

SYSTEMATIC MAP

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How are biodiversity and dispersal of species affected by the management of roadsides? A systematic map

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Abstract

Background: In many parts of the world, roadsides are regularly managed for traffic-safety reasons. Hence, there are similarities between roadsides and certain other managed habitats, such as wooded pastures and mown or grazed grasslands. These habitats have declined rapidly in Europe during the last century. For many species historically associated with them, roadsides may function as new primary habitats or as dispersal corridors in fragmented landscapes. Current recommendations for roadside management to promote conservation values are largely based on studies of plants in semi-natural grasslands, although such areas often differ from roadsides in terms of environmental conditions and disturbance regimes. Moreover, roadsides provide habitat not only for plants but also for many insects. For these reasons, stakeholders in Sweden have emphasised the need for more targeted management recommendations, based on actual studies of roadside biodiversity.

Methods: This systematic map provides an overview of the available evidence on how biodiversity is affected by various forms of roadside management, and how such management influences the dispersal of species along roads or roadsides. We searched for literature using 13 online publication databases, 4 search engines, 36 specialist websites and 5 literature reviews. Search terms were developed in English, Danish, Dutch, French, German, Norwegian, Spanish and Swedish. Identified articles were screened for relevance using criteria set out in a protocol. No geographical restrictions were applied, and all species and groups of organisms were considered. Descriptions of included studies are available in an Excel file, and also in an interactive GIS application that can be accessed at an external website.

Results: Our searches identified more than 7000 articles. The 207 articles included after screening described 301 individual studies considered to be relevant. More than two-thirds of these studies were conducted in North America, with most of the rest performed in Europe. More than half of the studies were published in grey literature such as reports from agencies or consultants. The interventions most commonly studied were herbicide use, sowing and mowing, followed by soil amendments such as mulching and fertiliser additions. The outcomes most frequently reported were effects of interventions on the abundance or species richness of herbs/forbs, graminoids and woody plants. Effects on insects and birds were reported in 6 and 3% of the studies, respectively.

Conclusions: This systematic map is based on a comprehensive and systematic screening of all available literature on the effects of roadside management on biodiversity and dispersal of species. As such it should be of value to a range of actors, including managers and policymakers. The map provides a key to finding concrete guidance for conservation- and restoration-oriented roadside management from published research. However, the map also highlights important knowledge gaps: little data was found for some geographical regions, research is heavily biased

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taxonomically towards plants, and no study was found on how species dispersal was affected by roadside management. The map could therefore be a source of inspiration for new research.

Keywords: Road ecology, Roadside management, Biodiversity, Species dispersal, Semi-natural grasslands, Linear landscape elements, Refugia

Background

Roadsides as habitats and dispersal corridors

The creation of road networks has been a critical component of the development of human civilisation. Over millennia, these networks have evolved from foot trails to complex highway systems. The modern transportation infrastructure has major impacts on the surrounding landscape, which traditionally have been studied mainly within the field of geography (cf. [1]).

In the 1970s, coincident with the development of landscape ecology, conservation biologists became interested in how roads fragment the landscape and interact with landscape processes [2]. Establishing a new road section or network in a landscape has been described as being equivalent to adding a new ecosystem to the existing one [1]. However, the concept of ‘road ecology’, a specific sub-discipline of ecology, was not coined until 1998 by landscape ecologist Forman [3].

Although a relatively new area of research, road ecology has been the subject of a fairly large number of studies. The growing scientific interest in road ecology is also reflected in international conferences arranged by ICOET in North America [4], IENE in Europe [5], ANET in Asia/Australia [6] and the global ICCB [7].

The vast majority of studies on ecological effects of roads have focused on direct negative impacts on abiotic aspects like hydrology, sediment and debris transport, water and air chemistry, microclimate and levels of noise, wind and light adjacent to roads [8]. Negative biotic effects such as wildlife collisions, population fragmentation, road avoidance behaviour and dispersal of invasive species have also been acknowledged [3].

During the last decades, roadsides have been highlighted as important dispersal corridors in many sub-disciplines of ecology. Plants and animals that use roads as dispersal corridors are often generalist species [8], and invasive species, predominantly generalists, may hence be dispersed more easily along roadsides than native ones. In fragmented landscapes, however, roadside habitats can also favour native species, e.g. spiders [9], insects [10, 11], and plants [12].

Seed dispersal by grazing animals has become less frequent in rural areas, but motor vehicles and agricultural machinery have partly taken up that role [13, 14]. No plant species have evolved specifically to be dispersed via motor vehicles, but Zwaenepoel et al. [15] found that

species dispersed in this way had significantly more persistent seed banks than other species (probably because seeds are often dispersed in soil sticking to vehicles [16]), indicating that vehicles can aid the dispersal through space of seeds that traditionally have been dispersed through time.

Recently, roadsides have been discussed as habitats in their own right rather than merely as dispersal corridors or stepping-stone habitats [17–19]. For instance, in the Netherlands and Australia, where large parts of the rural landscape have been transformed to intensively used farmland, roadsides are important habitats for native vegetation [20, 21]. In such cases, therefore, roadsides may be regarded as substitution habitats [22].

Roadsides provide habitat not only for plants, but also for insects and small mammals [23]. Mammals often use roadsides when they move around in the landscape [24, 25]. Flower-rich road verges attract bumblebees and other wild bee species, hoverflies, butterflies and many other insects that depend on nectar and/or pollen [11]. Moreover, roadsides can serve as nesting sites for many insects, especially if they are sandy and exposed to the sun. Such areas may also attract animals that formerly resided mainly on seashores, sandy banks, sand dunes, fallows, dry meadows, alvar habitats etc. Sandy and warm environments are important not least for snakes and lizards, some of which are now frequently found along roads and in other places where sand has been exposed due to human disturbance [26]. For several red-listed species, roadsides are among the most important habitats [27].

Roadside management

The occurrence of animals and plants along roads is highly dependent on how the roadsides are managed [8]. In many parts of the world, roadsides are regularly mown for traffic-safety reasons, and their vegetation will then remain at the same successional stage year after year. Hence, there are similarities in management and abiotic conditions between roadsides and habitats such as wooded pastures and mown or grazed semi-natural grasslands [28]. In contrast to roadsides, the latter habitats have declined rapidly in Europe during the last century [29], and today only a fraction of their former extent remains.

In some cases, roadside management includes more powerful ways of removing vegetation and reversing

late-successional vegetation stages, such as burning, harrowing or scraping. In contrast, due to their low productivity, roadsides on dry and nutrient-poor soils may need little management to meet traffic-safety requirements.

