

SYSTEMATIC REVIEW PROTOCOL

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Can linear transportation infrastructure verges constitute a habitat and/or a corridor for biodiversity in temperate landscapes? A systematic review protocol

Arzhvaël Jeusset^{1*}, Marianne Vargac¹, Yves Bertheau^{2,3}, Aurélie Coulon^{2,4}, Nadine Deniaud¹, Frédérique Flamerie De Lachapelle⁵, Emmanuel Jaslier⁵, Barbara Livoreil⁶, Véronique Roy¹, Julien Touroult¹, Sylvie Vanpeene⁷, Isabelle Witté¹ and Romain Sordello^{1*}

Abstract

Background: The role of linear transportation infrastructures (roads, railways, oil and gas pipelines, power lines, rivers and canals) in fragmenting natural habitats has been demonstrated. Yet, the potential of habitat or corridor of their verges (road and railway embankments, strips of grass under power lines or above buried pipelines, or waterway banks) for biodiversity remains controversial. In a context of decreasing natural habitats, the potential of anthropogenic areas for contributing to wildlife conservation should be considered. Moreover, how linear transportation infrastructure verges should be managed in order to favor biodiversity is a crucial question. The present work describes the protocol of the first systematic synthesis of evidence of the potential of linear transportation infrastructure verges as habitat and/or corridor for biodiversity. Outcomes of the study will be useful for helping managers to improve their practices or for prioritizing actions of ecological restoration.

Methods: The subject population will include both flora and fauna of the temperate climate, either species or communities. Exposures to linear transportation infrastructure verges, interventions of verge management (mowing, pruning, etc.) and environmental disturbances (pollution, wildfires, etc.) will be included. Both temporal and spatial comparators will be considered. Relevant outcomes will include dispersal, species richness and abundance. The scientific literature on the topic of the review may turn out to be very heterogeneous. Various management types, biodiversity outcomes and study designs might be conceived. If any combination of these is covered by a sufficient number of studies, we will perform a meta-analysis. At the least, we will produce a systematic map and a narrative synthesis.

Keywords: Green and blue infrastructure, Connectivity, Transmission line, Electric line, River

Background

For the last decades, human activities have resulted in a massive worldwide erosion of biodiversity [1]. Loss of natural habitats due to landscape urbanization and fragmentation stands among the reasons for these extinctions [2]. Landscape fragmentation splits natural habitats into multiple isolated patches [3, 4]. Breaking apart of

habitats *per se* has immediate and time-delayed effects on biodiversity [5], independently of habitat loss [6]. In the short term, fragmentation has negative consequences for habitat selection, abundance and species diversity [7–9]. In the long term, fragmentation limits or disrupts migration and dispersal of juveniles and adults, which can substantially impair metapopulation dynamics [10, 11]. Individual species are then exposed to various stochastic threats, leading in some cases to extinction cascades [12].

Both urbanization and the development of linear transportation infrastructures (LTIs) are causes of

*Correspondence: arzhvael.jeusset@mnhn.fr; sordello@mnhn.fr

¹ Service du Patrimoine Naturel (SPN), Muséum national d'Histoire naturelle (MNHN), 75005 Paris, France

Full list of author information is available at the end of the article

fragmentation [13, 14]. LTIs lead to a net disruption of the natural habitats that they cross, splitting them into several distinct patches. Most of the effects of fragmentation on biodiversity detailed above are true for LTIs and have been documented [15]. In particular, LTIs result in an indirect decrease of abundance and species diversity due to habitat fragmentation [16, 17]. They also cause direct animal mortality due to vehicle collisions, electrocutions and drownings of individuals attempting to cross the infrastructures [18–20]. Over several generations, LTIs were also shown to lead to a genetic isolation of populations [21–23]. The specific case of fragmentation due to the combination of several types of LTIs, such as a road crossing a waterway, remains to be studied.

In the last decades, scientists have paid a lot of attention to the potential of blue-green infrastructures, i.e. networks of ecological land and aquatic continuities, for decreasing habitat fragmentation in the short term [24]. Moreover, in the long term, maintaining a network of ecological corridors could mitigate the effects of global warming through enhanced dispersal of species to newly suitable areas [25]. In the context of biodiversity loss due to habitat fragmentation, the potential of anthropogenic areas for conserving nature deserves to be considered [26].

Up to now, studies about habitat fragmentation have considered LTIs transversally, i.e. they have focused on biodiversity dispersal flows perpendicular to LTIs. Yet, it is unclear whether LTI verges considered longitudinally, i.e. focusing on biodiversity dispersal flows parallel to LTIs, have potential for conserving wildlife. LTIs are generally made up of a transportation lane (road, railway, pipeline, power line, river or canal) and of verges (road and railway embankments, strips of grass under power lines or above buried pipelines, or waterway banks, etc.). A verge is a strip along, above or below the carriageway, inside the LTI boundaries, not directly used for transportation and belonging to the LTI manager. In most cases, verges are covered with plants and may constitute semi-natural habitats. It is thus interesting to assess if, despite their fragmenting effect, LTI verges could contribute to a network of blue-green infrastructures and thus to biodiversity conservation.

