Improved Contribution of Local Feed to Support 100% Organic Feed Supply to Pigs and Poultry

CAN THE RANGE CONTRIBUTE TO THE NUTRITIONAL NEEDS OF ORGANIC PIGS AND POULTRY?

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On-farm habitats, including woodlands, agroforestry, headlands, field margins and agri-environment scheme options such as game bird cover strips, support a wide diversity of floral and faunal resources that may provide opportunities to enhance feed provision from the range for monogastrics. There have been many biodiversity studies of these habitats and this desk study will collate these data and information to test the hypothesis that the range can contribute to the nutritional needs of pigs and poultry (ICOPP Deliverable 5.7).

Introduction

Organic principles insist that animals should be provided with the living conditions that accord with their physiology, natural behaviour and well-being (IFOAM, 2014) and organic standards require monogastrics to have access to outdoor areas ('the range'). In these systems, the animals would ideally derive part of their nutritional requirements from resources within the range, i.e. plants and invertebrates. In practise, however, it is very difficult to account for the contribution of these resources to meeting the needs of the animals, and so organic monogastric production, like conventional systems, relies primarily on the input of high amounts of supplementary feed containing cereals and oilseed products (Edwards, 2003). This can result in high nutrient losses from these outdoor systems as only a proportion of feed N input is retained by the animal (e.g. 30% feed input retained in pigs until slaughter (Eriksen *et al.*, 2006)), leading to concerns regarding eutrophication of the environment.

Recent studies, however, have indicated that reducing the input of supplementary feed can encourage foraging and in these cases, animals are capable of finding and utilising considerable amounts of different feed items from the range to balance the ration without negative effects on welfare or productivity. Horsted (2006) found that foraging on a diverse range area with abundant vegetation can contribute significantly to the nutritional needs of high producing laying hens, for example, they estimate that nutrient-restricted hens in some periods had up to 70% of their lysine and methionine requirement covered through forage material (Horsted, 2006; Horsted and Hermansen, 2007). Similarly, it is well documented that herbage intake has the potential to make an important contribution to mineral, trace element and vitamin supply for pigs, for example meeting 50% of the maintenance energy requirement and a high proportion of the amino acid, mineral and trace element requirements of dry sows (Edwards, 2003). A recent study by Jakobsen also confirmed that protein restricted growing pigs showed an increased foraging behaviour (through more rooting) compared to non-restricted pigs (Jakobsen, 2014).

While it is possible to modify the vegetation (and thus the available nutrients from forage) within the range through seeding and management, the associated fauna are to a large extent an unknown quantity. Chickens have been reported to feed on a wide range of invertebrates living in the surface soil including ground beetles (Carabidae), rove beetles (Staphylinidae), spiders (Araneae) and earthworms (Lumbricidae). Pigs have evolved as opportunistic omnivores that forage above as well as below ground and when kept in semi-natural environments, they eat a wide range of feed items including invertebrates (Andresen, 2000; Edwards, 2003; Jakobsen, 2014). Studies reported in Jakobsen (2014) have recorded 300 earthworms in the stomach of a single pig, and an intake of 414 to 1224 worms per day by village pigs weighing 20-40kg.

Animal proteins are of higher quality than those from plant origins (Ravindren and Blair, 1993). Insects have a high nutritive value; the protein content of edible insects ranges from 30% for wood worms to 80% for certain wasp species (Khusro *et al.*, 2012). Similarly, earthworms can also contribute significantly to meeting protein requirements, with crude protein content reported as 610g per kg dry matter for *Eisenia foetida* (Bassler *et al.*, 2000) and a mean of 43.8 and 9.2 mg lysine and methionine respectively per g dry matter for different species

(Pokarzhevskii *et al.*, 1997). Meal from cultivated invertebrates such as house fly larvae and pupae, earthworms, silkworm pupae, grasshoppers, bees and crickets have been used in animal feed (ADAS UK Ltd, 2005). Such systems are currently limited by the costs of production, which means that invertebrate proteins are more expensive to produce than plant proteins. However, in some habitats, naturally-occurring invertebrate densities can be quite considerable e.g. 322-480 earthworms per m^2 in clover grass fields equating to a total fresh weight biomass of 82-135g (van Eekeren *et al.*, 2010) and so may be able to contribute to the diet of foraging monogastrics.

The greatest barriers to integrating invertebrate resources from the range into feeding strategies for monogastrics are: (1) quantifying their availability; and (2) assessing their intake by the animals. Without this information, it is impossible to account fully for the contribution of the range in planning feeding strategies. This report aims to address the first gap in knowledge regarding availability of invertebrate resources by collating data on abundance and biomass of invertebrates in a range of on-farm habitats. This is done through a literature review of biodiversity studies, and a primary research project that compared soil faunal biodiversity in three habitats over a six month period. Finally, the data on abundance and biomass is translated into potential feed value using crude protein and amino acid data from analyses of invertebrate material.

