POLLINATOR CONSERVATION AND MANAGEMENT ON ELECTRICAL TRANSMISSION AND ROADSIDE RIGHTS-OF-WAY: A REVIEW

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Abstract—Early successional landscapes created through right-of-way management are increasingly being viewed as potential pollinator conservation zones. Habitat development initiatives in these landscapes are active, but vetted support for particular techniques and strategies is limited and technical information is diffuse. Our review examined 34 published works in order to outline the current depth and breadth of investigation into the conservation and management of pollinators on rights-of-way along roadsides and underneath electrical transmission corridors. Taxonomic surveys dominate the literature and are focused on diversity patterns in butterflies and moths; the importance of host plant presence as a determinant of abundance and diversity patterns is highlighted in select cases. Keystone agricultural pollinators, including managed and wild bees, have only been examined in a handful of studies. Investigations of pollinator service provisioning within or adjacent to rights-of-way are also lacking. There are no studies of vertebrate or migratory pollinating species. Contrasting results are reported for the impact of disturbance regimes associated with management (mowing and herbicide use), and there is only limited consideration of any potential negative impacts. Studies were also focused on Europe and North America, omitting rapidly developing regions that are experiencing the highest rates of landscape conversion, and where dependence on wild pollinators for food production is high. Successful pollinator species management requires more refined information, and significant gaps exist in the understanding of how rights-of-way can benefit all pollinators, we therefore encourage further management-based investigations in order to develop best practices.

Keywords: right-of-way, roadside, electrical transmission corridor, utility landscape, habitat management, pollinator conservation

INTRODUCTION

There is growing interest in developing and preserving pollinator habitats within managed infrastructure landscapes such as roadside verges and electrical utility corridors. Although landscape conversion is a leading cause of pollinator decline (Kremen et al. 2002; Buchmann & Ascher 2005; Murray et al. 2009) correctly managed green spaces within anthropogenic systems can provide a full range of habitat requirements and can act as reserves (Angold et al. 2006; McFrederick & LeBuhn 2006). Rights-of-way alongside or underneath transportation and electrical utility installations are suggested to be particularly influential because of the extent of this landscape type – over 25 000 000 kilometres of road and 300 000 kilometres of electrical utility corridors in the United States alone (see Table 1 for details and for information on networks in other countries); connectivity and intersection with multiple habitats (Soulé 1991; Smith 1993; Weber & Allen 2010); and the prescribed and often mandated management regimes (e.g., NERC 2009) that maintain an early successional landscape. The realization that slight modification to existing management practices within electrical utility and transportation landscapes could both save resources (financial and physical) and improve environmental quality for pollinators, combined with the growing public understanding of the important roles that these species play in human survival and livelihoods, has also spurred the broad adoption of adaptive management and *pollinator-friendly* techniques. Successful implementation of landscape management within these systems can be invaluable, creating millions of hectares of pollinator landscape spanning continents, but the availability of vetted guidelines and techniques will be a limiting factor.

Pollinating insects (beetles, flies, wasps, ants, bees, butterflies, moths, thrips, and a few others), birds, and mammals have specific food, nesting, and mating requirements that are fulfilled better in some habitats than others (Schmidt et al. 1995; Kearns and Inouye 1997; Kremen et al. 2002; Kremen et al. 2004). A visual inspection of most rights-of-way would suggest them to be ideal or potentially functional pollinator habitats. Naturalists and wildlife ecologists have documented species along these habitat remnants for quite some time (Soulé 1991; Nabhan 2001; Russell et al. 2005; WHC-USDA 2005). Even rare and endangered pollinators such as the Karner Blue Butterfly have made a re-appearance in the electrical utility corridors in Pennsylvania, USA (Smallidge et al. 1996, Lowell & Loundsbury 2000). But has there been significant investigation into habitat development techniques and

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management regimes to prescribe treatments? Inspired by our recent activities with resource managers and by scarce published evidence encountered in our own investigations we undertook a review of the body of scientific and technical literature relating to pollinators on infrastructure supporting landscapes.

In this review we aim to amalgamate the diffuse literature on the topic of pollinators and rights-of-way associated with transportation and electrical utility infrastructure. We work to assess the scope and detail of investigation to develop a summary of the discipline. We also aim to outline elements of current practice and management that both are and are not supported by science and highlight areas of roadside and electrical utility pollinator ecology that require further investigation. Before we present our review we provide some background on the general ecology of electrical utility and transportation installations as they may relate to pollinators and other important wildlife species, as well as summary of the survival needs of each pollinator guild.

TABLE 1: Estimates of the total potential pollinator habitat that could be created given the extent of national roadways in the 20 countries with the most extensive roadway networks. Countries marked with an † are those for which peer reviewed works accounting pollinations on rights-of-way exist. (*Estimates of potential habitat were calculated using management areas equal to 3 metres on each side of the roadway.)

