Maintained electrical transmission corridors can provide valuable bumblebee habitat for conservation and ecosystem service provision.

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Abstract

Decline in pollinator abundance and diversity is not only a conservation issue but also a threat to crop pollination. Maintained infrastructure corridors, including electricity transmission lines, are potentially valuable wild pollinator habitat. However, this potential is hindered by a lack of evidence comparing wild pollinator's abundance and diversity on transmission corridors with other recognized wild pollinator habitats. We study the influence of transmission corridors on a key pollinator group, bumblebees, in Sweden's Uppland region by comparing bumblebee abundance and diversity in transmission corridors with that in other habitats. Our results show that a transmission corridor's presence has no impact on the surrounding area's bumblebee diversity. However, transmission corridors and other maintained habitats have an abundance and diversity of bumblebees as high as semi-natural grasslands and do sustain species important both from a conservation and an ecosystem service provision perspective. Under their current management regime transmission corridors already provide valuable bumblebee habitat, but given that forage plant density is the main determinant of bumblebee abundance, they could be further enhanced by establishing and maintaining key forage plants. We show that in northern temperate regions habitats like those within maintained transmission corridors can complement agri-environmental schemes (AES) to assist in both bumblebee conservation and securing the ongoing provision of the ecosystem service they provide.

Keywords

Bombus, ecosystem service, pollination, maintained electricity transmission corridor, EU Common Agricultural Policy, Sweden.

Introduction

Pollinators provide an essential ecosystem function, as 80% of plants are dependent on animal pollination for their reproduction (Ollerton et al. 2011). The provision of ecosystem services by pollinators is equally essential, with 35% of total global crop production dependent on animal pollination (Klein et al, 2007). The discrepancy between supply and demand for honeybees provision of pollination has resulted in wild pollinator's contribution to this service gaining more recognition (Breeze et al. 2014), as wild pollinators service is often equal, complementary or superior to that provided by honeybees (Garibaldi et al, 2013). While only a minority of bee species provide most of the pollination service to crops (Kleijn et al. 2015) the main non managed pollinators worldwide are bumblebees (e.g. *Bombus terrestris* and *lapidarius* in Europe). Bumblebees (*Bombus sp.*) are alse regarded as a key pollinator group in temperate regions and as they forage more effectively in colder temperatures than other bees, their importance increases with latitude (Corbet et al, 1994).

Pollinators are threatened by human induced environmental change, including habitat loss, climate change and pesticides use (Winfree et al. 2011, Gonzalez-Varo et al. 2013). There's evidence that bumblebees are more sensitive to these changes than other bee species (Bartomeus et al. 2013) and despite some bumblebee species are thriving and can use human modified habitats, others are declining or near-extinct (Bartomeus et al 2013, Cameron et al. 2011). A factor adversely affecting bumblebee populations is habitat destruction (Vanbergen et al, 2013) and a corresponding loss of preferred host plant species (Scheper et al. 2014). Semi-natural grasslands, a habitat favoured by bumblebees for both nesting and foraging (Svensson et al, 2000) have decreased by 12.8% from 1990 to 2003 in Europe (FAO, 2006), while populations of 31 of Europe's 68 bumblebee species are declining, 16 of which are threatened with extinction (Nieto et al 2014).

In response to declines in pollinators many government and international organisations are recognising the importance of maintaining pollinator services (EU, 2011). With the benefit pollinators provide at the global and EU level being estimated at €153 and €15 billion respectively (Gallai et al. 2009), ecosystem service provision is a significant policy area. The policy responses include regulations, education and incentives. Such incentives available in the EU includes payments made through the EU Common Agricultural Policy (CAP) Agri-environmental schemes (AES'). The use of AES' for ecological enhancement and their application on farmland have been shown to boost bumblebee nesting and foraging habitat (Lye et al. 2009, Cavell et al. 2007 & 2011, Scheper et al. 2013). However, human-modified areas outside the farmland have received little attention so far from the policy makers.