In Sweden, roadside management is currently being discussed as an important part of overall landscape management for biodiversity. The Swedish Board of Agriculture recently estimated that 190,000 hectares of managed grasslands occur along built infrastructure in Sweden, 164,000 ha of which constitute roadsides [30]. This equals more than a third of the total cover of meadows and pastures in Sweden (ca. 450,000 ha) [31]. Many species that historically were mainly associated with agricultural grasslands now thrive along roads. For example, almost 300 animal and plant species included in the Swedish Red List of threatened species are found in roadside habitats [27].

Current recommendations for roadside management to promote conservation values are largely based on botanical research studies of open semi-natural grasslands such as meadows and pastures, not least in northern Europe [32]. However, the narrow linear nature of verges, the use of road salt for de-icing, ditching and reinforcement activities, sowing of exotic plant material and other measures specific to infrastructure maintenance are likely to impact species and communities differently to traditional management of open grasslands. Moreover, much of the existing evidence on ecological effects of roadside management comprises grey literature not assessed by external reviewers. For these reasons, key stakeholders in Sweden have emphasised the need for more targeted management recommendations, based on actual studies of roadsides.

Topic identification, scientific basis and stakeholder input

The topic of the proposed systematic map was suggested by the Swedish Board of Agriculture at a meeting with stakeholders arranged by the Mistra Council for Evidence-Based Environmental Management (EviEM) in 2013. A pilot review of the present state of knowledge on biodiversity aspects of roadside management was then conducted by the EviEM Secretariat. The review was largely based on contacts with specialists and other stakeholders [33], but it also included a brief scoping study of relevant scientific literature.

The Swedish Triekol research programme recently published a narrative review of about 400 scientific articles with possible relevance to the effects of roadside management on vascular plants, but nearly all of these articles were based on studies of meadows and other semi-natural grasslands rather than actual roadsides [34]. It was concluded that systematic investigations of

the management of roadside vegetation are almost completely absent (see also [32]).

A few recent reviews have focused on linear elements in the landscape, including roadsides. An Australian systematic review by Doerr et al. [35] studied to what extent plants and animals use linear structures as corridors for dispersal, but only four Australian studies of roadsides were included. The review produced a number of management recommendations relevant to Australia, but it also identified considerable knowledge gaps, and it is currently being updated [36]. Ansong and Pickering [14] systematically reviewed the literature on seed dispersal by cars, and several other review articles on this topic have recently been published (e.g. [13, 37]). Suárez-Esteban et al. [38] have reviewed studies that compare vegetation along road verges and other linear gaps in the landscape with that of adjacent habitats.

There was consensus among contacted stakeholders that roadside habitats in Sweden have great potential conservation value for native animals and plants. Government agencies and researchers agreed that there is a need for a systematic review of the effects of different management techniques. In particular, they underlined the importance of analysing the impacts of roadside management on (a) insects, (b) dispersal or movement rates of species along roadsides, and (c) alien versus native animal and plant species.

It was pointed out by these stakeholders that several questions relating to roadside management remain unanswered. Do animals benefit from management regimes targeted towards promoting floristic values? Are roadsides 'ecological traps' that attract large number of insects but cause low reproductive rates and high mortality? Should management activities be differentiated depending on road size, landscape context (forested or agricultural landscapes), land-use history etc.? Finally, many stakeholders emphasised that effects of roadside management on the establishment and dispersal of alien species need to be evaluated.

Objectives

This systematic map is intended to provide an overview of the available evidence on how biodiversity (e.g. species diversity, genetic diversity or abundance of individual species or functional/taxonomic groups of animals, plants, fungi or bacteria) is affected by various forms of roadside management, and how such management influences the dispersal of species along roads or roadsides.

Other built infrastructure habitats such as railways, powerline corridors, buffer strips etc. are not included in the map, since their attributes and management differ radically from those of roadsides. Nor are studies of semi-natural meadows or pastures included—these

habitats have been extensively covered by other reviews, and they are not subject to the same set of environmental conditions as roadsides.

Primary question: *How are biodiversity and dispersal of species affected by the management of roadsides?*

Components of the primary question

<i>Population:</i>	Roadsides
<i>Intervention:</i>	Roadside management, e.g. mowing, removal of shrubs and saplings, pruning, coppicing, control of invasive/nuisance species, herbicide use, sowing or planting, burning, grazing by livestock, tillage and other forms of soil cultivation, mulching, topsoiling, use of erosion-control mats or blankets, fertiliser addition, liming, irrigation, ditching and maintenance of ditches
<i>Comparator:</i>	Non-intervention or alternative forms of roadside management
<i>Outcomes:</i>	(1) Measures of local or regional diversity of animals, plants, fungi or bacteria, e.g. alpha/beta/gamma species diversity, genetic diversity, abundance of individual species, or abundance of functional/taxonomic groups of organisms (including measures of the total abundance of vegetation). (2) Measures of species dispersal along roads or roadsides, e.g. species distribution patterns or movement rates of individuals or propagules.

Methods

The design of this systematic map was established in detail in a protocol [33]. It follows the guidelines for systematic reviews and evidence synthesis issued by the Collaboration for Environmental Evidence [39]. As described in the protocol, we established the scope and focus of the map in close cooperation with stakeholders, primarily in Sweden. Before submission, peer review, revision and final publication of the protocol, a draft version was open for public review at the website of the Mistra Council for Evidence-Based Environmental Management (EviEM) in October–November 2015. Comments were received from scientists and environmental managers, and the protocol was revised accordingly.

Searches

When searching for relevant literature, we used online publication databases, search engines, specialist websites and literature reviews. Whenever possible, we applied the search terms specified below. In many cases, however, the search had to be simplified as some sites do not accept long and complex search strings.

No time, language or document type restrictions were applied.

Search terms

The review team conducted a scoping exercise to assess alternative search strings, testing them against a set of some 20 articles known to be relevant. The exercise resulted in the selection of the following search terms:

Population: roadside*, "road side*", (road* AND (verge* OR edge*)), roundabout*, "traffic island*", "median strip*", "central reservation*", boulevard*, parkway*, (avenue* AND tree*)

Outcomes: *diversity, dispers*, species, abundance, vegetation

The terms within the 'population' and 'outcomes' categories were combined using the Boolean operator 'OR'. The two categories were then combined using the Boolean operator 'AND'. An asterisk (*) is a 'wildcard' that represents any group of characters, including no character.

At some of the websites listed below, searches were also made for relevant literature in Danish, Dutch, French, German, Norwegian, Spanish or Swedish, using search terms in these languages. Full details of the search strings used for each search are recorded in Additional file 1, together with search dates and the number of articles found.