Materials and Methods

Primary research

As part of an MSc research thesis, a primary research project investigating soil faunal abundance and biomass in three habitats on a poultry farm (FAI Farms Ltd, Wytham) in Oxfordshire, UK, was carried out between September 2013 and March 2014 (Bauer, 2014). The three habitats sampled were:

a) Agroforestry (Fig. 1a): ten year old cherry trees (*Prunus avium*) planted at 5m distance in rows 5m apart, understory of rye-grass permanent pasture.

b) Permanent pasture (Fig. 1b): organic rye-grass mixture, no manure applied, grazed in rotation by sheep and a small flock of laying hens.

c) Woodland (Fig. 1c): deciduous woodland, consisting of ten year old birch trees, spaced at approximately 1m within the rows and 2m between rows.

Fig. 1. FAI Farm, Oxford. (a) Agroforestry; (b) Pasture and (c) Woodland

Each month two soil cores measuring 25cm x 25cm to a depth of 10cm were taken from each habitat and hand-sorted for 30mins, with all invertebrates encountered extracted, counted and preserved in 80% alcohol. Invertebrates were divided into the following groups:

1. Lumbricidae (earthworms)
2. Araneae (spiders)
3. Coleoptera (beetles)
4. Insect larvae
5. Other arthropods (centipedes, millipedes, woodlice etc.)
6. Mollusca (slugs and snails)

The invertebrates were transferred to Ziploc bags, according to group and then stored in a freezer. Once a minimum of 10g per category had been gathered, these samples were sent for analyses of amino acids, dry matter and nitrogen content at the laboratory at Aarhus University in Denmark. Due to small sample sizes, the spiders, adult beetles and other arthropods were pooled into a single 'arthropod' group for analyses. Methods of analyses followed Commission Regulation 152/2009 for sampling and analysis for official controls of feedstuffs.

Literature review

There have been many studies of invertebrate biodiversity within agro-ecosystems over the last 20 years, driven primarily by concerns over the impact of modern agriculture on farmland flora and fauna. These studies tend to report biodiversity as abundance or density (i.e. number of individuals per sampled area), and species richness/density (i.e. number of species). Fewer studies report biomass. This review has focused primarily on biodiversity studies of invertebrates below ground, on the soil surface and in vegetation, in a number of cropped and non-cropped habitats found within the agricultural matrix (listed below). From each paper, information on abundance, biomass (where available) and habitat type was extracted and collated into a database.

Habitats

Cropped habitats:

- Agroforestry
- Fallow
- Crop residues - stubbles
- Permanent pasture
- Legume leys

Non-cropped habitats:

- Woodlands
- Field margins and headlands
- Game bird cover strips

Results

Abundance and biomass of soil invertebrates

Primary research

A total of 1001 invertebrates were sampled from the three habitats over the seven month period, with earthworms being the most abundant group (439 individuals) (Bauer, 2014). There was seasonal variation in abundance, with beetles and spiders abundance decreasing during the winter months, while earthworm numbers increased from autumn into winter (Fig. 2).