Outside of such planned approaches for pollinator conservation is the growing recognition of managed infrastructure corridors, such as electricity transmission corridors (hereafter transmission corridors; Russell et al. 2005, Wagner 2014, Berg 2011, 2013), roadsides (Hopwood et al. 2010, Hanley et al. 2015) and railway embankments (Moron´ et al. 2014) as valuable pollinator habitat (Eldegard et al. 2015). The routine, utilitarian maintenance and disturbance of maintained infrastructure corridors provides the early successional landscapes required by many classes of pollinators (Wojcik & Buchmann 2012). Roadside mowing has increased bee and butterfly abundance in the Netherlands (Noordijk et al, 2009), bee fauna in mown transmission corridors is richer than in adjoining annually mown grassy fields in Maryland, USA (Russell et al. 2005), while in Sweden butterflies were more abundant in transmission corridors than in semi-natural grasslands (Berg et al. 2011, 2013). In the USA Integrated Vegetation Management (IVM) in transmission corridors has improved threatened butterflies Frosted Elfin (*Callophrys irus*) and Karner Blue (*Lycaeides Melissa samuelis*) habitats (Environment 360, 2014; Forrester et al. 2005). While roadside verges and railway embankments can be considered part of the semi-natural habitats and many studies show positive effects of these on pollinators (Winfree et al. 2011), transmission corridors, especially in northern Europe, create a unique habitat by providing herbaceous vegetation in an otherwise forested landscape. Moreover, transmission corridors have the potential to act as dispersal paths connecting different habitats (Haddad 1999). However, many aspects about pollinator abundance and diversity is yet unknown, including how transmission corridors compare to other recognised valuable pollinator habitat and how the maintenance costs of different managed infrastructure corridors and their respective populations of pollinators compare (Wojcik & Buchmann, 2012).

With the many threats to pollinator populations the identification of transmission corridors and other maintained infrastructure corridors as valuable habitat is timely. Here, we study the influence of transmission corridors on a key pollinator group, bumblebees, in Sweden's Uppland region by comparing bumblebee diversity in transmission corridors with that in other habitats. Declines in bumblebee habitat and diversity in Sweden mirror those in the rest of Europe, with the area of grasslands being estimated at being below 10% of its extent a century ago (Palmgren 2010), whilst 18 of 41 Swedish species are in decline and seven are threatened with extinction (Nieto et al. 2014).

We compared bumblebee abundance and alpha and beta diversity on seven different semi-natural habitat types in 10 two km radius areas (five bisected by a transmission corridor and five not) across 1156km^2. Specifically we asked,

1. Whether areas bisected by a transmission corridor have a greater bumblebee abundance and/or greater bumblebee alpha and beta diversity than similar sized areas not containing a transmission corridor?

2. What is the difference in bumblebee's abundance of ecosystem service providers and threatened species across the seven surveyed habitat types?

3. What influence does flower abundance and forage plant species have on bumblebee abundance and diversity across all seven habitat types?

4. What is the relative cost of specific habitat management and/or enhancement?

Method and materials

Site selection

The Swedish national transmission corridor grid (the system of 220-400 kV lines) occupies approximately 40,000 hectares, with 36,000 hectares being uneconomic to cultivate, bordered by forest and so requires maintaining. In arable areas the approximately 60m^2 areas at the transmission tower's bases (hereafter the tower bases) require maintenance as these can't be cultivated. This network is owned, maintained and operated by Svenska kraftnät (SK), a state-owned public utility. SK's transmission corridors are subject to an easement that allows them the perpetual right to construct, keep and maintain the transmission corridor grid on the owner's land. In the Uppland region transmission corridors are maintained on an eight year cycle. In year zero transmission corridors are cleared of tall vegetation, year three trees threatening transmission lines are felled, year four transmission corridor access roads are cleared and year seven fast growing trees are felled. SK's maintenance is done solely by mechanical means. (J Bjermkvist, SK, pers comm.)

To investigate transmission corridors influence on the surrounding area, we selected ten areas of four km^2 (2 x 2 km squares) in Sweden's Uppland region. All were approximately 50% closed canopy forest 50% open areas (range 45-70%), and were between 3.2 and 6.4km apart. There can be a wide variation in foraging distances between species, with radio-tracked *B. terrestris* and *B. ruderatus* workers foraging up to 2.5km and 1.9km respectively from their respective nest (Hagen et al. 2011), while *B. muscorum* have a much smaller foraging range of between 100-500m from their nest (Walter-Hellwig & Frankl 2000). The distances between our study's surveyed areas therefore minimised the chance that bumblebees recorded in one area were also recorded in another. Five sites were bisected by a section of transmission corridor (widths ranging between 50-70m), of which between 1.2-1.5km km was bordered by closed canopy forest. At the time of surveying four sites were in year three of their maintenance schedule (all the tall vegetation was removed in 2011), the remainder was in year six (all tall vegetation was removed in 2008). The other five sites were at least three km from any transmission corridor. Stretches of between 0-3km of the maintained ten metre wide 230V transmission line corridors, an ubiquitous feature in Uppland, were present in most sites. As the maintained but shaded sections of these smaller transmission corridors provided little or no flowering plant habitat, hence containing limited bumblebee foraging habitat (*pers ob),* we consider their presence is unlikely to have affected our results.

