The potential of verges and verge management

Mees van den Munckhof
External Supervisor: Rens Vaessen Examiner: Merel Soons
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Msc Bio Inspired Innovation Utrecht University

Figure 1: A seemingly biodiverse verge in Norway (Made by author)

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Layman's summary

The increasing growth of the global population causes an increase in road density. This causes fragmentation of natural habitats and has a negative effect on biodiversity. However, accompanying roads are verges, strips of land that could serve a purpose in battling the negative effects of roads and fragmentation. By reviewing literature, the potential of verges to replace natural habitats and provide services for nature and humans was investigated. Additionally, management possibilities that could further improve the potential of verges were reviewed. Overall findings revealed that verges could serve a purpose as a natural habitat for plants and insects. Other animal groups were not investigated enough to draw a conclusion. The potential for habitat provision does, however, depend on the situation, as verges take on many different forms. In addition, there is a possibility that verges provide habitat, while decreasing success of species that settle in this habitat.

In addition, verges can provide many different services for humans as well. Some of these are air and water filtration and carbon capture. Still, verges can also provide disservices, like damage to infrastructure and wildlife mortality. Services, however, do seem to outweigh the disservices.

Finally, several management practices that probably improve the verges potential to provide services for natura as well as humans are reduced mowing frequency (0-2 times per year), optimizing mowing timing (outside of peak flowering times), not mowing too close to the ground, clipping removal, prioritizing areas further away from roads, improving soil properties and finally prioritizing wider verges over small verges. However, management practices chosen should still be dependant on the specific context. Finally, some important aspects relating to implication of verge management alterations are given, along with gaps in knowledge and potential future research options.

Introduction – the effect of roads and verges on biodiversity.

With a growing global population, and with increased industrialisation and urbanisation, road networks are getting denser worldwide. Due to this increase in human infrastructure, natural habitats are being lost, degraded and fragmented (Bekker & Iuell, 2003). On top of this, traffic along these roads cause light, noise and chemical pollution as well as head-on collisions with fauna (Ouédraogo et al., 2020). These factors are putting strain on the worlds' biodiversity (Chaudron, Perronne, Bonthoux, & Di Pietro, 2018). As a result of this development, declines have been reported for many taxa of faunal species, across both vertebrates and invertebrates (Hetherington, Sterling, & Coulthard, 2021).

Still, roads are often accompanied by verges, strips of vegetation. According to Rijkswaterstaat (2013), in 2013, 20.000 hectares of the Dutch land surface consists of verges. This number has surely increased since then with the increasing amount of infrastructure and urbanisation in the Netherlands. This large area could serve a purpose in creating and reconnecting natural habitats, while also providing ecosystem services such as pollination and natural pest control in a agriculture context. (Chaudron, Perronne, Bonthoux, et al., 2018). To protect the worlds' biodiversity, there is a need to protect our remaining natural areas and connect these as much as possible. This is especially true in the Netherlands, as it is a highly urbanised and densely populated country. In this sense, road verges have gained the interest of landscape planners as a potential biodiversity hub in urban and rural areas alike, in order to compensate for the negative effects of the growing infrastructure density. Still, several questions remain to be answered.

> *To what extent can verges actually replace natural habitats?*
>
> *What ecosystem services (and disservices) can verges provide?*
>
> *How could verges be managed in a way that optimizes the verges' potential to provide ecosystem services?*

By way of a literature review an attempt was made to gather knowledge in order to find answers to these questions. Hopefully, these answers could provide insight into the potential of verges and the possible management options to improve this potential.

Methods - literature search

In an effort to summarize the already existing knowledge on this topic, a scientific literature search was conducted using the scientific search engine SCOPUS, selecting on articles that contain the words "verge* OR roadside*", "management*" and "biodiversity" as the aim of this review was to specify the effect of different verge management practices, mainly on biodiversity. Also, only literature from the last 5 years was considered, in order to review the most recent of findings concerning verge management. After filtering for relevance, this search yielded 30 different literature sources, 8 of which were literature reviews themselves, reviewing articles on the topic of road verges and biodiversity of the last couple of decades. Using this collection of literature, the previously stated questions were answered as best as possible.

To what extent can verges actually replace natural habitats?

So, what potential do verges have to serve as a replacement for natural habitat? The most frequently discussed potentials of verges is that of a habitat provider or corridor for the conservation of biodiversity that has been lost due to urbanisation and agricultural intensification. For instance, a review by Lázaro-Lobo & Ervin (2019) looked into the effect of verges on plant species, using studies from all over the world, with most coming from Europe. They found that, for 3 quarters of all found studies, road verges had a positive effect on species richness for species that originally occurred in the verge area. However, next to this beneficial effect of verges, in most studies they found that verges can also facilitate distribution of exotic and unwanted species.