Global Rank (extent of road network)	Country	Amount of roadways (kilometres)	Estimated habitat potential (hectares)*
1	United States†	6 506 204	3 903 722
2	China	3 860 800	2 316 480
3	India	3 320 410	1 992 246
4	Brazil	1 751 868	1 051 121
5	Japan	1 203 777	722 266
6	Canada†	1 042 300	625 380
7	France	1 027 183	616 310
8	Russia	982 000	589 200
9	Australia†	812 972	487 783
10	Spain	681 298	408 779
11	Germany†	644 480	386 688
12	Sweden	572 900	343 740
13	Italy	487 700	292 620
14	Indonesia	437 759	262 655
15	Poland	423 997	254 3982
16	United Kingdom†	394 428	236 657
17	Mexico	366 095	219 657
18	South Africa	362 099	217 259
19	Turkey	352 046	211 228
20	Pakistan	260 760	156 456
	Total	25 491 076	15 294 646

The survival needs of pollinators

Among the most ancient pollinators are the beetles (Coleoptera) and flies (Diptera). Species in both orders range from extreme generalist floral visitors to extreme specialist that visit and pollinate but a few or even one kind of flowering plants (Kevan 2002). Generally, beetle pollinators (including scarabs, staphylinids and sap beetles) are somewhat indiscriminate in the flowers they visit, foraging for pollen and sometimes nectar on open bowl-shaped blossoms such as magnolia flowers or the capitula of flowers in the sunflower family (Asteraceae) (Kevan & Baker 1998). Similarly, flies can be generalist visitors and sometimes highly effective pollinators due to their hairy bodies. Other flies are floral specialists on various trap flowers (e.g., *Arisaema*). One of the most important of all fly pollinator groups are the flower flies in the family Syrphidae (Kevan 2002; Shepherd et al. 2003). Flower flies are dominant floral visitors and important pollinators wherever they occur. Females require one or more protein meals (from pollen and nectar) before they can develop eggs, which drives their floral visitation.

Butterflies and moths use separate host plants as adults and larvae. Nectar from a diverse set of flowers provides the energy required for flight. Adult females search for and oviposit on or near preferred host plants and larvae later emerge from eggs and begin immediate feeding, remaining on their food plants until they move to the soil or a limb or crevice in which to pupate. Sunning locations, such as bare ground or rocks, are important to maintain elevated temperatures for active flight; within managed landscapes there are reported correlations with increased sunlight and increased butterfly numbers (Carter & Anderson 1987). In North America, monarch butterflies (*Danaus plexippus*) undertake a continental migration and require appropriate high energy food sources distributed across a vast landscape (Brower et al. 2006). With habitat loss resulting in significant declines in monarch numbers in recent years, the roles that linear corridor habitats can play in migration support are under investigation.

Bees are the dominant pollinators of flowering plants (Buchmann & Nabhan 1996; Kevan 2001; Buchmann & Asher 2005; Ollerton et al. 2011) and are vital to agricultural productivity. All bees require high quality sources of pollen and nectar. This is especially true for long-lived eusocial species in annual and perennial colonies such as bumble bees (*Bombus* spp.) and honey bees (*Apis mellifera*) whose carrying capacity requirements have been studied (Schmidt et al. 1995). The proximity of nesting sites to food resources confines local populations as bees are limited by relative body size (Greenleaf et al. 2007) and the metabolic demands of flight in their dispersal (Heinrich 1979). The vast majority of bee species are ground-nesting requiring patches of bare soil of the right texture and moisture located close to their food plants (Michener 2001), but about 10% of bees nest in broken pithy stems such as brambles (*Rubus* etc.) and other plants. Bumble bees require cavities such as the abandoned underground nests of mice and other rodents. Honey bees (*Apis mellifera*) nest within hollow trees, or in cavities at the ground surface or rock cavities. This is especially true for Africanized honey bees (*Apis mellifera scutellata*) (Winston 1992).

Wasps are less hairy than bees and being carnivorous are less interested in blossoms except as nectar sources. Certain wasps can be excellent pollinators; one family of wasps in particular, the Masaridae, behave like bees in that they collect and provision larval cells with mixtures of pollen and nectar like most bees (Gess & Gess 2004). Among the Hymenoptera, the ants are very minor pollinators and may be more antagonistic in their relationships with angiosperms (Ashman & King 2005).