In order to capture the main habitat types present, we conducted multiple transects per area. Overall, we surveyed 158 transects spread across seven habitat types, six of which have previously been identified as valuable bumblebee habitat (Svensson et al. 2000). The 158 transects consisted of 32 transmission corridor sites, 18 sites on maintained roadsides, 18 in forests, 19 along forest/grassland boundaries, 20 within semi-natural grasslands, 29 within cereal crop edges and 22 within maintained drains. To our knowledge none of the surveyed transects were in areas that had been purposely ecologically enhanced. The surveyed roadsides (all quiet tertiary or quaternary roads) are mown annually (p*ers comm*. M. Lindqvist, Trafikverket) whilst drains are maintained on an as-needed basis. The semi-natural grasslands surveyed comprised of areas meeting the EU's definition of permanent pasture and grassland (EU 2009). Each transect consisted of a 50m long by 3m wide by area situated in a section containing a high density of flowering plants. Within the selected section we surveyed for bumblebee abundance and diversity by slowly walking along it for 15 minutes. Where possible the bumblebees were identified while flying or foraging. Those that couldn't be readily identified were caught by net, and if possible identified then released. Caught specimens not identified in the field were killed then identified later. *B. terrestris* and *B. lucorum* were combined as *B. terrestris* (Carvell et al. 2004). Collection handling time was discounted and if the transect's end was reached before 15 minutes it was walked back again. The host plant of each foraging bumblebee was also identified to species level. To correspond with peak bumblebee activity in Uppland (Svennson et al, 2002) each site was surveyed twice between 9th July 2014 and 25th August 2014, with at least 2 weeks between each survey. All surveys were undertaken between 9 am and 5.30 pm and only during dry periods in temperatures above 15 ^{o}C. Flower density on the transect was estimated as the total percentage of the transect area covered by flowers (categories used: "<1%", "1-5%", "6-10%", "11-20%", "21-40%", "41-60%" and ">61%" coverage). As all surveying was conducted by one person this semi-quantitative measure enabled a quick yet consistent assessment of flower density on all transects.

Statistical analysis:

In order to compare species abundance and richness (alpha diversity) across sites, and habitats, we build a generalized linear model with species richness or abundance per transect as a function of site type (transmission corridors/non transmission corridor) and habitat. Flower density was also included as a covariable. To account for the hierarchical structure of the data, transect, nested in site was included as random factor. Residuals were investigated to ensure they fulfilled the model assumptions and to meet the assumptions of homoscedasticity we used a constant variance function.

Beta diversity was analysed on two scales. First, we investigated if sites containing a transmission corridor have lower turnover rates among the different habitats. We expect transmission corridors to connect different habitats and allowing for a higher dispersal of bumblebees, hence lowering overall beta diversity. Second, we investigated beta diversity among different areas of the same habitat. We expect more disturbed habitats (e.g. crop edges) to be used by the same opportunistic species in all sites (low beta diversity), while semi-natural habitats to contain a more unique composition among sites (high beta diversity). To determine species turnover, we used additive partitioning of species richness (Tylianakis et al. 2005, Lande 1996, Veech et al. 2002, Crist et al. 2003). Alpha diversity was defined as the mean number of species per plot (i.e. species richness). Transmission corridor sites beta diversity was calculated as the total number species found within a corridor site (gamma diversity) minus the mean number of species per plot of that transmission corridor site (alpha). Habitat beta diversity was calculated as the rarefied number species found across all habitats of a given type (gamma) minus the mean number of species per plot of that habitat type (alpha). Rarefication in gamma diversity was done to 90 individuals to avoid difference in sampling intensity across habitats.

From the pool of bumblebee species recorded, we explored which habitats are used by bumblebees listed by IUCN (Nieto et al. 2014) as threatened in Europe: *B. muscorum*; and listed as declining elsewhere in Europe (Shepper et al. 2013): *B. humilis*, *B. sylvarum* and *B. soroensis,* hereby termed threatened species. We also recorded which habitats are used by species that are the main providers of the ecosystem service crop pollination in Europe, being *B. terrestris, B. lapidarius, B. pascuorum, B. hypnorum, B. pratorum and B. hortorum* (Klejn et al. 2015), hereby termed provider species. We built a generalized linear model with abundance of threatened species and abundance of provider species per transect as a function of habitat and flower density. Transect, nested in site was also included as random factor and to meet the model assumptions of homoscedasticity we used a constant variance function.

Finally, to assess plant importance for bumblebees in the surveyed habitats, we calculated for the plant- bumblebee recorded interactions the plant strengths (Bascompte et al. 2006) for the pool of transmission corridor habitats, semi-natural grassland habitats and all habitats combined. Strengths are defined as the sum of pollinators' dependencies on that plant, being pollinators' dependencies the fractions of visits done to that plant with respect to all its visits. In that way, a plant can have high strength values if it attracts lots of pollinators that depend little on it, or if it attract a few pollinators, but that depend a lot on it. Note that this metric highlights plant use, not preference. A plant can be used a lot mainly because its the most abundant, not because is preferred.