These findings were backed up later by Vanneste et al. (2020), who looked into plant diversity in road verges across temperate Europe. They found that 52% of species were similar when comparing verges and their natural counterparts, grasslands. This indicates that at least to some extent. verges have the potential to provide habitat that is similar to natural grasslands. Thus, verges can provide habitat for plant species, among which are slow growing specialists. Still, 11% less specialists were found and 14% more generalists in verges when compared to grasslands. These generalists could include earlier mentioned exotic and unwanted species, while the specialist species could be originally occurring vegetation.

Finally, a study by Oldén, Pitkämäki, Halme, Komonen, & Raatikainen (2021) about the potential of verges in central Finland to provide habitat for meadow plants revealed the same pattern. They compared vascular plant and bryophyte diversity in 3 different areas: road verges, mown meadows and grazed meadows. They found that many species were similar across all three areas. However, some meadow specialist plants weren't found in verges. Road verges did, however, host more generalist and ruderal species like bryophytes. Thus, road verges seem able to harbour some of the plant diversity that originally occurred in landscapes in which these verges reside. However, road verges are, in most cases, not identical to original grassland habitats and therefore are not fully able to replace the habitat provision function that these original grasslands performed. In addition, verges also provide habitat and presumably facilitate distribution for exotic and unwanted plant species.

If verges are able to provide habitat for originally occurring primary producers, does this also indicate that original consumers could find refuge in road verges? According to Villemey et al. (2018), they can. By means of a review, Villemey et al. looked into the possibility of verges accompanying linear infrastructures (roads, train rails and power lines etc.) to perform habitat provision or corridor functions for insects in temperate landscapes. They found that insect species richness did not differ between natural habitats and verges. Also, insect abundance seemed higher in verges when compared to natural habitats, probably due to the higher number of pollinators on non-highway verges when compared to natural habitats.

This increased abundance of pollinators is of significant importance. To reverse the global decline of pollinators, support in agricultural landscapes is crucial. Therefore, Phillips, Gaston, Bullock, & Osborne (2019) looked into the potential of verges to support pollinators. They surveyed flowers and pollinators in southwest England. They found that verges housed greater flower abundance, species richness and pollinator abundance than field interiors. However, there seemed to be less pollinators within 2 meters of the roads when compared to a 2–11-meter distance from the roads and even fewer pollinators nearby busier roads. Still, according to Phillips, Gaston, Bullock & Osborne, verges are clearly able to support pollinators by providing flower resources.

Haaland (2017) looked into the occupancy and abundance of a specific pollinator species: the scarce copper butterfly at 44 different patches with different characteristics southern Sweden. These patches

included parks, urban grasslands managed by local authority to improve biodiversity, unmanaged abandoned crop fields, road verges, meadows and pastures. While Haaland found that highest abundance of this specific species was found in unmanaged crop fields and meadows on the edge of urban areas, road verges were also occupied by the scarce copper, albeit with lower abundance. Also, other sites like pastures, were not occupied by the butterflies. Therefore, road verges are important for butterflies in urban areas. Thus, based on several findings, verges do indeed have the capacity to provide habitat for insects (Haaland, 2017; Benjamin B Phillips et al., 2019; Villemey et al., 2018)

Ouédraogo et al. (2020) conducted a similar review as Villemey et al. (2018) but focused on vertebrate groups instead of insects. They stated that verges indeed have potential to provide habitat depending on the considered biological group. Verges could support small mammals. In addition, verges could perform a corridor function for small mammals according to Galantinho et al. (2020). They state that for the wood mouse in a Mediterranean woodland, verges played a role mitigating adverse effects of roads by promoting migration and connectivity. Also, according to Ouédraogo et al., road verges seem to negatively affect birds. While Kroeger et al. (2022) also expected to find this negative effect of verges on birds in their global meta-analysis, they found no significant effect of verges on bird richness. This could be explained by the fact that some bird taxa enjoy reduced predation risks and other bird taxa are more mobile than others and therefore less prone to collisions. These positive effects could equal out the negative effects such as collisions experienced by other bird species.

According to most findings, verges are able to provide habitat to some extent for native flora and fauna species, depending on specific groups. This is indicated by the high similarity in plant and animal community compositions when comparing verges to natural counterparts, such as grassland and meadows. In addition, similar or greater species richness and abundance for pollinators and (more specifically) butterflies further indicate the habitat provision potential of verges. Finally, for some small mammals, verges could perform a corridor function.