Publication databases

The search included the following online databases:

- (1) Academic Search Premier
- (2) Agricola
- (3) Biological Abstracts
- (4) GeoBase + GeoRef
- (5) Helda (University of Helsinki)
- (6) IngentaConnect
- (7) JSTOR
- (8) Libris
- (9) Scopus
- (10) SwePub
- (11) Transport Research International Documentation (TRID)
- (12) Web of Science Core Collection
- (13) Wiley Online Library

Search engines

Internet searches were performed using the following search engines (the last two for searches with Spanish terms only):

Google (<http://www.google.com>)
 Google Scholar (<http://scholar.google.com>)
 Dialnet (<http://dialnet.unirioja.es>)
 SciELO (<http://www.scielo.org>)

In most cases, the first 200 hits (based on relevance) were examined for appropriate data. When searching for literature in Swedish, we checked the first 300 and 700 hits in Google and Google Scholar, respectively.

Specialist websites

Websites of the specialist organisations listed below were searched for links or references to relevant publications and data, including grey literature.

Aarhus University (<http://www.au.dk>)
 Australasian Network for Ecology and Transportation (<http://www.ecoltrans.net>)
 Collaboration for Environmental Evidence (<http://www.environmentalevidence.org>)
 Conservation Evidence (<http://www.conservationevidence.com>)
 Danish Centre for Environment and Energy (<http://dce.au.dk>)
 Danmarks Miljøportal (<http://www.miljoportal.dk>)
 Environment Canada (<http://www.ec.gc.ca>)
 European chapter of the Society for Ecological Restoration (SER) (<http://chapter.ser.org/europe/>)
 European Commission Joint Research Centre (<http://ec.europa.eu/jrc/>)
 European Environment Agency (<http://www.eea.europa.eu>)
 Highways England (<http://www.gov.uk/government/organisations/highways-england>)
 Infra Eco Network Europe (<http://www.iene.info>)
 International Conferences on Ecology and Transportation (<http://www.icoet.net>)
 International Union for Conservation of Nature (<http://www.iucn.org>)
 Natural England (<http://publications.naturalengland.org.uk>)
 Natural Resources Canada (<http://www.nrcan.gc.ca>)
 Natural Resources Wales (<http://libcat.naturalresources.wales>)
 Natuurtijdschriften (<http://natuurtijdschriften.nl/natuur>)
 Nordic Council of Ministers (<http://www.norden.org>)
 Norwegian Environment Agency (<http://www.miljodirektoratet.no>)
 Norwegian Institute for Nature Research (<http://www.nina.no>)

Norwegian Public Roads Administration (<http://www.vegvesen.no>)

Scottish Natural Heritage (<http://www.snh.gov.uk>)
 Swedish Board of Agriculture (<http://www.jordbruksverket.se>)
 Swedish County Administrative Boards (<http://www.lansstyrelsen.se>)
 Swedish Environmental Protection Agency (<http://www.naturvardsverket.se>)
 Swedish Transport Administration (<http://www.trafikverket.se>)
 Swedish University of Agricultural Sciences (<http://www.slu.se>)
 UK Centre for Ecology and Hydrology (<http://www.ceh.ac.uk>)
 UK Department for Environment, Food & Rural Affairs (Defra) (<http://randd.defra.gov.uk>)
 UK Environment Agency (<http://www.environment-agency.gov.uk>)
 UK Forest Research (<http://www.forestry.gov.uk>)
 United Nations Environment Programme (<http://www.unep.org>)
 University of Copenhagen (<http://www.ku.dk>)
 US Department of Transportation (<http://www.transportation.gov>)
 US Environmental Protection Agency (<http://www.epa.gov>)

Other literature searches

As a check of the comprehensiveness of our searches, relevant articles and reports were also searched for in bibliographies of five literature reviews [34, 38, 40–42]. Moreover, each member of the review team used national and international contacts to get information on current research related to the topic of the review.

Article screening and study inclusion criteria**Screening process**

When screening a sample of 100 articles found in Web of Science with the search string described above, we noted that only about a third of the articles could safely be excluded as irrelevant based on their titles alone. For that reason, articles found by searches in literature databases were first evaluated for inclusion based on titles and abstracts combined. This assessment was made by a single reviewer (S), who in cases of uncertainty tended towards inclusion. At an early stage of the screening, a subset consisting of 100 of the articles was also assessed by a second reviewer (CB). The consistency of the two reviewers' assessments of these articles was checked with a kappa test. Since the outcome, $\kappa = 0.675$, indicated a 'substantial' agreement [43] and since the inconsistency had chiefly been caused by the main reviewer being more

inclusive than the second one, the screening was allowed to proceed without revision.

Articles found to be potentially relevant on the basis of title and abstract were then judged for inclusion by a reviewer studying the full text. This task was shared by all members of the review team. The articles were randomly distributed within the team, but some redistribution was made to avoid having reviewers assess studies authored by themselves or articles written in an unfamiliar language. In cases of uncertainty, the reviewers chose inclusion rather than exclusion, but an article that was regarded as highly questionable though not obviously irrelevant could also be categorised as 'doubtful'. All articles that the main reviewer categorised as either doubtful or worthy of inclusion were also assessed by one or two other reviewers. Any disagreements were reconciled case by case, largely based on decisions taken by the review team as a whole on how to deal with various kinds of borderline topics.

Articles found using search engines, specialist websites or literature reviews were entered at the second stage of this screening process. A list of articles rejected on the basis of full-text assessment is provided in Additional file 2 together with the reasons for exclusion. This file also contains a list of articles that we assessed as potentially relevant based on title and abstract but were unable to find in full text.

Study inclusion criteria

Each study had to pass each of the following criteria in order to be included:

- **Relevant subjects:** Roadsides. A roadside was defined as the unpaved zone along a road that is exposed to roadside management. On small, unpaved roads, studies of the road itself could also be included. While stakeholders suggested that the review include studies of roadside management in temperate, boreal and subalpine zones (and high-altitude areas in subtropical and tropical zones), we found little reason to impose any geographical restriction at all, since many basic ecological mechanisms will be the same everywhere. Therefore, we included relevant studies from anywhere in the world.
- **Relevant types of intervention:** Roadside management, including but not restricted to mowing, removal of shrubs and saplings, pruning, coppicing, control of invasive/nuisance species, herbicide use, sowing or planting, burning, grazing by livestock, tillage and other forms of soil cultivation, mulching, topsoiling, use of erosion-control mats or blankets, fertiliser addition, liming, irrigation, ditching and

maintenance of ditches. Such measures were also considered as relevant where they had been applied during construction of new roadsides.