The costs of maintaining and/or enhancing the relevant habitat types were gathered from EU member material (Defra 2014; Scottish Government 2009), peer-reviewed literature (Dahlström et al. 2013) Svenska kraftnät and Trafikverket (the Swedish Transport Administration).

Results

In total we recorded 1016 specimens, comprising 20 bumblebee species. These were recorded foraging on 24 plant species.

Having a transmission corridor bisecting the area did not change abundance (Table 1, Fig 1A) or richness of bumblebees (Table 1, Fig 1B). Similarly, we found no differences among habitats in total abundance or richness (Table 1, Fig 2 A and B). As expected flower abundance is the strongest predictor of bumblebee abundance and richness (Table 1).

Patterns of species beta diversity reveal that sites with a bisecting transmission corridor are not more homogenous in species composition than sites without a transmission corridor (test for differences in beta diversity: n = 10, $F_{1,8}$ = 0.03, P = 0.85, Fig 1B). We also show that species turnover among plots of the same habitat is similar with all habitats harboring between 11 and 15 rarefied species (i.e. gamma diversity; Fig 2B).

Provider species were present in most habitats. *B. pascuorum* and *B. terrestris* were the most abundant and ubiquitous species, present in all habitats, while *B. lapidarius* was found in all habitats except forest. Overall the abundance of provider species is not different across habitats (Fig 3A, Table 2). Interestingly, threatened species were found not only in grasslands (*B. sylvarum* and *soroeensis*), but also in roadsides (*B. humilis*, *soroeensis* and *sylvarum*) and transmission corridors (*B*. *muscorum* and *humilis*), but were rarely found in the other habitat types (Fig 3B, Table 2). Flower abundance does not explaining threatened species abundance (Table 2).

Throughout all the studied areas *Carduus crispus*, *Trifolium pratense* and *Centaurea jacea* *we*re the most important foraging plants for sustaining both threatened and provider species (Table 3, Fig 4). However, plant importance varied between transmission corridors and grasslands. For example species in the genus *Trifolium* are more important in grasslands than in transmission corridors due to its abundance. Overall, important plant species sustains many species not heavily reliant on it as well as threatened species (e.g. *B. sylvarum, B. humilis;* Fig. 4).

The costs of maintaining and/or ecologically enhancing habitats were varied. For example, the current maintenance of transmission corridors in Uppland costs approximately €60/ha per year (J Bjermkvist, SK, pers comm.) and the cost of mowing Uppland roadsides similar to those surveyed costs between €500-1000/ha per year. (pers comm. M. Lindqvist, Trafikverket). Such maintenance is fundamental to these network's operation and hence there is no obvious reason that it be discontinued in the foreseeable future. In comparison, the EU resourcing of Swedish AES' for grassland maintenance and enhancement costs between €121-506/ha per year (Dahlström et al. 2013), while in the UK ecological enhancement of arable areas costs approximately € 350/ha per year (Lye et al). The two wild pollinator habitat enhancement options (low and high inputs) recommended by Cavell et al. (2007) range between € 42-679/ha/year respectively.

Discussion

The current transmission corridor maintenance regime results in these areas having bumblebee abundance and diversity equivalent to that recorded on the semi-natural grasslands and supports the increasing recognition that such areas are valuable wild pollinator habitat. The similarity in bumblebee abundance and diversity between transmission corridors and grasslands, especially for threatened species, is significant as in Sweden (Svennson et al. 2002; Sandell, J 2007) as well as the rest of the EU (EU 2015) such grasslands are recognized as being both highly valuable areas of biodiversity and significant bumblebee habitat but their area has been drastically reduced over the last 100 years.

Road sides and transmission corridors, both extensively modified areas, provide habitat for threatened and provider species in Sweden. Bumblebees of these groups have numbers of individuals per transect similar to those found in grasslands or forest/grassland boundaries. The studied road sides are all quiet rural roads with little traffic and tend to be rich in flower cover (30% coverage on average, similar to that found in grasslands). However, maintained drains and crop edges also have a good flower coverage similar to transmission corridors (13-20%), but sustain less bumblebee individuals, specially of threatened species. It is possible that the dense grass sward observed in many of the surveyed drains limited the habitat available for the light demanding, low growing and favoured foraging species such as *T. pratense* (Kleijn and Raemakers 2008), while overall surveyed crop edges were the narrowest habitat type and hence provided the least amount of habitat for foraging plants (<1m), thereby providing limited habitat. As forested areas of tall evergreen trees (predominantly *Pinus sylvestris* and *Picea abies*) had little flower cover (average of 5%) it's not surprising that they host few bumblebees. In comparison, transmission corridors and roads bisecting those forest patches are flower rich areas and may have an aggregation effect concentrating the surrounding pollinators in resource rich areas (Lye et al. 2009). However, note that flower cover does not explain threatened species abundance, indicating that other factors, like nesting sites may be more limiting for this species (Lye et al. 2009). While the effect of electric and magnetic field radiation from high voltage powerlines has little known direct effect on bees (Wojcik & Buchmann 2012) and quiet roads may represent a minor threat to bumblebees (Hopwood 2008), these potential risks may be countered by being suitable small rodent habitat, thereby potentially increasing nesting availability (Svennson et al. 2002, Clarke et al.2008). Despite these important local effects, our results do not indicate that transmission corridors enhance the overall abundance or richness of bumblebee species on the area for example, by better connecting open habitats or by having a spillover effect on surrounding habitats.