Factors influencing habitat provision potential

While verges might be able to perform a habitat provision function to compensate loss of natural grassland areas, they are not able to fully replace these areas. Which factors cause the differences between grassland areas and verges? A first difference lies in soil properties, with cation levels positively affecting specialist plant numbers and phosphorus positively affecting generalist plant diversity (Vanneste et al., 2020). Olden et al. (2021) agree that different soil conditions of verges compared to meadows might cause an increase of ruderal plant species and decrease of specialist plant species. Secondly, vegetation restoration increases insect biodiversity, while artificialisation decreases this biodiversity (Villemey et al., 2018). Thus, in verges that hold original vegetation, more insect species are likely to be present. This could be explained by the fact that original insect species might more easily colonize habitat that resembles their original habitat. Thirdly, not removing cuttings seemed to also negatively affect flower and pollinator abundance (Phillips et al., 2019). This is due to nitrogen accumulation in the soil, which helps generalist plant species outcompete specialist plant species. This in turn negatively affects pollinator abundance. The scarce copper, for instance, has affinity to high flower abundance, indicating the indirect effect of not removing cuttings on pollinator species (Haaland, 2017). Finally, corridor function provision by verges, at least for wood mice, is compromised by vegetation cutting of the verges and ploughing in the surrounding area (Galantinho et al., 2020).

Context dependency

Besides stated factors that could influence the potential of verges to perform habitat provision and corridor functions, it is also important to note that this potential is highly context dependant. Verges can take many different forms, dependant on climate, traffic density, road characteristics among other factors (Figure 2).

Figure 2: Roads and verges in wildly different contexts. Adapted from Phillips, Bullock, Osborne, & Gaston (2020)

Part of this context is landscape structure (the characteristics of the surrounding landscape). For instance, in their review, Villemey et al. (2018) found that a higher grade of urbanization and agriculture in the immediate vicinity of verges lowered plant biodiversity in these verges, while more natural environments promoted biodiversity in these verges. At the same time, Lázaro-Lobo & Ervin (2019) reviewed that verges had the most pronounced positive effects for native plant species richness in landscapes that are greatly impacted by intensive agriculture, urbanization and forest management, while negative effects on plant species richness were concentrated in areas that have not been highly altered by humans. Thus, while a more natural environment might improve biodiversity in verges, verges might, at the same time have more pronounced negative effects on biodiversity in more natural surrounding areas. This context dependency also plays a role for vertebrate diversity according to Ouédraogo et al. (2020). Kroeger et al. (2022) agreed that, specifically for birds, richness differences between habitats were dependant on landscape context as well. Type of road however had no significant effect on bird species richness. Also, while it was expected that more natural areas are related to a negative road impact, no such consistent difference was found between habitat types.

On a smaller scale, habitat complexity could affect habitat provision function. Leonard, McArthur, & Hochuli (2018) investigated the effect of habitat complexity on arthropod community composition in verges along major roads and in public parks in Sydney, Australia. While these community compositions differed significantly when comparing parks and verges, habitat complexity did not explain this difference. Still, habitat complexity did affect arthropod abundance in parks, with higher complexities increasing abundance. Thus, they do suggest that habitat complexity might play a role, but not for all habitat types.

In conclusion, while similar contexts might not always result in similar changes in verge habitat provision and corridor potential, context most definitely affects this potential in different ways for flora and fauna alike.

Ecological trap

Apart from mentioned factors and contexts affecting habitat provision and corridor functions of verges, the overall consensus in the field seems to be that verges are indeed able to perform said functions. On the topic of habitat provision, however, there is still a possibility that verges are ecological traps for the species they house. According to Gardiner, Riley, Bommarco, & Öckinger (2018) roads and their verges threaten fauna due to direct mortality, caused by collisions with wildlife for roads and mowing and herbicide use for verges. In addition, flora and fauna can be exposed to pollution from the roads. Still, verges can provide habitat for threatened species among others, due to their resemblance to natural habitat counterparts.