- **Relevant type of comparator:** Non-intervention or alternative forms of roadside management. Comparisons can in principle be made both temporally and spatially. Studies with a 'BA' (Before/After) design compare data collected at the same site prior to and following an intervention. Other studies may be based on comparison of different areas along a roadside, some that have been subject to a certain kind of management and some that have not. These may be termed as 'CI' (Comparator/Intervention) studies, or 'BACI' (Before/After/Comparator/Intervention) if they present data collected both before and after the intervention. Studies of interventions made at different distances from a road were not included in the review when effects of roadside management were confounded with distance from the road.
- **Relevant types of outcome:** (a) Measures of local or regional biodiversity, e.g. alpha/beta/gamma species diversity, genetic diversity, abundance of individual species, and abundance of functional/taxonomic groups of organisms (including measures of the total abundance of vegetation). (b) Measures of species dispersal along roads or roadsides, e.g. species distribution patterns or movement rates of individuals or propagules. All species and groups of animals, plants, fungi and bacteria were considered to be relevant. We also included studies where none of the types of outcome listed above were explicitly reported, but where it was likely (based on other results or on the methods description) that data relevant to our review had actually been sampled and might be available courtesy of the study authors. Such studies were only included if published in 2006 or later, however. Ratings of intervention effects based on visual assessments of vegetation vitality were not considered to be relevant.
- **Relevant type of study:** Primary field studies.
- **Language:** Full text written in English, Danish, Dutch, French, German, Norwegian, Spanish or Swedish.

Study quality assessment

No formal quality appraisal was made of studies subsequent to their inclusion in the review, since this is not considered necessary for the purposes of a systematic map [39]. In some cases, nevertheless, we recorded that studies provided inadequate data on locations, methods, interventions or outcomes.

Data coding strategy

Basic information on each study found to be relevant was extracted from the included articles and recorded in an Excel file. The studies were described and categorised based on the following types of data (to the extent that they were available):

- Full reference
- Publication type (codes listed in Additional file 3)
- Language of article
- Location of study area (country, state/province, region or site(s), geographic coordinates)
- Road number or name
- Road type (codes listed in Additional file 3)
- Adjacent land use (codes listed in Additional file 3)
- Study design (BA/CI/BACI)
- Type of roadside management (codes listed in Additional file 3)
- Intervention category (codes listed in Additional file 3)
- Intervention(s) specified using free text
- Additional interventions (not compared by the study)
- Outcome category (codes listed in Additional file 3)
- Species group(s) studied (codes listed in Additional file 3)
- Focal species
- Remarks

Descriptions recorded in the database were normally extracted from the included articles, but if no geographical coordinates were given, we recorded approximate coordinates based on published site names, maps or verbal descriptions of study locations (or coordinates provided in another article describing the same site). Similarly, data on road type and adjacent land use were usually taken from the articles, but in some cases we added such data ourselves based on what we found in Google Earth.

In cases where some of the data reported by a study fell outside the scope of our review (e.g. where some of the study sites were not roadsides), we recorded information only on those parts of the study that fulfilled our inclusion criteria.

The first round of data recording was shared by all members of the team. Two of us (CB and SJ) double-checked all entries in the map database for consistency.

Results

Literature searches and screening

The main searches for literature using English search terms were conducted in October 2015. A total of 15,127 articles were returned from the thirteen publication databases listed in the “[Methods](#)” section—see Fig. 1.

Removal of duplicates left 7145 unique articles. After screening on title and abstracts, 2706 of these articles remained included. Most of the articles rejected at this stage were excluded because they did not report on relevant outcomes (45%), did not study roadside management (24%) or did not study roadsides at all (16%).

Searches using search engines returned 89 potentially relevant articles (8 found with English search terms, 3 with Danish, 5 with Dutch, 1 with French, 0 with German, 2 with Norwegian, 31 with Spanish and 39 with Swedish ones) in addition to those that had already been identified.

Similarly, searches at specialist websites located another 38 potentially useful publications (22 found using English search terms, 0 with Danish, 5 with Dutch, 1 with Norwegian and 10 with Swedish ones). One additional article that we had not identified ourselves was found in one of the literature reviews that we checked after having concluded our online searches.

In all, the searches resulted in 2834 articles considered promising enough to be assessed in full text. The majority of these articles had been published in peer-reviewed scientific journals, but about one-third (33%) consisted of reports from e.g. agencies or consultants, conference proceedings, theses, policy documents, newsletters or other kinds of grey literature. Most of the latter category of articles were identified when we searched in transport research international documentation (TRID), a large online bibliographic database of transportation research. Here, our search string returned 1530 articles not found in any of the other twelve publication databases that we used. Based on titles and abstracts, we categorised 627 of these articles as potentially relevant. Of them, we were able to retrieve only 231 (37%) in full text. By contrast, we found full-text versions of 79% of the potentially relevant articles that we had identified using the twelve other databases.

The total number of articles retrieved in full text was 1995 (70% of all articles categorised as potentially useful). After screening based on full-text reading of these articles, 207 of them remained included. The most common reason for exclusion at this stage was absence of usable information on how roadsides were managed (see Additional file 2; Table 1). Of the 53 articles excluded due to language, most were written in Korean (15), Chinese (10) or Portuguese (10).

The majority of the 207 articles included in the systematic map (197, or 95%) were written in English. The remaining articles were written in one of several languages: Dutch (3), Swedish (3), Danish (2) or Norwegian (2).

Almost 60% of the included articles (120) had been published in peer-reviewed scientific journals. Nearly all