From our observations there is considerable potential for enhancing bumblebee habitat on transmission corridors, as within these the main forage plants are mostly limited to smaller areas not dominated by shading shrubby vegetation (*pers ob*). With floral abundance being a major determinant in bumblebee diversity and abundance there's the opportunity for tailored enhancement work. Our results also support the importance of legumes and other nectar rich flowers as significant resources for most bumblebee species (Kleijn and Raemakers 2008). However, in comparison with semi-natural grasslands, transmission corridors have less representation of some key plants like *T. pratense.* As a possible means of enhancing bumblebee populations, those could be sown in transmission corridors. For arable areas this strategy is already prescribed under the UK's AES' (Dicks et al. 2015, Cavell et al. 2007). In addition, early flowering *salix* species such as *Salix caprea* are of key importance to the foraging of early emerging bumblebee queens and subsequently their successful colony establishment, with >1000m^3 crown volume/ha positively influencing bumblebee abundance (Svensson 2002). During our pre-survey visits to select the study areas we noted emerging queens foraging on *salix* species on the transmission corridor edges. Maintaining *salix* spps and increasing their abundance in areas of transmission corridors where they don't threaten the powerline is a yet untested, but a potential habitat enhancement method. However, flower abundance later in the season is maybe the most critical for later emerging species as denoted by the fact that most threatened bumblebee species occur late on the season (Scheper et al. 2014). Increasing the amount of open habitat within transmission corridors, by removing woody shrubs and dense grass swards then enhancing strategic sections into flower-rich habitat could also be a way of increasing foraging plant habitat and hence bumblebee diversity and abundance (Russell et al. 2005, Noordijk et al. 2009, Dicks et al. 2015), but would likely increase maintenance costs. Such actions could assist in providing the approximately 2% of flower-rich habitat within 100ha of farmland required to maintain and support provider species colonies (Dick et al. 2015).

Agriculturally unproductive areas within transmission corridors will continue to be maintained in the long-term, and this level of maintenance should continue to provide bumblebee habitat equivalent to that on grasslands. As the maintenance of transmission corridors is simple, standard and easily applied, funding the enhancement of biodiversity in maintained, unproductive areas within transmission corridors could be an effective way both enhance bumblebee conservation and the ecosystem service they provide. The application of such enhancement techniques would enhance the ecological value of these often thought-of waste lands without any opportunity cost through lost economic return on the land. Opportunity costs can be considerable, as for example winter wheat, the major crop in Uppland, can provide a farmer of returns between approximately €565/ha-€1505/ha (Production of cereals 2014; Wheat Price Daily 2015). The permanence of maintained infrastructure corridors in the landscape also means that any enhancement on them is likely to provide long-term benefits. Such actions would likely aid in the meeting of the EU's *Biodiversity Strategy to 2020* of "*Halting the loss of biodiversity and the degradation of ecosystem services in the EU by 2020*" (EU 2011).

Currently, the EU AES' are limited to areas that are cultivated for crop production or maintained in good agricultural and environmental condition (EU 2013), and no alternative funding is directed to regularly maintained areas such as transmission corridors and other maintained infrastructure corridors, where tall vegetation is controlled for utilitarian purposes. The use of transmission corridors as pollinator habitat is limited to certain areas and can not substitute AES, but can complement it. It has been shown in other contexts that tailoring of inputs for specific results is possible, with the application of AES' in simple, resource poor landscapes eg croplands, having the greatest benefit to provider species, whilst applying AES' in more complex landscapes provides more benefit to threatened species (Scheper et al. 2013). The extensive geographic extent of transmission corridors through many landscapes in northern Europe provides valuable but yet to be tapped opportunities for bumblebee conservation. However, how good are transmission corridors for other organisms remains to be tested.