Still, there is limited data on survivorship of flora and fauna and dispersal capabilities. If flora and fauna species that settle in verges experience difficulties dispersing and reproducing, they could be caught in an ecological trap. For example, Fekete et al. (2017) specifically looked into habitat provision by verges for the rare lizard-orchids in several European countries. They found that the orchids were present in verges, but they seemed to prefer locations closer to the road than expected. This could be because this area is prone to traffic disturbances, equalling out the competitive playground and allowing for the orchids to take the upper hand. Also, mowing seems to have a positive effect on orchid colonization and survival. However, the number of flowers bearing fruit increased with distance from the road, likely caused by dust and heavy metal accumulation close to the road. Also, pollination plays an important role in reproduction of orchids, and pollinators are directly negatively affected by traffic. This means that, while verges could provide habitat for orchids, the immediate vicinity of the road could form an ecological trap, as orchids accumulate heavy metals, are disturbed by dust and have lower chances of being pollinated.

What ecosystem services (and disservices) can verges provide?

Besides habitat provision and corridor functions can road verges provide other services? A systematic review by Phillips, Bullock, Osborne, & Gaston (2020) looked into this. They stress that road verges could provide ecosystem services especially in areas where natural area density is low, for instance in urban areas. Several ecosystem services that road verges could provide are air and water filtration, health, and aesthetic functions for humans. Also, verges could provide a carbon sink, taking up carbon dioxide from the air and storing it in the vegetation and the soil. Road verges are also situated next to roads, which gives them a role in combatting traffic pollution. Finally, they provide habitat for pollinators, which in turn improves agricultural production. Still, verges can also provide disservices by damaging infrastructure and displacing original habitats. Also, they increase vehicle-wildlife collisions.

Possible ecosystem services verges provide were also reviewed by Bautista, Camargo, & Bachmann (2020). In addition to findings previously stated by Phillips, Bullock, Osborne, & Gaston (2020) Bautista, Camargo & Bachmann also named the potential to promote the road heritage conservation and to improve local landscapes to develop sustainable tourism. Also, they state that biomass waste from management activities could be used to create biofuel, used as a composting stock or it could be used for local recycling chains. Finally, Ding & Eldridge (2022) looked into the ecosystem functions of verges compared to adjacent agricultural land in a grassy woodland in east of Australia. They found that roadside verges are able to support carbon stocks and they were less prone to erosion and modification. These effects were got stronger as width of verges increased.

Thus, based on several review papers, verges are able to perform more services than disservices (Figure 3). Therefore, verges could help mitigate negative effects of roads and traffic. Their capacity to provide ecosystem services and no disservices furthermore seems to depend on the design and management of verges.