At present, few studies have considered LTI verges longitudinally and the studies that have investigated the potential of habitat or corridor of LTI verges provided contrasted results. For instance, according to Bolger et al. [27], revegetated highway rights-of-way could serve as ecological corridors for Californian native rodents and fragmentation-tolerant bird species. On the contrary, Benítez-López et al. [28] showed that mammal and bird population densities, with the exception of raptors,

decline with their proximity to infrastructures. Moreover, antagonisms may exist between the potential positive role of habitat or corridor of LTI verges for biodiversity and the risk of animal collision with moving vehicles [29]. A verge management practice can be beneficial to some species and detrimental to others [30, 31]. Besides, some verge management practices positive for biodiversity may be impossible to operate for safety reasons (maintenance of a low-vegetation along roads to avoid collisions, mowing of power line verges to prevent wildfires, etc.) [32].

As there is no consensus in the scientific community regarding this topic, a systematic review taking into account all studies and synthesizing their results seem necessary. Such a review will be helpful for making recommendations to LTI managers by identifying the conditions to which LTI verges could play a role of habitat and/or corridor for biodiversity. Other sorts of literature reviews have been published regarding the role of one specific type of LTI for biodiversity [33, 34]. However, no systematic review exists regarding the potential of all types of LTIs to provide habitats and/or corridors for biodiversity.

The systematic review presented in this paper was initiated by French LTI managing companies and the French government, who wished to investigate the potential for LTIs to provide habitat or corridor for biodiversity. Indeed, in France, the concept of green infrastructures led in 2007 to the development, by the “Ministère de l’écologie, du développement durable et de l’énergie” (MEDDE), of a public policy project named “Trame Verte et Bleue”. Through this project, French administrative regions are currently identifying local ecological networks and developing action plans to preserve and restore these continuities. Moreover, this issue has now to be considered in local urban planning. Through different territorial scales, various stakeholders work on the issue of habitat fragmentation. As the LTI network is very dense in France, LTI managers can significantly contribute to ecological networks. For instance, the French road network, which is over a million kilometer long, is the longest ($\frac{1}{4}$ of the European network) and one of the densest (1.77 km/km^2) of Europe. As a comparison, Spain, which has an area close to the one of France, has a road density six times lower (0.32 km/km^2). SNCF Réseau owns more than 50,000 km of railway lines, 30,000 of which are currently used, which constitutes the longest railway network of Europe. In France, the role of LTIs in habitat fragmentation is thus strong, compared to other countries. Meanwhile, as the LTI network is dense, the inherent area of verges is considerable. The total area of French road verges is estimated to 4500 km^2 , which is superior to the total area of

3450 km² of the seven terrestrial national parks [35]. LTIs have thus a significant potential for contributing to green infrastructures. Aware of these issues, several French LTI managing companies gathered in an informal group, named “Club des Infrastructures Linéaires et Biodiversité” (CILB), to contribute to biodiversity conservation. Among the members of the CILB, six railway, power line, pipeline and waterway French companies¹ decided to assess if their LTI verges could contribute to blue-green infrastructures and how to better manage these verges. The systematic review was assumed to be a relevant methodology for finding a scientific answer to this practical question from LTI managers. The French ministry of ecology (MEDDE), through its research incentive program relative to transportation ecology, named “Infrastructures de Transport Terrestre, Ecosystèmes et Paysage” (ITTECOP), undertook a call for tender for the systematic review, with the help of the CILB and the “Fondation pour la Recherche sur la Biodiversité” (FRB). The FRB, a French foundation supporting research in biodiversity, also trained the review team members in the implementation of systematic reviews and helped the review team with its methodological expertise. The “Muséum national d’Histoire naturelle” (MNHN), with the help of the “Institut national de recherche en sciences et technologies pour l’environnement et l’agriculture” (IRSTEA), was selected to conduct the present project.

Objective of the review

The objective of the review is to assess if LTI verges can be used as corridors for longitudinal dispersal movements and if they can provide a habitat for biodiversity. The review will also assess the effect of different management practices (mowing, grazing, etc.) on the potential role of habitat and/or corridor of LTI verges. Considering the constraints (such as safety) that managers are facing to maintain the function of transportation of LTIs, we will try to recommend practices that will contribute to biodiversity conservation. The review will proceed by first mapping the studies relevant to the broad review question followed by synthesis of subsets of studies relevant to more specific questions.

Mapping question

The broad mapping question will be: Can LTI verges constitute a habitat and/or a longitudinal corridor for biodiversity in temperate landscapes?

Synthesis questions

The mapping question can be split into the following topic groups: habitat/corridor and exposure to LTI verge/verge management intervention. This categorization leads to four topic group combinations. Examples of sub-questions for each combination are given below:

- Habitat-Intervention: Does mowing increase, decrease or have no effect on LTI verge biodiversity?
- Habitat-Exposure: Is the biodiversity of a LTI verge higher, smaller or equal to the biodiversity of meadow of the surrounding landscape?
- Corridor- Intervention: Does pruning increase, decrease or have no effect on insect dispersal in a LTI verge?
- Corridor-Exposure: Is mammal dispersal in a LTI verge higher, smaller or equal to mammal dispersal in a hedgerow of the surrounding landscape?