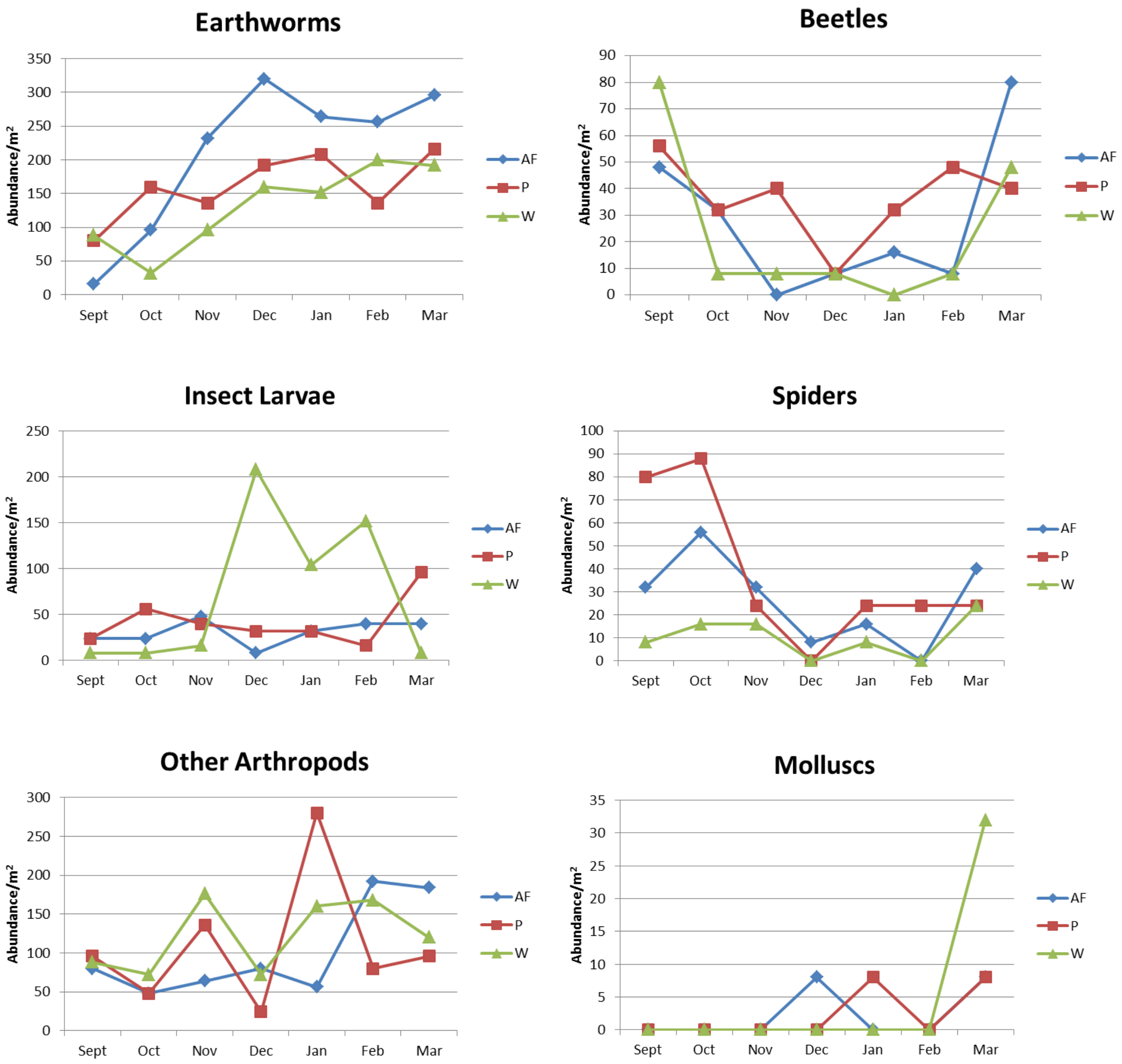

Fig. 2. Abundance/m^2 of ground invertebrates sampled in agroforestry (AF), pasture (P) and woodland (W) habitats between September 2013 and March 2014

An analysis of variance (ANOVA), with habitat and month of sampling treated as factors, showed statistically significant differences in abundances between habitats for earthworms, spiders and insect larvae (Table 1). Tukey tests revealed that there were significant differences between agroforestry and woodland for earthworms (higher abundances in agroforestry), pasture and woodland for spiders (higher abundances in pasture) and woodland and agroforestry for insect larvae (higher abundance in woodland).

Table 1 ANOVA of invertebrate abundance in different habitats (AF= agroforestry; W=woodland; P=pasture)

Taxa	df	F value	P value	Significant Differences
Earthworms	2	4.67	**0.021**	AF-W
Beetles	2	5.33	2.667	
Spiders	2	3.93	**0.036**	P-W
Larvae	2	5.03	**0.016**	W-AF
Other Arthropods	2	0.23	0.794	
Molluscs	2	0.50	0.614	

Literature review

Thirteen additional research papers provided data on abundance and/or biomass of soil invertebrates on farmland in northern Europe (Moreby *et al.*, 1994; Giller, 1996; Binet *et al.*, 1997; Brown, 1999; Frouz, 1999; Didden, 2001; Schmidt *et al.*, 2001; Smith, 2007; van Eekeren *et al.*, 2010; Fuller and Smith, 2012; Ruedy and Smith, 2012; Jakobsen, 2014; Crowley *et al.*, In prep). These data are shown in Appendices1-4, and summarised in Table 2. Earthworms were the most abundant invertebrates in all habitats, with means of between 207/m^2 in arable fields to 270/m^2 in non-cropped in-field habitats such as field margins and buffer strips. Densities varied considerably however (min 63 to max 548/m^2), reflecting differences in soil type as well as management. Insect larvae were also present in high numbers in grassland habitats, while litter-dwelling invertebrates such as woodlice and centipedes were more numerous in non-cropped habitats where leaf litter is able to accumulate.