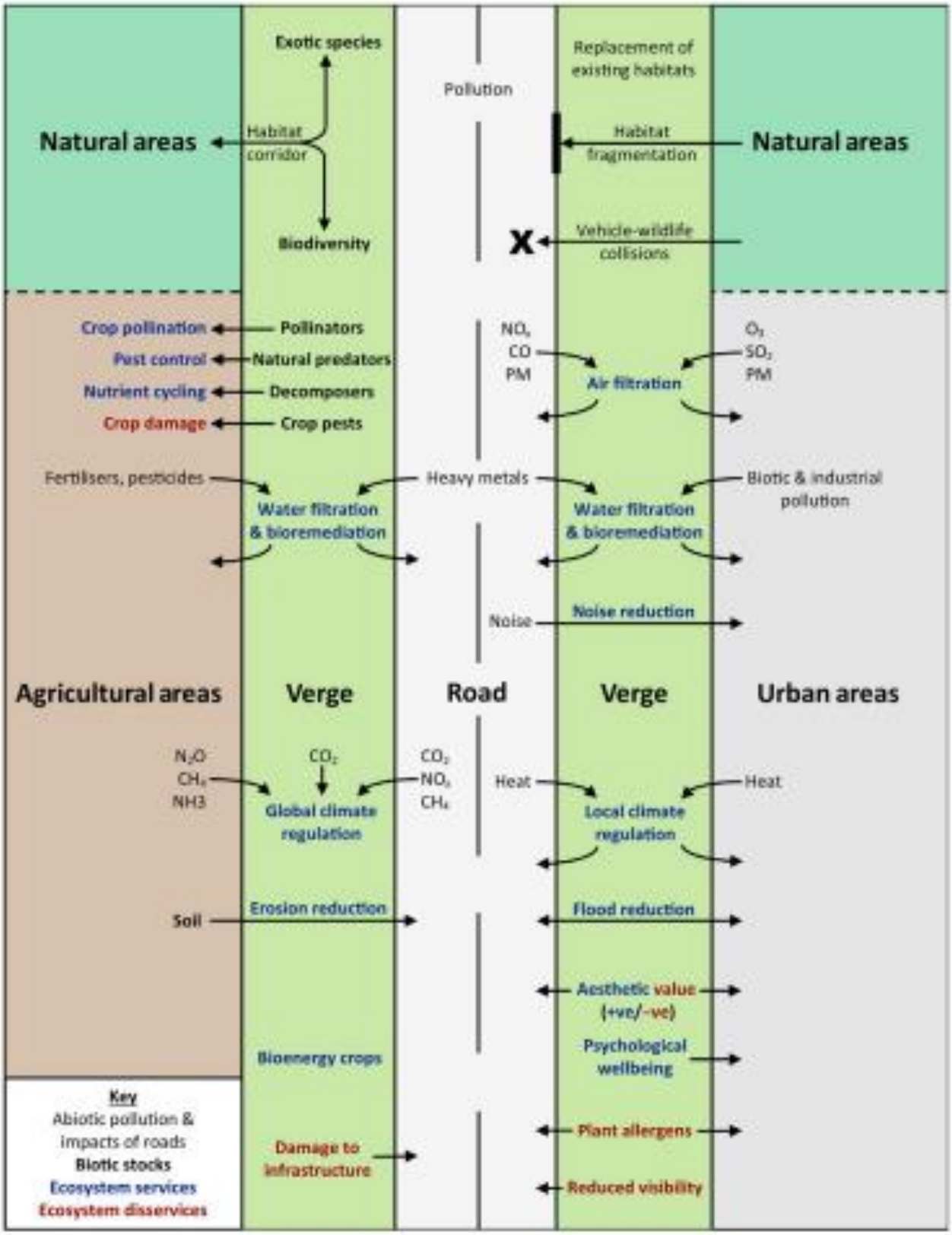

Figure 3: Schematic to summarize potential ecosystem (dis-)services provided by verges. Adapted from Phillips, Bullock, Osborne, & Gaston (2020)

How could verges be managed in a way that optimizes the verges' potential to provide ecosystem services?

So, what verge management practices could optimize the potential of verges to provide services? By way of a systematic review, Bernes et al. (2017) investigated the base of knowledge on the effects of verge management practices on biodiversity, using articles from North America (71%) and from Europe (23%). They found that the most frequently investigated management practice was to periodically remove vegetation by mowing (Figure 4). Within this practice factors that can be varied include mowing frequency, time and structure. Another frequently mentioned approach found for restoring original vegetation is to alter soil properties.

Mowing practices

In a follow-up review, Jakobsson, Bernes, Bullock, Verheyen, & Lindborg (2018) found that in Europe (29 studies) and North America (24 studies) the effects of mowing on plant species richness were dependant on mowing frequency and clippings removal. According to their review, an optimal mowing regime for increasing plant species richness and diversity includes two mowing cycles (one early and one late in the year) and removal of clippings.

Figure 4: Industrial verge mowing (Retrieved from https://www.thenorthernecho.co.uk/news/19256692.north-yorkshire-verge-mowing-cut-boost-wildlife)

Mowing frequency, timing and clippings removal

Chaudron, Perronne, & Di Pietro (2018) also looked into the effect of mowing timing on plant assemblages in road-field boundaries in West-central France. Contrastingly, they found that a late mowing positively affected nitrophilous species in verges and competitive, rather than ruderal species in the arable fields. Nitrophilous species generally outcompete other species in verges, and competitive species in the field margin include weeds, which are detrimental for crop production. Therefore, they suggested a single early mowing of verges in order to promote plant species conservation as well as control risk of weeds in field margins. Wigginton & Meyerson (2018) compared plant diversity and cover in verges in Rhode Island of three different vegetation management types (no mowing, reduced mowing, which is 1-2 times per year, and traditional mowing, which is 3-6 times per year). Non-mowed sites had the highest native species richness, the lowest introduced species richness and the lowest introduced species cover. Invasive species richness and abundance did not seem to be affected by management type. Since there seems to be no adverse effect of not mowing, Wigginton and Meyerson recommend passive restoration or not mowing in order to save costs wherever this does not create traffic danger. They do state however that reduced mowing could improve air quality and reduce CO2 emissions.