Once the systematic map will be produced, these sub-questions might be addressed in a synthesis if they are covered by a sufficient number of studies.

Components of the mapping question

Table 1² displays the components of the mapping question. The present study will not consider the transversal effects of LTIs on biodiversity, such as landscape fragmentation, which has already been demonstrated. It will focus on the longitudinal effects of LTI verges and LTI verge management on biodiversity. Yet, both potential positive (role of habitat/corridor, etc.) and negative (dispersal of invasive species, sink habitat effect, absence of role of habitat/corridor, etc.) longitudinal effects of LTI verges on biodiversity will be considered.

Methods

Search terms

The search terms identified by the review team are displayed in Additional file 1.³ A first search string, combining some of the search terms with Boolean operators, was tested on web of science. The search hits were

¹ Réseau Ferré de France, Voies Navigables de France, Réseau de Transport d’Electricité, GRT Gaz, Transport et Infrastructures Gaz France and Electricité Réseau Distribution France.

² LTI managers funding the study were met at the beginning of the project to list the types of verges that they own and the management practices that they apply on those.

³ For all keywords listed, wildcards may be used, to allow the use of derivations of the word’s root and to account for the possibility of finding a word in various spellings (English from Great Britain or from the United States) and with various endings (singular or plural).

Table 1 Description of the PECO/PICO items of the primary question

Population	All species and communities of the temperate climatic zone ^a
Exposure	LTI verges (road, railway, power line and pipeline verges and waterway banks)
Intervention	Management practices or environmental disturbance of LTI verges
Comparator	Both temporal and spatial comparators, including but not restricted to: Temporal comparators: Ecosystem present before infrastructure construction (when the habitat of the previous ecosystem and of the verge will be similar) Verge before management intervention Spatial comparators: Nearby undisturbed similar ecosystem Nearby unmanaged similar verge
Outcome	All outcomes relating to corridor or habitat assessment, including but not restricted to, species dispersal and species richness

^a The Köppen–Geiger climate classification will be used to identify articles with a study zone in the temperate climate. As the funders of the study are interested in western Europe, only the Cfa, Cfb, Cfc, Csa, Csb and Csc temperate zones will be included in the scope of our study. See <http://people.eng.unimelb.edu.au/mpeel/koppen.html> (Accessed 17 Nov 2015) for the googleearth layers of the Köppen–Geiger climate classification

compared to a list of 102 includable studies identified by subject experts^{4,5} (see Additional file 2) and the comprehensiveness was assessed. The search string was then modified, by removing some of the search terms and including new ones, until the highest comprehensiveness was reached. The search strings finally selected are detailed in Table 2.

A first scoping of search hits revealed that a global search string including all LTIs brought many irrelevant results linked to waterways. As a consequence, the search was split into a first string concerning all LTIs except waterways and a second string specific to waterways, which reduced the total number of search hits without decreasing the comprehensiveness.

For each of the non-waterway and waterway searches, two different search strings (strategies 1 and 2; Table 2)

were developed in parallel, reaching similar high levels of comprehensiveness. As no argument justified to choose one rather than the other, both strings were retained, results were merged and duplicates were removed. Both search strings (strategies 1 and 2; Table 2) include LTI synonyms, verge synonyms and outcomes and the terms within each category are combined using the Boolean operator 'OR'. However, while strategy 2 combines each of the three categories with the Boolean operator 'AND', strategy 1 combines the categories of verge synonyms and outcomes with the Boolean operator 'OR' and the category of LTI synonyms to the two other categories with the Boolean operator 'AND'. Strategy 1 is based on the consideration that neither the list of verge synonyms nor the list of ecological outcomes is exhaustive. Thus, it combines both of them with the Boolean operator 'OR' hoping that articles about unlisted outcomes will be found by the use of a verge synonym and conversely. Strategy 2 separates verge and outcome synonyms in different strings but allows synonyms with a broader meaning so as to obtain a high comprehensiveness anyway.

The same search strings will be used on search engines and specialist websites as on databases. However, if search engines and specialist websites do not allow the same options (wildcards, quotation marks, etc.) as publication databases, search strings will be modified using the database help in order to obtain the search string most similar to the original one. Final search strings used for each database, search engine and specialist website will be recorded in an Appendix, together with search dates. Searches in databases will be undertaken using english terms only, while searches in search engines and specialist websites will be performed either with English or French terms. No time or document type restrictions will be applied.

⁴ E-mail addresses of experts were obtained through mailing lists in ecology (Ecodiff, Transenviro, Wftlistserv and IENE, detailed in the following endnotes) and directories owned by members of our research team. The directories contain the contact details of 1902 persons working on green infrastructures, including scientists, LTI managers and government officers. Most of these persons work in France but the directories also include 21 international contacts, coming from 14 countries.