Conclusions

Bumblebee abundance and diversity is threatened by many factors. Given both the intrinsic value of bumblebees and the ecosystem service they provide actions are being taken to counter these threats. Ours and others studies have shown that the creation of valuable wild pollinator habitat is an unintended byproduct of the maintenance of transmission and other infrastructure corridors. Our study also shows that if a management goal is the maintenance of valuable wild pollinator habitat, the current transmission corridor maintenance regime is a cost-effective approach that can be considered. The permanence and extent of transmission corridors in the landscape and the need for their regular maintenance means that any wild pollinator habitat created within them will persist. There are simple, proven management practices to enhancing bumble richness and abundance but more research is needed to evaluate and optimize the types and locations of conservation actions. We need a logical source of funding for such work and any future reviews of the Europe 2020 Strategy, CAP, or other relevant EU policy may provide opportunities to expand the habitat enhancements to such valuable pollinator habitat provided by maintained infrastructure corridors.

All data and code to reproduce this analysis are deposited in www.github.com/ibartomeus/powerlines

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Tables and figures:

Table 1: Flower density is the main predictor explaining bumblebee abundances and richness. Having a transmission corridor bisecting the landscape does not increase abundance or richness. The table show bumblebee abundance and richness models.

Bumblebee abundance	**Degrees of freedom**	**F-value**	**p-value**
Flower density	1,73	13.25	<.001
Habitat	6,73	1.67	0.14
Transmission corridor	1,8	1.16	0.31
Bumblebee richness			
Flower density	1,73	11.73	0.001
Habitat	6,73	1.33	0.25
Transmission corridor	1,8	2.96	0.12

Table 2: Abundance differences across habitats for ecosystem services provider and threatened species. While provider specie mirror the general abundance pattern, for threatened species we found habitat differences, but flower cover is not longer significant.

Provider species abundance	**Degrees of freedom**	**F-value**	**p-value**
Flower density	1, 134	11.01	0.001
Habitat	6, 134	1.52	0.18
Threatened species abundance			
Flower density	1, 62	0.02	0.89
Habitat	6, 62	2.72	0.02

Table 3: Plant species strengths (the sum of pollinator dependencies) across all interactions observed in transmission corridors, grasslands and over all habitats. Ranking are in parenthesis because raw numbers ca not be compared among habitats. Plants with high strengths are the most important in supporting a combination of ecosystem service providers and threatened species. Strength values can be high because plants support several pollinators with low dependence on the plant, or because it supports pollinators that depend a lot on the plant for foraging.

Plant Species	**Strength** (all	**Strength**	**Strength**

	habitats)	(corridors)	(grasslands)
Centaurea jacea	3.49 (1)	4.71 (2)	1.00 (6)
Trifolium pratense	2.85 (2)	0.36 (8)	2.82 (2)
Carduus crispus	2.28 (3)	6.43 (1)	0.63 (7)
Cirsium arvense	1.80 (4)	0.85 (6)	3.09 (1)
Calluna vulgaris	1.31 (5)	2.42 (3)	-
Lythranceae salcaria	1.12 (6)	1.35 (4)	-
Trifolium hybridum	0.75 (7)	0.27 (9)	1.14 (5)
Satureja vulgaris	0.71 (8)	0.02 (12)	1.35 (4)
Centaurea scabiosa	0.70 (9)	-	-
Succisa pratensis	0.67 (10)	0.96 (5)	-
Trifolium repens	0.54 (11)	-	-
Lathyrus pratensis	0.44 (12)	0.05 (11)	0.56 (8)
Leontodon autumnalis	0.43 (13)	-	1.81 (3)
Campanulaceae rapunculoides	0.32 (14)	-	-
Filipendula ulmaria	0.24 (15)	0.44 (7)	0.08 (10)
Melampyrum pratense	0.17 (16)	-	0.43 (9)
Centaurea cyanus	0.16 (17)	-	-
Carduus helenioides	0.14 (18)	-	-
Arctium tomentosum	0.12 (19)	-	-
Malva spp	0.11 (20)	-	-
Campanulaceae rotundifolia	0.11 (21)	-	-
Crepis tectorum	0.10 (22)	-	-
Prunella vulgaris	0.07 (23)	-	-
Epilobium adenocaulon	0.06 (24)	-	-
Vicia cracca	0.06 (25)	-	0.05 (11)
Lamium maculatum	0.06 (26)	-	-
Trifolium medium	0.05 (27)	-	-
Galeopsis terrahit	0.04 (28)	-	-
Carduus arvense	0.03 (29)	0.12 (10)	-
Solidago virgaurea	0.03 (30)	-	-

Lamiastrum galeobdolon	0.02 (31)	-	-
Hypericum maculatum	0.01 (32)	-	-
Taraxacum spp	0.01 (33)	-	-
Sonchus glabrescens	0.01 (34)	-	-

Figure 1: Species abundance and richness is not different in sites bisected or not by a transmission corridor. A) Mean number of individuals collected per plot in transmission corridor and non transmission corridor sites. B) Mean species richness per plot in transmission corridor and non transmission corridor sites (black bars) and species beta diversity (grey bars) across habitats in sites with and without transmission corridor (grey bars). The sum of both bars can be seen as the gamma diversity of each site (n = 10 sites).