Thus, while Jakobsson et al. (2018) stated that overall two mowing cycles per year is most effective for plant biodiversity, Chaudron, Perronne, & Di Pietro, (2018) and Wigginton & Meyerson (2018) didn't agree with this statement. Firstly, it is worth noting that the latter two articles didn't solely focus on plant biodiversity, but also considered concerns of an economical nature. Wigginton & Meyerson considered costs for verge management, while Chaudron, Perronne & Di Pietro considered adverse effects of weed pressure from verges to arable land. Secondly Chaudron, Perronne, Bonnin, & Rattier

(2020) later compared the influence of mowing regime on road verge potential to provide services and disservices to adjacent agricultural fields. In contrast to Chaudron & Peronnes earlier article, in this case they found that weed pressure did not increase when a single mowing late in the year was used as a management practice. This shows that, even in a similar climate and area, the effects of management on verges might still differ, indicating its context dependency. All in all, however, it seems that reduced to no mowing has a positive effect on plant biodiversity, when compared to extensive mowing. Also, if mowing is part of management, clippings should be removed in order to prevent nutrient accumulation in the soil, as this would promote the growth of nitrophilous competitive species at the cost of specialist species.

Focussing on the effect of mowing on pollinators, Chaudron, Perronne, Bonnin, & Rattier (2020) compared an agro-environmental mowing regime consisting of a late mowing, high mowing height and removal of clippings to a 'standard' mowing regime consisting of an early mowing, low mowing height and no removal of clippings. They found an increase in the number of flowers and pollinators under the agro-environmental mowing regime. This indicates a positive effect of the agro-environmental mowing regime on pollinators. On the same topic, B B Phillips, Wallace, et al. (2020) reviewed how road verges could be enhanced to aid pollinator conservation. They state that traffic and road pollution can cause mortality and other negative impacts on pollinators, but there are more benefits than costs for pollinators. Road verges could be more suitable as habitat providers for pollinators with strategic management. They argued that mowing frequency should be reduced to 0-2 times per year. Phillips et al. (2019) furthermore indicated the importance of mowing at times that do not coincide with peak flowering times, in order to ensure that there is ample of food for pollinators during the year.

Finally, Mody et al. (2020) looked into the influences of several management factors on abundance of 13 arthropod taxa and management costs in Southwest Germany. Mowing regime had a large effect, as 63% higher arthropod density was found in unmown verge spots when compared to mown verge spots. It is necessary to note, however, that the compared spots were present on the same verges. Therefore, it might also be the case that arthropods find shelter in not mowed, high vegetation, while they forage in mowed, more flower rich vegetation. Therefore, to fully explain the effect of mowing verges on arthropod diversity and abundance, one would have to compare a fully mown verge to a fully unmown verge. Still, according to Mody et al. any arthropod taxa can find refuge in verges and flowery verges increases arthropod abundance.

Phased mowing

Having mowed and not mowed vegetation spots on the same verge is another management practiced called 'phased mowing'. This measure is used to ensure the availability of both food and shelter for pollinators throughout the year. When phased mowing is practiced, there are always some parts of the vegetated area that are left untouched, in order to maintain several stages of succession to improve habitat heterogeneity (Wigginton & Meyerson, 2018). According to Zhelnovach, Belokon, Manidina, & Tkalich (2021), phased mowing is needed to ensure pollination and further vegetation development

In conclusion, mowing regime in verges has an effect on plant an arthropod diversity, with an optimal mowing frequency lower than 3 times per year, preferably removal of clippings and mowing times outside of peak flowering periods. In addition, phased mowing could form an important addition to a mowing regime specifically for pollinators.

Altering soil properties

Finally, restoring original vegetation could be facilitated by altering soil properties. Vanneste et al. (2020) found that soil properties affect plant community composition, with cation levels positively affecting specialist plant numbers and phosphorus positively affecting generalist plant diversity. Thus, soil restoration and management could further improve road verge potential to house meadow biodiversity, especially since meadow habitats are in a decline. (Oldén et al., 2021). This is especially important for verges, as often in road construction projects imported soil is used. These soils have different properties than the original soil at specific sites. Thus, in order to restore natural vegetation and original wildlife, soil restoration to original soil properties might be necessary.

Influence of traffic

Apart from management practices, there are several factors that might cause constraints for the potential effects of management on verges. For instance, pollutants caused by traffic can affect pollinator activity in verges. According to Phillips et al. (2021), pollinator densities decrease by 55% in the first 2 meters of verge from the roads, compared to 7-9 meters, even though flower spread and richness are similar among these areas. They found that simulated traffic turbulence reduced pollinator-flower visit durations by 54% and that high metal pollutant concentrations within the first 2 meters from the road might also deter pollinators, resulting in up to 75% fewer visits. In addition, Zhelnovach, Belokon, Manidina, & Tkalich (2021) investigated the overall degradation of roadside plant communities on a highway in the industrial and agricultural region of Ukraine. They found that all species belonged to halophytes, as a result of soil salinisation due to road de-icing methods. 78% of species were ruderal, indicating loss of biodiversity. Also, grass density increased with distance from the road, indicating the adverse effects of the highway on the plants. Based on these findings, to utilize the full potential of verge management, it might be more practical to focus management efforts on low traffic verges or areas away from the roads. This sentiment is also echoed by Benjamin B Phillips et al. (2019).