⁵ We first requested experts to send us the five scientific articles that they considered the most relevant regarding our research topic. Following the e-mail request, 77 scientific articles were sent to us by 21 experts. Out of these articles, 50 were collectively assessed, by the research team, as relevant considering our scientific question. Studies that were excluded of the list mostly dealt with road-kills, habitat fragmentation, wildlife overpasses, green infrastructures in general, environmental impact assessment of LTI construction, naturalist inventories out of the temperate climatic zone and pedology of LTI verges. Those subjects were considered by the research team as subsidiary to the scientific question. On top of these 50 articles provided by experts, 23 scientific articles, known by the members of the research team to address our scientific question, were added to the list. Nevertheless, at that stage, few articles of the list were related to pipelines, waterways and railways. Thus, 29 relevant scientific articles were searched on google scholar in order to balance the proportion of articles of the list related to each LTI. The final list of 102 approved key articles is detailed in Additional file 2.

Table 2 Search strings for two groups of LTIs and two strategies

LTI	Strategy	Language	Search string
Roads, railways, pipelines and power lines	1	English	<i>LTIs</i> : ("transport* infrastructure*" OR road* OR highway\$ OR motorway\$ OR freeway\$ OR rail* OR pipeline\$ OR powerline\$ OR "power line" OR "power lines" OR "transmission line*" OR "electric* line" OR "electric* lines" OR "electric* pylon*") AND <i>Verges/Outcomes</i> : (corridor\$ OR dispersal\$ OR habitat\$ OR refuge\$ OR "right* of way*" OR verge\$ OR abundance OR richness OR composition\$ OR *diversity OR communit*)
		French	<i>LTIs</i> : ("infrastructure\$ de transport\$" OR route\$ OR autoroute\$ OR "voie\$ ferrée\$" OR "chemin\$ de fer" OR pipeline\$ OR gazoduc\$ OR oléoduc\$ OR "ligne\$ électrique\$" OR "ligne\$ à haute tension" OR "ligne\$ à très haute tension" OR "ligne\$ THT" OR "pylône\$ électrique\$") AND <i>Verges/Outcomes</i> : (corridor\$ OR dispersion\$ OR habitat\$ OR refuge\$ OR dépendance\$ OR emprise\$ OR abondance OR richesse OR composition\$ OR *diversité OR communauté\$)
	2	English	<i>LTIs</i> : (road* OR highway* OR motorway* OR rail* OR "transmission line* corridor*" OR powerline* OR pipeline* OR "electric* pylon*") AND <i>Verges</i> : (corridor* OR habitat* OR verge* OR right\$-of-way* OR proximity OR contiguous OR line\$) AND <i>Outcomes</i> : (dispers* OR population* OR communit* OR abundan* OR distribution\$ OR "species composition*" OR attendance)
		French	<i>LTIs</i> : (route\$ OR autoroute\$ OR "voie\$ ferrée\$" OR "chemin\$ de fer" OR pipeline\$ OR gazoduc\$ OR oléoduc\$ OR "ligne\$ électrique\$" OR "ligne\$ à haute tension" OR "ligne\$ à très haute tension" OR "ligne\$ THT" OR "pylône\$ électrique\$") AND <i>Verges</i> : (corridor\$ OR habitat\$ OR dépendance\$ OR emprise\$ OR proximité OR contigu* OR ligne\$) AND <i>Outcomes</i> : (dispersion\$ OR population\$ OR communauté\$ OR abondance\$ OR distribution\$ OR "composition\$ d'espèces" OR "composition\$ spécifique\$")
		English	<i>LTIs/Verges</i> : (riparian OR riverside\$ OR riverbank\$ OR "river* *bank*" OR [(waterway\$ OR canal\$ OR channel\$) AND *bank*]) AND <i>Outcomes</i> : (corridor\$ OR dispersal\$ OR habitat\$ OR refuge\$ OR abundance OR richness OR *diversity OR composition\$ OR communit*)
		French	<i>LTIs/Verges</i> : (riparien* OR [(rivière\$ OR "voie\$ navigable\$" OR cana* OR chena*) AND (berge\$ OR bord\$ OR côté\$)]) AND <i>Outcomes</i> : (corridor\$ OR dispersion\$ OR habitat\$ OR refuge\$ OR abondance\$ OR richesse\$ OR *diversité\$ OR composition\$ OR communauté\$)
Waterways	1	English	<i>LTIs/Verges</i> : (riparian OR riverside\$ OR riverbank\$ OR "river* *bank*" OR [(waterway\$ OR canal\$ OR channel\$) AND *bank*]) AND <i>Outcomes</i> : (corridor\$ OR dispersal\$ OR habitat\$ OR refuge\$ OR abundance OR richness OR *diversity OR composition\$ OR communit*)
		French	<i>LTIs/Verges</i> : (riparien* OR [(rivière\$ OR "voie\$ navigable\$" OR cana* OR chena*) AND (berge\$ OR bord\$ OR côté\$)]) AND <i>Outcomes</i> : (corridor\$ OR dispersion\$ OR habitat\$ OR refuge\$ OR abondance\$ OR richesse\$ OR *diversité\$ OR composition\$ OR communauté\$)
	2	English	<i>LTIs</i> : (river* OR channel\$ OR stream\$) AND <i>Verges</i> : (riparian\$ OR *bank* OR proximity OR bridge\$) AND <i>Outcomes</i> : (dispers* OR communit* OR richness OR diversity OR drowning OR roosting OR "alien plant*")
		French	<i>LTIs</i> : (rivière\$ OR chena* OR ruisseau\$) AND <i>Verges</i> : (riparien\$ OR berge\$ OR proximité OR pont\$) AND <i>Outcomes</i> : (dispersion\$ OR communauté\$ OR richesse\$ OR diversité OR noyade\$ OR nichoir\$ OR "plante\$ invasive\$")

The quotation marks ("") allow to look for an exact phrase

* Any group of characters, including no character

\$ Zero or one character

Publication databases

The search will be conducted on the following publication databases:

- Web of science core collection
- Zoological record

These online databases will be used because they cover ecology and are accessible by the members of the research team. Although it would be interesting to include Scopus, no member of the research team has access to it.

