78)	1.16 (0.35)	2.50 (0.46)
	1 m	5.89 (1.41)	0.95 (0.26)	1.66 (0.27)
	2 m	4.60 (1.00)	0.86 (0.48)	0.80 (0.28)
Small Hymenoptera	0.1 m	32.41 (5.19)	20.30 (5.98)	14.74 (0.48)
	1 m	33.31 (3.06)	15.58 (4.95)	11.49 (0.08)
	2 m	36.14 (5.04)	12.13 (2.03)	9.18 (0.59)
Large Hemiptera	0.1 m	3.51 (0.69)	1.00 (0.44)	3.22 (1.13)
	1 m	3.68 (0.77)	0.37 (0.12)	1.67 (0.15)
	2 m	2.73 (0.11)	0.65 (0.19)	1.18 (0.41)
Small Hemiptera	0.1 m	3.81 (0.78)	2.66 (1.23)	4.68 (1.46)
	1 m	3.64 (1.32)	1.55 (0.76)	2.52 (1.39)
	2 m	3.44 (0.91)	1.49 (0.68)	2.13 (0.82)
Large Lepidoptera	0.1 m	0.70 (0.15)	0.63 (0.37)	2.40 (0.60)
	1 m	0.71 (0.06)	0.39 (0.20)	0.73 (0.25)
	2 m	0.66 (0.29)	0.16 (0.12)	0.30 (0.09)

diversity (Fig. 1C). Interestingly within the cultivated area (≥5 m), ground flora species richness, abundance and diversity were not affected by distance, suggesting that the edge effect is limited to within the first 5 m of the crop (species richness D effect: $F_{3,6} = 1.48$, $P = 0.311$; L*D interaction: $F_{6,12} = 0.17$, $P = 0.986$; biomass D effect: $F_{3,6} = 0.42$, $P = 0.748$; L*D interaction: $F_{6,12} = 0.20$, $P = 0.971$; Diversity D effect: $F_{3,6} = 1.79$, $P = 0.249$; L*D interaction: $F_{6,12} = 0.79$, $P = 0.595$).

Table 4 – Invertebrate abundance of selected Orders with distance into cultivated areas (headland, 0 m, 5 m, 25 m, 50 m and 100 m/61 m), mean number of individuals per sticky trap. Standard error is given in brackets reflecting variation within land-uses (willow SRC, arable and set-aside) between sites ($n = 3$).

Order	Distance	Land-use		
		Willow SRC	Arable	Set-aside
All (total abundance)	Headland	1934.54 (194.19)	1412.46 (97.35)	1280.22 (250.30)
	5 m	1264.44 (177.43)	1187.48 (138.70)	1469.59 (215.48)
	25 m	1278.26 (213.06)	1360.70 (104.97)	1334.05 (129.03)
	50 m	1278.48 (103.90)	1338.83 (72.77)	1283.00 (165.71)
	100/61 m	1002.19 (86.52)	1464.89 (278.23)	1217.94 (176.73)
Small Diptera	Headland	54.08 (4.15)	39.60 (4.93)	42.89 (13.37)
	5 m	23.07 (6.25)	36.11 (3.26)	51.93 (12.35)
	25 m	22.78 (5.89)	46.41 (7.80)	47.01 (8.27)
	50 m	20.19 (1.91)	43.87 (7.21)	41.52 (9.84)
	100/61 m	16.89 (1.26)	45.25 (11.11)	43.78 (11.57)
Large Coleoptera	Headland	2.71 (0.68)	2.67 (0.95)	4.85 (2.91)
	5 m	0.44 (0.11)	2.63 (0.70)	3.22 (0.78)
	25 m	0.52 (0.26)	2.33 (0.72)	3.04 (0.58)
	50 m	0.78 (0.23)	2.03 (0.54)	2.85 (1.02)
	100/61 m	0.56 (0.11)	2.26 (0.70)	3.12 (1.11)
Thysanoptera	Headland	3.54 (2.25)	1.46 (1.26)	1.85 (0.98)
	5 m	0.26 (0.13)	2.56 (1.84)	2.67 (1.67)
	25 m	0.44 (0.23)	2.00 (1.40)	2.05 (1.51)
	50 m	0.85 (0.32)	2.84 (2.31)	2.15 (0.87)
	100/61 m	0.59 (0.30)	1.77 (0.98)	2.94 (1.14)