Table 2. Mean abundance/m^2 of ground invertebrates in on-farm habitats summarising data from literature review.

	Cropped-arable		Cropped-pasture		Non-cropped – in-field		Non-cropped – woody elements	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Earthworms	**207.4**	63.3 – 548	**259.7**	90.7 – 480	**269.5**	149 – 337.2	**221.8**	107.9 – 294.5
Coleoptera Adults	**37.76**	21.93 – 55.82	**31.40**		**60.23**	33.19 – 79.96	**55.11**	9.48 – 136.8
Centipedes	**15.41**	11.85 – 18.96	**37.33**		**32.54**	13.47 – 59.85	**84.35**	32.59 – 151.7
Millipedes	**18.37**	14.22 – 22.52	**11.26**		**40.12**	6.52 – 77.63	**16.59**	5.92 – 36.15
Woodlice	**2.96**	0 – 5.93	**7.703**		**117.7**	35.56 – 243.6	**240.4**	43.26 – 614.5
Insect Larvae	**9.48**	4.74 – 14.22	**85.33**		**35.48**	4.74 – 66.37	**23.70**	18.37 – 30.22

Nutritional value

Primary research

Due to small sample sizes, the beetles and spiders were pooled with the other arthropod samples for nutritional analyses. Crude protein contents per dry matter (DM) are highest for molluscs, followed by larvae and arthropods (Table 3). The same sequence applies to lysine content. Molluscs and earthworms are highest in lysine content, 37.01 and 33.64 g/kg DM respectively, followed by larvae (29.63 g/kg DM) and then arthropods with a much lower level of 22.42 g/kg DM. Methionine was highest in earthworms (9.37 g/kg DM), closely followed by molluscs (9.23 g/kg DM), larvae (8.56 g/kg DM) and then arthropods (6.00 g/kg DM).

Table 3. Protein and amino acid contents of invertebrate material collected from the Oxford farm

Constituent	Earthworms	Arthropods	Molluscs	Insect Larvae
Dry matter	26.02	38.58	14.01	25.23
Protein (N*6.25) % DM	51.66	39.13	62.59	48.09
Amino acids (g/kg DM):				
Alanine	29.25	18.92	31.16	26.03
Arginine	33.03	23.24	39.20	25.99
Asparagine	47.25	33.64	63.91	45.71
Cystine	6.53	4.88	8.11	4.60
Glutamine	65.82	43.34	78.49	58.54
Glycine	26.86	24.64	36.81	21.87
Histidine	11.91	10.01	13.80	14.21
Isoleucine	21.54	15.35	26.54	19.13
Leucine	36.20	23.09	43.17	27.98
Lysine	**33.64**	**22.42**	**37.01**	**29.63**
Methionine	**9.37**	**6.00**	**9.23**	**8.56**
Phenylalanine	19.60	14.54	26.01	20.72
Proline	17.20	16.43	26.26	20.58
Serine	25.13	16.12	32.38	21.14
Threonine	23.06	14.30	28.50	19.70
Valine	24.29	17.81	31.09	25.25

The data on abundance and biomass from the three habitats are translated into potential feed value using crude protein and amino acid values from nutritional analyses of invertebrate material (Table 4, Fig. 4). The potential feed values per m^2 increases from September to March, reflecting the increase in abundance of earthworms (Fig. 4).

Table 4. Nutritional value (g/m^2) of invertebrates in agroforestry, woodland and pasture habitats averaged across the sampling period Sept 2013-March 2014.

Taxa	Habitat	Yield g/m^2			
		DM	CP	Lys	Met
Earthworms	Agroforestry	30.3	15.6	1.02	0.28
	Woodland	18.9	9.7	0.63	0.18
	Pasture	23.1	11.9	0.78	0.22
Arthropods	Agroforestry	10.2	4.0	0.23	0.06
	Woodland	3.9	1.5	0.09	0.02
	Pasture	26.0	10.2	0.58	0.16
Molluscs	Agroforestry	0.9	1.4	0.03	0.01
	Woodland	1.7	2.9	0.06	0.02
	Pasture	0.9	1.4	0.03	0.01
Insect larvae	Agroforestry	3.1	1.5	0.09	0.03
	Woodland	7.3	2.1	0.22	0.06
	Pasture	4.3	3.5	0.13	0.04
TOTAL	Agroforestry	44.5	22.5	1.37	0.38
	Woodland	31.8	16.2	1.00	0.28
	Pasture	54.3	27	1.52	0.43

