THE IMPORTANCE OF YOUNG PLANTATION FOREST HABITAT AND FOREST ROAD-VERGES FOR GROUND-DWELLING SPIDER DIVERSITY

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ABSTRACT

The potential of forest roads to enhance habitat diversity within plantation forests is an important conservation issue. If properly managed, these open spaces allow structurally diverse vegetation to grow at the road-verges, which may support greater invertebrate abundance and species richness, increasing overall forest biodiversity. We investigated spider diversity along road edges in young plantation forests in Ireland, the influence of road-verge vegetation and the consequences of doubling the standard forest road-width currently used in Ireland. Active ground-dwelling spiders were studied in eight Sitka spruce (*Picea sitchensis*) plantations using pitfall trapping one year after planting and five years after planting. A total of 16,741 spiders were caught, from which 141 species were identified from 14 families. Ten spider species of conservation importance were found in the road-verges demonstrating their importance as habitats for spider diversity. We found no difference in ground-dwelling spider diversity between road-verge and forest interior plots at this stage in the rotation. We found no advantage or disadvantage of increasing the road-width of forest roads for ground-dwelling spider diversity of young plantation forests. The findings of this study are discussed in the context of the management of plantation forests for biodiversity conservation and associated forest policy development.

INTRODUCTION

At the beginning of the twentieth century, forest cover in Ireland had been reduced to < 1% of the landscape, largely through anthropogenic activity (Department of Agriculture, Fisheries and Food 2008). Since this time the area of forest cover has been increasing and today approximately 11% of the landscape is forested (Forest Europe *et al.* 2011). This increase has mainly been achieved through state-funded afforestation with non-native conifer plantation forests, and the government aim is to further increase the national forest cover to 14% by 2030 (COFORD Council 2009).

Biodiversity conservation is a key issue in the global environmental arena at present (Buckley 2004). As a member of the EU and a signatory to the UN Convention on Biological Diversity, Ireland is committed to the implementation of EU Directives aimed at maintaining and enhancing biodiversity in plantation forests (DAHG 2011). The biodiversity contained within non-native plantation forests is of particular interest due to the negative impact of deforestation on global biodiversity and the potential for non-native reforestation to contribute to biodiversity conservation (Carnus *et al.* 2006; Brockerhoff *et al.* 2008). Plantation forests are expanding worldwide and in countries such as Ireland and the UK, where plantation forests make up a large proportion of the forest estate (Forest Europe *et al.* 2011), they offer opportunities to contribute to compliance with EU Directives and commitments to biodiversity conservation.

The diversity of invertebrate species is an important component of forest ecosystems and the delivery of ecosystem services, as they play functional roles in food webs, pollination and nutrient cycling (Petersen and Luxton 1982; Gunnarsson 1996; Kevan 1999; Sanders *et al.* 2008). In particular, ground-dwelling spiders play an important predatory role in terrestrial food webs as generalist predators and regulate the litter invertebrate communities in forest ecosystems (Clarke and Grant 1968; Moulder and Reichle 1972). They also respond to habitat structural diversity and are useful indicators for changes in the ground layer habitat of forests (Uetz 1991; Oxbrough *et al.* 2005), particularly as they are a large, taxonomically well-known group of invertebrates which are easily sampled (Pearce and Venier 2006). Monitoring of arthropod bioindicators in plantation forests can be used to infer overall forest biodiversity and is an effective and cost-effective tool for designing and assessing sustainable forest management plans (Maleque *et al.* 2009).

Until recently, there was little information available on the ecology and distribution of this important species group in Irish forests and much of the information on Ireland's spiders came from open habitats, such as bogs, fens, grasslands and heathlands (Higgins 1985; Helsdingen 1996; Nolan 2002). Increasing interest in sustainable forest management and biodiversity conservation has revealed gaps in our knowledge of forest spider communities, and a number of studies have been undertaken in recent years (Smith *et al.* 2005; Iremonger *et al.* 2006; O'Halloran *et al.* 2011). Recent publications on species distributions (van Helsdingen 1996) and ecology (Nolan 2008) have also provided more information on Irish spiders, although the conservation status of most spider species is still not known in sufficient detail to plan for the conservation of priority species.

The capacity of plantation forests to enhance and maintain biodiversity and associated ecosystem function is dependent on appropriate forest planning and management, including the creation or retention of features which influence biodiversity (Carnus *et al.* 2006). Stand level management for biodiversity should not be based only on total abundance and species richness, but should include management for individual species of conservation priority which may be present in the assemblage, which will also increase the contribution of forests to landscape biodiversity.

Invertebrate species richness and abundance is positively correlated with increased light availability which stimulates ground flora diversity thus increasing habitat heterogeneity (Sparks and Greatorex-Davies 1992; Greatorex-Davies *et al.* 1994; Sparks *et al.* 1996). This effect is seen within 5m of the road providing new habitat for invertebrate species within forest plantations (Watkins *et al.* 2003; Avon *et al.* 2013). Through their contribution to open space within plantation forest roads increase overall spider abundance and species richness (Oxbrough *et al.* 2006a). In landscapes with largely fragmented forests, such as that found in Ireland, there is the potential for forest roads to make a positive contribution to forest biodiversity where they increase habitat heterogeneity attracting species that may otherwise be rare or absent (Warren and Fuller 1993; Mullen *et al.* 2003; Gittings *et al.* 2006).