Hummingbirds and bats are vertebrate pollinator species, many of which are migratory, following seasonal patterns of blooms from overwintering to breeding areas. In these cases, the energy requirements of flight need to be provided by nectar rich plants present throughout their migratory range (Berlanga et al. 2010). Hummingbirds specialize on flowers with tubular shapes which are often more woody and shrub-like species including *Salvia* species (Buchmann & Nabhan 1996). In addition to feeding sites, hummingbirds require a landscape with sufficient vertical structure and cover to support nesting. Preferred nesting sites include areas where hardwood trees with ample leafy cover can be found. Insects provide protein for growing hummingbird chicks; again a diverse local ecosystem is needed to support these species. Bats feed more narrowly on cacti and species within desert landscapes (Buchmann et al. 1999; Molina-Freaner et al. 2004). Roadsides are not generally populated by plant species that might attract bats, but electrical utility corridors passing through the Sonoran Desert and other regions of the American southwest are, and could potentially be important migratory habitats. Bats in particular have suffered declines in the range of their food plants along north-south migration routes within North America (Buchmann et al. 1999).

Roadways and their associated verges

Roadways, whether they are rural dirt roads, paved city streets, or interstate super highways, all produce varying effects, both negative and positive on landscapes, wildlife, and people. The most obvious and far-reaching impact on landscapes and their biota is the simple bisection and fragmentation of habits that comes with road-building and maintenance. Roads of all types and sizes fragment natural, urban, and agricultural landscapes into ever-smaller areas, irregular polygons, often referred to as habitat islands (Forman 1995; Dramstad et al. 1996). Dividing landscapes into smaller parcels has profound consequences on the plants and animals of those regions and neighbouring areas (Fahrig 2003). Fewer species can live and reproduce on smaller habitat islands (MacArthur & Wilson 1967). Thus, roadways divide habitats up into smaller irregular areas that then often become impoverished in terms of the number of plants and animals that can live there, unless re-colonized from adjacent source areas, in the oceanic island analogy, the mainland (Smith 1993). Range requirements for plants and animals, rather than strict abundance, may determine the likelihood of local extinctions (Ney-Nifle & Mangel 2000). It should be remembered, however, that habitat diversity and environmental structure are often more important than size alone when creating a nature preserve or managing existing habitats; the results of our review support this.

Along with the direct effects, roadways often act as barriers or channels to move or direct the daily movements of animals in their paths, or more dramatically, the migration routes of migratory species, especially for mammals. Alternatively, they have been shown to promote species movement, although in some cases this could account for the spread of invasive species (Getz et al. 1978; Garland & Bradley 1984; Von Der Lippe & Kowarik 2007). Anthropogenic inputs are common along roads. Vehicular traffics introduces and spreads gasoline, motor oil, ethylene glycol (anti-freeze), other chemicals and vast amounts of pulverized bits of automobile tires across the landscape everywhere there are roads. Furthermore, roadways are managed with chemical and mechanical disturbances that can cause potential negative impacts on species.

There are also positive impacts that roadways have on their nearby landscapes and on pollinator communities. The greening of roadside plants, both native and exotics, is due to rain water harvesting by the paved surfaces and channeling of runoff waters to the roadside verges. Plant growth is often exuberant, thick, and tall among roadsides during the growing seasons. As will be discussed in more detail, roadside flowers have documented associations with many pollinating insects (Way 1977), including butterflies and moths (Ries et al. 2000; Saarinen et al. 2005; Valtonen et al. 2006; Williams 2008), flies (Free et al. 1975; Raemakers et al. 2001), and especially bees (Way 1969; Hopwood et al. 2010). The utility of roadsides had been recognized by beekeepers that have these landscapes as transient bee pastures to capture honey flows (Harper-Lore & Wilson 2000). Roadways could also possibly create new areas, strips or patches of open compacted ground and may enhance nesting of certain native ground-nesting bees. Some authors have suggested that roads and their associated verges can play significant roles in habitat connectivity, perhaps compensating for the some of the negative impacts (Forman et al. 2002). Thus roads have both beneficial and negative effects for plants, animals, and people. Table 2 lists and contrasts many of these ecological effects.

Electronic power transmission lines and their maintenance corridors

High voltage electric power transmission lines, their towers, and associated access roadways provide most of the same negative and positive effects of regular roadways discussed above. There are differences, however, in their total effects on urban, rural, and wilderness landscapes. Like roads, electrical transmission line corridors impact landscapes and wildlife habitats directly and most importantly by fragmenting them into smaller and smaller pieces as discussed for island habitats. For some species, they may also connect habitats and allow movement between feeding or breeding areas, especially for larger mammals (Yahner 2004; Weber & Allen 2010). Electric and magnetic field (EMF) radiation from high voltage lines may pose a threat to animals living under or near these lines; both anecdotal and published accounts suggest that honey bees exhibit aggression and lower productivity when they are underneath

Table 2. Postulated ecological effects of creating new roadways and electric power transmission line corridors on insects and other wildlife.