Search engines

Internet searches will be performed using the following search engines:

- Google (<https://www.google.fr/>)
- Google scholar (<https://scholar.google.fr/>)

Specialist websites

Websites of the specialist organizations listed below will be searched for links or references to relevant publications and data, including grey literature:

- Australasian Network for Ecology and Transportation (<http://www.ecoltrans.net/>)
- Conservation Evidence (<http://www.conservationevidence.com/>)
- Documentation des Techniques Routières Françaises, Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement (<http://dtrf.setra.fr/>)
- Infra Eco Network Europe (<http://www.iene.info/>)
- International Conference on Ecology and Transportation (<http://www.icoet.net/>)
- Infrastructures de Transport Terrestre, Ecosystèmes et Paysage (ITTECOP) (<http://ittecop.fr/>)
- Ministère de l'Écologie, du Développement durable et de l'Énergie (MEDDE) (<http://www.developpement-durable.gouv.fr/>)

Other literature searches

To alert the research community to this systematic review and to ask for grey literature, national and international experts of transportation ecology will be contacted by e-mail, through the Ecodiff,⁶ Transenviro, Wftlistserv and IENE⁷ mailing lists and by posting a call

on a social media (<https://fr.linkedin.com/>). Moreover, each member of the review team will use its professional network to get information on research related to the topic of the review and to find non peer-reviewed literature, including reports published in French and English. Organizations funding the study will also provide us with their unpublished reports. Finally, authors of unobtainable articles will be contacted by email to ask for their publications.

Study screening and inclusion criteria

Scientific articles collected in databases will be assessed for inclusion at three successive levels: first on titles, second on abstracts and third on full-texts. At each stage, in case of uncertainty, articles will be retained for assessment at the following stage. Article eligibility, at the title screening stage, will be based on the list of selection criteria detailed in Table 3. These criteria encompass both the subject (ecology and related disciplines) and the population (all species of the temperate climatic zone⁸) of the study. During title screening, studies will be classified into one of the following groups: vertebrates, invertebrates or flora/fungi. Next, each article found to be potentially relevant on the basis of its title will be judged for inclusion on the basis of its abstract. Article assessment on abstracts will rely on the same criteria as for the title stage. Moreover, criteria regarding the exposure/intervention, the comparator, the outcomes or the study type will be added, as detailed in Table 4. Articles will then be assessed on full-texts. Since grey literature does not comply with scientific publishing standards, its assessment will be performed directly on full-texts. Article assessment on full-texts will be based on the same criteria as for the title and abstract stages. Moreover, some inclusion/exclusion criteria specific to the full-text stage, such as the study language, the climate of the study zone or the type of study design, may be added as the review proceeds. A list of studies rejected on the basis of full-text assessment will be provided in an additional file, together with the reasons for exclusion.

Before the onset of screening, the review team members taking part in the assessment process will test the consistency of their inclusion/exclusion decisions. For each of the sets of articles about waterways and other LTIs and for each of the assessment stages on title and abstract, a sample of articles will be randomly selected and studies will be screened by each of the reviewers

⁶ Ecodiff is a French mailing list about ecology and evolution, which counts around 7000 subscribers. <http://www.sfecologie.org/ecodiff/>. Accessed 22 Sep 2015.

⁷ Transenviro, Wftlistserv and IENE are international mailing lists about transportation ecology. Together, the Transenviro and Wftlistserv mailing lists gather about 600 contacts and the IENE mailing list counts around 300 contacts. <http://www.itre.ncsu.edu/CTE/Lists/index.asp#wftlistserv>, <http://www.iene.info/>. Accessed 22 Sep 2015.

⁸ The Köppen–Geiger climate classification will be used to identify articles with a study zone in the temperate climate. As the funders of the study are interested in western Europe, only the Cfa, Cfb, Cfc, Csa, Csb and Csc temperate zones will be included in the scope of our study. See <http://people.eng.unimelb.edu.au/mpeel/koppen.html> (Accessed 17 Nov 2015) for the GoogleEarth layers of the Köppen–Geiger climate classification.