Verge width

Besides traffic influences, verge width could also play a role in management efficiency. In this context, Monasterolo, Poggio, Medan, & Devoto (2020) looked at width of verges, land use in the verge vicinity and landscape heterogeneity and their effects on composition and abundance of flowering plants and pollinators in the Argentine Pampas. They found that communities in road verges were dominated by exotic species. The widest road verges had higher plant richness and higher pollinator visitor abundance, while land use and heterogeneity did not affect richness and abundance of pollinators or plants. Thus, to maximize management potential, wider road verges could be prioritized over smaller verges.

What Management Practices work?

Based on the gathered literature, we are able to provide a basic picture of how verges could be managed to improve their ecosystem service providing potential.

1. Firstly, verges should be mowed about once or twice a year, not too often as to allow species to settle and not too little, in order to prevent overgrowth and sustain habitat heterogeneity.
2. Secondly, the time of mowing should be late summer/after summer to provide vegetation with a time window to flower and seed. This allows species to settle and also allows pollinator species to profit from the flowering vegetation.
3. Thirdly, mowing should not be too close to the ground, also in order to not unnecessarily damage plants in the undergrowth.
4. Fourthly, phased mowing of verges, instead of mowing the whole area at once, allows pollinating insects to enjoy flowers all year round.
5. Fifthly, clippings should be removed, to prevent accumulation of nutrients in the soil.
6. Sixthly, verges accompanied by roads with low-density traffic should be prioritized in ecological management, in order to prevent having to deal with adverse effects of said traffic. In addition, polluting effects of traffic could perhaps be contained by using some sort of separations between the road and the verges.
7. Seventhly, soil properties should be checked and managed to create the desired effect of verge management. For instance, if the desired effect is for the verge to serve as habitat for local vegetation and insects, it is important to make use of original soil or replicate the soil properties as a basis for said verge.
8. Finally, the wider the verge, the better. Wider verges are able to support a larger diversity of vegetation and a higher abundance of pollinators. Therefore, wider verges should be prioritized, or narrow verges should be made as wide as possible.

While these practices have overall been found to have a positive effect on plant and wildlife diversity, every situation is different and context differences should always be considered when choosing specific verge management practices in a certain situation.

About implementation

Now that a set of verge management practices have been established, how could these be implemented in practice? First off, The attitudes of different stakeholders toward verge management have to be considered. Lampinen & Anttila (2021) gathered information from 373 verge management stakeholders in Finland by using online questionnaires. They found that verge attributes like species richness, traffic safety, familiarity with biodiversity and semi-natural grasslands form attitudes of stakeholders towards management practices. Most clearly, management alterations are met with varying opinions. The biggest hurdle for such alterations seem to be insufficient resources and decreased traffic safety. Overall, positivity towards the concept of verge management as a means to conserve grasslands species decreased in the order of environmental administration – traffic administration – verge managers. The same holds true for the notion of feasibility to implement alterations like late mowing, use of local soil, clipping removal, stakeholder education and the use of volunteers. This indicates the need to clearly communicate values of biodiversity to stakeholders and to consider values of these stakeholders as well. The need for clear communication between management stakeholders is also emphasized by Bautista et al. (2020).

Furthermore, Lampinen & Anttila found that all management stakeholders had a majority of members who considered volunteer participation an improbable management practice. However, According to Marshall, Grose, & Williams (2019) citizen participation could be a promising way to drive verge management. They found that, in Melbourne, verge gardening (verge management conducted by civilians) occurred in almost a quarter of urban verges (22.1%) Thus, local government could facilitate verge gardening by educating and engaging citizens in order to perform low cost and involved verge management, especially in urban areas. Still, according to Bernes et al. (2017) It has become clear that roadside biodiversity is still regarded as a side-product of road-safety. Therefore, it is important to communicate possible ecosystem services that well-managed verges could provide to the general public. In addition, to create financial incentive, Bernes et al. point out the possibility to use mowing clippings as a feedstock for bioenergy production.