Grant-aided afforestation in Ireland requires that at least 15% of the planted forest area is designated as an 'Area for Biodiversity Enhancement' and should include 5%–10% retained habitat such as hedgerows and native broadleaf trees and 5%–10% open space, which may include forest roads and rides (Department of the Marine and Natural Resources 2000). The Forest Road Scheme in Ireland aims to improve the environmental and biodiversity value of the forests through grant aiding for the construction of harvest roads (Department of Food, Agriculture and the Marine 2012). Forest roads can be planned and managed so that from the time of planting they make a positive contribution to biodiversity (Warren and Fuller 1993; Ryan *et al.* 2004). The standard minimum road-width currently recommended in Ireland by the Forest Service is 15m, including a 5m wide road surface and the verges up to the tree bases on each side of the road (Ryan *et al.* 2004). However, there is usually very little undisturbed open space in the road-verges as branches from maturing trees can directly shade this area and the space is also used for positioning of drains and banks (Iremonger *et al.* 2006). Previous research in Britain has recommended that forest roads should be 1–1.5 times as wide as the height of the trees, to prevent shading of the verges (Kirby 1992; Warren and Fuller 1993). In an Irish context, Mullen *et al.* (2003) recommend a combined width of 20–30m for the road-verge and road in Sitka spruce plantations, yet there are no studies published to describe spider communities in roads of different width in Ireland.

In light of the inclusion of forest roads in Irish forest policy and the potential to increase forest open space through increasing road-width, the contribution of forest roads to spider diversity must be assessed from an ecological standpoint. This study set out to investigate: (1) whether forest roads support species of conservation value in plantation forests, (2) whether forest roads make a positive contribution to spider diversity and (3) whether increasing the width of forest roads impacts on spider diversity.

MATERIALS AND METHODS

EXPERIMENTAL DESIGN

Eight experimental study sites were selected in second rotation Sitka spruce plantation forests (Fig. 1). A base-line survey was carried out in 2005 when the trees were one-year-old and a repeat survey was undertaken in 2010, six years into the forest cycle.

In each site, a 400m long section of the road located at least 50m from the edge of the forest was used. The first 200m of these road sections was the standard 15m treatment width, including a 5m wide