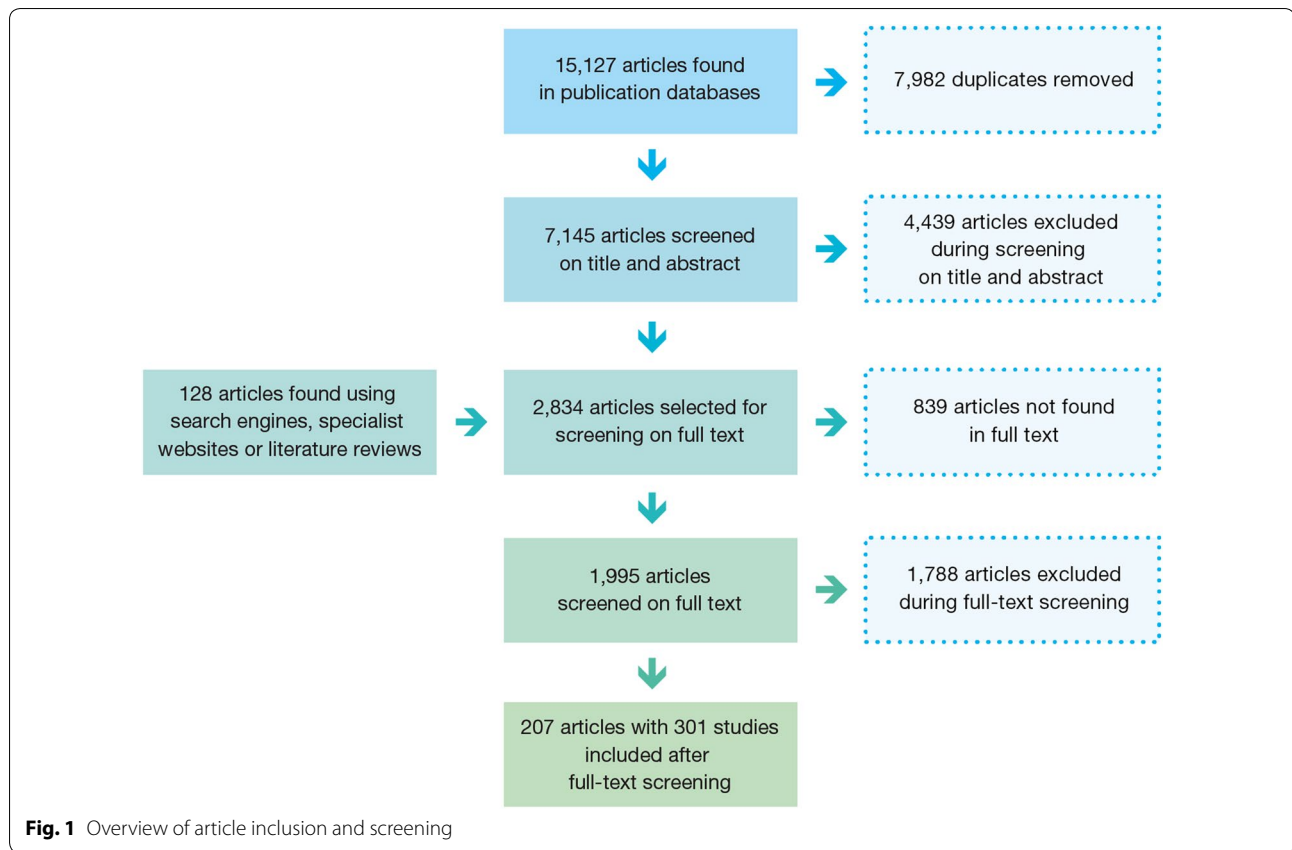


Table 1 Reasons for exclusions of articles at full-text screening

Reason for exclusion	No. of articles	% of articles
Not a study of roadsides	277	15
Not a study of roadside management	1050	59
No usable comparator data	165	9
No usable data on biodiversity or species dispersal	149	8
Not an observational field study	119	7
Full text not in English, Danish, Dutch, French, German, Norwegian, Spanish or Swedish	53	3
No usable primary data, but potentially usable as a review	14	1
Redundant (results also reported elsewhere)	13	1

Some of the articles appear more than once in the table, since they were excluded for more than one reason

of these articles (112) had been identified through our searches in Web of Science, Scopus and similar ‘general-purpose’ publication databases that cover broad ranges of scientific literature. The remaining 87 articles that we included can be characterised as grey literature. About three quarters of them (65) were found in TRID, and the majority (68) consist of reports issued or commissioned by state departments of transportation in the United States and/or by federal US agencies. The grey publications also include 7 reports from agencies or research institutes outside the US, 6 Bachelor’s, Master’s or Ph.D. Theses, and 6 papers in conference proceedings.

Both the journal articles and the grey literature included in this systematic map cover a period that began in the early 1960s and extended to 2014 or 2015. On average, however, the former publications are more recent than the latter, with 84% of the journal articles but 60% of the grey literature dating from 2000 or later.

A number of the included publications (26) report on more than one relevant study each. This applies to parts of the grey literature in particular. Three reports on roadside management in the states of Virginia and Washington, all of them dating from 1977 to 1980 [44–46], present data from a total of 59 studies that we considered

to be relevant to this systematic map. The overall number of individual studies included in the systematic map is 301.

The database that constitutes the core of this systematic map provides basic information on each study found to be relevant. In addition, the database contains links that search Google Scholar for the title of each included article. They will return links to abstracts and full-text versions of the articles if these are available through Google Scholar. This information is available in an Excel file (Additional file 3), and also in an interactive GIS application that can be accessed at the EviEM website (<http://www.eviem.se/en/projects/Roadside-management/>). The GIS application plots study locations on a zoomable world map, and data on the studies can be retrieved by clicking on the symbols in the map. The application also provides a table with the same content as the Excel file. Both the GIS application and the Excel file allow data to be filtered and sorted.

Mapping the quantity of papers relevant to the question

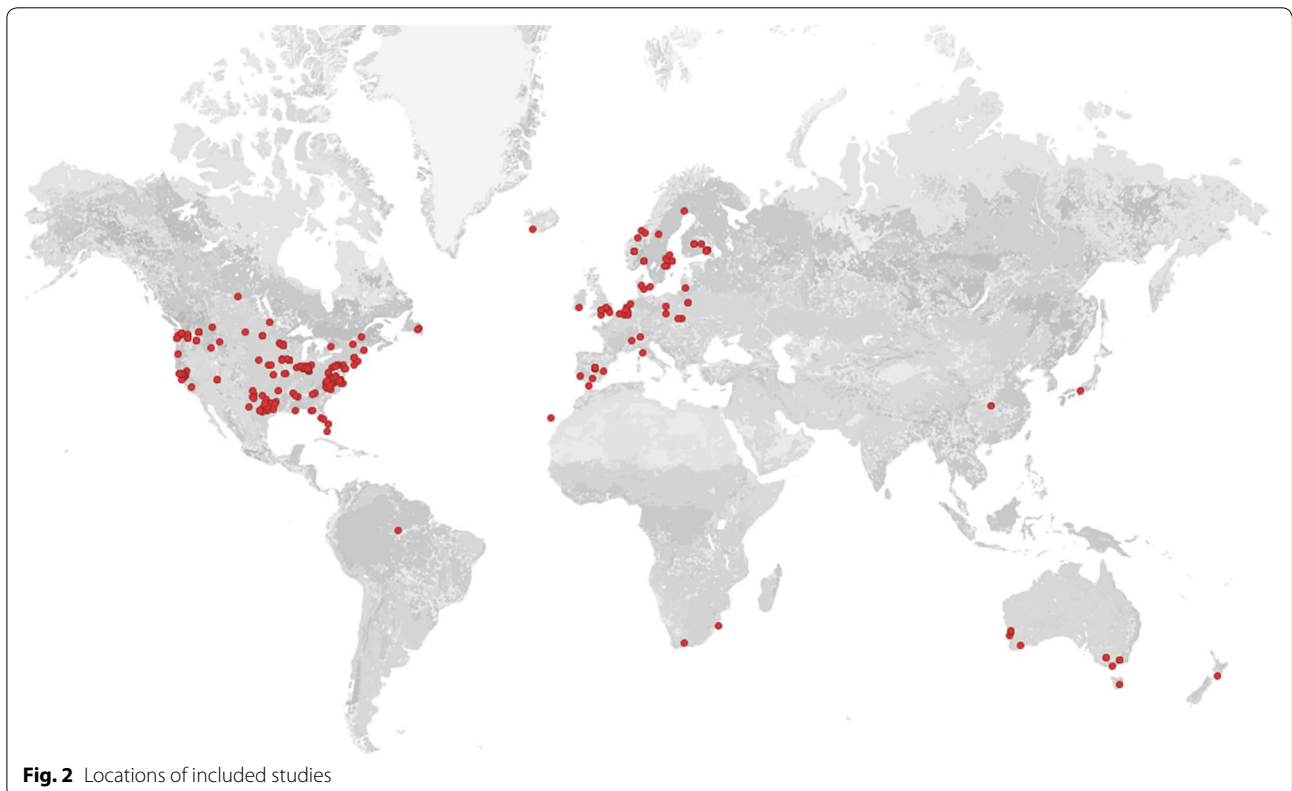
More than two-thirds (212) of the 301 studies included in the map were conducted in North America (205 of them in the US), whereas 72 were performed in Europe, 2 in Africa, 2 in Asia, 13 in Australia/New Zealand and 1 in South America (see Fig. 2, Additional file 3 and the GIS application available at <http://www.eviem.se/en/projects/>