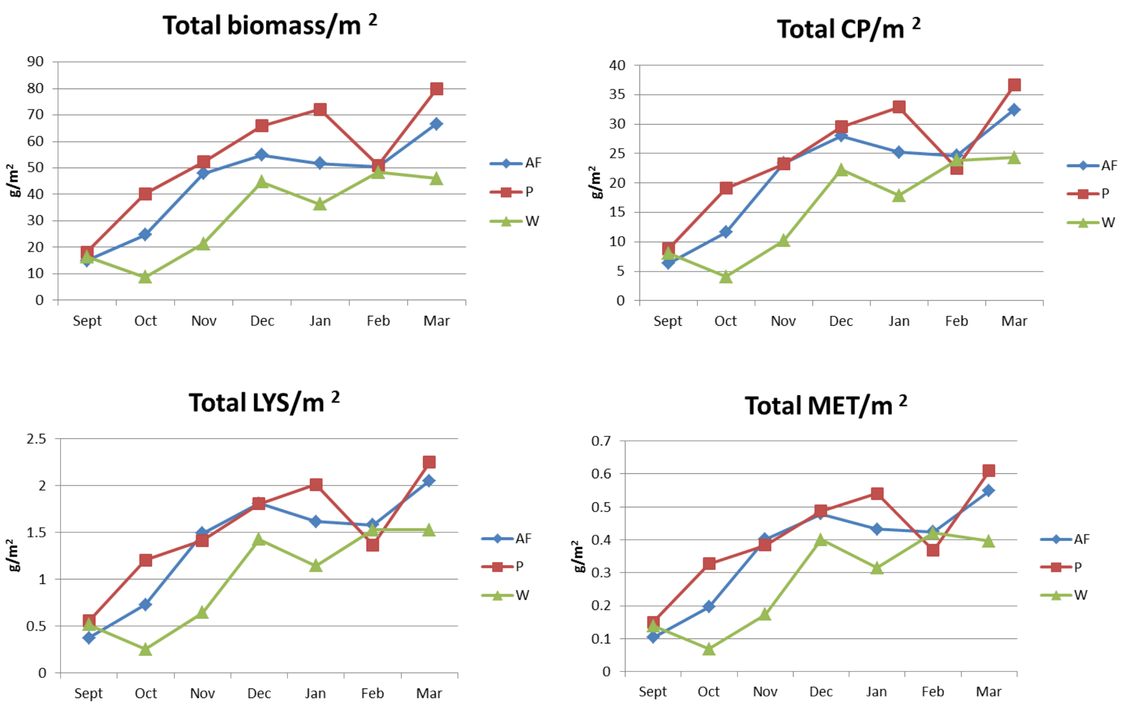

Fig. 3. Nutritional value (g/m^2) of invertebrates in agroforestry (AF), woodland (W) and pasture (P) habitats sampled monthly from September 2013 to March 2014. CP = Crude protein; LYS = lysine, MET = methionine

Literature review

Abundance data collated from the literature has been converted into feed resources/m^2 using the average weight/individual and nutritional analyses from the primary research project above (Table 5). This is based on a number of assumptions, and therefore is only a very rough generalisation of available resources within farmland habitats. For example, body weights may vary considerably from species to species, as may nutritional values.

Table 5. Feed resources and nutritional value of soil invertebrates from a number of on-farm habitats

		Cropped: arable				Cropped: pasture				Non-cropped: in-field				Non-cropped: woody elements			
	DM g/indiv	DM g/m^2	CP g/m^2	LYS g/m^2	MET g/m^2	DM g/m^2	CP g/m^2	LYS g/m^2	MET g/m^2	DM g/m^2	CP g/m^2	LYS g/m^2	MET g/m^2	DM g/m^2	CP g/m^2	LYS g/m^2	MET g/m^2
Earthworms	0.14	29.04	15.10	0.99	0.26	36.35	18.90	1.24	0.33	37.73	19.62	1.28	0.34	31.06	16.15	1.06	0.28
Coleoptera Adults	0.11	4.15	1.62	0.09	0.02	3.45	1.35	0.08	0.02	6.63	2.58	0.15	0.04	6.06	2.36	0.13	0.04
Centipedes	0.03	0.46	0.18	0.01	0.00	1.12	0.44	0.02	0.01	0.98	0.38	0.02	0.01	2.53	0.99	0.06	0.02
Millipedes	0.03	0.55	0.21	0.01	0.00	0.34	0.13	0.01	0.00	1.20	0.47	0.03	0.01	0.50	0.19	0.01	0.00
Woodlice	0.03	0.09	0.03	0.00	0.00	0.23	0.09	0.01	0.00	3.53	1.38	0.08	0.02	7.21	2.81	0.16	0.04
Insect Larvae	0.1	0.95	0.46	0.03	0.01	8.53	4.10	0.26	0.08	3.55	1.70	0.11	0.03	2.37	1.14	0.07	0.02