Roadways and Roadsides:	
Negative Effects	*Positive Effects*
• Direct elimination of habitat area (new installation). • Bisect and fragment landscapes into habitat islands (new installation). • Conduits for dispersal of weeds and exotic animals. • May alter migratory patterns, especially larger animals. • Allows deep access into wildlands for further exploitation. • Increases frequency of wildfires (tossed cigarettes). • Introduction and spread of gasoline, exhaust fumes, rubber particles from tires. • Mortality due to interactions with vehicles and traffic (road kill).	• Water runoff creates hedgerow effect of new growth. • Increased flowering promotes bees, other pollinators, grazing by herbivores. • Thoughtful management fosters or resets succession promoting colonizing species. • Creates new bare ground along edges, promoting bee nesting. • Road-killed individuals provide important food for avian raptors, other birds, mammals and certain invertebrates.
Transmission Power Line Corridors and Maintenance Roads:	
Negative Effects	*Positive Effects*
• Bisect otherwise unbroken habitats into habit islands (new installation). • Raptors may be electrocuted when using transmission towers as hunting perches. • Electric and Magnetic Field (EMF) radiation from high voltages may pose threats to animals living under them. Honey bees have been implicated.[1]	• Chemical or mechanical thinning opens up habitats. • Many wildlife species require and favour these early successional stages. Many animals live and prefer to forage along these new edge habitats. • Bare soil in maintenance roads favours ground-nesting bees and wasps. Increased rodent nesting may favour bumble bees. • Flowering and fruiting may increase food for birds and mammals. • Avian raptors often use transmission towers as perches from which to hunt.

[1](Wellenstein, 1973; Rogers et al. 1982; Lee and Reiner, 1983)

high voltage electrical utility wires (Greenberg et al. 1981; Rogers et al. 1982; Lee & Reiner 1983).

Although both road and electrical utility landscapes are managed with safety in mind, electrical utility rights-of-way, and especially those underneath high voltage wires, are systematically and vigorously cleared of taller vegetation that might interact with power lines. The impacts of a tree-wire interaction can be significant as was seen in the 2003 Northeastern black-out in the United States and Canada where nearly 30 million people lost power – the culprit was a tree growing too close to overhead lines and an eventual blow out when extreme heat caused the wires to sag into the tree. Strict guidelines and policies are now in place within the electrical transmission industry to prevent such an incident from repeating (NERC 2009). To eliminate the risk of trees interacting with overhead lines, transmission line corridors are either mechanically or chemically treated for vegetation management. This adds physical structure and edges to habitats, and allows the growth and reproduction of understory plants that will exclude taller growing species. Many of these plants produce flowers for pollinators along with fruits, seeds and berries for birds, mammals and other wildlife species. Electrical corridors are thus continually reset to earlier seral or successional stages. Many types of wildlife thrive in such altered habitats including favoured game species such as quail, pheasants, and wild turkeys, which in the United States have made a significant comeback due to electrical utility corridor conservation programmes (King & Byers 2002; Willyard et al 2004; Goodrich-Mahoney et al. 2008). Conversely, management that is too aggressive and frequent can cause ecological deserts. Again, Table 2 presents the anticipated positive and negative impacts of electrical utility rights-of-way.

METHODS

A keyword literature search was conducted using a combination of electronic scholarly databases and world-wide-web search engines. Our interest was in peer reviewed scientific literature, technical publications, or any other form of literature that land managers might look to for guidelines. The key words used in this search were any combination of: *pollinator, pollinators, bee, bees, butterfly, butterflies, moth, moths, bat, bats, bird, birds, hummingbird, hummingbirds, beetle, beetles, fly, flies,* and *beneficial insects* in conjunction with either: *right-of-way, ROW, utility corridor, electrical utility corridor, power lines, verge, road side, transportation corridor, transmission corridor*, and *IVM* or *Integrate Vegetation Management*. The reference lists cited in each paper were also searched for further relevant publications that were not acquired in the primary search. Contacts were made with experts in the fields of utility and roadside management to widen the search. Only references that were explicitly focused on pollinators and pollinator habitat management in electrical utility and roadside rights-of-way were retained for analysis.

To better assess the taxonomic diversity of pollinators that have received attention in right-of-way landscapes, the taxonomic resolution of each investigation was noted, including the general pollinator group studied and, if applicable the number of species, guilds, or groups examined. Studies were classified as surveys, comparative studies, or experimental. The selection of works was categorized by geographic region and the type of right-of-way (electrical utility or roadside). The duration of each study was noted in order to gauge how well temporally variability in populations and landscape change over time has been addressed. Finally, published works were sorted as either scientific or technical to determine the proportion of data generating work versus management-oriented guidelines.