[Roadside-management/](http://www.eviem.se/en/projects/Roadside-management/)). One of the studies is counted twice, since it was conducted in both Switzerland and the US.

The dominance of US studies was mainly due to the large number of grey literature reports from state-level roadside managers. Studies published in scientific journals had a more even geographic distribution, 51 having been performed in the US, 56 in Europe, and 24 elsewhere in the world.

Information on the types of road where effects of roadside management had been investigated was available for only 40% of the studies, but 61 of them had been carried out along large roads (four-lane highways or heavily used two-lane roads), 60 along less heavily used but paved roads, and 19 along small, unpaved roads. Similarly, information on land use in areas adjacent to the roads was available for less than a third of the included studies, but 48 of them had data on roadsides surrounded by arable land, 36 on roadsides in forested areas, 35 on roadsides surrounded by grass- or scrubland (managed or not), and 17 on roadsides in urban or suburban areas.

Most of the interventions studied could be characterised as regular maintenance or restoration of roadsides (147 and 134 studies, respectively), whereas 39 studies reported on measures taken when roadsides were established along recently constructed roads.



The interventions most commonly studied were herbicide use (29% of the studies), sowing (29%) and mowing (28%)—see Table 2. Many studies investigated several different kinds of intervention, individually and/or in combination. Most of the studies published as grey literature focused on herbicide use, biological amendments (e.g. sowing or planting), or soil amendments (e.g. fertiliser addition, liming, topsoiling, mulching, tillage, irrigation or erosion control), whereas studies of non-chemical vegetation disturbance such as mowing, mechanical removal of shrubs/saplings, grazing or burning more often were published in peer-reviewed scientific journals (Fig. 3).

The outcomes most frequently investigated were effects of roadside management on herbs/forbs (77% of the studies), graminoids (69%) and woody plants (35%) (Table 2). Effects on insects and birds were reported in 6 and 3% of the studies, respectively. The outcomes were reported as abundances of single species or groups of species in 83 and 47% of the included studies, respectively, as total abundance of vegetation in 25% of them, and as species richness or some kind of diversity index in 23 and 3% of the studies, respectively. Diversity measures such as species richness were reported considerably more often in studies published in peer-reviewed journals than in studies published as grey literature (42 and 11%, respectively). However, the share of grey literature reports that included data on species richness or diversity indices increased from 4% before 2000 to 23% after the millennium.

We found no usable studies on how species dispersal was affected by roadside management.

Most of the studies (89%) had a CI design, whereas 6% had a BACI design, 3% had a BA design, and 2% combined two of these designs.

Discussion

This systematic map is based on searches for roadside management studies conducted anywhere in the world. Since all roadsides are similar in the sense that they are heavily impacted by humans [1, 3], it may be of interest to compare management effects at a global scale. This also means that the results of such comparisons could potentially be relevant to roadside managers all over the world. However, the studies we found had a major geographical bias in that the vast majority of them were conducted in North America (71%) or Europe (23%). Only a few studies had been performed in subtropical regions and almost none in the tropics. This bias is found throughout conservation biology and reflects the wealth of countries and their expenditure on such research [47].

Interventions

The studies included in this systematic map cover a wide variety of methods applied in roadside management.

Nevertheless, it is clear from the evidence base that the focus of research into such management has shifted over time. Studies of roadside maintenance made in the 1980s and earlier were dominated by efforts to find efficient ways of keeping vegetation in check for traffic safety reasons. More recent research has increasingly dealt with ecological aspects of roadside management, and with conservation or restoration of roadside biodiversity in particular. This development has been reflected by increasing amount of data on species richness in grey literature such as reports commissioned by roadside managers. The change of priorities is probably due at least partly to awareness of the current global decline of grasslands [48, 49] and the potential for providing similar habitats by appropriately managed roadsides [50, 51].

Most of the studies in the map were conducted at roadsides still chiefly managed to maintain traffic safety. Nevertheless, the majority of studies included an experimental set-up designed to test directly for ecological effects of various intervention types and intensities. Many of them investigated more than one management technique. About 20% of all included studies applied a full factorial design to explore the individual and combined effects of two or more different interventions, but few of these studies looked for interactions between the interventions.

Mowing is the most frequently investigated non-chemical method for managing vegetated roadsides, regardless of the main purpose of this kind of management. Studies of the effects of mowing can e.g. clarify how managers may optimise the function of roadsides as substitutes for meadows, pastures and similar semi-natural grasslands [19]. Other management options based on non-chemical disturbance of vegetation include grazing, burning, and mechanical removal of shrubs and saplings. These methods have been studied less extensively than mowing, however. In particular, we found surprisingly few studies that examined effects of roadside grazing (six studies, of which five were made in Australia and one in South Africa, but none in North America or Europe). One likely reason is that grazing is comparatively uncommon along roadsides, since traffic safety may be compromised if livestock are kept close to major roads.