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Table 5 – Comparison of the effect of land-uses (willow SRC, arable and set-aside) and distance into cultivated areas (headland, 0 m, 5 m, 25 m, 50 m and 100 m/61 m) on species richness, ground flora biomass and diversity (ANOVA model 2).

Factor	d.f.	Species richness			Biomass			Diversity		
		MS	F	P	MS	F	P	MS	F	P
L	2, 4	26.97	13.64	0.016	445.48	24.65	0.006	3.61	3.49	0.133
D	5, 10	3.42	2.03	0.159	84.96	49.10	0.001	0.54	1.57	0.254
D*L	10, 20	2.07	5.26	0.001	33.38	12.97	0.001	0.30	3.73	0.006

Results shown for fixed main effects (L = Land-use, D = Distance) and their interaction; the un-replicated fields precluded testing of random effects F′, B′, T′ and interactions with them.

3.4. *Flora composition*

Comparison of the most abundant plant species in willow SRC, arable and set-aside showed that whilst some species were present in all land-uses, differences exist in the species composition of the three land-uses (Table 6). For example *Urtica dioica* and *Glechoma hederacea* were found in high abundance in willow SRC but do not feature in the top ten most abundant species for the other land-use types (Table 6). As indicated by the biomass data the mean amount of bare ground also varied greatly with lowest levels in arable and highest in willow SRC (Table 6).

3.5. *Plant strategies*

The fraction of annual verses perennial cover was not detectably affected by land-use ($F_{2,4} = 50.67$ $P = 0.07$). However, a large amount of variation in the fraction of