RESULTS

Our literature search resulted in only 29 peer reviewed studies spanning a time period from 1969 to 2011 that were retained as either pollinator specific or pollinator relevant, and an additional 5 published technical guides that are aimed at assisting land managers in producing pollinator-friendly landscapes. The majority of works on the subject of pollinators in managed infrastructure landscapes were produced from 2000 onward. Most studies are very limited in temporal scope, focusing on one season or one year, which is not considered sufficient to adequately assess pollinator populations that are known to be highly temporally variable (Williams et al. 2001; Hilton & Miller 2003; Cane et al. 2005). Only two studies have exceeded the short time frame, one is an ongoing study of butterfly habitat development along roadside for threatened butterfly species in the Netherlands (Wynhoff et al. 2011); the other is a 51-year study of a famous Pennsylvania electrical transmission corridor (Yahner 2004). Table 3 presents a summary of the various foci of the recovered research and Appendix I provides a full summary of each study.

The majority of studies (19 of 29, or 66%) examined roadsides. Studies of electrical utility rights-of-way focused only on overhead electrical transmission corridors. Three of the pieces were reviews of landscape management techniques, one of which presented a combined review of both roadside and electrical landscapes (Smallidge & Leopold 1997). The geographic focus of work is heavily biased to North America (62%) and Europe (31%); however in North American there are only studies from Canada and the United States, and none from Mexico. Within the United States works are focused in the east and mid-west, with one study in the Pacific Northwest. Work from Canada comes from Quebec. European studies have been conducted in Finland, the Netherlands, Germany, and the United Kingdom. There is one study from Australia. No published accounts from Central and South America, Africa, or Asia were recovered.

The majority of investigations into pollinators on rights-of-way have been comparative, contrasting the fauna found along rights-of-way with that found in natural habitats (Smallidge et al. 1996; Lanham & Nichols 2000; Hopwood 2008; Larsen 2010), or comparing managed rights-of-ways to unmanaged systems (Ries et al. 2000; Russell et al. 2005; Hopwood et al. 2010; Wynhoff et al. 2011). The earlier studies recorded surveys of plant-insect interactions within right-of-way landscapes (Way 1969; Way 1977; Free et al. 1975). Most studies focus on understanding the positive impacts of electrical utility instillations, but a handful do examined the potential negative impacts associated with pollinator mortality and roadways (Seibert & Convoer 1991; McKenna et al. 2001). Experimental approaches are limited and have focused on three subject areas: understanding the responses of honeybees to high voltage (Wellenstein 1973; Rogers et al. 1982; Lee & Reiner 1983), testing the impacts of varied management regimes on butterflies and moths (Noordijk et al. 2010), and testing if targeted habitat development techniques are successful in increasing butterfly occurrence (Forrester et al. 2005).

Butterflies and moths were the most rigorously studied, including three studies of the endangered Karner Blue Butterfly (*Lycaeides melissa samuelis*) in the United States (Smallidge et al. 1996; Forrester et al. 2005; Lowell & Loundbury 2000) and one study of the success of reintroduced *Phengaris* (*Maculinea*) *teleius* and *P. nausithous* species in the Netherlands (Wynhoff et al. 2011). Studies of bees examined communities of native bee communities on electrical utility corridors (Russell et al. 2005) and along roadsides (Hopwood 2008), the response of honey bees to electric and magnetic waves underneath high voltage power lines (Wellenstein 1973; Greenberg et al. 1981; Rogers et al. 1982) and one study focused on bumble bees along roadsides (Hopwood et al. 2010). Studies of pollinators in general included flies and focused on Syrphidae (Free et al. 1975). No studies examined the interactions that hummingbirds and pollinating bats might have with managed electrical utility and roadside landscapes. Studies on pollinating beetles were also lacking.

The technical guidelines recovered in this review include habitat provisioning for all native pollinators (NAPPC 2010; WHC 2005), as well as some that are specific to butterflies (UK Forest Council 1987) and bees (Xerces Society 2010). Guidelines have been produced by organizations within the United States and in the UK.

DISCUSSION

There are multiple beneficial insect associations on roadsides and underneath electrical corridors that contain native flora. Early and beginning works in the field (Way 1969; Free et al. 1975) indicated that pollinator diversity was much higher than expected in these landscapes. Since then, the pace of work has increased and the presence of pollinators in infrastructure landscapes managed as early successional habitat has been documented in both peer reviewed and grey literature. The three reviews acquired in our overview (Way 1977; Lee & Rener, 1983; Smallidge & Leopold 1997) provide broad summaries of species diversity patterns along roads and underneath power lines. Peer

Table 3: Summary statistics for literature reviewed

Pollinator group studied*						
	Bees	Butterflies/Moths	Beetles	Flies	Bats	Hummingbirds
no	13	16	0	2	0	0
%	45%	55%	0%	7%	0%	0%
Geographic area of study						
	North America	South America	Europe	Australia	Africa	Asia
no	18	0	9	1	0	0
%	62%	0%	31%	3%	0%	0%
Type of study						
	Compare	Survey	Experiment	Review		
no	16	4	6	3		
%	55%	14%	21%	10%		
Landscape type**						
	Road	Electrical				
no	19	11				
%	68%	39%				

*some studies included more than one group
**some studies examined both roadsides and electrical landscapes

reviewed accounts of electrical utility rights-of-way and roads provide a verification that landscapes that "appear" to be pollinator positive do in fact contain many species of butterflies, moths, bees, and flies.