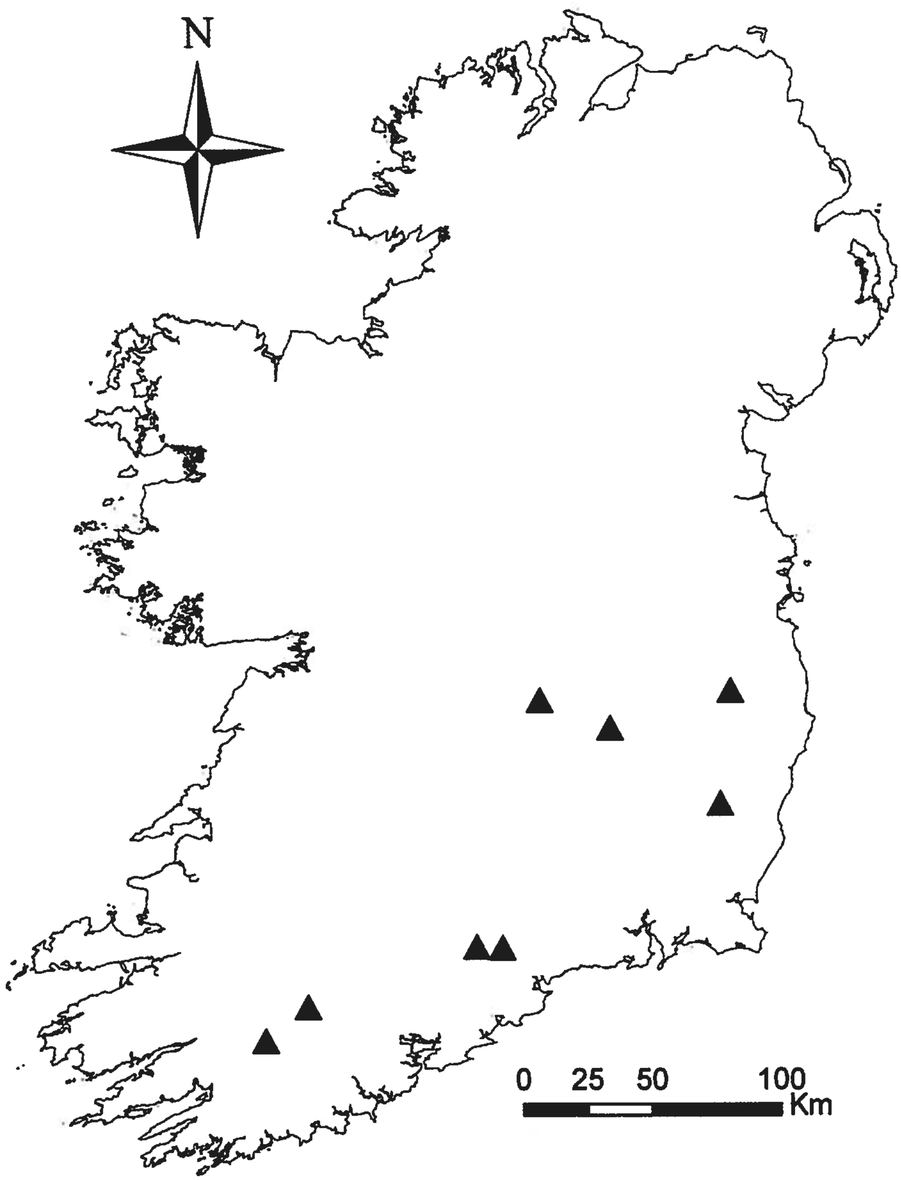

Fig. 1—Distribution of study sites across Ireland.

road and 5m of road-verge either side (hereafter referred to as standard). The other 200m was widened to a 30m treatment width including a 5m wide road and 12.5m road-verge either side (hereafter referred to as wide). Three sampling plots were set up in each treatment at 50m, 100m, and 150m, making a total of three sampling plots per treatment and two treatments per site.

The sampling plots were placed on the south facing side of the road and each consisted of three plot positions: Open 1, Open 2 and Forest (Fig. 2). The standard road-width treatment was arranged so that Open 1 was parallel to the road edge, halfway between the road edge and the tree line. Open 2 was also placed halfway between the road edge and the tree line; this was approximately 2.5–3m from the trees. There was a gap of 2m between Open 1 and Open 2. The Forest plot was placed 5m into the forest after the tree line. The wide treatment was arranged so that Open 1 was placed halfway between the road edge and the tree line. Open 2 was placed 2.5–3m before the tree line to match Open 2 in the standard treatment. The Forest plot was placed 5m into the forest after the tree line. Open 1 sampled spider assemblages utilising the middle of the road-verge, Open 2 sampled spider assemblages which may be subject to shading and Forest plots were used as a reference point to compare changes in the road-verge habitat and associated spider assemblages to those in the forest.

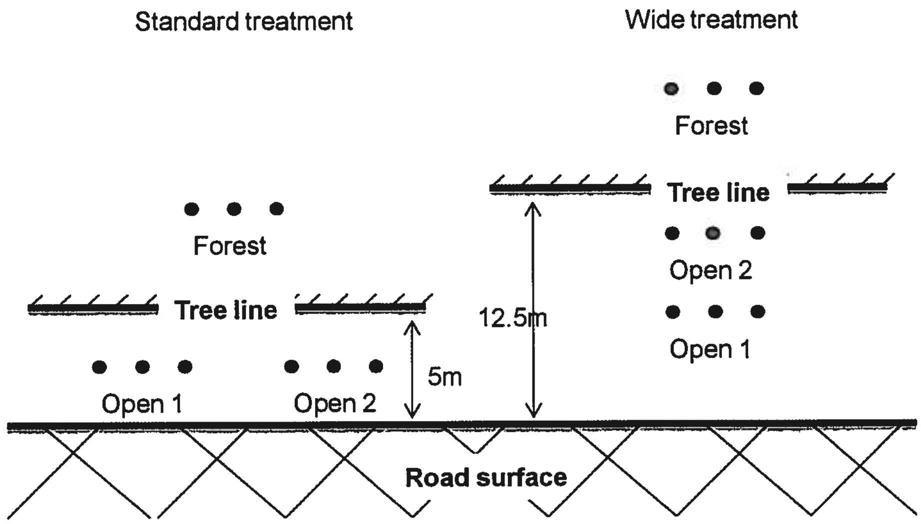

Fig. 2—Plot (Open 1, Open 2 and Forest) configuration for sampling spiders in the road-verges and forest interior of standard and wide road-width treatments.

SPIDER SAMPLING

Pitfall traps, filled with 3cm of ethylene glycol (anti-freeze), were used to sample active ground-dwelling spiders. Traps were plastic cups of approximately 7cm diameter and 9cm high which were dug into the ground, so the rim was just below the surface. Drainage slits were cut 1cm from the top of the cup to allow water to escape and prevent flooding of the traps. In each plot position (Open 1, Open 2 or Forest) two pitfall traps were placed in a line with a 2m gap between each trap. The contents of each pitfall trap were collected every three weeks from May to July totalling three collections and 63 trapping days. The plastic cup was placed back in the ground and filled with fresh anti-freeze after each collection. The contents of the traps were transferred to labelled sample bottles and stored in 70% ethanol. Due to trap disturbance at one site in 2010 an extra three-week trapping was carried out.

Adult spiders were identified to species level using Roberts (1993) and nomenclature follows Platnick (2012); juveniles were counted but not identified due to difficulties with species level identification. Habitat specialist species which are associated with open or forest habitats were determined based on Nolan (2008). Conservation status of rare species was assigned based on Nolan (2008) which uses British records by Dawson *et al.* (2008), as there is little information on the status of many spider species in Ireland.