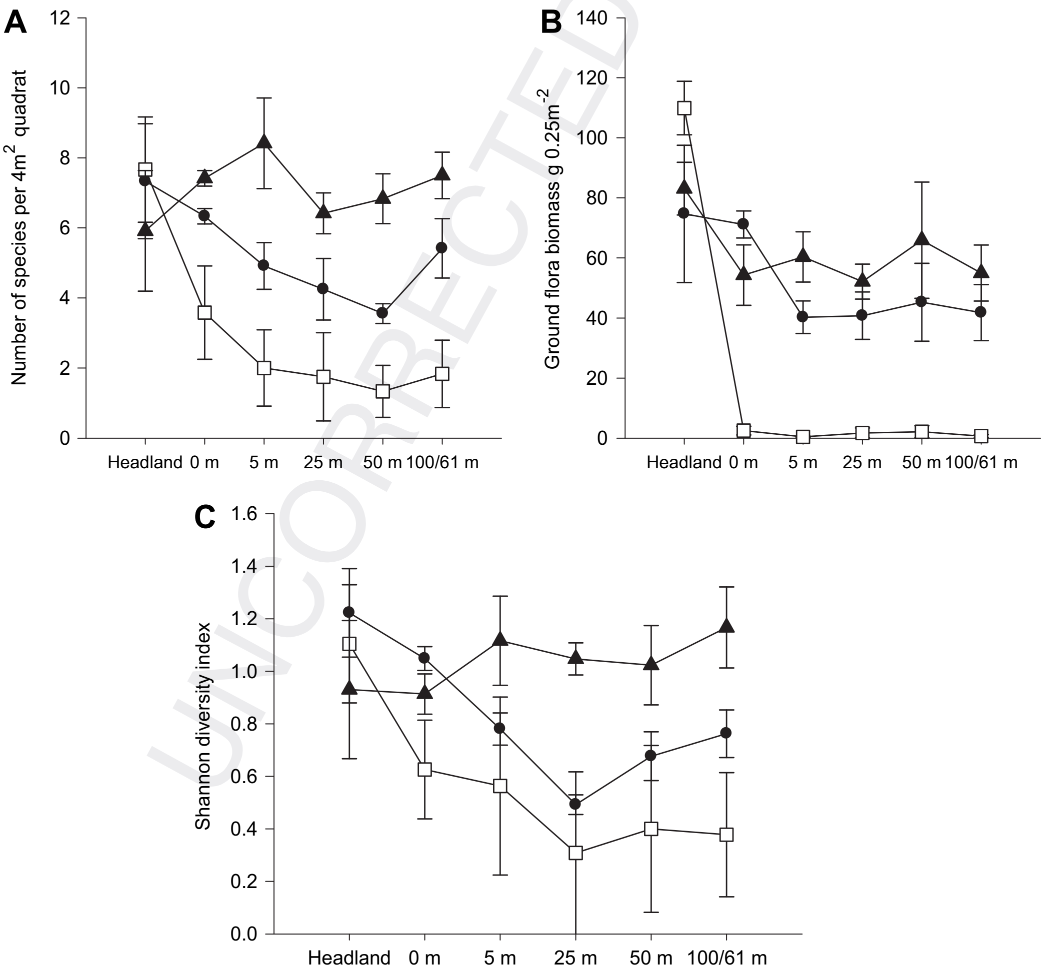

Fig. 1 – Variation in the mean ground flora (A) species richness, (B) biomass and (C) diversity with land-uses (willow SRC, arable and set-aside) and distance into the cultivated areas (headland, 0 m, 5 m, 25 m, 50 m, and 100 m/61 m). Circles represent willow SRC, squares arable, and triangles set-aside. Error bars give standard errors, reflecting variation within land-use between sites (*n* = 3). Scale bars are not consistent.

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Table 6 – The ten most abundant ground flora species within each land-use (willow SRC, arable and set-aside), based on sum cover of all quadrats percentage of bare ground also shown.

Willow SRC	% cover	Arable	% cover	Set-aside	% cover
Elytrigia repens	21.5	*Elytrigia repens*	2.8	*Holcus lanatus*	13.73
Urtica dioica	18.3	*Bromus sterilis*	2.8	*Agrostis stolonifera*	6.69
Holcus lanatus	18.3	*Arrhenatherum elatius*	1.8	*Taraxacum agg*	5.80
Dactylis glomerata	7.9	*Festuca rubra*	1.5	*Bromus hordeaceus*	5.18
A. stolonifera	5.3	*Galium aparine*	1.4	*Bromus sterilis*	3.64
Glechoma hederacea	3.9	*Fallopia convolvulus*	1.2	*A. elatius*	3.63
Festuca rubra	3.8	*Holcus lanatus*	1.0	*Agrostis capillaries*	3.37
Ranunculus repens	1.9	*Polygonum aviculare*	1.0	*Epilobium montanum*	2.83
Agrostis capillaris	1.8	*Dactylis glomerata*	0.7	*Chenopodium album*	2.38
Calystegia sepium	1.6	*Lolium multiflorum*	0.6	*Rumex acetosella*	2.04
Bare ground	7.7	Bare ground	80.9	Bare ground	23.02

annual and perennial cover was apparent in set-aside land and especially the arable land (Fig. 2A). In contrast, willow SRC was invariably dominated by perennial cover with mean annual cover per sampling location never greater than 2% (Fig. 2).

There was also a large amount of variation in life form especially in willow SRC (Fig. 2B). Effect of distance was present in all land-uses with increased grass cover in the headlands of all land-uses in comparison to the cultivated area ($F_{5,30} = 5.98$ $P = 0.001$) (Fig. 2B), but no overall effect of land-use was detected ($F_{2,4} = 5.29$ $P = 0.075$). The large variation in life form in willow SRC reflects the patchy nature of the flora cover in willow SRC, which both within and in particular, between sites often alternated between either grass cover or competitive forbs especial *U. dioica* (pers obs.). In contrast the cover in arable land appears more consistent and although not significant, the level of forb cover does increase with distance into the cultivated area (Fig. 2B).