Meeting the nutritional needs of pigs and poultry

Table 6. Daily protein/amino acid requirements of laying hens (brown eggs), sows and growing pigs (90% Dry Matter) (From http://www.merckmanuals.com/vet/index.html)

g/day	Gestating sows	Lactating sows	Growing pigs (Kg) fed ad-lib						Brown egg layers
			3-5	5-10	10-20	20-50	50-80	80-120	
Feed intake	1880.0	5350.0	250.0	500.0	1000	1855	2575	3075	110
Protein	233.12	936.25	65.00	118.5	209.0	333.9	399.1	405.9	16.5
Lysine	10.152	48.685	3.75	6.75	11.50	17.62	19.31	18.45	0.76
Met. & Cyst.	6.956	23.54	2.15	3.80	6.50	10.02	11.33	10.76	0.33*

* Methionine only

Table 6 summarises the daily protein and amino acid requirements of different stages of pig production, and of laying hens. Of all the invertebrates studied, earthworms present the most potential in contributing to the nutritional needs of poultry in particular, while having only a minor contribution to pig nutritional needs. One square metre of most habitats studied would contribute considerably to the daily requirements of laying hens for methionine, and in most cases, completely meet lysine requirements also (Table 7).

Table 7. Nutritional value of earthworms in meeting the protein and amino acid requirements of laying hens

Habitat	Resource g/m^2			% daily requirements		
	CP	LYS	MET	CP	LYS	MET
Primary research						
Agroforestry	15.6	1.02	0.28	95	134	85
Woodland	9.7	0.63	0.18	59	83	55
Pasture	11.9	0.78	0.22	72	103	67
Literature review						
Cropped: arable	15.1	0.99	0.26	92	130	79
Cropped: pasture	18.9	1.24	0.33	115	163	100
Non-cropped: In field	19.62	1.28	0.34	119	168	103
Non-cropped: woody elements	16.15	1.06	0.28	98	139	85

Discussion

Comparison of the three ranges (agroforestry, woodland and pasture) showed that different habitats support different assemblages of invertebrates, with significantly more earthworms in the agroforestry compared to the woodland, more spiders in the pasture compared to the woodland, and more invertebrate larvae in woodland than in agroforestry. The highest biomass was of earthworms, which increased in abundance throughout the sampling period of September 2013 to March 2014, probably responding to increasing soil moisture. The arthropods generally decreased in abundance during the winter months, increasing again in spring. Nutritional analyses of the invertebrates identified that they offer a good source of protein and the amino acids lysine and methionine; earthworms, molluscs and insect larvae are of higher value than arthropods.

Invertebrate abundances of the three sampled habitats were similar to the mean abundances summarising those found in the literature. However, the literature review also identified considerable variability in abundances across different habitat types, highlighting the difficulty of reliably predicting the contribution of feed resources from the range in terms of invertebrate material. Careful management can enhance the numbers of soil invertebrates, for example, by minimising tillage activities and increasing organic matter inputs.

Translating invertebrate abundances into feed resources for pigs and poultry, it seems that $1m^2$ of most habitats would provide enough earthworms to meet over half of the daily methionine requirements of laying hens. Both layers and broilers must have a minimum of $4m^2$ of outside area under Commission Regulation EC 889/2008. Obviously we would expect the number of earthworms would decline over time in response to poultry foraging, and the challenge would be to identify the optimal time to move the birds to new areas and rest the previous range to allow invertebrate populations to recover. Horsted (2006) found that protein-restricted laying hens, fed a wheat-only diet, gave priority to feed items of animal origin, especially immediately after hens had been moved to a new foraging area, with the amount of earthworms consumed reducing with time spent foraging the area, reflecting a drop in availability, although earthworm numbers recovered when the foraging area was kept without hens for a few weeks.

The nutritional contribution from foraging is dependent on a number of factors: availability, motivation, voluntary intake, nutritional value and the ability of the pig or chicken to ingest and utilize the material (Jakobsen, 2014). Earthworm species differ in their content of various amino-acids, due to consuming different bacterial populations, which are one of the main sources of essential amino acids for earthworms (Pokarzhevskii *et al.*, 1997). Some insects produce toxic chemicals and serve as vectors or intermediate hosts to pathogenic microorganisms like bacteria, viruses and helminth parasites (Khusro *et al.*, 2012). Physical damage to the gut may be caused by spiny insects, for example, spiny legs and wings of grasshoppers may puncture the crop of chickens and rupture the intestines (ADAS UK Ltd, 2005). Earthworms can accumulate toxic residues particularly heavy metals and agrochemicals but no adverse effects on chicken health have been reported (ADAS UK Ltd, 2005).