ENVIRONMENTAL VARIABLES

Habitat was surveyed using the Braun-Blanquet scale (Mueller-Dombois and Ellenberg 1974) to determine percentage cover of vegetation (+ = <1%, 1 = 1%–5%, 2 = 6%–25%, 3 = 26%–50%, 4 = 51%–75%, 5 = 76%–100%), using a 1-m^2 quadrat placed over both pitfall traps in each plot. Vegetation was classified as ground vegetation (0–10cm), lower field layer (>10–50cm) and upper field layer (>50–200cm).

The cover of deadwood, leaf litter, bare soil and stone was also recorded using the same method. Deadwood was split into two categories: deadwood under 10cm in diameter was classed as fine woody debris and deadwood over 10cm in diameter was classed as coarse woody debris, this included snags and tree stumps. Leaf litter type (i.e. broadleaf or coniferous) and depth were also recorded. The percentage of canopy cover was also calculated at each plot in the repeat survey, using GLA 2.0 from a hemispherical photograph (Frazer *et al.* 1999) taken at the centre of each 10 m × 10 m plot at a height of 1.3m.

DATA ANALYSIS

The two pitfall traps were pooled at each plot position (Open 1, Open 2 and Forest), across all collection periods and the three sampling plots in each treatment per site and site level data were used in all analyses.

Species richness and abundance were tested for normality and compared between plot position and treatment within each sampling year. This analysis was carried out using paired *t* tests for normally distributed data and paired Wilcoxon signed rank tests for non-normally distributed data. The species richness of habitat specialists, feeding guilds and rare species was also compared in this way.

The effect of plot position and road-width treatment on the composition of spider assemblages within each sampling year was compared with a permutational multivariate analysis of variance (PERMANOVA) (Anderson 2001). The analysis was performed on Hellinger-transformed species abundance data (Legendre and Gallagher 2001), using the Bray–Curtis dissimilarity measure and 4999 permutations.

Variation partitioning (Peres-Neto *et al.* 2006) was used to examine how much of the variation in species assemblages in the road-verges was explained by the subsets of the measured variables: habitat structure, treatment and plot position. Redundancy analysis was then used to examine the effect of significant subsets on species composition. This is a constrained ordination which tests how much of the variation in species assemblage is explained by the variables (ter Braak 1994). The habitat variables were checked for strong correlations and any that had a variance inflation factor above 10 were examined and if necessary removed (Borcard *et al.* 2011). Forward selection of the habitat variables was used to choose those which explained the most variation in the species dataset before using variation partitioning and redundancy analysis (Blanchet *et al.* 2008). Species abundance data were Hellinger-transformed, the variance of continuous explanatory variables was adjusted so that the mean = 0 and standard deviation = 1, and the analysis used 4999 permutations.

All statistical analysis was carried out using R (R Core Team 2012). Hellinger transformations, PERMANOVA and RDA were performed using the vegan package (Oksanen *et al.* 2012) and forward selection used the Packfor package (Dray *et al.* 2012).

RESULTS

A total of 16,741 spiders were caught during the baseline and repeat surveys. Juveniles constituted 3067 (18%) of this total and 13,674 (82%) constituted adult spiders from which 141 species were identified from 14 families. Twenty-nine of these species were classified as forest and shade associated species, 35 were classified as open specialists and 77 as habitat generalists. Two families comprised the majority of the assemblage: Linyphiidae (47%) and Lycosidae (45%). The dominant species caught was *Pardosa pullata* (Clerck, 1757) (33%) which is an open specialist from the Lycosidae family.

RARE SPIDER SPECIES

Ten rare species were recorded during this study. *Jacksonella falconeri* ($n = 1$) and *Meioneta mollis* ($n = 1$) are classed as endangered species in Britain. *Agyneta subtilis* ($n = 410$), *Erigonella ignobilis* ($n = 2$), *Hypselistes jacksoni* ($n = 5$), *Maro minutus* ($n = 72$), *Saaristoa firma* ($n = 13$) *Taranucnus setosus* ($n = 25$), *Trochosa spinipalpis* ($n = 3$) and *Walckenaeria dysderoides* ($n = 51$) are classed as vulnerable species in Britain. See Appendix 1 for details on the site location, road-width treatment, plot position and sampling year these species were caught in.

SPIDER DIVERSITY IN FOREST ROAD-VERGES

Species assemblages did not differ between the plot positions (Open 1, Open 2 and Forest) of the road-verge and forest in either the baseline survey ($F_{2,42} = 0.41$, $P = 1.00$) or the repeat survey ($F_{2,42} = 0.46$, $P = 0.10$). There was also no effect of plot position on any of the species metrics measured in the baseline or repeat surveys.

Variation partitioning of the measured variables revealed that habitat structure explained 19% of the variation in species composition in the road-verges ($F_{6,57} = 3.42$, $P = 0.005$), while treatment and plot position had no influence and produced values of $< 0\%$ (Fig. 3). There was also no shared variation explained by combinations of habitat and treatment (0%) or plot position and treatment (0%), and the combination of habitat and plot position produced a value of $< 0\%$. When minus values are produced by this analysis it means that the explanatory variable performs worse than random at explaining the variation in species composition (Borcard *et al.* 2011). Redundancy analysis of the habitat variables revealed that shrub and herb vegetation cover were the most influential habitat variables on spider species assemblages in the road-verges (Table 1).