Competitive (C+) and ruderal (R+) establishment strategies groups are affected by land-use (C+ $F_{2,4} = 9.53$ $P = 0.030$, R+ $F_{2,4} = 19.53$ $P = 0.009$) (Fig. 2C). Within these strategies arable and set-aside land had similar levels of cover (C $F_{1,2} = 3.72$ $P = 0.84$, R $F_{1,2} = 1.30$ $P = 0.37$) whilst willow SRC had a higher fraction of competitive cover and an almost complete absence of ruderal species. Competitive and ruderal cover were also affected by distances (C+ $F_{5,30} = 3.25$ $P = 0.018$, and R+ $F_{5,30} = 2.69$ $P = 0.040$) with the headlands of arable and set-aside land containing decreased ruderal and increased competitive cover compared to the cultivated area (Fig. 2C).

CSR+ species were present in all land-uses (Fig. 2C), with a similar fraction of cover and no interaction with distance present in willow SRC and set-aside (L * D $F_{5,20} = 0.51$ $P = 0.764$). In contrast in arable land, fraction of cover varied greatly with distance, being almost absent at 100/61 m yet accounting for over 60% of the mean cover at 25 m (Fig. 2B) resulting in a significant interaction between land-use and distance ($F_{10,30} = 2.16$ $P = 0.048$). However, overall CSR+ cover was similar across all land-uses ($F_{2,4} = 0.50$ $P = 0.640$).

Stress tolerant (S+) species were only recorded in set-aside land and at very low levels, accounting for only 2% ± 1.2% of total cover (Fig. 2C), making testing and conclusions on the distribution of this group inappropriate.

4. Discussion

4.1. *Winged invertebrates*

This study specifically examined invertebrate groups previously ignored in earlier studies of SRC biodiversity [4,14] and demonstrated clear differences in the assemblage of various winged invertebrate Orders in willow SRC compared with arable and set-aside, particularly at canopy height. This observation suggests that winged invertebrates in willow SRC are associated more with the willow canopy than with the ground flora; a finding consistent with Reddersen [32] who also concluded that for flower-visiting insect the ground flora within willow plantations is of little interest due to limited flowering. For the Hymenoptera, which show increased abundance at increased heights in willow, the attractiveness of the canopy may be related to the food sources in terms of leaf-feeding beetle larvae [33] and stem-feeding aphids [34]. Indeed individuals of Vespidae and Apidea families were observed feeding on honeydew produced by aphids on willow stem (R. Rowe pers Obs) a behaviour known for these families [35,36]. Our data suggest therefore, that willow SRC could provide an important resource for winged invertebrates and in particular Hymenoptera and Hemiptera species, even if weed control measures are increased in future as has been suggested by some plantation managers [37]. Nonetheless, we also note here that the wider role of the ground flora in supporting invertebrate community diversity within SRC plantations requires further research. It must also be noted that the arable fields were stubble at the time of this survey and although this would have limited effect on the "weed" flora recorded winged invertebrate diversity would have been affected by the limited crop cover. However, arable fields were expected to remain stubble or bare ploughed field for several months [38] so comparison to arable fields in this condition was deemed to be valid, although clearly temporal studies thoughout the full crops cycle are needed.

The increased abundance of winged invertebrates in willow SRC headlands together with the changes in Order abundance between the headlands and crop highlight the importance of headlands for overall abundance and diversity. This result supports previous work showing that the sheltered