Table 3 List of exclusion/inclusion criteria at the stage of title screening**Exclude**

For all LTIs:

- Studies regarding green infrastructures in general without considering the specific case of LTIs
 - Studies regarding overpasses/underpasses or fragmentation due to LTIs considered transversally, without considering the roles of habitat and corridor of verges
 - Studies regarding paleontology, phylogenetics, phylogeography and taxonomy (including studies describing newly discovered species)
 - Genetic studies without any relation to a natural habitat (in particular biodiversity meta-genomics studies)
 - Pedological studies without any relation to biodiversity
 - Studies regarding medicine, toxicology or chemical, noise or light pollution without any relation to biodiversity
- Specifically for fluvial LTIs (waterways):
- Studies regarding exclusively aquatic species, except if the title mentions the words floodplain, riparian, wetland, seasonal pond, intermittent -stream or spawning (in which case the study is considered to deal with the lateral part of the river, that is to say the banks, sometimes immersed other times emerged, which is part of the scope of the study)
 - Studies regarding lakes and islands or sand banks in the middle of rivers
 - Studies regarding river debris (organic matter, tree trunks, underwater leaves decomposition, except if the study deals with the submerged part of the bank, etc.)
 - Studies regarding drownings without any relation to the role of habitat of the banks
- Specifically for non-fluvial LTIs (roads, railways, power lines, pipelines):
- Studies regarding animal collisions without any relation with the role of habitat of the verges

Include

For all LTIs:

- Studies dealing only partially with the role of habitat or corridor of the verges
 - Studies regarding invasive species if the role of corridor or habitat of verges is mentioned
 - Studies regarding soil biodiversity
 - Studies dealing with the effects of chemical, noise or light pollution on verge biodiversity (even if the pollution comes from the infrastructure itself)
 - Studies out of the temperate climatic zone (they will be assessed at the full-text reading stage)
 - Studies regarding wildfires (they will be assessed at the full-text reading stage)
- Specifically for fluvial LTIs (waterways):
- Studies whose title mentions the words floodplain, riparian, wetland, seasonal pond, intermittent stream or spawning (in which case the study is considered to deal with the semi-aquatic part of the river, that is to say the banks, emerged during the dry season and immersed during the wet season, which is part of the scope of the study)
 - Studies regarding amphibious species
 - Studies regarding seed dispersal through waterway flow (hydrochory)
 - Studies regarding the role of waterway banks in animal drownings
 - Studies recommending management actions to perform under bridges (hanging bat roosting boxes for instance)
 - Studies regarding streams (they will be assessed at the full-text reading stage)
- Specifically for non-fluvial LTIs (roads, railways, power lines, pipelines):
- Studies regarding the role of verges in animal collisions
 - Studies recommending verge management actions to perform (including fencing to avoid collisions)
 - Studies dealing with species dispersal by the infrastructure itself (abandoned railways, seed dispersal by vehicles, etc.)

Table 4 List of inclusion criteria at the stage of abstract screening

Type of criteria	Description
Relevant population(s)	All biodiversity (at the species, community and ecosystem level), including fauna, flora, microorganisms, soil biodiversity and exotic invasive species, of the temperate climatic zone ^a
Types of exposure/intervention	Any study exposing biodiversity to a LTI verge (road, railway, power line or pipeline verges or waterway banks), to a LTI verge management (mowing, pesticide spreading, pruning, planting, fence laying, beehive setting up, bird nesting box and bat roosting box hanging, reptile artificial refuge setting up, etc.) or to a LTI verge disturbance (chemical, air, noise and light pollution and wildfires)
Types of comparator	Unexposed/intervention-free control site or before-exposure/before-intervention control site
Types of outcome	All outcomes relating to corridor and habitat assessment or effects of verge management, such as dispersal (including species invasions, hydrochory and seed dispersal by vehicles), species richness, Shannon index, Simpson index, beta diversity and abundance of different taxonomic or functional groups of organisms
Types of study	All type of studies should be included apart from modelling studies, studies making recommendations without making experimentation and studies making experimentations in laboratory conditions

^a The Köppen–Geiger Climate Classification will be used to identify articles with a study zone in the temperate climate. As the funders of the study are interested in western Europe, only the Cfa, Cfb, Cfc, Csa, Csb and Csc temperate zones will be included in the scope of our study. See <http://people.eng.unimelb.edu.au/mpeel/koppen.html> (Accessed 17 Nov 2015) for the GoogleEarth layers of the Köppen–Geiger Climate Classification

independently of each other. As more than two raters will take part in the study inclusion assessment, a Randolph's Kappa coefficient will be computed with the R statistical software. A coefficient of 0.6 will be set as the minimal acceptable level of estimated agreement between raters. If the coefficient is lower than 0.6, disagreements will be discussed by raters until common selection criteria are chosen and the operation will be repeated until reaching a coefficient superior to 0.6.

Potential effect modifiers and reasons for heterogeneity

In order to identify potential effect modifiers and reasons for heterogeneity of the results of included studies, eight external experts in landscape connectivity and transportation ecology, and seven scientists of the review team, were gathered and consulted during a one-day workshop. During the workshop, the golden protocol of an ideal study answering our primary question with unlimited resources was discussed. Then, potential effect modifiers and reasons for heterogeneity of our included studies were debated, considering that resources for conducting a study are actually limited.

The following potential effect modifiers were foreseen

- Study geographic location
- Site characteristics (type of LTI, type and width of verge, presence of fences, surrounding landscape and history of site disturbances)
- Timing of the study (study duration, seasonality, duration between exposure/intervention and data sampling, etc.)
- Biological group studied
- Verge management practices (mowing, grazing, vegetation burning, pesticide use, etc.)
- Comparator type (spatial/temporal, etc.)
- Sampling method (sample size, randomization of sample selection, number of replicates, etc.)