EFFECT OF ROAD-WIDTH ON SPIDER DIVERSITY

The baseline survey, one year after planting, found no effect of road-width treatment on species assemblage ($F_{1,42} = 0.84$, $P = 0.64$). There was

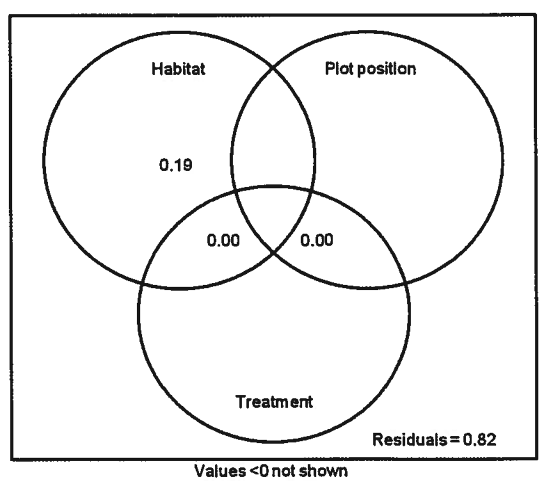

Fig. 3—Variation partitioning of spider species assemblages in the road-verges.

Table 1—Redundancy analysis results of the effect of habitat variables on spider species assemblages in the road-verges.

Habitat variable	$F_{1,57}$	*P*
Shrub vegetation (50–100cm)	7.83	<0.001
Herb vegetation (10–50cm)	3.87	<0.001
Deadwood	2.82	<0.001
Leaf litter	2.42	<0.001
Bare soil	1.82	0.02
Ground vegetation (0–10cm)	1.78	0.02

also no effect on relative abundance, species richness of forest specialists, open specialists or cursorial spiders (Table 2). However, in Open 1 plots the species richness of rare species was significantly greater in the wide treatment, and in Forest plots overall species richness and web-building spider species richness were significantly greater in the standard road-width treatment than in the wide treatment (Table 2). The repeat survey also found no effect of road-width treatment on species assemblage ($F_{1,42}$ = 1.39, P = 1.00) and there was no effect of road width on any of the species metrics measures (Table 3).

DISCUSSION

RARE SPIDER SPECIES

The retention of small patches of non-forest habitat within forest plantations may provide a 'life-boat' function for species of conservation concern (Johansson *et al.* 2013). We investigated the potential for road-verges to contribute to forest biodiversity conservation in Irish plantation forests in this manner. Two species of endangered spider and eight vulnerable spider species were recorded in the road-verges in young plantation forests in this study, indicating their importance as habitats for species of conservation priority.

Jacksonella falconeri (Jackson, 1908) is an endangered species and a habitat generalist found in litter in wetlands, grassland, heathland and forests. *Meioneta mollis* (O.P.-Cambridge, 1871) is an endangered species and included in the UK Biodiversity Action plan (JNCC 2013c), it is an open specialist found in low vegetation and litter in grasslands. *Agyneta subtilis* (O.P.-Cambridge, 1863) is a vulnerable species which is a habitat generalist found in moss and low vegetation and is associated with coniferous forests, as well as raised bog, fen, moist meadows and heathland. *Erigonella ignobilis* (O.P.-Cambridge, 1871) is a vulnerable species which is a habitat generalist and found in damp marshy habitats in damp litter and vegetation at pool edges. *Hypselistes jacksoni* (O.P.-Cambridge, 1902) is a vulnerable species which is an open specialist and found in wet heathland and wet grassland. *Maro minutus* (O.P.-Cambridge, 1906) is a vulnerable species which is a habitat generalist found on the soil surface and very low vegetation in grassland, coastal and dune systems, and forests. *Saaristoa firma* (O.P.-Cambridge, 1905) is a vulnerable species and included in the UK Biodiversity Action plan (JNCC 2013c), it is a habitat generalist found in moss, leaf litter and pine needles in damp

Table 2—Mean abundance and richness of species, habitat specialists and feeding guilds in each treatment × plot combination ± standard error during the baseline survey in 2005.

	Standard			*Wide*		
	Open 1	*Open 2*	*Forest*	*Open 1*	*Open 2*	*Forest*
Abundance	203.9 ± 48.3	221.0 ± 51.9	241.8 ± 62.8	200.9 ± 37.3	195.4 ± 31.1	204.9 ± 36.6
Total species richness	30.88 ± 1.92	**33.00 ± 11.67**	[a]33.88 ± 2.02	31.88 ± 2.29	29.50 ± 2.09	**[a]28.75 ± 3.07**
Forest specialist species richness	6.75 ± 0.80	7.88 ± 0.55	7.63 ± 0.63	7.50 ± 0.73	7.00 ± 0.46	6.38 ± 0.68
Open specialist species richness	8.50 ± 0.85	8.88 ± 0.79	9.63 ± 1.08	8.50 ± 0.96	7.63 ± 0.73	7.88 ± 1.08
Web-spinning spider species richness	24.63 ± 1.63	26.13 ± 2.00	**[b]26.88 ± 1.42**	26.13 ± 1.61	23.63 ± 1.70	[b]22.63 ± 2.27
Cursorial spider species richness	5.75 ± 0.53	6.25 ± 1.01	6.25 ± 0.80	5.38 ± 0.80	5.38 ± 0.75	5.75 ± 0.96
Rare species richness	**[c]1.5 ± 0.19**	1.63 ± 0.26	1.63 ± 0.42	**[c]2.13 ± 0.13**	1.88 ± 0.23	2.13 ± 0.35