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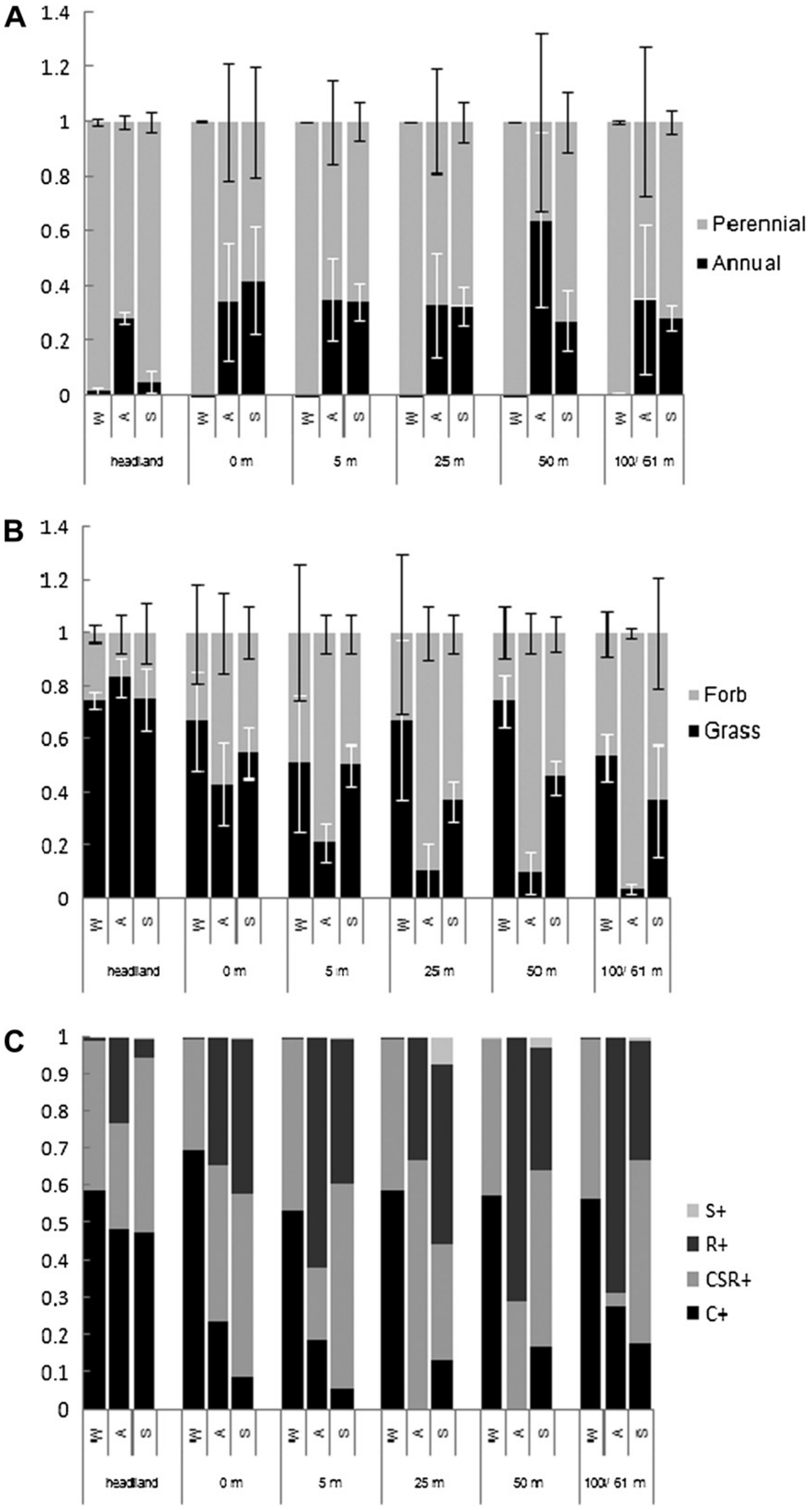

Fig. 2 – Variation in the fraction (A) life history (annual or perennial), (B) life form (grass or forb) and (C) establishment strategies (C+, CSR+, R+, S+), cover with distance. For clarity land-use are referred to by first letter, Willow SRC represented by W, arable by A, and set-aside by S. Error bars (standard error) removed from establishment strategies for clarity. Q2

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nature of willow headlands is beneficial to winged invertebrates [39]. There may also be an ecotone effect resulting in the increase in invertebrate abundance and the changes in Orders recorded.