Examples of how geographic location, site characteristics and timing can affect results of a study are respectively given below. Species diversity of a LTI verge will likely be higher in a Mediterranean region than in a northern region. Similarly, the site disturbance history, such as the flooding frequency, will probably affect the floristic composition of a waterway bank. Whether the abundance of a species is measured in spring or winter may affect results. As the present list is not exhaustive, a final list of effect modifiers and reasons for heterogeneity will be established as the review proceeds.

Study quality assessment

Following study inclusion assessment, the quality of included studies will be critically appraised. Based on

assessments of their reliability and relevance, included studies will be categorized as having high, medium or low susceptibility to bias. Studies with a high susceptibility to bias will be excluded from the map and from the review. The exact criteria of study quality assessment will be developed as the review proceeds, but they will likely include study design type, coherence of the sampling design, duration between intervention and data sampling, sample size, randomization of sample selection, sampling replication, level of detail of the methodology, comparator relevance for our question, presence of measures of variation of outcomes and description of potential effect modifiers.

Several types of study designs can provide answers to our primary question. Comparison of the impact of different kinds of management on the use of verges as a habitat or a corridor by biodiversity can be made both temporally and spatially. Studies with a before/after (BA) design compare data collected at the same site prior to and following an intervention. Some studies with a BA design use data collected on a single sampling occasion after the intervention, while others use data collected on repeated sampling occasions after the intervention. On the contrary to studies with a BA design, studies with a comparator/intervention (CI) design compare data collected at the same time at different sites, some sites that were subject to a type of management and some sites that were left unmanaged. Finally, studies with a before/after/comparator/intervention (BACI) design combine the two approaches, making both a temporal and spatial comparison. Actually, in a BACI design, data are collected both in a control site and before and after intervention in the study site. These types of study designs have different levels of quality. BA designs with a sampling collection on the long term will likely be more valuable than BA designs with a sampling collection on the short term, since they may account for lasting effects of the intervention and seasonal variation. Moreover, BACI study designs will probably be more reliable than BA and CI designs. Similarly, studies that detail potential effect modifiers will probably be more valuable than studies that do not describe the local environment.

Detailed reasoning concerning critical appraisal will be displayed in a transparent manner. The table of study quality assessment will be included as an appendix. For rejected studies, a short explanation of the reason for exclusion will also be provided.

On top of the scientists of the review team, some external experts might be asked to contribute to the critical appraisal if the number of included articles is high. Each article will first be critically appraised by one reviewer. Uncertain cases will then be critically appraised by a second reviewer. Quality assessment conclusions of the two

reviewers will then be compared, and where they differ, disagreements will be discussed until a consensus is reached.

Systematic map database

The studies included after critical appraisal will be mapped in a database. Table 5 displays the coding tool that will be used for the systematic map database. Key variables of interest and coding options within these variables were identified by the review team and subject experts. These key variables include the following type of information: bibliographic reference, geographical localization of the study sites, subject population, type of exposure/intervention, methodological design, setting/context and outcome measures. Studies may be coded with multiple keywords within each coding variable where appropriate. For instance, a study conducted in several regions will be coded with multiple keywords for the “Study region” variable.

Each included article will first be coded by one reviewer. Uncertain cases will then be checked by a second reviewer. Potential disagreements will be discussed until a consensus is reached.

The systematic map will describe the evidence on the review topic. It will also identify knowledge gaps and potential specific synthesis questions. The database will be easily searchable and freely accessible.

Data extraction strategy

Once the systematic map will be produced, a synthesis might be realized on more specific questions. In this case, data will be extracted from included studies as follows. Outcome means, measures of variation (standard deviation, standard error, confidence intervals, etc.) and sample sizes will be extracted from tables and graphs, using image analysis software when necessary. If only raw data are provided, summary statistics will be calculated. If relevant data are difficult to extract accurately from graphs or if they are assumed not to be published, authors might be asked to provide primary data. Data on potential effect modifiers will also be extracted from the included articles.

Data synthesis and presentation

The mapping phase will provide descriptive statistics of the regions, taxa and LTIs studied. A narrative synthesis will describe the quality of the results of all the included studies, along with the findings of studies of sufficient quality. Tables will be produced to summarize these results with respect to each of the specific questions. Meta-analyses of effect sizes will be conducted if questions, designs and data formalizations of the included studies are sufficiently homogeneous and if the susceptibility to bias of these studies is low enough. The questions and modalities of the meta-analysis might only be specified once the papers have been read and assessed in order

Table 5 Coding tool for the systematic map

Coding variable	Details/examples
Publication year	
Authors	
Title	
Publication type	Book chapter, journal paper, conference paper, thesis, organization report, etc.
Publisher	Name of the journal or institution publishing the document
Article language	English/French
Study country	
Study regions	
GPS coordinates	
Biological groups	Vascular flora, wild bees, etc.
LTIs	Roads/railways/power lines/pipelines/waterways
Type of habitat of the study site	Grassland, shrubland, hedge, forest, etc.
Type of habitat of the control/compared site	Grassland, shrubland, hedge, forest, etc.
Management practices	Mowing, pesticide spreading, pruning, planting, fence laying, beehive setting up, etc.
Type of comparison	Spatial/temporal/spatial and temporal
Measured outcomes	Species richness, Shannon index, etc.
Susceptibility to bias	Low/medium

to properly weight the results and choose the metrics for net-effect calculations. Publication bias analysis will also be carried out where possible with the Egger test or the fail safe number.