Significant comparisons of species metrics between treatments are indicated in bold. Comparisons between plot positions were non-significant ($P \geq 0.05$).
[a] $t_{1,7}$ = 3.30, P = 0.01, [b] $t_{1,7}$ = 2.82, P = 0.03, [c] $U_{1,7}$ = 0, P = 0.04.

Table 3—Mean abundance and richness of species, habitat specialists and feeding guilds in each treatment × plot combination ± standard error during the repeat survey in 2010.

	Standard			*Wide*		
	Open 1	*Open 2*	*Forest*	*Open 1*	*Open 2*	*Forest*
Abundance	65.9 ± 11.9	70.9 ± 12.3	72.4 ± 9.5	79.6 ± 13.7	76.4 ± 8.7	76.4 ± 9.8
Total species richness	29.88 ± 3.22	30.5 ± 3.03	32.50 ± 2.31	31.5 ± 3.42	33.13 ± 2.05	32.13 ± 2.39
Forest specialist species richness	7.00 ± 0.87	7.50 ± 0.82	8.25 ± 0.84	8.88 ± 0.93	9.13 ± 1.04	8.13 ± 0.97
Open specialist species richness	8.63 ± 1.07	8.63 ± 0.68	8.25 ± 1.03	7.50 ± 0.89	8.50 ± 0.60	8.63 ± 0.80
Web-spinning spider species richness	24.63 ± 2.28	24.63 ± 2.68	27.13 ± 1.92	26 ± 2.67	27.13 ± 1.68	26.63 ± 1.81
Cursorial spider species richness	4.88 ± 1.08	5.25 ± 0.45	4.88 ± 0.67	5.00 ± 0.71	5.63 ± 0.50	5.13 ± 0.77
Rare species richness	2.13 ± 0.35	1.50 ± 0.33	1.75 ± 0.25	1.38 ± 0.26	2.00 ± 0.38	1.88 ± 0.48

Comparisons of species metrics between treatment and plot position were non-significant ($P \geq 0.05$).

broadleaf and coniferous forests. *Taranucnus setosus* (O.P.-Cambridge, 1863) is a vulnerable species and an open specialist found in well-developed vegetation in open undisturbed damp or wet habitats. *Trochosa spinipalpis* (O.P.-Cambridge, 1895) is a vulnerable species and open specialist found in low vegetation in damp habitats. *Walckenaeria dysderoides* (Wider, 1834) is a vulnerable species found in shaded habitats and moss and litter in forests.

Recommended management for *J. falconeri* and *M. mollis* includes preventing the loss of exposed habitats with short vegetation, particularly heathland and grassland (British Arachnological Society 2013a; 2013b). *E. ignobilis*, *H. jacksoni*, *T. setosus* and *T. spinipalpis* rely mainly on open habitats with well-developed vegetation and the latter four species in particular require the presence of damp habitats (Helsdingen 1996; van Helsdingen 1998; Nolan 2008). The vegetation and moisture requirements of these species mean it is unlikely that they would be found in the forest interior of Sitka spruce plantation forests, particularly after canopy closure where the ground vegetation diversity is typically reduced due to the decreasing availability of light, nutrients and moisture (Anderson *et al.* 1969; Hill 1979; Avon *et al.* 2010). The vulnerable and endangered species found in the open habitat of these young plantation forests indicate that open areas within plantation forests support rare species. These findings support the retention of road-verges in plantation forests and demonstrate the importance of this open habitat for rare spider species. Forest management should include consideration of the importance of these areas for forest biodiversity.

SPIDER DIVERSITY IN FOREST ROAD-VERGES

The construction of roads through large, otherwise undisturbed forests, may bring about negative changes in biodiversity by increasing fragmentation which alters the physical and chemical environment, increasing disturbance and the spread of invasive species (Buckley *et al.* 2003; Avon *et al.* 2013; Johansson *et al.* 2013). However, in fragmented landscapes of plantation forest, that are devoid of open spaces in the absence of active management, roads may provide the opportunity to enhance biodiversity (Warren and Fuller 1993; Smith *et al.* 2007) and the design and management of forest roads are crucial for sustainable forest management (Lindenmayer *et al.* 2006). The inclusion of open spaces, including forest roads, is an objective of forest management for biodiversity conservation in Ireland (Department of the Marine and Natural Resources 2000).