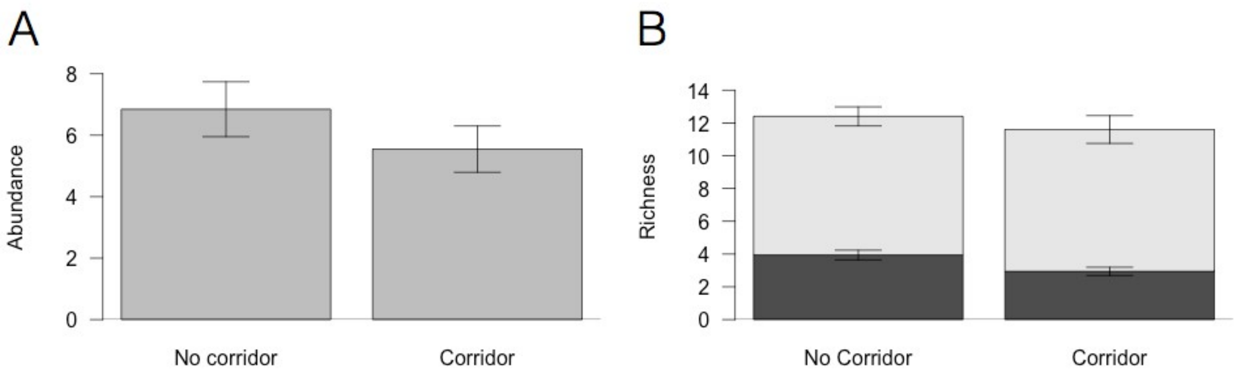


Figure 2: Species abundance and richness is not different across habitats. A) Mean number of individuals collected per plot in each habitat. B) Mean species richness per habitat (black bars) and species beta diversity (grey bars) between different plots of the same habitat. The sum of both bars can be seen as the gamma diversity of each habitat.

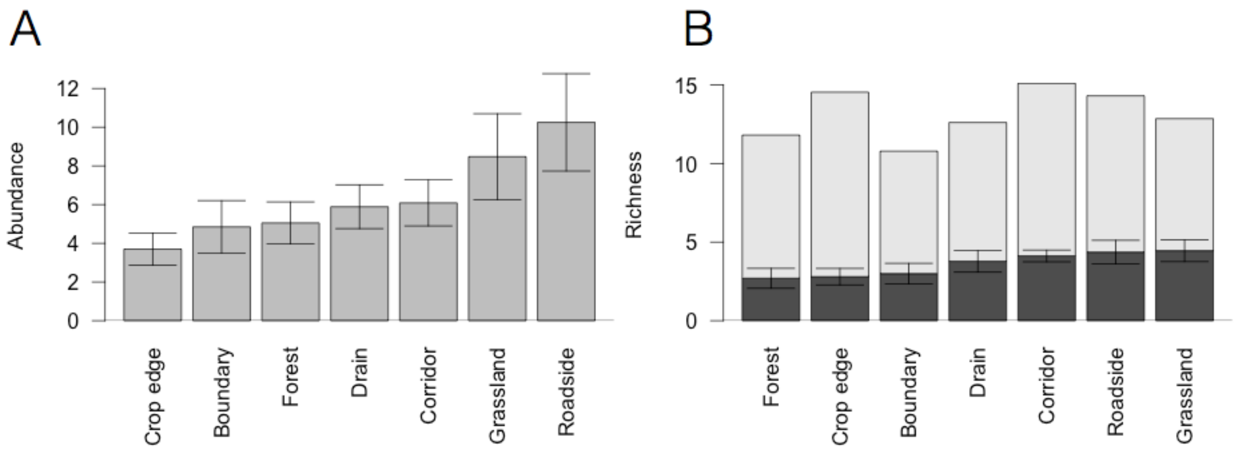


Figure 3: Species abundance of A) ecosystem service providers is not different across habitats while for B) conservation value species, transmission corridors, roadsides, grasslands and grassland-forest boundaries have higher abundances than the other habitats. The bars represent the mean number of individuals collected per plot in each habitat.