Maximising the potential of on-farm habitats with regards to pig and poultry production, to take advantage of the feed resources available within the range, would require careful planning and changes in management. It is likely to be more appropriate for smaller enterprises with mobile housing units. However, there is great potential for pigs and poultry to become an integrated and functional part of the whole farming system, providing not only food for human consumption, but also ecosystem services such as optimised nutrient recycling, making use of diverse crop rotations, and contributing to pest and weed control (Jakobsen, 2014). This requires a shift in perspective, thinking of pigs and poultry in terms of their capabilities rather than being passive receivers (Andresen, 2000). Overall, this would increase the eco-efficiency of the farming system, and result in better use of existing resources, e.g. farm woodlands, pigs to cultivate soil, weeding and pest control by chickens and pigs.

In conclusion, the invertebrate fauna of cropped and non-cropped on-farm habitats have the potential to contribute to pig and poultry nutritional requirements. However, there is considerable variation in the abundance of invertebrates in different habitats, and different times of the year, which means it is a challenge to be able to account for these potential resources when planning feeding regimes. Further research is needed to identify pig and poultry feeding preferences for invertebrates, and impacts of foraging on invertebrate populations.

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Appendices

Appendix 1: Abundance and biomass per m^2 of ground invertebrates in cropped arable habitats summarising data from the literature review.

Appendix 2: Abundance and biomass per m^2 of ground invertebrates in cropped pastoral habitats summarising data from the literature review.

Appendix 3: Abundance and biomass per m^2 of ground invertebrates in non-cropped in-field habitats summarising data from the literature review.

Appendix 4: Abundance and biomass per m^2 of ground invertebrates in non-cropped on-farm woody habitats summarising data from the literature review.

Appendix 1

		Annual crops Czech Republic (Frouz 1999)	**Barley** Denmark (Frouz 1999)	**Barley** Czech Republic (Frouz 1999)	**Barley** Sweden (Frouz 1999)	**Field beans** UK (Smith et al 2007)	**Maize** France (Binet et al 1997)	**Potatoes** Czech Republic (Frouz 1999)	**Vegetables** Netherlands (Didden 2001)	**Wheat** Czech Republic (Frouz 1999)	**Winter wheat** UK (Smith et al 2007)	**Winter wheat (conventional)** UK (Schmidt et al 2001)	**Winter wheat (conventional)** UK (Moreby et al 1994)	**Winter wheat (organic)** UK (Moreby et al 1994)	**Winter rye: reduced tillage 7.5cm (organic)** Crowley et al (in prep)	**Winter rye: shallow plough 15cm (organic)** Crowley et al (in prep)	**Winter wheat/white clover intercrop** UK (Schmidt et al 2001)	***Mean***	*Min.*	*Max.*
Earthworms	**no./m²**					114.4	162.0		63.30		177.8	194.0			228.0	172.0	548.0	***207.4***	*63.30*	*548.0*
	DM g/m²						10.93		1.72			9.32					35.60	***14.39***	*1.72*	*35.60*
Diptera Larvae	**no./m²**		950.0	1043	338.0			638.0		565.0								***706.8***	*338.0*	*1043*
	DM g/m²	19-56																***19-56***		
Diptera Adults	**no./m²**												85.38	79.54				***82.46***	*79.54*	*85.38*
Coleoptera adults	**no./m²**					21.93					33.78		55.82	39.52				***37.76***	*21.93*	*55.82*
Centipedes	**no./m²**					11.85					18.96							***15.41***	*11.85*	*18.96*
Millipedes	**no./m²**					14.22					22.52							***18.37***	*14.22*	*22.52*
Woodlice	**no./m²**					0.00					5.93							***2.96***	*0.00*	*5.93*
Insect Larvae	**no./m²**					4.74					14.22							***9.48***	*4.74*	*14.22*