The application of herbicides or growth retardants along roadsides was introduced in the 1950s and 1960s as an inexpensive alternative to mowing, not least in the US, and much of the early research on this topic explored the ability of various chemicals to control roadside vegetation (or ‘weeds’) in general. Later, however, chemical management of roadsides was increasingly restricted, and several of the more recent studies of herbicide use have investigated the possibilities of substituting conventional chemicals like phenoxyacetic acids with substances

Table 2 Combinations of interventions and organism groups studied (No. of studies)

Intervention	Organism group													
	Graminoids	Herbs/ forbs	Woody plants	Bryophytes	Lichens	Fungi	Mammals	Birds	Reptiles	Insects	Other arthropods	Other invertebrates	Bacteria	All species
Vegetation disturbance														
Mowing	54	61	28	1	0	1	5	7	0	12	1	1	0	85
Pruning	1	1	1	0	0	0	0	0	0	0	0	0	0	1
Removal of shrubs/ saplings	2	3	4	0	0	0	3	2	1	1	0	1	0	9
Grazing	3	3	6	0	0	0	0	0	0	0	0	0	0	6
Burning	11	12	4	0	0	0	0	1	0	1	0	0	0	14
Heating	1	1	0	0	0	0	0	0	0	0	0	0	0	1
Herbicide use	67	72	21	0	0	0	0	0	0	1	0	1	0	86
Biological amendment														
Sowing	63	76	21	2	1	0	0	1	0	3	0	1	3	86
Planting	11	12	10	1	1	0	0	2	1	1	0	0	0	19
Mycorrhizal treatment	4	2	4	0	0	0	0	0	0	0	0	0	0	7
Soil amendment														
Fertiliser addition	31	31	13	0	0	1	0	0	0	0	0	0	1	39
Liming	9	17	1	0	0	0	0	0	0	0	0	0	0	18
Topsoiling	11	11	7	0	0	0	0	0	0	0	0	0	0	11
Mulching or compost application	32	33	17	0	0	1	0	0	0	0	0	0	3	41
Use of erosion-control mats/blankets	11	10	7	0	0	0	0	0	0	0	0	1	0	11
Irrigation	6	5	4	0	0	0	0	0	0	0	0	0	1	7
Soil cultivation (e.g. tillage)	13	19	6	1	1	0	0	0	0	0	0	0	0	23
Ditching or ditch maintenance	3	3	3	1	0	0	0	0	0	0	0	0	0	3
Control of invasive/nui- sance species	43	52	18	0	0	0	0	0	0	1	0	0	0	61
Other interventions	5	6	3	0	0	0	0	0	0	2	0	0	0	11
All interventions	207	232	105	5	2	2	5	10	1	17	1	2	3	

Some of the studies appear more than once in the table, since they covered multiple interventions and/or groups of organisms

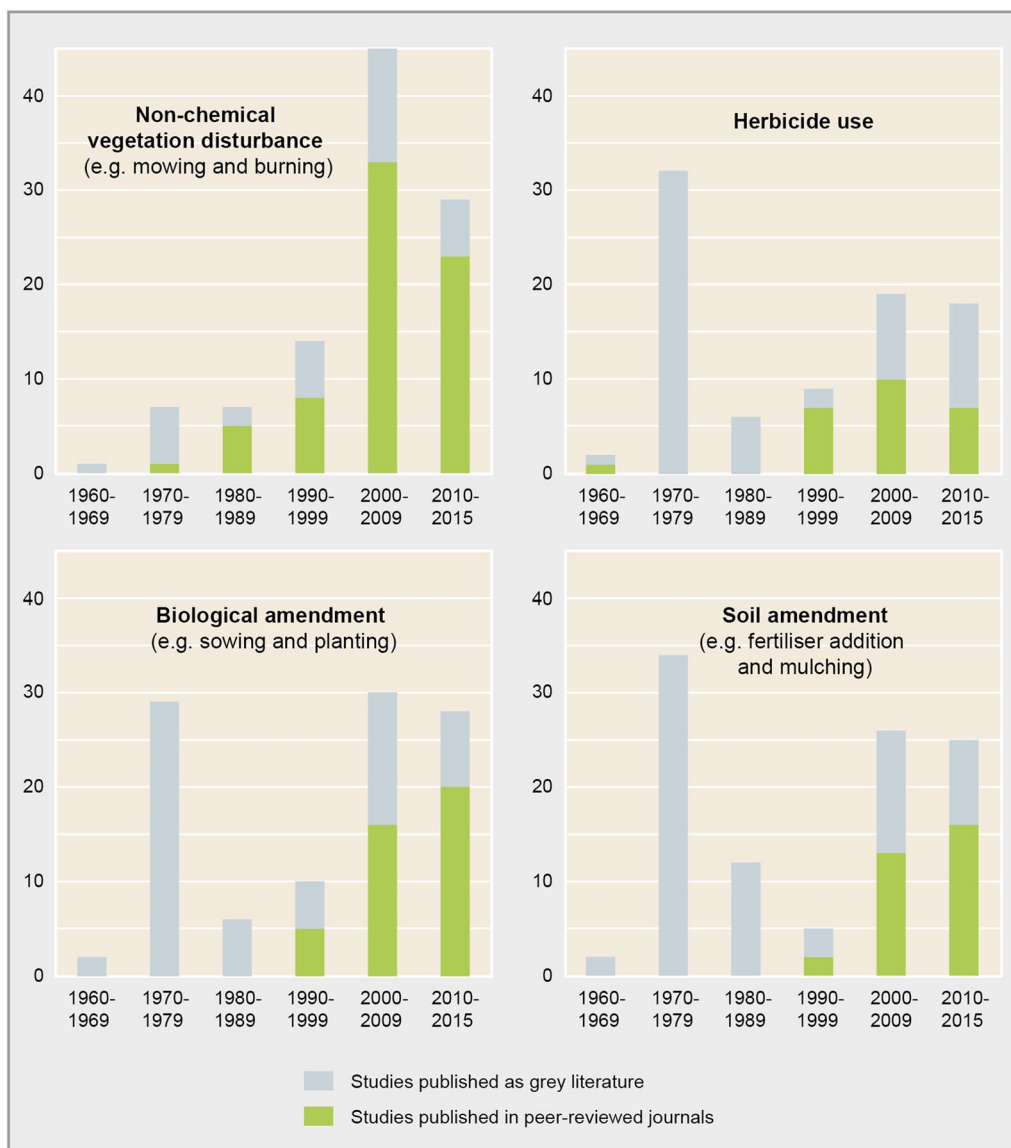


Fig. 3 Types of intervention studied (no. of studies)

considered to be less harmful. Nevertheless, conventional herbicides remain widely used as a means of controlling invasive species, although a recent systematic review has indicated that many large-scale schemes of that kind have been only moderately successful [52]. A considerable amount of research is still devoted to clarifying whether different chemical compounds can be used to control specific invasive plants along roadsides.

Nearly half of the studies included in the systematic map deal with attempts to revegetate roadsides rather than remove vegetation from them. In dry climates especially, the roadsides may remain more or less bare for many years after the construction of a road, unless active

measures are taken to reintroduce some kind of vegetation. Re-establishment or restoration of vegetation on roadsides is primarily based on sowing or planting of selected plant species, but it may also include various soil amendments, e.g. fertiliser addition, liming, topsoiling, mulching or soil cultivation. In this case, too, the focus of research has shifted in a way that reflects new priorities in roadside management. Increasingly, studies have explored the possibilities of restoring native vegetation along roadsides using local plant material or seed sources, not least where the current vegetation is dominated by exotic species introduced through earlier revegetation efforts.