All accounts of beneficial habitat associations, especially in managed and anthropogenic landscapes, are important, but what is more valuable to management-based ecosystems is addressing the impact of interventions and the responses of individual species. Successful pollinator species management requires more refined information, and significant gaps exist in the understanding of how roads and rights-of-way can benefit all pollinators. This lack of detailed accounts of autecology indicates that more study is needed in this landscapes type.

Pollinator groups that dominate rights-of-way

Butterflies, moths, and to a lesser extent, bees have been studied in infrastructure landscapes along roads and underneath transmission lines. The majority of works on diurnal moths and butterflies have outlined the importance of host plant presence as a significant factor in determining species occurrence (Smallidge et al. 1996; Valtonen et al. 2006; Larsen 2010). Butterflies in electrical utility rights-of-way responded to similar factors that promoted their occurrence in field boundaries and agricultural landscapes where they were more commonly associated with edge habitats (Sparks & Parish 1995). Management strategies that increased edges (especially ones that created more scalloped edges), favoured trees along sidelines, and increased bare ground provided better butterfly habitat (Carter & Anderson 1987). Sunlight was particularly important in species occurrence patterns, as this is important for basking behaviours that warm the body for flight (Smallidge et al. 1996). Moths and butterflies were often treated together in investigations, and generally responded to similar variables, but butterflies were more influenced by the presence of nectar plants, and diurnal moths responded to vertical structure in the landscape (Saarinen et al. 2005). Natural prairie lands and restored roadsides were found to be equivalent in Lepidopteran richness and diversity (Williams 2008), suggesting again that targeted initiatives produce beneficial results for butterflies. Lahham & Nichols (2000) also compared multiple right-of-way transects for trends in butterfly richness and found no significant difference, although abundance patterns did vary.

Native bee communities have primarily been studied along roadsides that have been planted with wildflowers. Hopwood (2008) provides an account of bees along roadsides that have been managed in various ways, noting that promoting the occurrence of local native plant species creates a landscape in which bumble bees and other native bees actively forage. Bumble bees in particular were positively influenced by roadside mowing (Noordijk et al. 2009). Comparative studies of targeted roadside restoration efforts that recreated prairies were shown to have faunal composition similar to that of nearby native prairies. Although basic wildflower plantings had more diverse bee faunas than mowed roadsides, selective prairie plantings showed the greatest success (Hopwood 2008), supporting the importance of the local floral community in determining pollinator community structure (see Potts et al. 2003).

Only one study of native bees and electrical utility landscapes has been published to date. Russell et al. (2005) examined native bee communities along an electrical right-of-way. This study took place along an electrical corridor that passed through a conservation reserve resulting in a situation where landscape management occurred only in an easement zone underneath the overhead wires. More diverse and more abundant communities of native bees were recorded underneath the overhead wires and this was attributed to a more floristically diverse landscape that was able to develop due to intermediate disturbance from mowing and herbicide treatment (Russell et al. 2005).

The impacts of management on pollinator populations

Electrical utility corridors and roadsides require continuous management for accessibility, visibility, and user safety. As noted above, there are often easements or mandates that allow their management even in environmentally sensitive areas. Most maintenance activities maintain vegetation at an early successionary stage that is presumed to be a positive habitat for pollinators. Noordijk et al. (2009) investigated the impacts of one of the most standard management practices along roadsides – mowing. Overall, mowing was shown to increase bee and butterfly occurrence (Noordijk et al. 2009), but initial decreases were documented after implementation that were attributed to a reduction in food plant availability. Management regimes that limited and timed mowing were the most successful in increasing beneficial species occurrence. For example, increasing mowing to twice a year and removing residues had the greatest positive impact on moth and butterfly diversity in managed systems in the Netherlands (Noordijk et al. 2009). Overall, single-season mowing was better than no mowing, but targeted mowing efforts produced the most pollinator richness (Ries et al. 2000; Wynhott et al. 2011). Bumble bees in particular were positively influenced by roadside mowing in this system (Noordijk et al. 2009). Champagne and Bourassa (2000) conducted an earlier study of mowing regimes along roadside in Quebec, Canada that yielded similar results; the highest biodiversity, including many pollinating species, was seen in areas mowed annually while more intensive mowing schedules (mowing three to five times a season) had lower richness and abundance measures

Weediness correlated with lower beneficial insect diversity (Way 1977; Ries et al. 2000; Valtonen et al. 2006). Herbicide treatment is a common method for weed eradication and the practice is often mandated by local invasive species action plan. The observed direct impact of herbicides on local pollinator communities would come from a direct reduction in their food supply, although the revived literature does not agree on an impact of herbicide application. Yahner (2004) did not find any measurable impacts on butterflies associated with herbicide use. Bramble et al. (1999) found greater butterfly diversity in land management systems that used herbicide treatment, although this treatment was targeted toward the removal of grasses and tree species. Larsen (2010) did, however, find that lower numbers of butterflies were associated with herbicide applications, but that butterfly numbers increased thereafter.