Figure 5: Verge gardening in Perth, Australia (Retrieved from https://www.abc.net.au/news/2021-03-27/perth-verge-gardens-grow-community-as-well-as-plants/100026918)

Finally, it is important to note that the sooner verges are used to better provide ecosystem services, the sooner these services could be benefitted from. Chaudron, Perronne, Bonthoux, & Di Pietro (2018) surveyed plant communities at road-field boundaries in Central-Western France and their changes over a 31-year period as a result of surrounding landscape structure. They looked at the effect of this landscape structure on plant species richness in verges. They found that, while landscape structure had a weak explanatory power, current species richness was better explained by past landscape structure rather than current landscape structure. These findings indicate that plant community diversity has a time-lagged response to changes in landscape, which suggests that current changes in management only affect biodiversity in the long-term. This is also worthwhile to consider when applying management changes, as the effects of these changes can only be noticed in the long-term.

Gaps in knowledge/potential research

Finally, in compiling the found literature, some gaps in knowledge and potential for future research has become clear. Firstly, too few studies looked into corridor potential of verges, even though this potential is often mentioned in reviews. Thus, research should focus more on the corridor potential of verges in order to grasp the full ecosystem service providing potential of verges (Ouédraogo et al., 2020). Both Villemey et al. (2018) and Bernes et al. (2017) agreed in their literature reviews, stating that due to a small amount of dispersal-focused studies, no conclusion could be drawn about the corridor function of verges

Furthermore, Bernes et al. (2017) found that the impact of verge management on biodiversity in the surrounding landscape hasn't been properly explored. This is important, as verge management might also positively affect biodiversity in surrounding areas. Also, according to Ouédraogo et al. (2020) management effect studies on vertebrates were too few to draw general conclusions, thus, to fully grasp the effect of management on biodiversity, more research on vertebrate biodiversity as a result of verge management is needed.

Finally, most research on habitat and biodiversity provision in verges estimate these services by determining species richness, diversity and abundance. It is important to note that, while these give an approximation of the biodiversity in a certain area, they don't indicate a stable and healthy ecosystem. According to Elo, Ketola, & Komonen (2021), species richness for ground beetles were very similar when comparing three different managed grassland types (road verges, pastures and meadows). However, they also investigated co-occurrence networks. These networks indicate relationships within ecosystems between species. Changes in these networks can indicate human disturbances and changes in environment. Elo, Ketola, & Komonen found differences in structure of these networks when comparing road verges to meadows and pastures, suggesting that mowing is not sufficient as a measure to create habitats originally found in (semi-)natural areas, even though species richness is very similar. The fact that co-occurrence patterns differ among grassland types indicates that similar management may not equate to similar response to management. Therefore, besides using species richness, diversity and abundance to estimate biodiversity, future research might need to consider other ways to also include ecosystem stability in future analyses.

Conclusion

In conclusion, verges have been shown to be able to, at least to some extent, replace natural habitats like grasslands. This is mostly evident by the similarity in species composition when comparing verges and natural counterparts for both flora and fauna. Still, factors like soil properties, vegetation composition and remaining clippings could impair this habitat providing potential. In addition, it the natural habitat provision potential is highly context dependant, as verges can take on wildly different forms. Furthermore, there is a possibility that, rather than providing a stable habitat for flora and fauna, verges serve as an ecological trap; a sort of 'last resort' habitat that impairs reproduction and migration of settled species.

Besides habitat provision, verges can provide several other ecosystem services and disservices. Among these services are air and water filtration, health improvement, aesthetics, carbon capture, pollution containment, ecotourism opportunities, biomass production and erosion prevention. Disservices are damage to infrastructure, displacement of original habitat and wildlife mortality due to traffic collisions. Overall, potential services seem to outweigh disservices, indicating the positive effects verges could have on nature and humans alike.

In addition, management practices could further improve positive effects of management. The most prominent practices found that could possibly improve the verges' effects are reduced mowing frequency (0-2 times per year), optimizing mowing timing (outside of peak flowering times), not mowing too close to the ground, clipping removal, prioritizing areas further away from roads, improving soil properties and finally prioritizing wider verges over small verges. However, management practices chosen should still be dependant on the specific context.

To actually implement changes in management, it is important to work and communicate with different stakeholders in order to convince them of the potential of well-managed verges. Also, citizen participation could be a way to improve verge management in urban areas. Time is also of importance, since there is a time-delayed effect of management on verge diversity. Therefore, the sooner management practices are changed, the sooner verge services can be provided.

Finally, there is still a lot of work to be done to fully grasp to what extent verges can provide alternatives to natural habitats and how management practices can be optimized and applied to specific cases. That being said, verges seem to have huge potential in battling the adverse effects of

the increasing density of human infrastructure, by providing habitat for nature and a variation of services for humans that are well worth the effort of verge management optimisation.

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