The forest road-verges in this study supported a similar ground-dwelling spider fauna as the forest interior, with the majority of species recorded being open specialists and habitat generalists. Forest- and shade-associated species, such as *Monocephalus fuscipes* (Blackwall, 1836) and *Tenuiphantes zimmermanni* (Bertkau, 1890), were still present in the road-verges and open specialists, such as *Pardosa amentata* (Clerck, 1757) and *P. pullata* (Clerck, 1757), were present in the forest interior. The road-verges had well developed ground, herb and shrub layers and still experienced full sunlight making the conditions ideal for many open specialist species. However, the forest interior also had well-developed vegetation although the trees were tall enough in the repeat survey to cast more shade here than in the road-verges. This mixture of open and forest specialist species is common where species composition remains similar to the pre-planting habitat until the time of canopy closure, as forest specialists and shade-associated species can be remnant populations from the previous rotation (Oxbrough *et al.* 2010). Additionally, even at this early stage in the forest cycle forest specialists may start to colonise (Oxbrough *et al.* 2006b; 2010).

Habitat explained more variation in species composition than treatment or plot position, although as the forest matures these are likely to be inter-correlated. Only 19% of the variation in spider assemblages found in the road-verges was explained by the measured habitat variables suggesting that other factors are also influencing species assemblages here. This is common when using multivariate analysis of ecological data where many species and many explanatory variables produce background noise (McCune 1997). However, shrub and herb cover were shown to have the strongest influence over spider diversity in the road-verges, and these vegetation types could be shaded out once the forest matures. The effect of road-verges on ground vegetation favours fast-growing, nutrient- and light-demanding non-forest species at distances of <5m from the road edge in forests (Watkins *et al.* 2003; Avon *et al.* 2010).

As plantation forests mature the road-verges have a lower canopy cover than the forest interior, and the increased light levels can result in a ground vegetation community that is different to the forest interior (Watkins *et al.* 2003; Avon *et al.* 2010). Consequently, the response of ground vegetation structure to the presence of roads may change as the forest matures, suggesting that the findings of this work cannot be extrapolated to all stages of the forest cycle. The trees in this study were approximately 2m tall and so cast little shade and the ground flora was well-developed along the road-verges. Repeat surveys of this experiment are recommended for all stages of the forest cycle in order to determine how spider diversity is affected by changes in canopy cover and habitat succession in plantation forest road-verges.

This study clearly demonstrates the importance of forest road-verges for open specialists and habitat generalists. As the forest cycle progresses, the subsequent change in habitat, including a decrease in ground vegetation and increase in litter cover, leads to a fundamental change in ground-dwelling spider species composition and a decrease in species richness (Oxbrough *et al.* 2005). Forest roads may then be expected to provide a refuge for open specialist spider species that would not otherwise persist in the forest interior.

EFFECT OF ROAD-WIDTH ON SPIDER DIVERSITY

The effect of forest roads on ground-dwelling spiders is mediated primarily through effects of light penetration which is greater at forest roads than it is in the forest interior (Mullen *et al.* 2003; Watkins *et al.* 2003). The effect of light penetration is reduced as forests mature due to the increasing shade provided as the trees grow taller (Warren and Fuller 1993; Avon *et al.* 2010). The standard road-width in Irish plantation forests at present is 15m, which if increased may improve the contribution of open spaces along forest roads to forest biodiversity (Smith *et al.* 2007).

We found no advantage or disadvantage for biodiversity of young plantation forests of increasing the road-width of forest roads. During the first five years of the forest cycle, increasing the width of forest road-verges had no detectable effect on the species composition of ground-dwelling spiders and there was little effect on the species richness of spiders in the road-verges. Forest plots in the standard treatment had higher species richness, which was driven by a greater species richness of web building spiders. This was not expected as Forest plots in both treatments were in areas that had always been in forest interior habitat. The reason for higher web-building species richness in the standard Forest plots one year after planting is unclear, and this difference did not persist until the time of the repeat survey.

Many of the species recorded in this study were from the Linyphiidae family, which are highly capable aerial dispersers and could potentially move between the two different road-width treatments and confound the results. However, even good dispersers, such as the Linyphiids, are strongly influenced by habitat structure and show strong habitat specificity at the scale of 2–3m in Irish forests (Oxbrough *et al.* 2006a). We therefore expect that any differences in habitat which may emerge between the treatments as the forest cycle progresses would also affect spider diversity regardless of dispersal ability.

Natural regeneration of Sitka spruce trees was observed along the road-verges during the repeat survey at several of the forests in this study. Therefore, management of forest roads is required to prevent regeneration of these trees areas along road-verges. If a wider road-width is found to be beneficial to spider diversity at later stages of the forest cycle, it will be important to actively manage the road-verges and remove any regeneration of the planted tree species that may cause shading.

CONCLUSIONS

The effect of forest roads on forest biodiversity is an important conservation and management issue. Forest road-verges provide important open habitat for ground-dwelling spider diversity in Sitka spruce plantation forests. Their importance extends to species of conservation importance, where they make a valuable contribution to the conservation of spider diversity, providing further support for their inclusion in forest management plans.

Increasing the width of the road-verge had no advantage or disadvantage for ground-dwelling spider diversity during the first five years of the forest cycle. However, the present study provides important baseline data against which future surveys of the effect of road-width treatment on the diversity of road-verges can be monitored.