Integrated Vegetation Management, or IVM, programmes are becoming more broadly implemented in right-of-way landscapes as they save resources and have been shown to improve wildlife habitat (Yahner 2004). These programmes include a combination of mowing, burning, hand removal, and localized herbicide use to achieve a desired landscape. Direct studies of pollinator community responses to IVM practices compared against traditional board scale mowing and herbicide management systems were not recovered in our review; however, our field research is currently testing these alternatives to provide quantitative results.

Managing to promote pollinators

A few studies in our review documented targeted management efforts that seek to capture the potential of roadsides and rights-of-way as conservation lands for species of concern. The endangered Karner Blue Butterfly (*Lycaeides melissa samuelis*) has been studied in some detail within the electrical utility corridors of Pennsylvania (Smallidge et al. 1996; Forrester et al. 2005; Lowell & Loundbury 2000). These landscapes were noted as one of the few remaining habitats in which *L. melissa samuelis* was found (Smallidge et al. 1996). Efforts to actively develop more appropriate habitat were undertaken, including the planting of preferred nectaring and larval plants, as well as instituting landscape management practices that support these floral species (Lowell & Loundsbury 2000). Research into the response of key floral species to management practices, including targeted mowing and isolated herbicide treatment, resulted in the development of a landscape more suitable for *L. melissa samuelis*. Together these studies show that less woody landscapes have greater occurrence of *L. melissa samuelis* (Forrester et al. 2005) and that microclimate also matters, with warmer areas having higher abundance (Smallidge et al. 1996). Today these electrical utility landscapes act as habitat reserves, and there have been significant improvements in local species occurrence.

A similar targeted management study conducted in the Neatherlands examined the success of species reintroductions into roadside habitats that, like in the case of the Karner Blue Butterfly, represented the only remaining areas of suitable habitat (Wynhoff et al. 2011). *Phengaris (Maculinea) teleius* and *P. nausithous* are species that have positive associations with local native ant species, and there are strong correlations between their occurrence and ant colony presence. In 2009 these species were reintroduced into roadside habitats as part of a management study to increase native ant presence and subsequently increase the occurrence of *P. (Maculinea) teleius* and *P. nausithous*. Tested management practices include early season mowing and summer mowing, as well as creating areas of open vegetation that increase ground temperature, which increases the productivity of the associated ants. Heavy disturbance was not positive for the ants, and therefore also reduced butterfly occurrence. The resultant prescribed management practice that will be used includes bi-seasonal mowing and residue removal to increase bare ground in favour of the ants, and butterfly numbers are expected to continue increasing (Wynhoff et al. 2011).

More complicated total ecological studies of management impacts and subsequent pollinator occurrence on rights-of-way are not available. Although general conclusions about best management practices for the pollinator community can be drawn from the existing literature, it is clear that conservation and management relies on a deeper understanding of the ecology of these landscapes and the local biology of their resident species.

Negative interactions between rights-of-way and pollinators

Accounts of the potentially negative impacts of roadsides focus on butterfly and moth mortality associated with traffic. Seibert & Conover (1991) conducted a study of general roadside mortality and noted the number of insects, especially butterflies and moths, to be higher than expected, and greater than the observed mammalian road kill that is more easily observed. Direct mortality related to vehicular traffic was investigated by McKenna et al. (2001), and indicated that there was an association with increased travel velocity and traffic volume and the number of dead Lepidoptera found lying on shoulders. This study also provided an estimate of the number of individuals killed along roadways each week in the state of Illinois at 20,000,000. Munguira & Thomas (1992) has contrasting results from the work they conducted in England; they recorded overall low and insignificant mortality rates (0.6 to 1.9%) attributed to vehicular traffic as compared to natural factors. Roads were not found to be barriers to the movement of butterflies, nor where populations of butterflies separated by even busy roadways genetically isolated from each other, again indicating fluid species movement (Munguira & Thomas 1992). What is missing from these studies is whether roadsides that are managed for native plant species or to promote wildlife habitat cause more kills than unmanaged roadsides and if this has any impact on local populations. We are aware of a few new studies that are underway in Britain, the Netherlands, and the United States to better quantify the direct threats of vehicular traffic to local insect populations.