Additional files

Additional file 1. List of search terms.

Additional file 2. List of includable studies identified by subject experts.

Abbreviations

LTI: linear transportation infrastructure; CILB: Club des Infrastructures Linéaires and Biodiversité; MEDDE: Ministère de l'écologie, du développement durable et de l'énergie; ITTECOP: Infrastructures de Transport Terrestre, Ecosystèmes et Paysage; FRB: Fondation pour la Recherche sur la Biodiversité; MNHN: Muséum national d'Histoire naturelle; IRSTEA: Institut national de recherche en sciences et technologies pour l'environnement et l'agriculture; BA: before/after; CI: comparator/intervention; BACI: before/after/comparator/intervention; RS: Romain SORDELLO; AJ: Arzhvaël JEUSSET; MV: Marianne VARGAC; BL: Barbara LIVOREIL; YB: Yves BERTHEAU; AC: Aurélie COULON; JT: Julien TOUROULT; SV: Sylvie VANPEENE; ND: Nadine DENIAUD; FFL: Frédérique FLAMERIE DE LACHAPELLE; EJ: Emmanuel JASLIER; VR: Véronique ROY; IW: Isabelle WITTE.

Authors' contributions

RS, YB, AC and JT conceived the review question. AJ, MV, RS and SV undertook the experts request for scientific key articles. AJ, RS, MV, AC, YB, SV and BL validated the control list. MV, FFL, AJ, RS, VR, EJ, ND, AC, YB, SV and BL contributed to the database selection. AJ, MV, RS, AC, YB, SV, BL and FFL contributed to the search terms brainstorming. AJ, MV, RS, FFL, VR, EJ and ND undertook the search comprehensiveness assessment and equation selection. RS, AJ and BL organized the external experts workshop for critical appraisal and AC, YB, SV attended to it. RS is the scientific coordinator of the project. BL offered support regarding the methodology of systematic reviews by attending regular monthly meetings with AJ and RS. FFL, VR, EJ, ND offered support for the bibliographical stage of the study. IW offered support for the statistical stage of the study. All authors joined regular steering committee meetings. All authors read and approved the final manuscript.

Authors' information

The systematic review research team includes 13 members with multidisciplinary skills: YB, AC, AJ, BL, RS, JT, SV and MV are scientists with different specializations in ecology. ND, FFL, EJ and VR are academic librarians. IW is a biostatistician.

Author details

¹ Service du Patrimoine Naturel (SPN), Muséum national d'Histoire naturelle (MNHN), 75005 Paris, France. ² Centre d'Ecologie et de Sciences de la Conservation (CESCO), Muséum national d'Histoire naturelle (MNHN), 75005 Paris, France. ³ SPE, Inra (Institut national de la recherche agronomique), Route de Saint Cyr, 78026 Versailles Cedex, France. ⁴ CEFE UMR 5175, laboratoire Biogéographie et Ecologie des vertébrés, CNRS-Université de Montpellier-Université Paul-Valéry Montpellier-EPHE, 1919 route de Mende, 34293 Montpellier, France. ⁵ Université Paris 6 Pierre et Marie Curie (UPMC), 75005 Paris, France. ⁶ Fondation pour la Recherche sur la Biodiversité (FRB), 75005 Paris, France. ⁷ Institut de recherche en sciences et technologies pour l'environnement et l'agriculture (Iristea), 13182 Aix-En-Provence, France.

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Competing interests

The authors declare that they have no competing interests.

Source of support

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Candidate selection

The MNHN was selected by the CILB, the ITTECOP and the FRB to conduct the systematic review following a public call for projects, for which the MNHN had submitted a proposal.

Project course

LTI managing organizations funding the project were met once before the redaction of the present manuscript, by RS, AJ and MV, in order to clarify their needs for information and the inherent scientific question. The ITTECOP was also met once by RS and AJ to present the first stages of the project and ask for directories of experts of transportation ecology.

The FRB, through its representative BL, had a particular role in the project as it is a backer of the project, a member of the research team and a representative of the Collaboration for Environmental Evidence, which approves environmental systematic reviews. Nevertheless, the role of the FRB in the decisions made by the research team remained advisory and the present document was proofread by independent peer-reviewers.

All project decisions regarding the design, the collection, the analysis and the interpretation of data were made freely by the authors of the study. All statements made in this report are under the responsibility of the authors and do not necessarily represent the views of the CILB or of the ITTECOP.

The protocol manuscript will be sent to the funding body for information when submitting it for publication.

Other projects

After responding to a call for tender, the MNHN was selected to conduct another project than the present one, named Trans-fer, which was also funded by Réseau Ferré de France (a member of the CILB) and the MEDDE. Trans-fer ended before the beginning of the present project and the two projects were steered independently.

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