Outcomes

We found a huge bias towards plants in the taxa considered by studies included in the map. Studies on other taxa, such as invertebrates, hardly looked at management of roadsides. This possibly reflects a focus on vegetation management for road safety, although latter studies have had a more conservation focus. This bias is found in the wider conservation literature (e.g. [53]) but seems particularly severe for roadside studies.

Also, while the hope is that roadsides may act to enhance biodiversity, the impact of roadside management on biodiversity in the surrounding landscape was never looked at. This is not surprising as the focus in studies is the roadside. However, if roadside management is to be designed to benefit biodiversity widely, then such impacts need to be studied. Some of the studies that we found report data not only from roadsides but also from meadows, pastures or similar semi-natural grasslands, but few of these studies were designed to investigate similarities or differences between roadside and non-roadside habitats. This limits their capacity of clarifying to what extent roadsides can act as refuges for species threatened by the current decline of semi-natural grasslands.

At least as importantly, we found no relevant studies of the effects of roadside management on species' dispersal. While there is an increasing literature on how roadsides act as corridors for species' movement [11, 12, 35, 54], little attention has been paid as to how management might enhance or diminish this role. This lack indicates an important research priority, and studies might build on recent work [55, 56] considering how management can enhance connectivity among grassland fragments. Livestock grazing and movement are often invoked as enhancing grassland connectivity through their dispersal of seeds, but grazing on roadsides is uncommon, as we found in this systematic map.

Limitations of the systematic map

This systematic map is limited to the studies we were able to find using search terms, databases and languages established in our protocol. Despite our ambition to be inclusive, we have undoubtedly missed some important studies. For instance, 53 papers identified as potentially relevant based on their English abstracts were subsequently excluded because they were not written in any of the eight languages that we master.

Besides searching for articles in peer-reviewed scientific journals, we went to considerable effort to identify, retrieve and assess studies published in the grey literature. The latter efforts were only partly successful—many reports that we judged as potentially relevant based on titles and abstracts turned out to be unavailable in full text online. The grey literature for which we could source

the full text was greatly dominated by studies conducted in the US. We obtained relatively few useful reports from other parts of the world, although we searched the websites of more than 40 national and international organisations and publication databases using search terms in eight different languages. Nevertheless, more than half of the studies that we included in the map were published in various kinds of grey literature.

Many of the studies found in the grey literature were several decades old, and some of them provide little information about methodology and interventions. Still, they constitute a very substantial portion of the available evidence on biodiversity effects of roadside management. It may be important to consider them not least since this can reduce the impact of publication bias—positive (statistically significant) results tend to be overrepresented in peer-reviewed scientific literature but less so in grey literature [39]. The grey literature that we identified includes several extensive and well-documented studies with a wealth of data on how different kinds of management have affected the biodiversity of roadsides (e.g. [57, 58]). Like any findings, however, those published in grey literature have to be used and interpreted with some care. If considered for inclusion in a systematic review, they will have to undergo critical appraisal [39]. This procedure, which can be seen as an alternative (or complement) to formal peer review, may be used to exclude studies found to have low or unclear validity.

Conclusions

Implications for management and policy

This systematic map is based on a comprehensive and systematic screening of all available literature on the effects of roadside management on biodiversity and dispersal of species. As such it should be of value to a range of actors, including managers and policymakers. It is challenging for practitioners to read and synthesise the evidence on individual interventions, but the map provides a key to finding concrete guidance for conservation- and restoration-oriented roadside management from published research. Next to aiding the management of established roadsides, the map can also be used as a source of inspiration for the design of new roadsides, e.g. by providing an overview of the range of interventions that can be applied.

The map includes more than a hundred studies of non-chemical interventions that may aid the conservation or restoration of biodiversity in roadsides, including their role as substitutes for grasslands and other habitats under threat in intensively managed landscapes. More specifically, we identified 98 studies of how the richness or abundance of species in roadsides is affected by vegetation disturbance by managers, such as regular mowing,

burning, grazing or selective mechanical removal of plants. Since all of these interventions entail removal of plant biomass they are comparable, and a review of their impact on biodiversity should permit some generalisable conclusions. Most of the studies have recorded management effects on vascular plants, but there are also 14 potentially relevant investigations of insects or other invertebrates. These studies should be of considerable interest to roadside managers, including e.g. transportation and conservation agencies, park authorities, municipalities, and farmers and other private landowners. This has been confirmed by our contacts with Swedish stakeholders.

It should be noted, though, that the mapping exercise has made clear to us that biodiversity of roadsides is generally still regarded as a side-product of regular road-safety management rather than a goal in its own right. This is reflected by the poor articulation of biodiversity-related management goals in the reviewed studies. Considering roadside management as part of a wider landscape management and thoroughly analysing the functions and services that can be delivered by roadsides will help to design more diversified and context-specific management strategies that take into account multiple functions and the trade-offs and synergies between them. The growing interest of biomass production in roadsides (e.g. [59]) can serve as an example in this respect. Feedstocks for bioenergy production are highly searched for, and roadsides could represent a considerable extra source given their large extent. Such multifunctional roadside use, with a potential to create win–win–wins for safety, biodiversity conservation and bioeconomy, could be considered when designing future roadside management plans.

Implications for research

By identifying areas where a substantive body of scientific knowledge has been accumulated, this systematic map provides a foundation for full systematic reviews on specific subtopics. Such reviews would provide a synthesis of available evidence, making the information more accessible and easily applicable by managers and policymakers.

However, although a substantial body of research exists, the map highlights important knowledge gaps: little data was found on some geographical regions (notably the tropics and subtropics), research is taxonomically heavily biased towards plants, and not a single study was found on how species dispersal was affected by roadside management. The map could therefore be a source of inspiration for new research. Important potential topics include the effects of management on patterns of multidiversity and multifunctionality in roadsides, and the relationship between them. Besides, the importance of roadsides for

biodiversity at the landscape scale is still heavily understudied, as is the role of roadsides for species dispersal. Finally, care has to be taken that biodiversity (and other) targets are clearly articulated when designing and publishing future research on roadside management.

We will now proceed with a full systematic review of how maintenance or restoration of roadsides based on non-chemical vegetation removal affects the diversity of vascular plants and invertebrates [60].

Additional files

Additional file 1. Literature searches.

Additional file 2. Articles excluded based on full-text reading, Articles not found in full text.

Additional file 3. Systematic map database.

Authors' contributions

All authors participated in literature searches, literature screening and extraction of metadata from included articles. CB and SJ double-checked the full-text screening, compiled the map database and checked all entries in the database. CB, JMB, RL and KV drafted the manuscript. All authors read and approved the final manuscript.

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The authors declare that they have no competing interests.

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All data generated or analysed during this study are included in this published article and its Additional files 1, 2 and 3.

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