We do not have an idea of the magnitude of direct vehicular impacts on keystone pollinators including bees, flies, and wasps. The studies reviewed have not indicated any direct bee mortality, even along roadsides that have been designed to attract bees (Hopwood et al. 2010). We also do not have a clear understanding of at what heights most insects fly across roads. There are contrasting findings regarding whether roads present barriers to bee movement. Bhattacharya et al. (2003) conducted a mark-recapture study of bees along suburban roadsides and did not find any evidence of movement across roadways. Our personal observation have documented bees crossing roads in cities and in suburbs (V. Wojcik, pers. obs.); Hopwood et al. (2010) also observed that bumble bees do in fact cross roads when foraging along roadsides, although they tend to preferentially forage along the linear transects created by wildflower seeding efforts. Road width, usage, traffic, and local floral resource presence are factors that might influence bee foraging movement, in which case site-specific characteristics would be determinants of flight patterns.

A handful of studies addressing pollinator health examined the impacts of high voltage wires and electromagnetic fields on honey bees, and indicated that lower productivity and behavioural changes (aggression) occurred (Wellenstein 1973; Rogers et al. 1982; Lee & Reiner 1983). Because right-of-way habitats are beginning to be seen as reserves for wild bees understanding the impacts of high voltage and electromagnetic fields on the native bee community will be of value. Parallel declines in productivity could be expected in native bees, but there is no data available. We recommend a comparative study of trap nest occupancy, nest productivity, brood development, and fecundity in natural settings and underneath high voltage lines.

In regard to general pollinator health, we believe that electrical utility rights-of-way present potentially healthy habitats, with less "pollution" compared to roadsides. The presence of run-off and contamination from roads can negatively impact bees, especially ground nesting species – but there is no investigation in this area. Plants growing along roadsides could also potentially accumulate toxins in their nectar and pollen, and these could be magnified in bees. A toxicity study of the impacts of roadway run-off on pollinator nesting and development was not found, and there is insufficient research on whether or not environmental toxins and pollutants accumulate in the soil or nectar of plants and if there are subsequent impacts to pollinator health.

Deficits in the literature

Nesting opportunities for bees in particular have been given little critical attention, although studies allude to the importance of available open space (Hopwood 2008) and guidelines produced by conservation organizations (NAPPC 2010) promote the development of open space for nesting. Furthermore, attempts at increasing nest site availability through either vegetation management or nest installation have not been investigated, yet Potts et al. (2003) indicated that the most important factors impacting the bee community in natural systems were the floral community, nesting site availability and time after fire (also a measure of disturbance). Parallels likely exist in managed electrical utility landscapes and the role of available nesting habitat as well as increasing nest site availability should be investigated.

No studies of flower beetles, hummingbirds, or bats were recovered in our investigation. While not key agricultural pollinators, many beetles, flies, hummingbirds, and bats play essential roles in maintaining local ecosystems. Some hummingbirds and bats are also species of concern that have suffered declines in their natural migratory habitat. Rights-of-way could be providing a potential network of habitat reserves for these species, but there is no account of their study or conservation in the current literature.

Many roads and electrical transmission corridors run parallel to agricultural landscapes that could benefit from pollinator populations present in these lands. No study to date has examined the impact that roads and electrical transmission lines can have on nearby agricultural productivity. If planting hedgerows near crops increases yield and if farms that are situated within more "natural" areas produce more crop (Kremen et al. 2000), then it is likely that nearness to correctly managed rights-of-way could have a similar benefit. This is an area that requires further investigation.

The most understudied parts of the world are areas where populations and supporting infrastructure are the most rapidly developing and where wild pollination is still a significant factor in agricultural productivity. Our review did not find any works from Africa, Asia, or South and Central America. Referring back to Table 1, four of the top five countries by road network length are not present in the literature, in fact, only four of the top 20 road networks have been given attention from scientists and land managers, and in some case this is restricted to only a few studies per region.

CONCLUSIONS AND SUMMARIES

Vegetation remnants alongside roads and underneath overhead transmission corridor provide habitat for pollinating species. We believe right-of-way landscapes can play a role in pollinator conservation and management. They are potential linear refuges, but how we manage these vegetative strips makes a difference. When these landscapes are managed appropriately or restored using native vegetation there is a strong positive effect on native pollinator diversity and local abundance.

We recommend increased monitoring and implementing tests of alternative management techniques to develop best management practices that directly promote pollinators. Furthermore, we encourage the investigation of off-site impacts and benefits that might be derived from roads and rights-of-way to agricultural landscapes. The network of managed roadways and electrical utility rights-of-way also mirrors many migratory pathways, especially those of monarch butterflies, some bats, and hummingbirds. Ideas of facilitated migration and the development of managed way-stations along roads and electrical utility crossings could hold potential for the conservation of these species but require a well-reasoned management approach. Successful species management requires more refined information, and significant gaps persist in our understanding of how roads and rights-of-way can benefit all pollinators.

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APPENDIX

Additional supporting information may be found in the online version of this article:

Appendix I. Catalogue of studies examining pollinators on right-of-way landscapes

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