Appendix 2

		Clover Czech Republic, (Frouz 1999)	**Clover** Netherlands, (Eekeren et al 2010)	**Lucerne** Sweden, (Frouz 1999)	**Lucerne** Denmark, (Jakobsen 2014)	**Grass/clover** Netherlands, (Eekeren et al 2010)	**Grass/clover** UK, (Crowley et al (in prep))	**Willow coppice agroforestry** UK, (Ruedy et al 2012 (unpub))	**Mixed timber agroforestry** UK (Ruedy et al 2012 (unpub))	**Legume ley** UK, (Ruedy et al 2012 (unpub))	**Willow/alder coppice agroforestry** UK, (Jones, Eggleton 2014 (unpub))	**Grassland** UK, (Jones, Eggleton 2014 (unpub))	**Grassland** Denmark, (Jacobsen 2014)	**Grassland** Netherlands, (Didden 2001)	**Grassland** Sweden (Frouz 1999)	**Grassland** Netherlands, (Eekeren et al 2010)	**Grassland** Czech Republic (Frouz 1999)	**Grassland** UK (Smith et al 2007)	**Grassland** Various (Giller 1996)	***Mean***	***Min***	***Max***
Earthworms	**no./m^2**		480.0			359.0	125.0	92.40	104.9	90.70	331.2	350.4		384.0		326.0		347.3		***261.9***	***90.70***	***480.00***
	DM g/m^2		35.13		49.18	28.62							27.84	20.92		19.78			3.10	***26.37***	***3.10***	***49.18***
Diptera Larvae	**no./m^2**	627.0		2536											721.0		823.0			***1177***	***627.0***	***253***
	DM g/m^2	140-158															82.10		60.00	***71.05***	***60.00***	***82.10***
Coleoptera adults	**no./m^2**																	31.41		***31.41***		
	DM g/m^2																		80.00	***80.00***		
Centipedes	**no./m^2**																	37.33		***37.33***		
	DM g/m^2																		140.0	***140.0***		
Millipedes	**no./m^2**																	11.26		***11.26***		
	DM g/m^2																		1000	***1000***		
Woodlice	**no./m^2**																	7.70		***7.70***		
Insect Larvae	**no./m^2**																	85.33		***85.33***		
Molluscs	**DM g/m^2**																		100.0	***100.0***		

Appendix 3

		Buffer strip (6m grass margin) Eastern UK (Smith et al 2007)	**Buffer strip (6m grass margin)** Southern UK (Smith et al 2007)	**Buffer strip (organic grass margins)** UK (Brown 1999)	**Fallow 0-8 years** Czech Republic (Frouz 1999)	**Fallow 1st yr** Germany (Frouz 1999)	**Fallow 2nd yr** Germany (Frouz 1999)	**Set-aside Southern** UK (Smith et al 2007)	***Mean***	***Min***	***Max***
Earthworms	**no./m^2**	281.2	337.2	149.0				310.52	***269.48***	***149.00***	***337.19***
	DM g/m^2	12.88							***12.88***	***12.88***	***12.88***
Diptera Larvae	**no./m^2**					2547	5430		***3988.50***	***2547.00***	***5430.00***
	DM g/m^2				42.00				***42.00***		
Coleoptera adults	**no./m^2**	79.96	67.56					33.19	***60.23***	***33.19***	***79.96***
Centipedes	**no./m^2**	13.47	24.30					59.85	***32.54***	***13.47***	***59.85***
Millipedes	**no./m^2**	36.22	6.52					77.63	***40.12***	***6.52***	***77.63***
Woodlice	**no./m^2**	73.87	243.6					35.56	***117.66***	***35.56***	***243.56***
Insect Larvae	**no./m^2**	35.33	4.74					66.37	***35.48***	***4.74***	***66.37***

Appendix 4

		Hedgerow Southern UK (Smith et al 2007)	**Temperate deciduous woodland** Various (Giller 1999)	**Temperate deciduous woodland** Southern UK (Smith et al 2007)	**Coniferous plantation** Southern UK (Smith et al 2007)	*Mean*	*Min*	*Max*
Earthworms	**no./m^2**	294.52		263.11	107.85	***221.83***	***107.85***	***294.52***
	DM g/m^2		5.30			***5.30***		
Diptera Larvae	**DM g/m^2**		330.00			***330.00***		
Coleoptera adults	**no./m^2**	136.89		18.96	9.48	***55.11***	***9.48***	***136.89***
	DM g/m^2		90.00			***90.00***		
Centipedes	**no./m^2**	151.70		68.74	32.59	***84.35***	***32.59***	***151.70***
	DM g/m^2		130.00			***130.00***		
Millipedes	**no./m^2**	36.15		5.93	7.70	***16.59***	***5.93***	***36.15***
	DM g/m^2		420.00			***420.00***		
Woodlice	**no./m^2**	614.52		63.41	43.26	***240.40***	***43.26***	***614.52***
Insect Larvae	**no./m^2**	18.37		22.52	30.22	***23.70***	***18.37***	***30.22***
Molluscs	**DM g/m^2**		270.00			***270.00***		