4.2. *Ground flora*

Our results illustrate the beneficial value of mature SRC cultivation for plant community composition in the agri-environment. In particular, we demonstrate significant variation in the primary life-history strategies exhibited by the component plant community; i.e. SRC plantations contain a consistently high fraction of perennial species and were dominated by Competitive (C+) and Competitive – Stress tolerant – Ruderal (CSR+) groups, such as *Holcus lanatus* and *U. dioica*. Although the dominance of such species is consistent with previous studies [14,15,40], here we show a clear difference between plant community composition in SRC and the main alternative land-use options.

The variation in plant life-history strategies between land-uses is likely to reflect the reduced level of disturbance experienced by SRC (harvesting every three years) in comparison to the more frequent disturbance in arable and set-aside land. As a result, willow SRC provides a more stable habitat and consequently may play a role as a reservoir for many components of farmland diversity. In this respect it may provide a similar role to that attributed to arable headlands, beetle banks, and semi-natural habitats [41–43]. The light levels within willow SRC plantations are however likely to be reduced in comparison to these more open habitats [15]. Indeed although no direct measure of light intensities were taken in this study earlier studies have shown that during the growing season photoactive radiation (PAR) is reduced by between 98% and 88% within uncut willow plantation [15]. This is likely to affect the plant species which will successfully establish within these plantations. Several of the dominant plant species recorded in SRC have wider benefits for biodiversity. *U. dioica* for example, is host plant for a wide range of invertebrate species including Aphididae [44] and Lepidoptera such as Noctuidae, Nymphalidae and Pyralidae families [45], while *Dactylis glomerata* is general considered a relatively high quality grass species and is a food plant for Orthoptera species [46] as well as Hesperidae and Satyridae larvae [45]. *G. hederacea* also provides a source of early spring pollen and nectar for pollinating insects [47].

This study also clarifies the distance to which an edge effect is apparent in willow SRC, with a consistent species richness and ground flora biomass in the cultivated area from 5 m into the crop onwards. This suggests that whilst the crop edge may be important in maintaining a wide range of species most of the crop can be considered a relatively consistent “interior” habitat.

4.3. *Implication for biodiversity and ecosystem service*

Differences in ground flora species, strategies and invertebrate Order abundance between the land-uses indicate that willow SRC can have positive benefits for farmland plant and winged invertebrate diversity by increasing spatial and hence, habitat heterogeneity in the landscape. Caution should be excised however, if willow SRC is to be established on areas with set-aside type management as this may lead to a decrease in plant species richness and a change in species composition.

Beyond the value of SRC for biodiversity in the agri-environment, the changes in ground flora and winged invertebrates could have wide ranging impacts for ecosystem process and services. The increased ground cover in willow SRC may also help to reduce soil erosion and improve water quality [4]. Whilst increase in plant species richness and the associated leaf litter in diversity, could be beneficial for soil organism diversity, and may also affect decomposition rates [48]. The increase in species richness and plant abundance in willow SRC and set-aside land are also likely to have positive effects on primary production [49] and therefore, could have important and positive effects on the abundance and diversity within other trophic levels [50].

In the case of winged invertebrates, the increased abundance and diversity of the Hymenoptera highlights the important role that SRC might play in ecosystem service provision. The Hymenoptera comprise many nectivorous and predatory species; the majority of the large Hymenoptera caught belonged to the *Vespidea* with small species also including many from the Chalcidoidea superfamily. Consequently this Order provides many species that fulfil the important roles of pollinators and biological control agents, services essential to continued arable crop production worldwide [51,52].

The establishment of willow SRC plantations clearly has the potential to increase farm-scale biodiversity and may have particularly positive effects for Hymenoptera species and some plant species. Careful location of these plantations could also further maximize these positive effects on both biodiversity and ecosystem services for example by locating plantation in areas of high erosion risk or in arable-dominated landscapes.

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