The importance of investigating the biodiversity of young plantation forests is particularly relevant in countries such as Ireland and Britain, which are undertaking large-scale afforestation programmes (Forest Europe *et al.* 2011) and where non-native tree species comprise a larger proportion of the forest estate. A significant proportion of forested areas in these countries will be newly established or young second and third rotations. Therefore, research into methods of maximising biodiversity in these young forests is required to inform policy development and forest management.

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Appendix 1—Locations of spider species of conservation importance in the baseline and repeat survey.

Species	*Conservation status*	*Site*	*Grid ref*	*County*	*No of individuals in baseline survey*	*Plot position in baseline survey*	*No of individuals in repeat survey*	*Plot position in repeat survey*
Agyneta subtilis	Vulnerable	Ballingate	S977605	Wicklow	31	SO1, SO2, SF, WO1, WO2, WF	3	SO1, SF
		Bawnoge	O016032	Wicklow	94	SO1, SO2, SF, WO1, WO2, WF	28	SO1, SO2, SF, WO1, WO2, WF
		Cardtown	S277995	Laois	7	SO2, WO1, WO2	18	SO1, SO2, SF, WO2, WF
		Carrigagulla	W373836	Cork	10	SO1, SF, WO1, WO2, WF	11	SO1, SO2, SF, WO1, WO2
		Cloontycarthy	W208707	Cork	14	SO1, SO2, SF, WO1, WO2, WF	9	SO1, SO2, SF, WO1, WO2, WF
		Fossy Hill	S550891	Laois	11	SO1, SO2, WO1, WO2, WF	13	SF, WO1, WO2, WF
		Lismore	S027063	Waterford	60	SO1, SO2, SF, WO1, WO2, WF	29	SO1, SO2, SF, WO1, WO2, WF
		Tooranaraheen	S128059	Waterford	37	SO1, SO2, SF, WO1, WO2, WF	35	SO1, SO2, SF, WO1, WO2, WF
Erigonella ignobilis	Vulnerable	Cloontycarthy	W208707	Cork	0	*NA*	1	SO1
		Lismore	S027063	Waterford	1	SF	0	*NA*
Hypselistes jacksoni	Vulnerable	Bawnoge	O016032	Wicklow	5	SO2, SF	0	*NA*
Jacksonella falconeri	Endangered	Bawnoge	O016032	Wicklow	0	NA	1	SO1
Maro minutus	Vulnerable	Ballingate	S977605	Wicklow	9	SO2, SF, WF	1	SO1
		Bawnoge	O016032	Wicklow	5	WO1, WF	9	WO1, WO2, WF
		Cardtown	S277995	Laois	34	SO1, SO2, SF, WO1, WO2, WF	4	SO1, SO2, SF
		Carrigagulla	W373836	Cork	5	SO1, WO1, WO2, WF	0	NA
		Fossy hill	S550891	Laois	4	WO1, WO2, WF	1	WF
Meioneta mollis	Endangered	Lismore	S027063	Waterford	0	NA	1	WO2
Saaristoa firma	Vulnerable	Cardtown	S277995	Laois	0	NA	1	WO2
		Carrigagulla	W373836	Cork	1	SO2	0	NA
		Cloontycarthy	W208707	Cork	2	SF, WF	2	SO1, WF

Appendix 1 (*Continued*)

Species	*Conservation status*	*Site*	*Grid ref*	*County*	*No of individuals in baseline survey*	*Plot position in base-line survey*	*No of individuals in repeat survey*	*Plot position in repeat survey*
		Lismore	S027063	Waterford	0	NA	1	SF
		Tooranaraheen	S128059	Waterford	3	WO1, WO2, WF	2	SO2, WO2
Taranucnus setosus	Vulnerable	Ballingate	S977605	Wicklow	0	NA	3	SO1, SO2, WF
		Bawnoge	O016032	Wicklow	0	NA	2	SO2, SF
		Cardtown	S277995	Laois	0	NA	1	WO2
		Carrigagulla	W373836	Cork	0	NA	3	SO1, SO2, WO1
		Cloontycarthy	W208707	Cork	1	SF	4	SF, WF
		Fossy Hill	S550891	Laois	1	SO1	8	SO1, SF, WO1, WO2, WF
		Lismore	S027063	Waterford	0	NA	2	SO1, WF
Trochosa spinipalpis	Vulnerable	Ballingate	S977605	Wicklow	2	SO1, WF	0	NA
		Lismore	S027063	Waterford	1	WO2	0	NA
Walckenaeria dysderoides	Vulnerable	Ballingate	S977605	Wicklow	5	SO2, WO1, WF	NA	NA
		Cardtown	S277995	Laois	0	NA	2	WO1, WO2
		Carrigagulla	W373836	Cork	3	WO1, WO2	2	SO2, WO2
		Cloontycarthy	W208707	Cork	28	SO1, SO2, SF, WO1, WO2, WF	10	SO1, SF, WO1, WO2, WF
		Lismore	S027063	Waterford	1	WO1	0	NA

Standard treatment (S), wide treatment (W), Open 1 plot (O1), Open 2 plot (O2), and Forest plot (F).