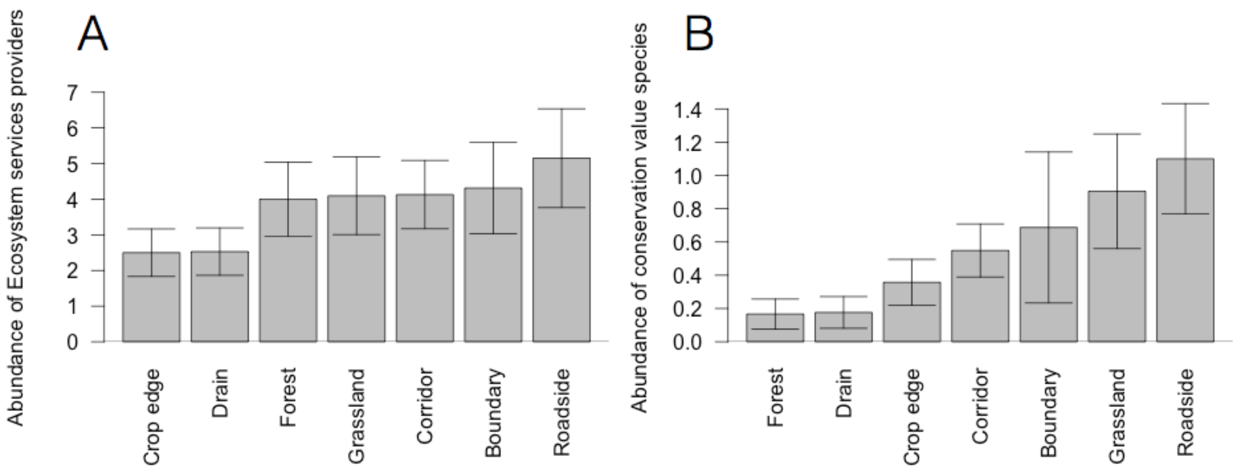
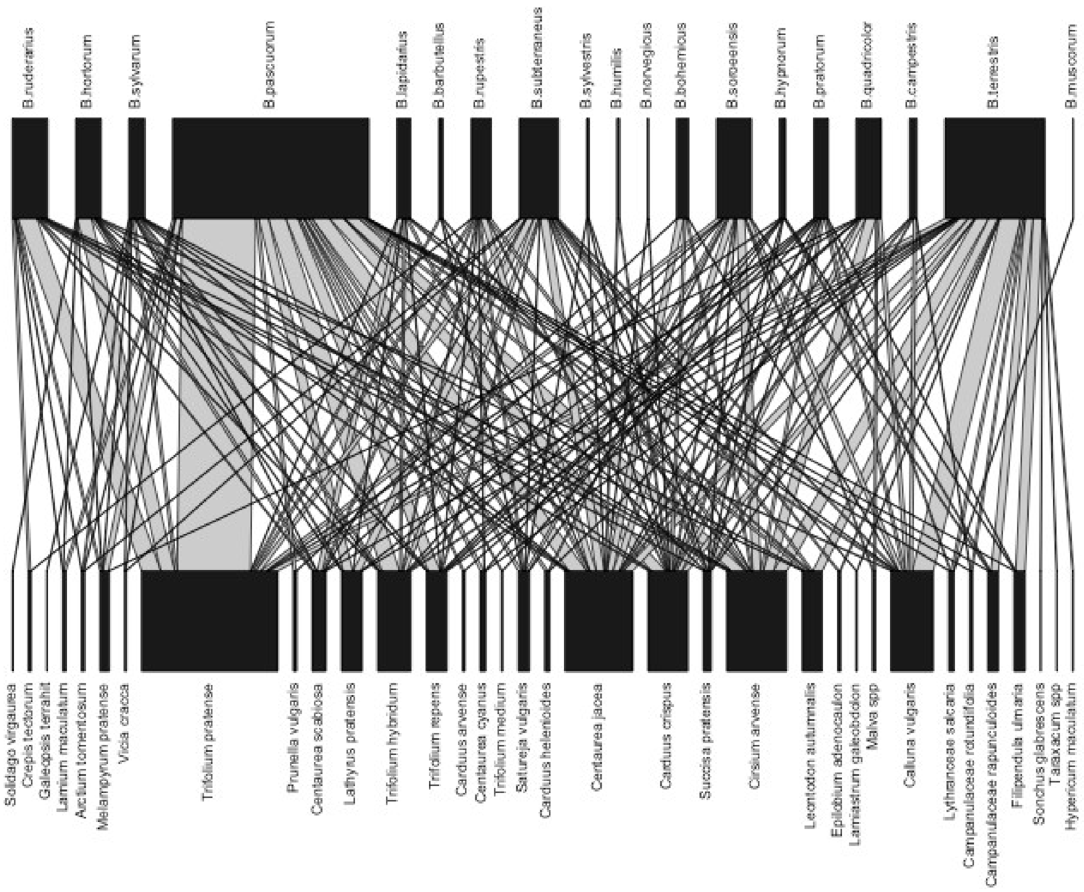


Figure 4: Relationship between bumblebees and the plants they visit. Black boxes are proportional to their total abundances. The grey links between bumblebees and the plants they visit are proportional to the visitation frequency.



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